



Daño a la infraestructura (pavimento) causado por el arbolado urbano en Puerto Vallarta, Jalisco

Damage to infrastructure (pavement) caused by urban trees in Puerto Vallarta, Jalisco

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Resumen

Se realizó un estudio para analizar los árboles que por su localización inadecuada causan daño significativo a la infraestructura, entre la que se destaca al pavimento de las áreas verdes urbanas de Puerto Vallarta, Jalisco, se describen los factores que explican el daño registrado. En 14 parques y plazas públicas, se realizó el censo de árboles y palmas. El nivel de daño se evaluó en las especies con ≥ 10 individuos por taxón en las áreas verdes y se hizo en función de tres factores: a) biológico (diámetro a la altura del pecho, altura total y área de copa); b) social (posibilidad de reparación de daños); y c) ambiental (distancia del árbol al pavimento, principalmente). Para el nivel de daño al pavimento (sin daño, poco daño, daño moderado, daño severo), se consideró la condición de la infraestructura y porcentaje de daño. De los 1 228 individuos arbóreos, 85 % no mostraba ningún daño visible a la infraestructura (pavimento) de los parques y plazas públicas. De las 20 especies estudiadas, *Enterolobium cyclocarpum*, *Ficus benjamina*, *Ficus insipida*, *Ficus lapathifolia* y *Simaruba glauca* fueron las que causaron daños de moderado a severo. El diámetro a la altura del pecho, altura total y área de copa fueron los factores que explicaron significativamente el daño al pavimento. Los resultados muestran que para disminuir el daño de los árboles y palmas a la infraestructura, se tienen que conocer los atributos biológicos de las especies por plantar, y con ello asegurarles el espacio suficiente para su desarrollo.

Palabras clave: Altura total, área de copa, diámetro de tronco, *Enterolobium cyclocarpum* (Jacq.) Griseb, pavimento, raíces.

Abstract

A study was carried out to analyze the trees that, due to their inadequate location, cause significant damage to the infrastructure —notably to the pavement of the urban green areas of Puerto Vallarta, Jalisco—, describing the factors that explain the registered damage. A census of trees and palms was made in 14 parks and public squares. The level of damage was only evaluated in species with 10 individuals each, present in green areas. Three factors were evaluated in the individuals and green areas: a) biological (diameter at breast height, total height, and crown area); b) social (possibility of repairing damages), and c) environmental (distance of the tree to the pavement, mainly). In order to evaluate the level of damage to the pavement (no damage, little damage, moderate damage, severe damage), the condition of the infrastructure and the percentage of damage to the pavement were considered. Eighty-five percent of the 1,228 tree individuals did not exhibit any visible damage to the infrastructure (pavement) of the parks and public squares. Of the 20 species considered, *Enterolobium cyclocarpum*, *Ficus benjamina*, *Ficus insipida*, *Ficus lapathifolia* and *Simaruba glauca* were the ones that caused moderate to severe damage. Stem diameter at breast height, total height, and crown area are the factors that significantly explain the damage to pavement. The results show that, if the damage caused by trees and palms to the infrastructure is to be reduced, it is necessary to know the biological attributes of the species in order to ensure sufficient space for their development.

Key words. Total height, crown area, stem diameter, *Enterolobium cyclocarpum* (Jacq.) Griseb, pavement, roots.

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Introduction

Urban trees are defined as publicly or privately owned trees that are located within an urban area and are part of the infrastructure (Akmal and Othman, 2012). It should be noted that trees are the main providers of ecosystem services in urban areas (Dobbs *et al.*, 2011), by providing some environmental, social and economic benefits. Among the environmental benefits they contribute, they improve the microclimate, store carbon dioxide, produce oxygen, reduce soil erosion, retain suspended particles, and provide shelter for several fauna species (Niemelä *et al.*, 2010; Escobedo *et al.*, 2011). Social benefits include increased physical and mental health, and comfort for people who engage in recreation and leisure activities in the green areas (Jiang *et al.*, 2014; Elmqvist *et al.*, 2015). Among the economic benefits, it has been documented that the presence of green areas with trees can increase the value of a residential area by up to 15 %, in addition to reducing energy costs in coolers due to their ability to regulate temperature (Tovar, 2006; Egas, 2017).

Although the benefits of urban trees are widely recognized, if their planting is not planned, they also generate problems to the environment. These include the costs for their establishment or maintenance (Tovar, 2006), as well as issues related to human health and welfare, since some taxa exhibit undesirable attributes for humans, such as the generation of volatile substances, the presence of toxic compounds in seeds and fruits, pests and pathogens, or species that produce unpleasant odors, like those of fruits in the process of rotting (Lyytimäki, 2017; Esquivel *et al.*, 2021; Roman *et al.*, 2021). On the other hand, pollen and some seeds cause skin or respiratory allergies that are more severe in sensitive people (Calaza e Iglesias, 2016; Lyytimäki, 2017).

The physical and mechanical problems from urban trees are the most recognized in previous works. Trees represent a hazard because they induce visible damage to

urban infrastructure or to the physical integrity of people (Tomao *et al.*, 2015; Lyytimäki, 2017). The main physical factors are derived from the physical state of the tree and the environment where it develops, or from external factors such as wind speed, rain, and snow, which increase the probability of the collapse of a tree or part of it (Matheny and Clark, 2009; Roman *et al.*, 2021).

Mechanical problems respond to the interaction of the tree with the environment in which it grows. These are damages to infrastructure or pipes, or issues with electrical, telephone or other types of wiring (Calaza and Iglesias, 2016), which reduce the safety of pedestrians, cyclists, and motorists, and even of the tree itself, in addition to reducing the aesthetics of green areas and producing a major economic problem for administrations, due to the high repair costs (McPherson, 2000; Roman *et al.*, 2021).

Damage to infrastructure caused by urban trees, such as pavements, sidewalks and planters can be explained by biological, social and environmental factors. Among the former, the variables growth rate, tree dimensions, root type, and origin of the species have been evaluated (Beltrán, 1979; Benavides *et al.*, 2004; Akmal and Othman, 2012; Acosta, 2013; Rodríguez and Ferro 2014; Giuliani *et al.*, 2015; Alani and Lantini, 2020; Hilbert *et al.*, 2020). As for the social factors, the variables that describe the site where the urban trees are located have been analyzed, among them: maintenance history, land use, and socioeconomic condition (Beltrán, 1979; Acuña, 1999; Akmal and Othman, 2012; Acosta, 2013). Environmental factors are the most frequently studied; they depend on variables such as precipitation, distance to infrastructure, soil condition and pavement type (Beltrán, 1979; Acuña, 1999; Benavides *et al.*, 2004; Akmal and Othman, 2012; Giuliani *et al.*, 2015; Alani and Lantini, 2020; Hilbert *et al.*, 2020). Studies on this subject determine potential solutions to reduce this problem, as well as to improve the patterns of selection of tree taxa in urban green areas.

In view of this panorama, the objective of the present work was to evaluate the damage to the pavement of the public squares in *Puerto Vallarta, Jalisco* caused by

the size and location of the trees; the biological, social and environmental factors that explain the level of damage to the infrastructure were identified; and recommendations were issued to avoid them in the long term. Based on the objectives of the study, three predictions related to biological, social and environmental factors were proposed. First, trees with larger dimensions (stem diameter, total height, and crown area) are expected to cause greater damage to the infrastructure of parks and squares (Hilbert *et al.*, 2020), because these organisms require more space for their development, which is restricted by poor selection and planning. Secondly, it is expected that individuals in parks located in areas with a high and medium socioeconomic status will exhibit a lower level of damage to infrastructure than those located in parks in areas with a low socioeconomic status (Acuña, 1999). This is due to the fact that the authorities or inhabitants of high and medium socioeconomic areas tend more to repair (or prevent) damage to infrastructure. Finally, it is expected that the shorter the distance between the trees and the infrastructure, the higher the level of damage will be (Akmal and Othman, 2012; Alani and Lantini, 2020), because the space required for tree growth, which is crucial to avoid damage, is not respected.



Materials and Methods

Study area

The study area is located in *Puerto Vallarta*, a municipality in the North Coast region of the state of *Jalisco*, Mexico (Figure 1). It borders to the north with the state of *Nayarit*; to the south, with the *Cabo Corrientes* and *Talpa de Allende* municipalities; to the east, with *San Sebastián del Oeste* and *Mascota*, and to the west, with the Pacific Ocean (Semar, 2016). *Puerto Vallarta* city is geographically located between the 20°28' and 20°56' N, and 104°58' and 105°20' W, at an altitude of 2 m. Its territorial extension is 1 300.67 km² (Semar, 2016), and a population of 291 839 inhabitants (Inegi, 2020).

This place is surrounded by tropical deciduous and sub-deciduous forest (Ramírez-Delgadillo and Cupul-Magaña, 1999). Within it, 14 green areas were selected as study sites, which included parks and public squares distributed throughout the city; green areas with a constant influx of local inhabitants, national and foreign tourists, with free and easy access, but above all located in parts of the city that allow work to be carried out under safe conditions (Figure 1).





Figure 1. Location of the parks and public squares surveyed in *Puerto Vallarta, Jalisco, Mexico.*

Biological factors

In each selected park and public square, all woody individuals, palm or tree, with a diameter at breast height ≥ 6.37 cm (Perimeter = 20 cm), were counted and measured; this diameter size ensures that the individual has become established and will have continuity of growth. Species identity and scientific name were corroborated in the Tropicos global database (<https://www.tropicos.org/home>). The measurements obtained were diameter at breast height (Forestry Suppliers IC 283D/5M diametric tape), total height (Haga 1950 altimeter) and crown area (Truper TFC-50ME tape). For branched individuals, the diameter of all the stems was added up. The crown area was obtained from the two main crown diameters, one from north to south and the other from east to west.

Social factor

The variable describing the social factor was the maintenance of infrastructure in areas with different socioeconomic levels, which has been considered in other studies and has been related to the possibility of repairing damage to the infrastructure (Akmal and Othman, 2012; Olivero-Lora *et al.*, 2019). The damage can be repaired by the local authorities or by the users. This variable was obtained from the valuation by zone, considering as a reference the material and appearance of the pavement (cobblestone, concrete, with or without potholes), presence of street commerce, underground or overhead wiring, low-income housing, and proximity to commercial areas, among others.

Environmental factor





This was represented with the variable distance to the infrastructure, interpreted as the space available for the tree to grow; thus, the space between the base of the tree and the nearest infrastructure, such as a sidewalk, sidewalk, walkway or borders that delimit a planter was measured; the infrastructure was mainly made up of cement cobblestone, paving stones and concrete (Acuña, 1999; Benavides *et al.*, 2004).

Level of damage

In order to quantify the damage caused by the size and location of the tree, two variables were considered and integrated: the condition of the infrastructure (pavement) and the percentage of damage to the infrastructure. The former was evaluated based on the presence or absence of damage to the infrastructure caused by a tree, by drawing an imaginary circle around the individual tree, with a standardized measurement of one meter radius, whose alteration was categorized and assigned a score from 0 to 3 (Table 1). The standardized area around the tree was established in order to systematically compare the individuals that generated


cracks and lifted the pavement, independently of registering the variables related to biological, social or environmental factors.

Table 1. Categories and scores for evaluating pavement cracking and heave.

No damage = 0 points	Minor cracks = 1 point	Cracks and moderate heave = 2 points	Cracks and severe heave = 3 points
			

The percentage of damage to the infrastructure was evaluated on the basis of the visible damage around the tree or palm. For the aims of this work, damage to foundations, drains, fences or any other type of construction was not considered because these were absent from the green areas. Having drawn an imaginary circle around the individual tree, with a radius of approximately one meter, the percentage of damage within the circle was determined, corresponding to one of the five categories already established and having an assigned score value (Table 2).

Table 2. Infrastructure damage percentage categories and scores.

Illustrative image of the visual assessment	Damage percentage category	Score
	No damage	0
	1-20	1
	21-40	2
	41-60	3
	61-80	4
	81-100	5

Finally, for each individual, tree or palm, the score of the infrastructure condition variables and the percentage of damage were added up, and the sum corresponded to a total score and a damage category (Table 3). The level of damage was determined for species with 10 individuals and present in any of the green areas under study; thus, the identified patterns were representative of the most abundant or frequent species.

Table 3. Pavement damage level categories and scores.

Level of damage	Score	Description	Color
No damage	0	Tree or palm that does not cause cracks or damage to sidewalks or infrastructure	Grey
Slight damage	1-2	Tree or palm that may present slight cracks and a percentage of damage on the infrastructure less than or equal to 20 %	Orange
Moderate damage	3-5	Tree or palm that can present from slight cracks to cracks and lifting, and a percentage of damage on the infrastructure of 21 to 60 %	Yellow
Severe damage	6-8	Tree or palm that may present cracks and severe uplift and a percentage of damage on the infrastructure of 60 to 100 %	Red

Data analysis

Non-parametric Kruskal-Wallis tests were performed (as Chi-square value; χ^2) in order to examine differences between pavement damage levels and biological (stem diameter, total height, crown area) and environmental (distance to infrastructure) variables. Contingency analysis (Chi-square test; χ^2) was used to evaluate the differences in the level of damage to infrastructure and the social variable (socioeconomic status). In order to visualize the similarities in the level of damage to the infrastructure caused by the woody species, a non-metric multidimensional scaling (NMDS) was performed using the Bray-Curtis index (Hammer *et al.*, 2001) as a clustering index. The analyses were performed using the JMP 8.0 (Proust, 2008) and PAST[®] 3.25 softwares (Hammer *et al.*, 2001).

Results

In the 14 parks and public squares surveyed, a total of 1 223 trees or palms belonging to 36 families, 78 genera and 96 species were recorded. Of the 20 most abundant and frequent taxa (Table 4), *Cocus nucifera* L. (COCNUC) and *Tabebuia rosea* (Bertol.) DC. (TABROS) were the most abundant (Figure 2); 1 091 individuals were quantified, of which 663 corresponded to introduced species, and 428, to nine native species.

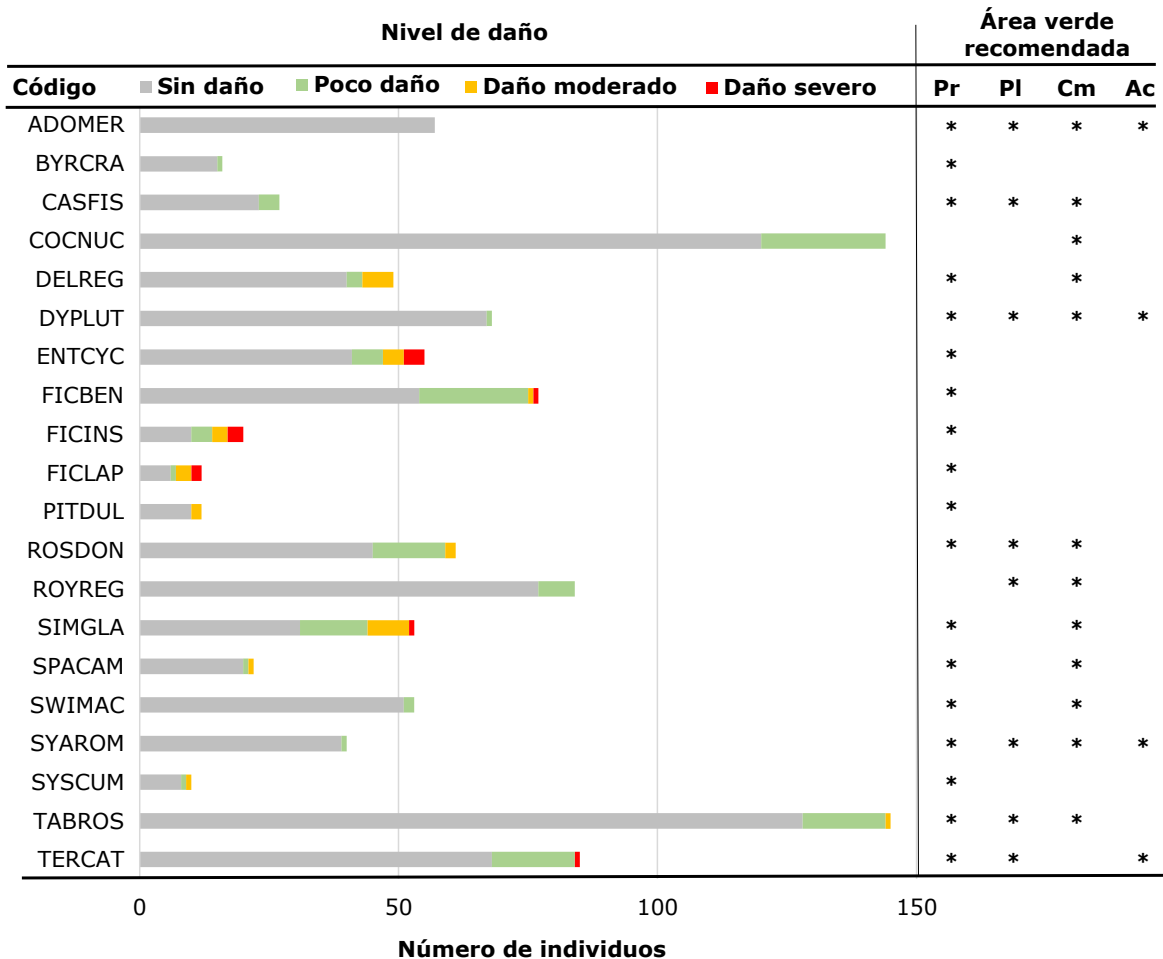
Table 4. Trees and palms with more than 10 individuals in the parks and public squares of *Puerto Vallarta, Jalisco, Mexico*.

No.	Species	Code	Family	Common name	O&D
1	<i>Adonidia merrilli</i> Becc.	ADOMER	Arecaceae	Manila palm	I
2	<i>Byrsonima crassifolia</i> (L.) Kunth	BYRCRA	Malpighiaceae	Nance	N
3	<i>Cassia fistula</i> L.	CASFIS	Fabaceae	Golden shower	I
4	<i>Cocos nucifera</i> L.	COCNUC	Arecaceae	Coconut palm	I
5	<i>Delonix regia</i> (Bojer ex Hook.) Raf.	DELREG	Fabaceae	Flamboyant	I
6	<i>Dypsis lutescens</i> Beentje & J. Dransf.	DYPLUT	Arecaceae	Areca palm	I
7	<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	ENTCYC	Fabaceae	Parota	N
8	<i>Ficus benjamina</i> L.	FICBEN	Moraceae	Benjamin fig	I
9	<i>Ficus insipida</i> Willd.	FICINS	Moraceae	Wild fig	N
10	<i>Ficus lapathifolia</i> (Liebm.) Miq.	FICLAP	Moraceae	Amate	N
11	<i>Pithecellobium dulce</i> (Roxb.) Benth.	PITDUL	Fabaceae	Monkeypod	N
12	<i>Roseodendron donnell-smithii</i> (Rose) Miranda	ROSDON	Bignoniaceae	Primavera	N
13	<i>Roystonea regia</i> (Kunth) O.F. Cook	ROYREG	Arecaceae	Cuban royal palm	I
15	<i>Simarouba glauca</i> DC.	SIMGLA	Simaroubaceae	Paradise tree	N
15	<i>Spathodea campanulata</i> P. Beauv.	SPACAM	Bignoniaceae	African tulip tree	I
16	<i>Swietenia humilis</i> Zucc.	SWIHUM	Meliaceae	Mahogany	N
17	<i>Syagrus romanzoffiana</i> (Cham.) Glassman	SYAROM	Arecaceae	Queen palm	I
18	<i>Syzygium cumini</i> (L.) Skeels	SYZCUM	Myrtaceae	Malabar plum	I
19	<i>Tabebuia rosea</i> (Bertol.) DC.	TABROS	Bignoniaceae	Pink trumpet-tree	N
20	<i>Terminalia catappa</i> L.	TERCAT	Combretaceae	West Indian almond	I

O&D= Origin and distribution; I = Introduced; N = Native.

Of the total number of individuals evaluated, 83.5 % caused no damage to the pavement due to their location; 12.5 % reached the level of slight damage; 2.9 %, of

moderate damage, and 1.1 % were classified as causing severe damage (Figure 2). Species that caused moderate and severe damage were *Enterolobium cyclocarpum* (ENTCYC), *Ficus lapathifolia* (Liebm.) Miq. (FICLAP), *Ficus insipida* Willd. (FICINS), and *Simarouba glauca* DC. (SIMGLA). According to the level of damage caused by the 20 taxa, a recommendation was assigned for their use in different urban green areas.

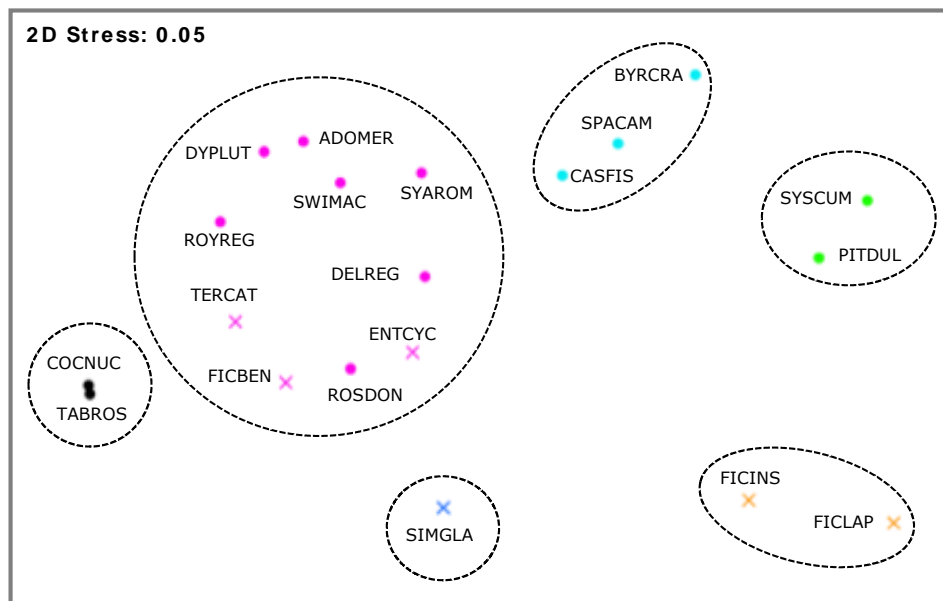


Código = Code; *Número de individuos* = Number of individuals; *Sin daño* = No damage; *Poco daño* = Slight damage; *Daño moderado* = Moderate damage; *Daño severo* = Severe damage; *Área verde recomendada* = Recommended green area.

Pr = Park; PI = Square; Cm= Median strip; Ac=Sidewalk.

Figure 2. Level of pavement damage in parks and public squares associated with the size and location of individuals of 20 selected tree and palm species.

Six groups of species were formed according to the level of damage associated with the pavement (Figure 3). The non-metric multidimensional scaling analysis (NMDS) showed that one of the groups is made up of 10 taxa with intermediate abundance levels —of 40 to 85 individuals—, which tend to occupy all damage categories. Another group was made up of the most abundant species: *C. nucifera* (COCNUC) and *T. rosea* (TABROS), most of whose individuals were not associated to damage. The NMDS result was shown to be significant, with a stress value of 0.05.

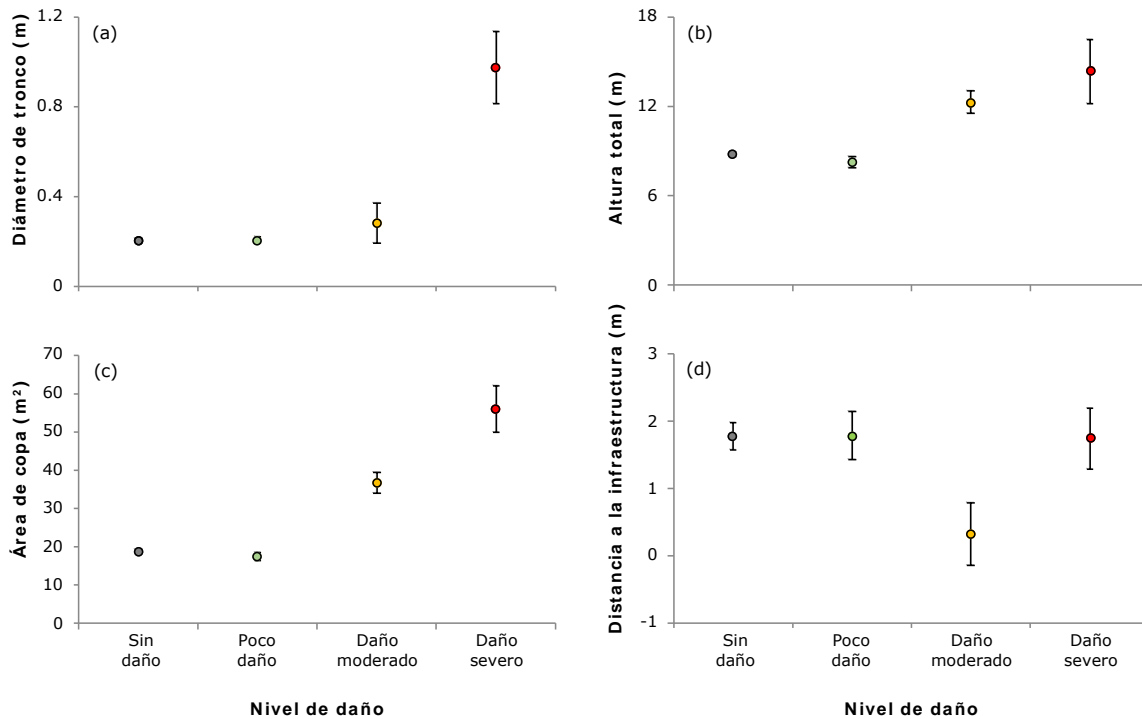


The colors represent the six groups identified. Species shown with x's have individuals that caused severe damage. The full name of the species can be consulted in Table 4.

Figure 3. Non-metric multidimensional scaling analysis (NMDS) for the 20 species of trees and palms associated with pavement damage in parks and public squares in *Puerto Vallarta*.

Biological, or dasometric variables significantly explain the level of pavement damage caused by the size and location of individual trees and palms (Figure 4).

The highest level of damage was generated by individuals with a larger stem diameter ($\chi^2 = 36.82$, $p < 0.001$; Figure 4a), greater height ($\chi^2 = 33.33$, $p < 0.001$; Figure 4b) and larger crown area ($\chi^2 = 54.02$, $p < 0.001$; Figure 4c). The Kruskal-Wallis nonparametric test showed differences in the level of damage at different distances from the infrastructure ($\chi^2 = 12.08$, $p = 0.0071$; Figure 4d).

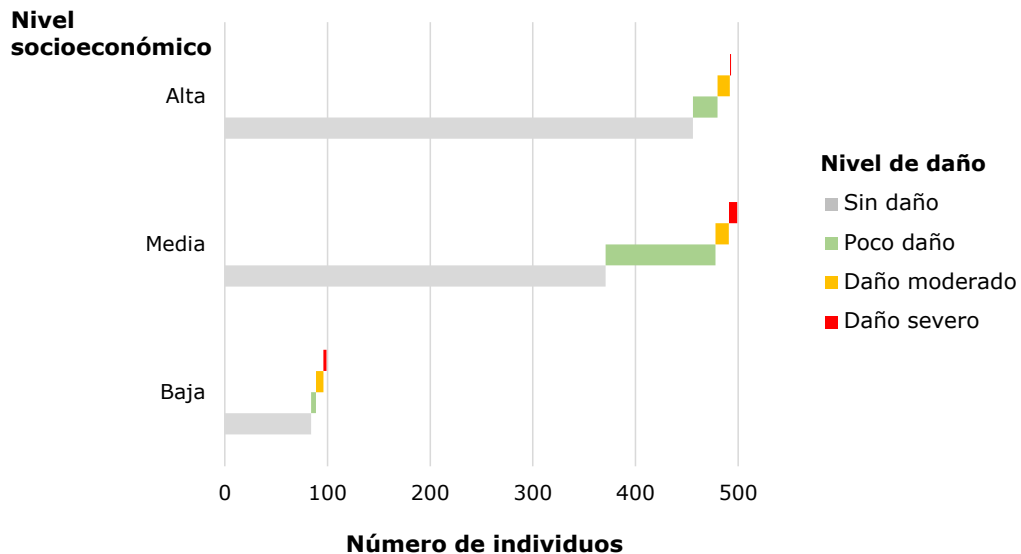


Nivel de daño = Damage level; *Sin daño* = No damage; *Poco daño* = Slight damage; *Daño moderado* = Moderate damage; *Daño severo* = Severe damage; *Diámetro de tronco* = Stem diameter; *Altura total* = Total height; *Área de copa* = Crown area; *Distancia a la infraestructura* = Distance to the infrastructure

Figure 4. Relationship between the level of pavement damage in public parks and squares and variables related to biological factors, a) stem diameter at breast height, b) total height, c) crown area, and the environmental factor d) distance to the infrastructure.

Socioeconomic level, as a social factor, significantly explained the possibility of repairing the damage caused by woody individuals to the infrastructure (Figure 5).

Based on the total number of trees and palms by socioeconomic level, the highest percentage of individuals that caused severe damage was significantly higher in the low socioeconomic level (3 %) than in the average (1.6 %) and high levels (0.2 %; $\chi^2 = 83.1, p < 0.001$). In parks and squares located in high socioeconomic areas, there was a significantly higher number of individuals not associated with damage (92.5 %), compared to the medium (74.3 %) and low (84.9 %) socioeconomic areas. This is because the high socioeconomic areas have the possibility of repairing the damaged infrastructure, which gives an appearance of absence of damage due to the poor location of the tree species.



Número de individuos = Number of individuals; *Nivel de daño* = Damage level; *Sin daño* = No damage; *Poco daño* = Slight damage; *Daño moderado* = Moderate damage; *Daño severo* = Severe damage; Socioeconomic level; Alta = High; Media = Medium; Bajo = Low.

Figure 5. Relationship between damage to the infrastructure of parks and public squares and socioeconomic status.

Discussion

The present study showed that the most abundant trees and palms in parks and public squares in *Puerto Vallarta* are mainly introduced species and do not cause any damage to the infrastructure. Many of them were introduced in America with the specific purpose of being used as ornamental, due to their high aesthetic value, and consequently, they have been massively planted; for this reason, it is common to find more introduced taxa than native taxa in Latin American cities.

Puerto Vallarta is no exception: more than 60 % of the trees and palms surveyed are introduced, the most abundant of which are *T. catappa*, *C. nucifera*, *R. regia*, and *F. benjamina*. Likewise, in their diagnosis of alignment trees in *Tuxtla Gutiérrez, Chiapas*, Román-Guillén *et al.* (2019) highlight almost the same species.

Although most of the species and individuals observed in the green areas evaluated in *Puerto Vallarta* were introduced, it was native tree species that caused the greatest level of damage due to their size and location. However, this situation is not bad, on the contrary: it shows that they are relict trees, specimens that were on the site long before it was modified. The construction of the studied squares or parks may have respected and preserved some of the trees originally established on the sites, without, however, providing enough space for their subsequent growth and development.

Delonyx regia, *E. cyclocarpum*, *F. benjamina*, *F. insipida*, *R. donnell smithii*, and *S. glauca* were among the most frequent species to cause damage to the pavement. The first three were declared unsuitable for planting in confined spaces (Acosta, 2013), as they have aggressive and wide-spreading roots. The damage caused by *F. lapathifolia* and *F. insipida* is explained by the fact that they are native species that probably already existed before the creation of these green areas, and whose required space was not respected. Moreover, these species grow wild in the mountains surrounding *Puerto Vallarta*. *Roseodendron donnell-smithii* and *S. glauca*

are rarely cited in studies of infrastructure damage; therefore, this study is the first record on the subject.

It should be noted that the individuals of *A. attilis* and *F. elastica* caused a serious level of damage to the pavement due to their location. However, the number of individuals of these species was insufficient to incorporate them in the analysis. Table 5 shows the tree species responsible for the greatest damage to the infrastructure and indicates which of them are documented in studies carried out in tropical areas.

Table 5. Tree species cited in other studies in tropical areas on damage to infrastructure caused by trees.

Species	Authors				
	Present study	Vargas, 2010	Román-Guillén et al., 2019	Acosta, 2013	Benavides et al., 2004
<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	*			*	
<i>Ficus benjamina</i> L.	*	*	*	*	
<i>Terminalia catappa</i> L.	*				
<i>Artocarpus attilis</i> (Parkinson) Fosberg.		*			
<i>Delonix regia</i> (Bojer ex Hook.) Raf.	*	*	*	*	
<i>Ficus insipida</i> Willd.	*				
<i>Ficus laphatifolia</i> (Liebm.) Miq.	*				
<i>Ficus elastica</i> Roxb. ex Hornem.		*	*	*	*
<i>Spathodea campanulata</i> P. Beauv.	*	*	*		
<i>Dypsis lutescens</i> Beentje & J. Dransf.	*			*	

The identification of six species groups based on damage level and abundance data allows clearer messages regarding their use to be conveyed to decision-makers. In particular, those taxa that caused the most damage and that are not the most abundant in the parks and public squares of *Puerto Vallarta* were grouped together. Likewise, with a robust statistical analysis we present herein the perception of the inhabitants of *Puerto Vallarta* —i.e., that *C. nucifera* (COCNUC) and *T. rosea* (TABROS) are the most abundant species and do not cause damage to the

pavement—; this information coincides with the data indicated in other studies (Bueno *et al.*, 2021).

Nonmetric multidimensional scaling analysis (NMDS) proved to be an effective and useful tool for grouping species that cause similar levels of damage to the infrastructure; it should be noted that, so far, it has not been used in the published literature.

The trees that induced moderate to severe damage to the infrastructure (pavement) were the largest, adding up to 4 % of the total. The hypothesis which stated that trees with greater diameter at breast height, total height and crown area, and their location caused the greatest damage to the infrastructure (pavement) was fulfilled. This is consistent with the study by Hilbert *et al.* (2020). Larger trees demand more space to develop, regardless of the pruning treatment applied in urban green areas.

With respect to the prediction that the shorter the distance between the trees and the infrastructure, the higher the level of damage, it was determined that most of the trees causing moderate and severe damage were located less than 2 m from the infrastructure (pavement). The above was a generalized result, and only a few *A. merrilli* individuals with a diameter at breast height of 6.4 to 20.2 cm and a total height between 3 and 11 m did not cause any damage to the pavement, despite being located at a distance of zero meters from any building. This shows that an important attribute to consider is the distribution of root growth, since there is a difference between planting, at the same distance from the infrastructure, a flamboyant (*D. regia*), which has superficial and aggressive roots; a royal palm (*R. regia*), whose roots are fibrous, or a pink poui (*T. rosea*), which is pivot-rooted with few laterals (Esquivel *et al.*, 2020).

Likewise, in regard to the environmental factor, it is important to consider in future studies the type of pavement surrounding the tree beds, as, according to Beltrán (1979) and Giuliani *et al.* (2015), there is less likelihood of damage if the infrastructure closest to the tree is made of hydraulic concrete, since its composition is harder and less porous. This data may explain, in part, the results obtained for

the social factor, which suggested that areas with a low socioeconomic level would exhibit greater evidence of infrastructure damage due to the reduced possibility or availability of repair by local authorities or users near the green area. It may also be due to poor initial planning, insufficient resources for the establishment and maintenance of the trees, or a lack of interest on the part of the municipal authorities in repairing the damage (Tovar, 2006). Based on the above, the type and quality of pavement is a characteristic that varies between socioeconomic areas.

Conclusions

In the parks and public squares of *Puerto Vallarta*, most (85 %) of the trees and palms are located at a distance that will not cause considerable damage to the pavement. The species that are associated with moderate to severe damage to the infrastructure due to their size at maturity include: *E. cyclocarpum*, *F. benjamina*, *F. laphatifolia*, *F. insipida*, and *S. glauca*. Four of these are native species that were possibly already present before the creation of the parks and public squares, and these did not respect the space required for their development.

The evaluated biological, environmental and social factors significantly explain the association of damage to the infrastructure, especially the size of the individuals. In order to reduce the damage caused by trees and palms to the infrastructure, it is recommended to properly select the species to be used and, above all, to know their biological attributes and ecological requirements, to provide them with sufficient space for developing.

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Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Tahamara Esquivel drafted the manuscript; Sandra Quijas conceived the idea, reviewed the manuscript, performed the statistical analyses and secured funding for the project. Both authors contributed to the field work, proofreading and approval of the manuscript.

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