Hazard indicators in urban trees. Case studies on *Platanus x hispanica* Mill. ex Münchh and *Morus alba* L. in Mendoza city-Argentina *

Indicadores de riesgo en el arbolado urbano. Casos de estudio en *Platanus hispanica* y *Morus alba* en la ciudad de Mendoza-Argentina

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Abstract

Urban forests significantly benefit cities and people´s wellbeing. However, under suboptimal growth conditions, they can pose risks. The tree risk and tree hazard assessments in public spaces bring together several protocols for preventing damage to people and property. This article aims to strengthen the database on forest resources at the urban scale and to identify key characteristics of relevant species of street trees in Mendoza-Argentina. In terms of methodology, trees of *Platanus hispanica* (London Plane tree) and *Morus alba* (Mulberry tree) were evaluated *in situ* by indicators related to the probability of failure such as defects, injuries and stress signals. The results show deterioration of part of the urban forest, as well as the greater resilience of *P. hispanica* when compared to *M. alba*. We conclude that systematically implementing these assessments will provide guidelines for the sustainable management of urban trees, improving forest infrastructure under sustainable development guidelines.

Keywords

Platanus hispanica • *Morus alba* • risk assessment • urban forest • urban tree management

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Resumen

Los bosques urbanos aportan numerosos beneficios a las ciudades y a la calidad de vida de sus habitantes. No obstante, pueden ofrecer riesgos cuando su crecimiento no es óptimo. La evaluación de riesgo o peligrosidad de árboles en el espacio público reúne una serie de protocolos para prevenir daños a personas y bienes materiales. Este articulo busca fortalecer la base de información del recurso forestal a escala urbana e identificar características particulares de especies relevantes del arbolado público de Mendoza-Argentina. En términos metodológicos, se evalúan in situ una muestra representativa de ejemplares de *Platanus hispanica* y *Morus alba* con defectos, lesiones y signos de estrés. Los resultados muestran el grado de deterioro de parte del universo forestal urbano, como también la resiliencia de *P. hispanica* sobre *M. alba*. Se concluye que la aplicación de estas evaluaciones en forma sistemática y planificada, aportará directrices para el manejo sustentable del arbolado urbano; que mejore la infraestructura del bosque bajo lineamientos de desarrollo sustentable.

Palabras clave

Platanus hispanica • *Morus alba* • evaluación de riesgo • bosque urbano • manejo del arbolado urbano

Introduction

Trees growing in cities are conditioned by certain variables compromising their performance.

In this case, Mendoza-Argentina, with approximately 700,000 street trees only in the metropolitan area, has gained national and international recognition as an "oasis city." However, Mendoza has an arid climate and restrictive growth resources-mainly drought and thermal stress- (14). These circumstances require efficient management and monitoring in order to ensure this natural resource and the numerous ecosystem services provided.

The most frequently used species in urban alignments, particularly in the city of Mendoza, are *Platanus hispanica* (9%), *Morus alba* (39%), y *Fraxinus excelsior L and Fraxinus americana.* (20%), accounting for 68% of total street trees (15, 17). *Platanus hispanica* (London Plane trees) and *Morus alba* (Mulberry trees) are species widely used in the city of Mendoza, both for their size, of 1st and 2nd magnitude respectively, and for their shade and ecosystem services of regulation and comfort. In this context, urban trees provide numerous benefits, improving the urban climate, mitigating "heat island" intensity effects in climates with high heliophany; hydrating the atmosphere and reducing summer heat loads with consequent energy savings (22); allowing the retention of suspended particles and noise mitigation by foliage; increasing comfort conditions in public spaces and significantly contributing to urban aesthetics (15). According to dendrochronological analyses carried out *in situ* (13), the studied specimens show an approximate age of between 90 years (Mulberry trees) and 119 years (London Plane trees), while also showing symptoms of water and thermal stress and some obvious hazard indicators, such as cracks, hollows, and exudates.

Risk assessment of trees growing in urban public spaces (2, 4) supports subsequent improvement of tree growing conditions, enhancing benefits and preventing damage to people, material losses or service outages. Among several methods for risk assessment of urban trees, those using visual assessment and best known in urban arboriculture are the "Tree Hazard Evaluation Method" (16), "A Guide to Identifying, Assessing, and Managing Hazard Trees in Developed Recreational Sites of the Northern Rocky Mountains and the Intermountain West" (8), and "Best Management Practice - Tree Risk Assessment" (6). In this work, we applied the rapid visual evaluation protocol (1, 3).

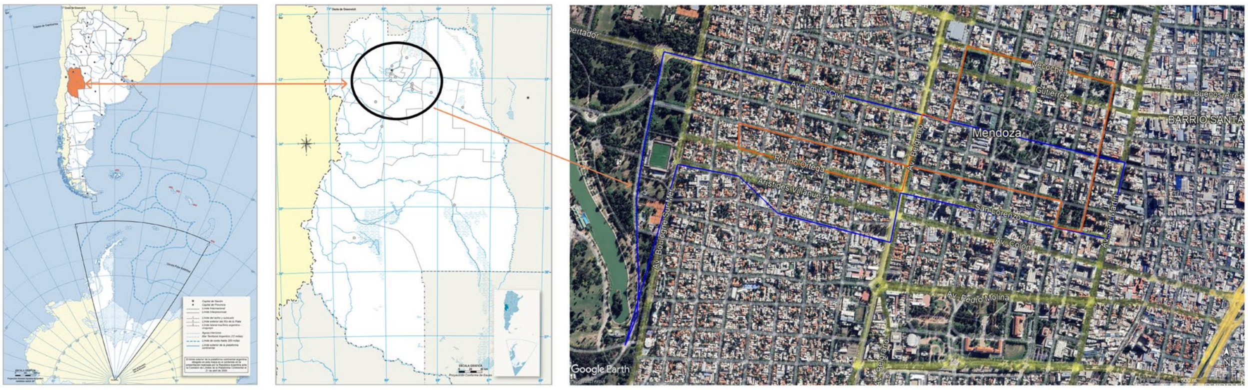
Our objectives are to strengthen the database and the analysis of urban forest in terms of risk assessment identifying key characteristics of important species in the city while providing guidelines for sustainable management of urban trees.

The hypothesis stated that "Growth patterns of urban trees reflect changes occurring in the city, such as frequent and severe pruning, impermeabilization of irrigation ditches, construction of infrastructure and land development. These stress factors, together with water scarcity and rising temperatures, impact growing conditions and increase tree failure likelihood. *Platanus hispanica* is comparatively more resilient to these impacts than *Morus alba*".

Materials and Methods

Study area

The province of Mendoza, situated at the foot of the Andes Mountains, is in central-western Argentina and included in the South American arid diagonal, between 32° and 37°35' south latitude - 66°30' and 70°35' west longitude (figure 1). Mendoza city is characterized by sustained aridity, a temperate-dry climate (BWk-Koppen), restricted water resources (average rainfall 250mm/year) and high constant solar radiation throughout the year (1840 MJ/m^2). The annual potential evapotranspiration (ET) is 782mm, indicating a water deficit of 532mm. The Mendoza Metropolitan Area (MMA) is an urban conglomerate with more than two million inhabitants characterized by massive presence of trees in an urban structure -tree/inhabitant ratio = 0.50 in 2021; (19); *i.e.,* one tree every two inhabitants.



Source/Fuente: IGN (Instituto Geográfico Nacional).

Sources: authors' elaboration and Google Maps.
Fuentes: elaboración de las autoras y Google Maps.

Figure 1. Location of the study area and map of the assessment route. Yellow and blue lines indicate walking tours.

Figura 1. Ubicación del área de estudio y mapa de la ruta de evaluación. Líneas naranja y azul indican los recorridos realizados.

The urbanized area has a high percentage of green spaces and tree alignments parallel to urban blocks and road layouts. An artificial irrigation network made up of irrigation canals carry water from the mountain snowmelt (14) supporting this forestation. However, the sustained scarcity of water resources during the decade 2010-2020 and the progressive loss of irrigation efficiency compromised growth, structural stability and forest health.

Tree Assessment

The two most frequent species were surveyed following a circuit that passed through the areas of low building density (< 2m^2/m^3) to the densely built-up area (>2 to 4 m^2/m^3). In the surveyed area, around 840 tree individuals were observed in street alignments, at regular planting intervals. Data collection was carried out between 22nd and 24th March 2023, in the area located between Colón Street (to the south), Emilio Civit/Sarmiento Street (to the north), San Martín Street (to the east) and Boulogne Sur Mer Street (to the west) (figure 1).

For risk assessment, walking tours were conducted along sidewalks and streets, according to a level 1 assessment (6), based on the rapid assessment method according to Coelho Duarte (2021b). This method aims to identify obvious tree defects and hazardous situations, without determining a final risk level.

The assessments resulted in a profile of probable failures per species and biomechanical adaptations. For this, the risk management of urban trees guide by Pokorny (2003) was used. Chapter 3, *How to detect and assess hazardous defects in trees*, describes tree defects divided into seven categories.

Results and Discussion

A total of 47 trees with hazardous defects were detected, 16 London Plane and 31 Mulberry trees, representing 6.5% of assessed trees. This low percentage of trees with higher likelihood of failure is expected and consistent with Coelho-Duarte (2021a), who recommends three different levels of assessment to optimize risk management.

Tree Hazard Indicators

Table 1, shows tree hazard indicators identifying defective trees by species.

Table 1. Number of trees for each hazard indicator and occurrence (%) by species.
Tabla 1. Número de árboles para cada indicador de riesgo y ocurrencia por especie (%).

Tree Hazard Indicators	*Platanus hispanica*		*Morus alba*	
	Trees	**%**	**Trees**	**%**
Root problems	8	50	6	19
Cracks	2	13	15	48
Weak branch unions	7	44	26	84
Decayed wood	10	63	23	74
Poor tree architecture	10	63	12	39
Cankers	12	75	9	29
Dead trees, tops, and branches	7	44	1	3
Conflicts with infrastructure	9	56	29	94
Structural support	1	6	8	26
Total	**16**		**31**	

Decayed Wood

Decayed wood results from the interaction among the tree, biodeterioration agents (such as bacteria, fungi or xylophagous insects) and environmental conditions (such as humidity and temperature) (7). In living trees, as decay progresses, cavities and hollows may appear, reducing structural strength and stability of the individuals (2). Rotten wood, the presence of fungal fruiting bodies, cavities, hollows, cracks, wood bulging and bark oozing are indicators of advanced wood decay (16, 20, 28).

In 63% of London Plane trees and 74% of Mulberry trees, some type of decay was observed during the assessment circuit, most of it due to severe or inadequate pruning, in which the trees are not able to complete wound compartmentalization (figure 2, page 156). Cavities with rotten wood were observed in trunks, while branch advanced decay with large pruning cuts showed, in some cases, wound wood and in others, loss of wood and cavities. No fungal fruiting bodies were observed during data collection, probably caused by the study taking part during late summer-autumn, with high temperatures.

In some trees, decay was associated with longitudinal cracks, especially in trees with codominant stems and included bark and cankers. Defects simultaneously occurring, and potentiated can increase failure likelihood, like cracks separating codominant stems with deterioration in the union area (8, 20). This combination of problems was mainly observed in Mulberry trees, associated with crown shape and consecutive pruning.

Among tree defence strategies against biodeterioration agents, the process of heartwood formation consists of wood gaining natural durability thanks to biochemical changes (7, 11).

Another important defence mechanism of trees is compartmentalization, first described by Shigo (1977) who stated four tree barriers formed in the *Compartmentalization of Decay in Trees* (CODIT) model, with changes at the chemical and anatomical level, preventing microorganisms from advancing into the wood. More recently, the letter D for *Decay* is also used as *Damage*, as compartmentalization can occur after a wound, with prior tissue infection (12).

In London Plane trees, wound wood formation was observed, even when pruning cuts or wounds caused by vehicular traffic, were large (figure 2).

Figure 2. Decay defect observed on **a-** *Morus alba* on Peatonal Sarmiento and **b-** *Platanus hispanica* with dry branches on Montevideo Street.

Figure 2. Defecto de pudrición observados en **a-** *Morus alba* de la Peatonal Sarmieneto y **b-** *Platanus hispanica* con ramas secas, en calle Montevideo.

Cracks

A crack is a separation in the wood tissue (16), and one major defect in more severe cases as they indicate the tree is already failing (20). Cracks can be formed when a trunk or branch does not support a certain load, either due to poorly closed wounds, split of weak unions or branches with overloaded limbs (2). They can also be caused by frost damage or sunscald (28). Vertical cracks following the direction of longitudinal fibers, were present in 48% of Mulberry trees, combined with the presence of codominant V-shaped stems and decay (figure 3a, page 157). In London Plane trees, they were rarely observed (13%), mostly associated with dead wood (figure 3b, page 157). These defects have a high to imminent likelihood of failure, and treatment should be recommended.

Root problems

Site factors such as reduced space for root development, shallow, compacted, or poor soil, cause tree decline in urban areas (27). Limited space for root growth of these first magnitude species, such as London Plane trees, and second magnitude like Mulberry trees, is compounded by impermeabilized irrigation ditches of Mendoza. Although this does not normally result in direct tree damage, decreasing soil moisture and oxygen availability, reduces tree ability to recover from injury, insect attack and/or disease (5). Also, root weakness results in loss of anchorage and support (28), increasing the possibility of whole-tree overturning. Thus, significant changes in the critical root radius (CRR) can lead to a high failure potential especially when more than 40% of the roots within this zone are damaged (9, 20). In Mulberry trees, impacts of ditch impermeabilization were observed in 19% of the trees (figure 4a, page 157). In 50% of London Plane trees some root problems were observed, such as girdling and exposed roots in search of oxygen (figure 4b, page 157).

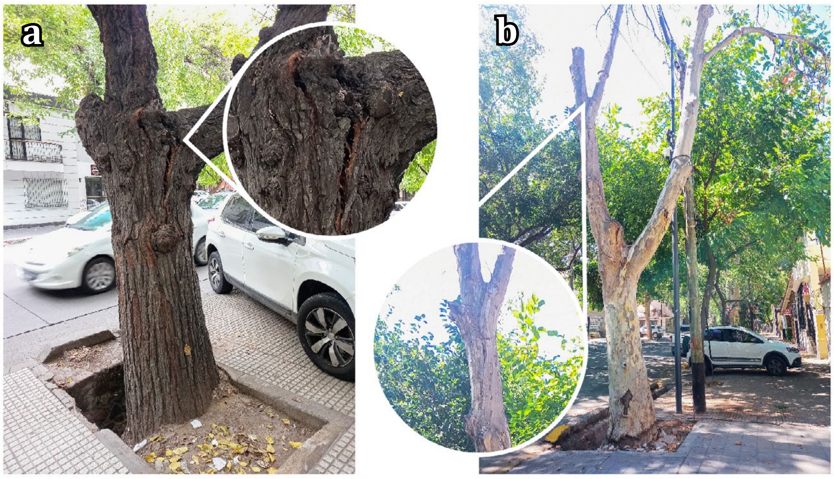


Figure 3. Crack defect in **a-** *Morus alba* and **b-** *Platanus hispanica*.
Figura 3. Defecto de grietas en **a-** *Morus alba* y **b-** *Platanus hispanica*.

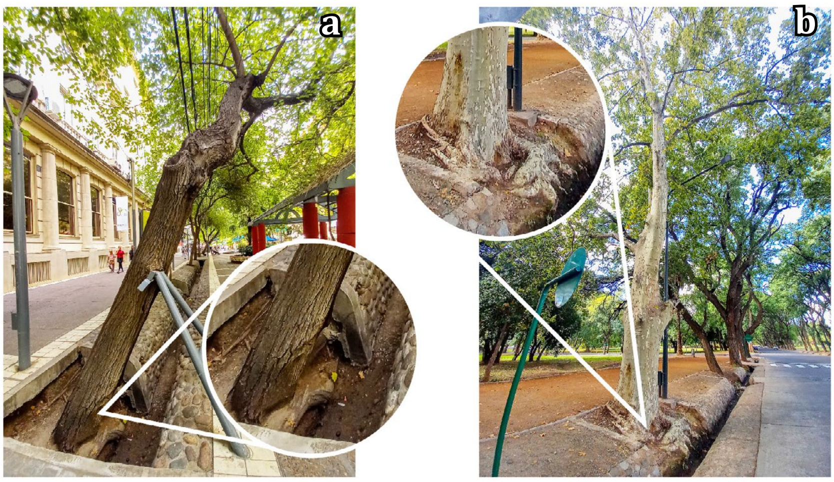


Figure 4. Root problems related to pot dimensions or planting site, and impermeabilization; **a-** *Morus alba*; **b-** *Platanus hispanica*.
Figura 4. Problemas del sistema radical relacionado con las dimensiones de la cazuela o sitio de plantación, e impermeabilización; **a-** *Morus alba*; **b-** *Platanus hispánica*.

Girdling roots compress root collar, hindering water, nutrients, and sap transport from and to the roots (9, 10). These roots can originate in the nursery itself, in seedlings grown in small pots, or when the tree is grown in a small rigid space, where structural roots are unable to grow laterally (16).

Weak branch unions

Wood at the stem union has anatomical changes that generate greater cohesion (25) to fulfil the function of absorbing and transmitting wind loads until they dissipate into the soil (28). Epicormic shoots emerge from dormant adventitious buds activated by stress conditions, such as topping (12). These buds may be present in the outer growth layers, resulting in superficial attachment. The larger the epicormic shoot, the greater the load on this weak union. On the other hand, included bark may be generated during the development of bifurcated stems or branch insertions which, instead of generating the more cohesive axillary wood, grow with bark between the stems, resulting in no connection between them. This may occur due to an intrinsic species trait, as in those with opposite buds, or after inappropriate management, altering bud development (24). Included bark can be detected by the V-shaped insertion, as opposed to a strong union, which would be U-shaped. Both included bark -especially between codominant stems resulting in opposing loads of similar magnitude- and epicormic shoots are types of weak unions present in trees (20). Eighty-four percent of Mulberry trees showed codominant, V-shaped structural branches with a very small angle of insertion and branches overextended towards the roadside. In some cases, this defect was combined with cracks, cankers, or rots (figure 5a). This makes stem splits the main likelihood of failure. In London Plane trees, 44% had weak unions, mainly in the most intensively managed trees, where the crown is largely made up of epicormic shoots and, in some cases, these weak unions were combined with decayed wood (figure 5b).

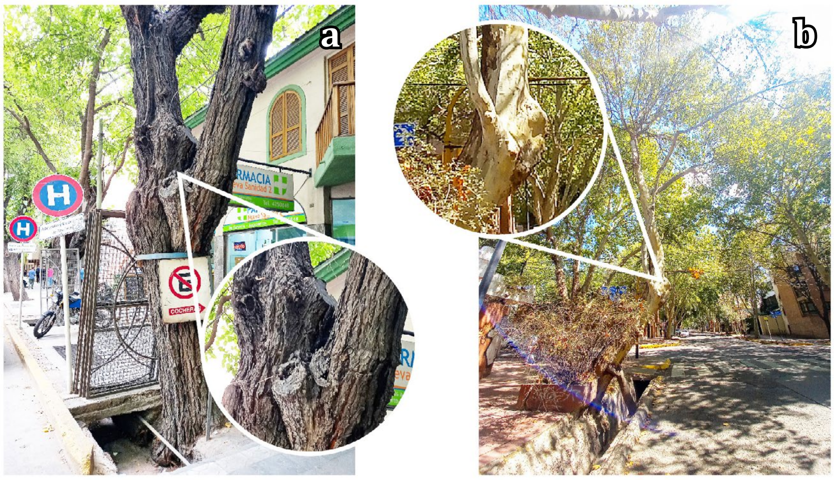


Figure 5. Defects concerning weak branch unions or codominant stems;
a- *Morus alba*; **b-** *Platanus hispanica*.

Figura 5. Defectos referidos a uniones débiles de ramas o troncos codominantes;
a-*Morus alba*; **b-** *Platanus hispanica.*

Cankers

Cankers are areas with damaged cambium (16) on trunks, branches, and roots (2). They can be caused by fungi, insects, lightning or mechanical damage, such as wounds caused by vehicles, lawn mowers, among others. According to Pokorny (2003), regardless of the origin of the damage, more than 40% affectation of the circumference of a tree may cause failure and, in turn, if the canker is associated with decay, it can quickly weaken the tree. In the streets of Mendoza city, cankers were mainly associated with pruning wounds and decay, being recorded in 29% of the Mulberry trees and 75% of the London Plane trees. Figure 6a (page 159), shows a Mulberry tree with abnormal basal growth, appearing as a "wood belt" (16), which may have been caused by damage during changes in the sidewalk. In one specimen of London Plane an abnormal discoloration, combined with branch dieback, may have been associated with disease. In another case, a gall-like growth was observed, with a significant change in bark texture (figure 6b, page 159). According to Mattheck *et al.* (2015), this form is not associated with a severe structural problem. The problem is aggravated when the canker is associated with decayed wood.

Figure 6. Canker present in **a-** *Morus* and **b-** *Platanus*.

Figura 6. Defectos compatibles con cancros en **a-** *Morus* y, **b-** *Platanus*.

Poor tree architecture

Poor architecture suggests imbalance and weakness of branches, trunk, or whole tree. According to Pokorny (2003), indicators could be unbalanced crown leaning, overextended, twisted, bent or harp-shaped branches, multiple stems or epicormic shoots originating from the same area and stump sprouts.

Among the trees assessed, 63% of the London Plane trees and 39% of the Mulberry trees showed some problem related to architecture, especially observed in those subsequently intervened by pruning, resulting in an unbalanced, curved shape (figure 7a) and with overextended branches towards the roadside. Although these indicators, according to Pokorny (2003), correspond to a moderate likelihood of failure, these defects are in some cases combined with the presence of decayed wood (figure 7b).

Figure 7. a- Imbalance in the morphology of a Mulberry tree in Peatonal Sarmiento. **b-** London Plane tree with poor architecture accompanied by decayed wood.

Figura 7. a- Desequilibrio en la morfología de Morus, en Peatonal Sarmiento. **b-** Platanus con arquitectura pobre acompañada de madera seca.

Dead trees, tops, and branches

Dead branches can remain attached to the tree for a long time, and suddenly break off as they no longer have the tension that keeps them attached (20). This was observed in 3% Mulberry trees, and 44% London Plane trees, especially where impermeabilisation hindered water availability (figure 8). The dieback observed in London Plane specimens may be associated with site factors leading to root decay, such as soil compaction or impermeabilisation that impede root gas exchange reducing root mass and, consequently, water and nutrient absorption (16). As a result, the tree starts to die out from the branch tips inwards (20).

Figure 8. London Plane individuals showing signs of dieback.

Figura 8. Ejemplares de plátanos con signos de "muerte regresiva".

Slenderness (H:D)

Slender trees may be more prone to mechanical failure, causing permanent bending or stem breakage (8). The slenderness index, characterizing likelihood of failure, is calculated by dividing tree total height by the diameter at breast height (both in meters). Many authors classify the likelihood of failure as possible for slenderness between 60 and 80, probable between 81 and 100, and imminent over 100. When "lion tailing" pruning is done, leaving branches accumulated at the ends of main stems, slenderness is increased. Another factor increasing this index is tree planting near tall buildings, reducing light availability, and promoting growth in height without an increase in trunk diameter (15) something the tree will correct only under healthy, vigorous conditions (28). Figure 9 (page 161), shows this behavior in a London Plane specimen showing signs of crown lifting pruning. In addition, the epicormic origins of these branches, with a weaker union, as well as the presence of non-compartmentalized pruning wounds with decay, can increase likelihood of failure.

Conflicts with infrastructure

In addition to the risk of structural failure, interference with pedestrian walkways, underground utilities or utility poles and wires should be considered in the risk assessment (6). The presence of aerial utility wiring in the city of Mendoza with either Mulberry or London Plane trees (figure 10, page 161), increases the need for frequent interventions on the tree crown to reduce the occurrence of friction between branches and wires. These conflicts were observed in 94% of the Mulberry trees and 56% of the London Plane trees. Greater deterioration is observed in the Mulberry trees in general, compared to the London Plane trees.

Figure 9. Defect in London Plane trees compatible with slender individuals.
Figura 9. Defecto en Platanus compatible con ejemplares esbeltos.

Figure 10. Conflicts with utility wiring and lighting poles; **a-** *Morus alba*; **b-** *Platanus hispanica*.

Figura 10. Interferencias con cableado y postes de iluminación pública; **a-** *Morus alba*; **b-** *Platanus hispanica*.

Biomechanical adaptation

Biomechanics study how trees adapt to different growth sites, climatic conditions, and stresses (2). Ditches create special conditions for root performance, and in many cases, impermeabilization adds resistance making root growth limited. In some individuals of both species, structural roots and root collar growth, was observed above ground level and towards the roadside curb (figure 11, page 162). Although this tissue contains dormant adventitious buds, that become active under stress-generating epicormic shoots, it does not provide the expected structural anchorage (16). In addition, the wood in this area is exposed to mechanical damage and deterioration agents such as fungi and xylophagous insects.

Figure 11. Structural roots and root collar growth above ground level.
Figura 11. Crecimiento de las raíces estructurales y del cuello por arriba del nivel del suelo.

Structural support

Supports are necessary when the tree has a probable or imminent likelihood of failure due to high pedestrian/vehicle occupancy rate or presence of targets that cannot be moved (12). This generally occurs when tree adaptation is slow compared to the response needed to reduce the hazard. In the study area, supports were observed on Mulberry trees tying co-dominant stems, where a crack separating them was already visible (figure 5a, page 158). Supports were also observed on steeply inclined trees in both species (figure 12).

When using supports, tree reactions such as wound generation or positive adaptive response must be monitored, and the option of relocating, reinforcing, or removing the support, should be evaluated. However, in some cases, supports generated wounds or cracks, indicating it should have been removed after the tree corrected the lean.

Figure 12. Individuals of *Platanus* and *Morus* with structural supports, orthopedics or "crutches".
Figura 12. Ejemplares de *Platanus* y *Morus* con soportes estructurales, ortopedias o "muletas".

General discussion

The failure profile indicated that the main problems identified in London Planes were cankers with decay, combined with poor branch architecture, caused by successive and intensive pruning to release aerial wiring. These problems indicating a "probable" likelihood of failure, were more evident in streets with ditch impermeabilization and/or inefficient irrigation. In most streets, London Plane trees were in good phytosanitary condition and the wounds were compartmentalized.

On the other hand, Mulberry trees showed more dangerous defects, with an "imminent" likelihood of failure. Indicators were the presence of cracks in the codominant stems union with bark included, or along overextended structural branches, in both cases combined with decay. Mulberry trees were also intervened year after year, with large cuts releasing utility wiring. In many cases, this resulted in an imbalanced architecture of the crown, with branches overextending towards the roadside. Additionally, pruning cuts were not effectively compartmentalised, with evident decay, cankers, and exudations. In addition to interventions due to competition with the aerial utilities, changes around the root system also affected some individuals, such as changes in soil level and impermeabilization of ditches, also observed in London Planes.

In addition to the obvious conflict with the city's grey infrastructure, these trees are ageing without adequate maintenance. The literature indicates that large, mature trees generate more ecosystemic services than small trees (18, 21, 26). The problem is established when these large individuals deteriorate and with indicators of "probable to imminent" likelihood of failure. This, combined with high occupancy rate of the area and the large size of parts that can fail, results in high to extreme risk. In this scenario, increasing decay and consequent reduction in vigor, in addition to the already detected conditions of water and heat stress, seriously impact ecosystem services and tree safety. This reinforces the need for the development of short-term strategic management including the replacement of trees posing the highest risks.

Conclusions

This rapid visual assessment allowed for an efficient survey of street trees, identifying main problems in two major species in Mendoza city -*Platanus hispanica* and *Morus alba*- and in areas with the highest occupancy rate, where the fall of a whole or part of a tree could cause significant damage. Potential failure or defect profiles increase efficiency in surveying monitoring zones, making assessments more effective, especially in areas with higher vehicular and pedestrian traffic flow.

In cases with a probable to imminent likelihood of failure, we recommended following the risk management protocol and making more in-depth assessments at a level 2 or basic visual level, indicating risk mitigation treatments.

In comparative terms, London plane showed the presence of cankers with decay, combined with poor branch architecture, while mulberry trees showed more dangerous defects, and "imminent" likelihood of failure, cracks in the union area of codominant structural branches with bark included and signs of decay. In this sense, London plane is recommended for new urban forests in highly consolidated areas and under intense anthropic pressure, compared to Mulberry tree.

Although this case study does not provide an in-depth assessment of species adaptation, the defect profiles can be considered as a preliminary conclusion on London Plane trees being more resilient to pruning interventions compared to Mulberry trees. However, changes near the root zone, and in the frequency and amount of irrigation, lead to a considerable decrease in vigor.

The planning and integration of knowledge, scientific advances and practical experience have a positive impact on the management and preservation of urban forests as a public resource in cities. This is even more relevant in the case of Mendoza, given climatic and geographical conditions in terms of water restriction, environmental vulnerability, and advances in urbanization patterns.

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