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Risk assessment of trees protected by law in Curitiba squares, Paraná, Brazil

Análisis de riesgo de los árboles protegidos por la ley en las plazas de Curitiba, Paraná, Brasil

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SUMMARY

The aim of this article was to evaluate the likelihood of failure of trees protected by law located at Curitiba squares, Paraná, through the adaptation of the tree risk assessment proposed by the International Society of Arboriculture (ISA). Among all 14 trees analyzed, 11 types of defects were identified in the trunk, with the predominance of canker and codominant stems; 12 in the crown, with the presence of dead and broken branches; and seven in the root system, where root lifting was the most recurrent problem. The evaluation of the tree risk assessment indicated that eight of the 14 trees demonstrated moderate risk (57.14 %), presenting 5 to 12 defects; five had a low risk (35.71 %), with one to seven defects; and one was categorized as a high risk of failure (7.14 %), which had 17 defects. Half of the trees presented the risk assessment associated with defects in the trunk, two of them with problems in the crown, and two others had more defects in the root system. These results highlight the importance of monitoring and maintaining the quality of urban forests, a fact that contributes to the safety and well-being of the population that visit Curitiba squares.

Key words: arboriculture, protected tree, trees failure, urban forest.

RESUMEN

El objetivo de este artículo fue evaluar la probabilidad de daño de los árboles protegidos por la ley ubicados en las plazas de Curitiba, Paraná, mediante la adaptación de la evaluación de riesgo de árboles propuesta por la Sociedad Internacional de Arboricultura (ISA). Se identificaron 11 tipos de defectos en el tronco, con predominio de tallos cancerosos y codominantes; 12 en la corona, con la presencia de ramas muertas y rotas; y siete en el sistema de raíz, cuya elevación de raíz fue el problema más recurrente. La evaluación de la evaluación del riesgo de árboles indicó que 8 de los 14 árboles mostraron un riesgo moderado (57,14 %), presentando de 5 a 12 defectos; cinco tuvieron un riesgo bajo (35,71 %), con uno a siete defectos; y uno se clasificó como un alto riesgo de fracaso (7,14 %), que tenía 17 defectos. La mitad de los árboles presentaron la evaluación de riesgo asociada con defectos en el tronco, dos de ellos a problemas en la corona y otros dos tenían más defectos en el sistema radicular. Estos resultados resaltan la importancia de monitorear y mantener la calidad de los bosques urbanos, un hecho que contribuye a la seguridad y el bienestar de la población que visita las plazas de Curitiba.

Palabras clave: arboricultura, árbol protegido, daño en árboles, bosque urbano.

INTRODUCTION

Urban forest comprises trees that promote social, environmental and economic benefits by mitigating urban heat island effects, conserving biodiversity and favoring energy savings real and estate valuation (Biondi 2015). In addition, these trees may have special attributes that add patrimonial value to urban environments.

Historically preserved trees could be categorized into several terminologies, such as mature trees (Hall and Bunce 2011), in England; champion or heritage trees (Orłowski and Nowak 2007), in Poland; ancient trees (Urbinati 2015), in Italy; remarkable trees (Estellita *et al.* 2007), in Jaboticabal or even trees protected by law (Curitiba 2009), in Curitiba, both located in Brazil. In general, these trees may present many characteristics in common, such as exceptional size for its species, a peculiar crown architecture, botanical rarity, ecological relevance, significant aesthetic and landscape features or historical, cultural and religious importance (Lai *et al.* 2019).

The trees protected by law in the city of Curitiba are listed by the Municipal Historic Heritage of the state of Paraná, Brazil, which categorized trees into immunes to cutting and pruning (*árvores tombadas*) and only immunes to cutting (*árvores imunes ao corte*) (Curitiba 2009). Among this last category established by Decree nº 1181 of 2009, only monitored interventions by local authorities are allowed, such as pruning, removal or replacement, to guarantee the species' vigor (Curitiba 2009).

The most relevant criteria to select protected trees by the Municipal Historic Heritage of Paraná is the tree exceptional size; although, as those individuals require special management, they were not included in the normal pruning cycle of Curitiba city and actions were only carried out by demand or if some tree part might fall.

Protected trees are generally located at places with relevant historical and economic value, such as residential gardens and squares. Therefore, they contribute to the preservation of the city's historic and scenic heritage and also to the population environmental awareness (Biondi 2015, Tomao *et al.* 2015). However, in public places with great flow, such as Curitiba squares, the direct exposure of targets (people, vehicles, urban equipment, residential and commercial properties) may increase the likelihood of tree failure impacting a target.

The elevated height and advanced age of protected trees are factors that aggravate the risk of tree failure because it may be associated with their vigor reduction, as well as the safety of the population and urban structures. Thus, it is necessary to assess periodically the general growth and development of these trees to reduce the consequences of tree failure.

Tree risk assessment is a useful tool for urban forest management, being highly recommended for senescent trees, especially those with some degree of instability. However, as these individuals are often older than others, they are more susceptible to an intense wood biodeterioration that causes alterations in its anatomical structure and physical, chemical and mechanical properties.

In the quantitative evaluation, the likelihood of failure and its consequences are estimated by numeric values. While in the qualitative assessment, these variables are determined by categorical scales through the use of the likelihood matrix and risk rating matrix (Smiley *et al.* 2012), which complements the information acquired in the quantitative evaluation.

Following this context, visual evaluation through forms provided by the International Society of Arboriculture (ISA) has deeply contributed to the risk assessment of trees due to its systematic process for identifying, analyzing and assessing over quantitative and qualitative parameters (Smiley *et al.* 2012).

Although both approaches developed by ISA (2013) have subjectivity and ambiguity as limitations, they are practical, quick, low-cost assessments and the most complete compared to other usual protocols, such as those designed by Matheny and Clark (1994), Lonsdale (1999) and Albers *et al.* (2003).

However, to reduce the subjectivity of the ISA protocol, it is necessary to adapt its evaluation parameters to specific cases, since the determination of tree risk failure is subjective. Thus, we adjusted the ISA protocol to reduce such subjectivity and increase its effectiveness.

The aim of this study is to evaluate the likelihood of failure of trees protected by law at Curitiba squares, Paraná, through the qualitative tree risk assessment form proposed by ISA.

METHODS

Study area. This study was implemented in the city of Curitiba, the State of Paraná, situated in the southern region of Brazil (IPPUC 2015). The municipality comprises a total area of 435.27 km² (43,527 ha), subdivided into 75 neighborhoods and 10 administrative units, called "regionals" (IPPUC 2015).

According to the climatic classification of Köeppen-Geiger, this region presents subtropical humid mesothermal (Cfb) characteristics, which are described as severe and frequent frost in the winter and without a pronounced dry season (IPPUC 2015). Its average annual temperature and rainfall are 17.4 °C and 1486.5 mm/year, respectively (IPPUC 2015).

Curitiba was predominantly covered by Mixed Ombrophilous Forest (MOF), as part of the Atlantic Forest Biome and grasslands areas. Currently, the area comprised by Curitiba's urban forest represents 43.69 % of the municipality, of which 34.70 % corresponds to the private urban forest and 8.98 % to the public urban forest (Grise *et al.* 2016).

General characteristics of protected trees. The location of Curitiba's protected trees was listed below to determine the representativeness of species in each urban forest typology, varying from public parks, woodlands, squares and street trees to private green spaces such as gardens and woodlands. Table 1 shows the number of species and individuals for typologies and the percentage of trees in each one.

Notwithstanding, there is superior representativeness of protected trees in private areas than other urban forest typologies, trees located in public areas pose a higher risk due to the exposure of more people to these areas.

Thus, only protected trees located at public city squares were evaluated since they summarize the ease of data collection and 28 % of the total trees in one urban forest type. Furthermore, this typology may provide different tree risk assessment, considering they exhibit tree large size, wherein their surroundings are avenues with an intense flow of people and vehicles. Table 2 shows the list of species evaluated and their squares' location.

Tree risk assessment. The evaluation of tree risk was estimated through the protocol Basic Tree Risk Assessment Form developed by the International Society of Arboriculture (ISA 2013), whose application is recommended for arboreal and palm trees with potential risk of failure. The tree risk categorization was determined by the likelihood of failure (related to the amount of tree defects), the likelihood of impact and the consequence of the failure of the three most important parts: crown, trunk and roots.

Nonetheless, we adapted the way of analyzing the likelihood of tree failure proposed by the ISA protocol because it considers a distinct amount of possible defects to the tree parts. In other words, as the protocol admits 17 possible defects to the crown (mainly related to branch health), 13 to the trunk (such as presence of cankers and codominance) and 11 to the root system (such as uplift and cut roots), we believe there was evidence of bias against the root's failure due to the reduced numbers of possible defects associated with this part, which overestimated the probability of failure related to crown defects.

Thus, we used a mathematical constant as weight to balance the defects of the tree parts and therefore each part contributes equally to the determination of the likelihood of failure. Thus, it was feasible to determine the Relative Likelihood of Failure (RLF) of tree parts, which will reduce the subjectivity in determining this variable:

$$\text{RLF of crown} = DC * 5.88 \quad [1]$$

$$\text{RLF of trunk} = DT * 7.69 \quad [2]$$

$$\text{RLF of roots system} = DR * 9.09 \quad [3]$$

Where:
RLF: Relative likelihood of failure; DC: Number of defects in the crown; DT: Number of defects in the trunk; DR: Number of defects in the roots.

Table 1. Representativeness of protected trees in different types of the urban forest in Curitiba, Paraná.
Representatividad del corte de árboles inmunes en diferentes tipos de bosque urbano en Curitiba, Paraná.

Typologies	Nº of species	Nº of trees	Trees/Typology (%)
Private woodlands and gardens	18	23	46
Public city squares	13	14	28
Street trees	8	10	20
Public city parks	2	2	4
Public woodlands	1	1	2
Total	42	50	100

Source: Modified from Curitiba (2009).

Table 2. List of protected species situated at Curitiba public squares, Paraná.
Lista de inmunes especies cortadoras situadas en las plazas públicas de Curitiba, Paraná.

nº	Scientific name	Popular name in Brazil	Square name	District	Height (m)
1	*Araucaria columnaris* (J.R. Forst.) Hook.	Araucária	Tiradentes	Centro	27
2	*Caesalpinia leiostachya* (Bent.) Ducke	Pau-ferro	Tiradentes	Centro	25.5
3	*Carya illinoiensis* K. Koch	Nogueira	Didi Caillet	Centro Cívico	25
4	*Cedrela fissilis* Vell.	Cedro-rosa	Eufrásio Correa	Centro	23
5	*Enterolobium contortisiliquum* (Vell.) Morong	Timbaúva	Hafez Al Assad	Portão	25
6	*Ficus gomelleira* Kunth *et* C.D. Bouché	Figueira	Tiradentes	Centro	20
7	*Handroanthus albus* (Cham.) Mattos	Ipê-amarelo	Tiradentes	Centro	15.5
8	*Hymenaea courbaril* L.	Jatobá	29 de março	Mercês	20
9	*Livistona* sp.	Palmeira-leque	General Osório	Centro	35
10	*Olea europaea* L.	Oliveira	Santos Andrade	Centro	12.5
11	*Peltophorum dubium* (Spreg.) Taub.	Canafístula	Villa Lobos	Jardim Social	16
12	*Phoenix canariensis* Wildpret	Tamareira	Eufrásio Correa	Centro	15.5
13	*Phoenix canariensis* Wildpret	Tamareira	Eufrásio Correa	Centro	21.5
14	*Schizolobium parahyba* (Vell.) S.F. Blake	Guapuruvu	Santos Andrade	Centro	40

Source: Modified from Curitiba (2009).

Hence, the Tree Risk Scale associated with each tree part was defined according to the Relative Likelihood of Failure, varying from 0 to 100 % as shown in figure 1.

For all evaluated trees, we established the likelihood of impact as high, since the trees or branches that would eventually fail are extremely likely to impact at least one or all targets in the squares, such as people, vehicles and urban structures. According to ISA Tree Risk Assessment Manual (2013), if there is a constant target with no protection factors and the direction of fall is toward the target, the likelihood of impact is the highest of the group.

Likewise, according to the ISA (2013), we classified the consequences of failure as "Significant" for all evaluated trees, since in case of tree failure, the damages done to the people's life present in the Curitiba squares were considered as moderate to high.

The general tree risk categorization was defined by the higher risk rating of its parts - crown, trunk, and roots.

In general lines, the risk assessment of 14 protected trees distributed in 5 squares of Curitiba concerned about the quantification of current defects, tree risk categorization and the ratio between the number of defects per tree and its category of risk.

RESULTS

Quantification of defects. Among the 14 trees evaluated, we identified only four individuals without any type of defect in the crown (the two of *P. canariensis*, *A. columnaris*, and *Livistona* sp.) and six did not demonstrate apparent problems in the roots (*C. illinoiensis*, *P. canariensis*, *A. columnaris*, *C. leiostachya*, *H. albus*, and *P. dubium*), unlike the trunk part, which presented at least one type of defect in all trees evaluated. Table 3 shows the problems frequently found in each tree part.

According to table 3, the most affected part of the trees was the trunk, which presented 11 defects types, predominating the occurrence of canker and the absence of apical dominance (codominance). The crown was ranked as the second part largely affected by problems, presenting 12 kinds of defects, mainly for dead and broken branches. The root system demonstrated seven associated problems,

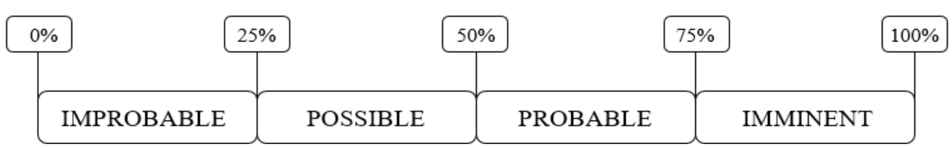

Figure 1. Risk Scale associated with the likelihood of failure in each tree part.
Escala de riesgo asociada con la probabilidad de falla en cada parte del árbol.

Table 3. List of recurrent problems in each part of the evaluated trees.
Lista de problemas recurrentes en cada parte de los árboles evaluados.

Tree structure and number of affected trees (NTA)					
Crown	NTA	Trunk	NTA	Roots	NTA
Dead branches	9	Canker	8	Uplift	6
Broken branches	4	Codominant	8	Canker	4
Unbalanced	2	Check	6	Cuts	3
Mistletoe	2	Included bark	4	Interlaced	3
Epicormic shoot	1	Exudation	4	Dead	1
Epiphyte	1	Sapwood rot	4	Rot	1
Split	1	Pests	3	Exudation	1
Dead or missing bark	1	Dead or missing bark	2		
Weak branch union	1	Abnormal bark color	2		
Heartwood rot	1	Inclined	2		
Sapwood rot	1	Heartwood rot	1		
Previous failures	1				

being the uplift (exposition of the root system) and the canker the common ones. Although the crown has a higher number of defects than those presented by the trunk, the crown part presents larger recurrence.

The tree risk categorization. The Risk Scale of the protected trees is presented in table 4. It shows that 8 of the 14 trees evaluated presented moderate risk (or 57.14 %), while five of them had a low risk (or 35.71 %) and one was categorized as possessing high risk of failure (or 7.14 %).

Ratio between the number of defects per tree and its category of risk. Table 5 shows the number of problems associated with the likelihood of failure in each of the trees evaluated.

All trees categorized on moderate risk showed at least four defects in one part, besides *S. parahyba*, *O. europaea*, *C. illinoiensis*, *C. leiostachya*, *P. dubium* and *F. gomelleira* which presented the highest number of defects in their trunks; *H. courbaril* and *E. contortisiliquum* had their tree fall risk scale strongly associated with root defects; *O. europaea* and *H. albus* highlighted by presenting more defects in their crowns. On the other hand, trees with low risk did not have defects in at least one of its parts.

Olea europaea was the species evaluated on highest risk, presenting 17 defects, while other individuals that classified on moderate risk had between five and 12 defects, and those on low risk had one to seven associated problems. Although, in the case of this study, there is a direct relationship between the crown defects -get visible reachable on little trees- and the root system defects -get visible reachable above ground level-. The number of defects, the likelihood of failure and the intensity of these defects may influence the risk scale attributed to them.

DISCUSSION

Quantification of defects. Visual assessment methods are recognized as efficient for determining the probable risk of rupture of urban trees. Reyes de la Barra et al. (2018), comparing four methods of visual risk assessment of urban tree fall, found that visual tree assessment appears to be a reliable tool for predicting tree damage or deterioration and an effective alternative for tree risk assessment.

The fact that ISA protocol admits the highest number of potential trunk defects may be explained by the fact that this is the most accessible part to identifying problems, while crown and root system defects are visible within small trees and above ground level, respectively, which restricts the number of defects to be verified.

For this reason, we have adapted the ISA protocol so that the three parts of the tree contribute equally to determining the probability of tree failure.

The presence of trunk cankers in eight of 14 individuals is clearly explained by the common practice of pruning in large diameter branches by Municipal Tree Managers, which complicates the wood compartmentalization and leaves exposed injuries. According to Urbinati (2015), trees with advanced age and relatively reduced vigor are more likely to present this type of defect, since the capacity to compartmentalize the injury in these circumstances is reduced and may facilitate the inoculation of pathogens and saproxylic insects on the trunk. Terho (2009) adds that the deterioration of wood by xylophagous agents is a factor that decreases the mechanical strength of a tree, favoring the risk of a collapse by the trunk.

Furthermore, trunk codominance was also found in eight of 14 trees. According to Fini *et al.* (2015), this structural defect is harmful and worrisome because it may significantly affect the target's security when near to fault trees. The authors also stated that risks increase significantly if the branches are weakly connected to the trunk. For Smiley (2003), this structural deformity may have an association or not with the included bark defect and the weak union of the trunks. As an example, in our research it was verified that three, out of four trees with included bark, presented an association with codominant trunks. Smiley (2003) emphasized that when this kind of association between defects occurs, the codominant ramifications are significantly weaker, which potentiates the likelihood of failure.

In relation to the problems observed in the crown, the most recurrent ones were the presence of dead, broken and dry branches, which means that at least one of these defects was verified in each of the 10 trees diagnosed. Thus, the removal of this type of branches through pruning is essential against the infestation by xylophagous agents and other fungi, as well as to preserve the tree structural characteristics (Badrulhisham and Othman 2016). In addition, Kane *et al.* (2015) warned that these branches contribute directly to the increase of rupture potential and consequently to the associated risk for the tree.

There is a ratio between the crown length and the root system, in terms that large trees may have proportional roots areas for balancing top branches. However, street tree beds may not be able to accommodate the high volume of the root, especially in places where soil depth is reduced or compacted. According to Kadir and Othman (2012), the limitation of root growth space in subsoil results in the roots seeking to develop on or above the surface. This movement characterizes the uplift of the root system, which can lead to breaking, settling or sinking of the sidewalk.

The tree risk categorization. In general, trees with a low risk of failure are structurally more stable. In other words, there are not enough reasons for concerning and it is unnecessary the use of sophisticated equipment since the external condition verified tends to reflect the internal condition of trees.

Likewise, trees categorized on moderate fall risk also do not need an advanced equipment evaluation because the probability of rupture would be significant only in extreme environmental conditions. Trees are self-optimized

Table 4. Risk Scale of the parts of the protected trees of Curitiba – PR (Matrix 1: likelihood of failure and impact; Matrix 2: risk rating matrix).

Escala de riesgo de las partes de los árboles inmunes de corte de Curitiba – PR.

Species	Tree part	Likelihood								Risk rating of the part (Matrix 2)	Tree risk scale
		Failure				Failure and Impact (Matrix 1)					
		Im.	Po.	Pr.	In.	Un.	Sw.	Li.	Vl.		
	C	X				X				Low	
1	T	X				X				Low	Low
	R	X				X				Low	
	C	X				X				Low	
2	T		X				X			Moderate	Moderate
	R	X				X				Low	
	C	X				X				Low	
3	T		X				X			Moderate	Moderate
	R	X				X				Low	
	C	X				X				Low	
4	T	X				X				Low	Moderate
	R		X				X			Moderate	
	C	X				X				Low	
5	T	X				X				Low	Moderate
	R		X				X			Moderate	
	C	X				X				Low	
6	T		X				X			Moderate	Moderate
	R	X				X				Low	
	C	X				X				Low	
7	T	X				X				Low	Low
	R	X				X				Low	
	C	X				X				Low	
8	T	X				X				Low	Moderate
	R		X				X			Moderate	
	C	X				X				Low	
9	T	X				X				Low	Low
	R	X				X				Low	
	C			X				X		High	
10	T		X				X			Moderate	High
	R	X				X				Low	
	C	X				X				Low	
11	T		X				X			Moderate	Moderate
	R	X				X				Low	
	C	X				X				Low	
12	T	X				X				Low	Low
	R	X				X				Low	
	C	X				X				Low	
13	T	X				X				Low	Low
	R	X				X				Low	
	C	X				X				Low	
14	T		X				X			Moderate	Moderate
	R		X				X			Moderate	

Note: C: Crown; T: Trunk; R: Roots; Im.: Improbable; Po.: Possible; Pr.: Probable; In.: Imminent; Un.: Unlikely; Sw.: Somewhat; Li.: Likely; Vl.: Very likely.

Table 5. Number of problems associated with the risk of the trees evaluated.
Número de problemas asociados al riesgo de los árboles evaluados.

nº	Species	Number of problems found				Tree risk scale
		Crown	Trunk	Roots	Total	
1	*Araucaria columnaris*	–	1	–	1	Low
2	*Caesalpinia leiostachya*	1	4	–	5	Moderate
3	*Carya illinoiensis*	3	4	–	7	Moderate
4	*Cedrela fissilis*	2	3	3	8	Moderate
5	*Enterolobium contortisiliquum*	1	3	4	8	Moderate
6	*Ficus gomelleira*	1	5	1	7	Moderate
7	*Handroanthus albus*	4	3	–	7	Low
8	*Hymenaea courbaril*	2	3	4	9	Moderate
9	*Livistona* sp.	–	1	1	2	Low
10	*Olea europaea*	9	6	2	17	High
11	*Peltophorum dubium*	1	4	–	5	Moderate
12	*Phoenix canariensis*	–	3	–	3	Low
13	*Phoenix canariensis*	–	1	1	2	Low
14	*Schizolobium parahyba*	1	4	3	8	Moderate

structures that have compensatory mechanisms to mitigate the stress caused by mechanical injuries, thus allowing better management responses (Mattheck and Tesari 2004, Ramirez *et al.* 2018). Although the advanced methods of tree risk assessment are more accurate and technological, they are also more expensive and cumbersome and have to be performed by technical expertise operators in relation to the visual analysis.

Although sophisticated risk assessments are effective for diagnosis of internal problems, it is still incomprehensible how the collected information by these instruments affect the likelihood of failure. It means these kinds of equipment are very punctual and may not be directly converted into a risk of failure. Hence, the use of advanced detection methods can reduce subjectivity, although it is not completely eliminated.

Ratio between the number of defects per tree and its category of risk. Among all trees evaluated, *O. europaea* was characterized as high risk because it showed a superior number of associated defects in relation to the others, being in the process of senescence. According to Vogt *et al.* (2015), the removal of dead and high-risk trees should be carried out as quickly as possible, unless damage to people or structures can be avoided by interdicting the site. However, since the squares are large public spaces, where the interdiction of the area would cause major disturbances, it is recommended to remove the individual at high-risk failure.

It is important to highlight that the decision of removal should be considered specifically for each species because only the fact of a tree presenting high-risk assessment does not indicate the need for removal. According to Terho (2009), the intensity of the defects presented will justify or not the action of removing a tree.

Therefore, trees categorized on high risk indicate the need for constant monitoring, since the intensity of defects associated with them tends to be higher, and consequently their likelihood of failure may be more significant over time.

CONCLUSIONS

It was possible to verify that the part of the tree with the highest number of defects was the trunk, as expected, as this is the most visible part of the tree. The most recurrent trunk defects were the presence of canker and the codominance of the branches. The crown presented the second largest number of defects, especially dead and broken branches. The uplift of the root system was the problem found in a more recurrent way.

Taking into account the risk of tree failure, most individuals had moderate risk, therefore, in general the number of defects was directly proportional to the risk category in which the trees were classified.

The adaptation of the protocol to the qualitative visual evaluation contributed to the determination of failure trees likelihood and allows obtaining practical and low-cost information of the diagnosis of the trees protected by law in Curitiba squares. In this way, the results may support arborists in monitoring and decision-making about the most effective measures to solve problems to maintain the quality of urban forest, which reflects on the safety and well-being of population that attends squares.

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