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Artigos

Vulnerability to biological invasion of *Hovenia dulcis* Thunb. in green areas of Curitiba, Paraná, Brazil

Vulnerabilidade à invasão biológica por *Hovenia dulcis* Thunb. em áreas verdes de Curitiba, Paraná, Brasil

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ABSTRACT

Alien invasive species alter biodiversity, landscape structure, ecosystem functions and services, and habitats of native species of flora and fauna. Multicriteria analysis in a Geographic Information Systems (GIS) environment can be used to evaluate the vulnerability of urban green areas to biological invasion by these species. The objective of this research was to investigate natural and anthropic parameters related to the vulnerability to biological invasion by the *Hovenia dulcis* Thunb. in Curitiba, Paraná, Brazil. A vulnerability assessment was done in the Curitiba's urban green areas with lower degrees of anthropization. Six factors related to the presence of *Hovenia dulcis* were considered: nine points of species occurrence; altitude and slope (topographic metrics); and area, shape, and isolation between areas (landscape metrics). The Analytic Hierarchy Process (AHP) method was used to define weights for each factor. The vulnerability was assessed as very low (0 – 0.2); low (0.21 – 0.4); moderate (0.41 – 0.6); high (0.61 – 0.8); and very high (0.81 – 1). Spatial analyses were performed on QGIS® 3.10 software. The occurrence points of the species represented 45% of the generated model, followed by the landscape factors, mainly the shape of the fragments (17.69% of the model). Within the selected urban green areas, 995.15 ha corresponded to the high vulnerability class, and 839.54 ha to the moderate vulnerability class to invasion by the species. The western, southern, and northern parts of the city are the most vulnerable, which are also the most urbanized. Passaúna Park is the green area most susceptible to invasion by the species mainly due to its irregular shape, most susceptible to the edge effect. Curitiba has a high vulnerability to biological invasion by *Hovenia dulcis* in its green areas, especially in those located in more urbanized regions.

Keywords: Geographic distribution; Invasive alien species; Urban forest

RESUMO

As espécies exóticas invasoras alteram a biodiversidade, a estrutura da paisagem, as funções e serviços do ecossistema e os habitats das espécies nativas da flora e fauna. Análises multicritério em ambiente de Sistemas de Informação Geográfica (SIG) podem ser usadas para avaliar a vulnerabilidade das áreas verdes urbanas à invasão biológica por essas espécies. O objetivo desta pesquisa foi investigar parâmetros naturais e antrópicos relacionados à vulnerabilidade à invasão biológica por *Hovenia dulcis* Thunb. em Curitiba, Paraná, Brasil. Uma avaliação de vulnerabilidade foi feita nas áreas verdes urbanas de Curitiba com menores graus de antropização. Foram considerados seis fatores relacionados à presença de *Hovenia dulcis*: nove pontos de ocorrência da espécie; altitude e declive (métricas topográficas); e área, forma e isolamento entre fragmentos de habitat (métricas da paisagem). O método *Analytic Hierarchy Process* (AHP) foi utilizado para definir pesos para cada fator. A vulnerabilidade foi avaliada como muito baixa (0 – 0.2); baixa (0.21 – 0.4); moderada (0.41 – 0.6); alta (0.61 – 0.8); e muito alta (0.81 – 1). As análises espaciais foram realizadas no *software* QGIS® 3.10. Os pontos de ocorrência da espécie representaram 45% do modelo gerado, seguidos pelos fatores paisagísticos, principalmente a forma dos fragmentos (17,69% do modelo). Nas áreas verdes urbanas selecionadas, 995,15 ha corresponderam à classe de alta vulnerabilidade e 839,54 ha à classe de vulnerabilidade moderada à invasão pela espécie. As regiões oeste, sul e norte da cidade são as mais vulneráveis, e também as mais urbanizadas. O Parque Passaúna é a área verde mais suscetível à invasão pela espécie principalmente devido à forma irregular, mais propensa ao efeito de borda. Curitiba tem uma alta vulnerabilidade à invasão biológica por *Hovenia dulcis* em suas áreas verdes, principalmente naquelas localizadas em regiões mais urbanizadas.

Palavras-chave: Distribuição geográfica; Espécies exóticas invasoras; Floresta urbana

1 INTRODUCTION

Biological invasion is a global environmental threat, which is intensified due to the increasing impacts on natural ecosystems (DECHOUM *et al*., 2015; NIELSEN; FEI, 2015). Invasive alien species can spread and colonize new areas affecting the diversity of native species and are the second leading cause of biological diversity loss, only after habitat destruction (BIONDI; MULLER, 2013; JUHÁSOVÁ *et al*., 2017).

When these species are introduced into environments outside their places of origin, they adapt and reproduce easily, competing for space, light, and nutrients with native species, reducing the availability of these resources and affecting ecological processes (BIONDI; MULLER, 2013; INSTITUTO HÓRUS, 2019). Hence, the biodiversity, landscape structure, ecosystem functions and services, and habitats for native species of flora and fauna are altered (SZYMURA *et al*., 2018).

Thus, due to the negative impacts caused by invasive species on natural resources, mostly in fragments of native vegetation, control strategies have been developed (SHACKLETON *et al*., 2017). Among these strategies, understanding the spatial distribution of invasive alien species is a priority, because it allows identifying their invasion potentials (SZYMURA *et al*., 2018; PIRI *et al*., 2019).

Spatial distribution can be known through multicriteria analysis in a Geographic Information Systems (GIS) environment, weighting layers of environmental information pertinent to the occurrence of the species (SCHMIDT; BARBOSA, 2016; REIS *et al.*, 2019). The AHP method is a planning system for decision-making using multiple criteria (PIRI *et al*., 2019). The principle of the AHP approach is to fragment a complex problem into minor problems, aiming to guide experts and decision-makers to determine the relative importance of each of the elements in a hierarchical manner (SCHMIDT; BARBOSA, 2016; MU; PEREYRA-ROJAS, 2017). This hierarchy represents the objectives and functions of each factor concerning the highest and lowest priorities over a given aspect. Thereby, the AHP method can indicate relationships between objectives (or criteria) and possible alternatives for solving a problem (MU; PEREYRA-ROJAS, 2017).

This method consists of a paired comparison of specialists, with weights of importance for a given approach. Our approach assumes that the occurrence of invasive alien species is driven by environmental factors associated with climate, pedology, topography, landscape structure, competition with native vegetation, and, mainly, by human activities (SZYMURA *et al*., 2018).

In the urban environment, the dispersion of invasive alien species is facilitated by the human presence, which assists in their introduction and expansion through intentional or non-direct transport of propagules (PINTO *et al*., 2014). However, few studies have addressed the environmental vulnerability to biological invasion in cities, and its potential impacts on their urban green areas. Also, knowledge about how environmental and anthropic parameters influence this vulnerability is incipient.

Hovenia dulcis Thunb. (known as *uva-do-japão*), a tree species belonging to the Rhamnaceae family, is a species native to Japan, Korea and East China, where it occurs at altitudes close to 2000 m and in reliefs with greater sun exposure (HYUN *et al*., 2010). The species is fast-growing and was introduced in South American countries as an ornamental, windbreaker, and other forestry purposes (BIASI *et al*., 2020). However, *Hovenia dulcis* has been threatening forest formations by their aggressive expansion over native vegetation, being dominant in some places, due to neglected control and the period of extensive fruiting throughout the year, whose pseudo fruits are attractive to the dispersing fauna (INSTITUTO HÓRUS, 2019).

Hovenia dulcis is classified in category I of alien invasive species according to Ordinance 59/2015 from the Environmental Institute of Paraná (IAP), indicating that their transport, seed and seedling production, cultivation, trade, donation, or intentional acquisition are prohibited (IAP, 2015). *Hovenia dulcis* was found in fragments of native vegetation, such as parks and forests (MIELKE, 2012; BIONDI; MULLER, 2013; BIASI *et al*., 2020), and sidewalks, and private gardens in cities in southern Brazil. Thus, it is perceived how harmful this species can be outside its region of origin, in urgent need of measures for the management of its individuals, especially in urban environments. Thus, it is important to estimate the most vulnerable sites to invasion by *Hovenia dulcis* in urban green areas, due to the relevance of these areas for the conservation of native species.

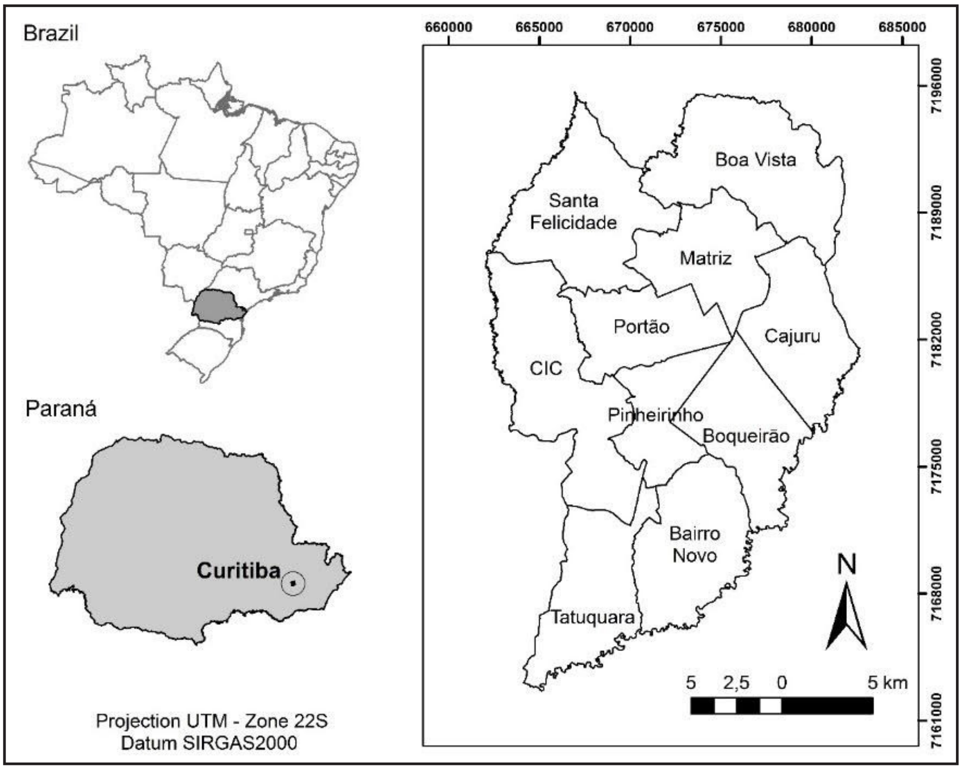
The present research was conducted based on the hypothesis that the more altered the urban landscape, the higher are the levels of vulnerability to biological invasion by flora species. In this context, the objective of this study was to investigate the natural and anthropic parameters related to the vulnerability of urban green areas in Curitiba, Paraná, Brazil, to the invasion by *Hovenia dulcis.*

2 MATERIAL AND METHODS

2.1 Study area

The study area covers the municipality of Curitiba, capital of the State of Paraná, South region of Brazil, whose ground zero is located in the coordinates 25°25'46,89754" S and 49°16'16,56011" W (Figure 1) (INSTITUTO DE PESQUISA E PLANEJAMENTO URBANO DE CURITIBA (IPPUC), 2018). The city has a north-south extension of 33 km and east-west of 21 km; it is subdivided into 75 districts and 10 administrative units called regionals and has 94.65% of its total area urbanized (IPPUC, 2018).

Figure 1 – Location of Curitiba, Paraná, Brazil, and its administrative division (regionals)



Source: Authors (2020)

The terrain is gently undulated, with a relatively regular surface (IPPUC, 2018). The average altitude is 934.6 m, ranging from 864.9 m in the southern region to 1,021 m in the northern region, where the slopes are more pronounced (IPPUC, 2018).

The climate, according to the Köeppen-Geiger classification, is Cfb (humid and mesothermal subtropical), with mild summers and moderate to severe winters (IPPUC, 2018). The average annual temperature is 17.4 °C, the average rainfall is 1,486.5 mm/year and the relative humidity is approximately 83% (WREGE *et al*., 2012).

The urban forest of Curitiba corresponds to 43.69% of the city's total area (GRISE; BIONDI; ARAKI, 2016a). Less than 5% of the city is covered by its 1,113 urban green areas, however, and the total amount of vegetation present in parks and woods, exclusively, corresponds to 3.15% of its urban forest (GRISE; BIONDI; ARAKI, 2016b; IPPUC, 2018).

2.2 Methodological procedures

The vulnerability assessment about the biological invasion by *Hovenia dulcis* in Curitiba was made using the urban green areas with lower levels of anthropization as the basis, according to Reis *et al*. (2019). This study selected 48 parks and woods; 21 Private Reserves of Municipal Natural Heritage (PRMNH); 9 Urban Biodiversity Conservation Forests (UBCF), 1 Ecological Station (ES), and 1 Wildlife Refuge (WR), totaling 80 urban green areas. For this, a shapefile file was used with the overlapping of vector files provided by the Urban Planning Institute of Curitiba (IPPUC), dated July 2018.

Six parameters, five abiotic and one biotic, pertinent to the occurrence of the species in the urban area, were selected and established in the form of relative numbers (Table 1). The factors were selected based on specific scientific literature (BASNOU; IGUZQUIZA; PINO, 2015; JUHÁSOVÁ *et al*., 2017; NIELSEN; FEI, 2015; SHACKLETON *et al*., 2017; SZYMURA *et al*., 2018; INSTITUTO HÓRUS, 2019) added to expert consultation.

The geographic coordinates of nine points with the confirmed occurrence of *Hovenia dulcis* in Curitiba were used. Whether the plants settled spontaneously or were planted was not considered, since it is an alien invasive species. The only certainty was that these points represented adult specimens of the species, indicating the success in their establishment and that these points were collected in different altitude quotas.

For each point of registration of the species, a buffer of 30 m was made, because it is an average value of seed dispersal distance of *Hovenia dulcis* by fauna, according to Lima, Dechoum and Castellani (2015). Weight 5 was assigned for each buffer around the occurrence points of the species and weight 1 for the rest of the Curitiba area.

Table 1 – Abiotic variables used in the AHP method for *Hovenia dulcis* in Curitiba, Paraná

Code	Variable	Type	Unit	Range	Source
bio.1	Altitude	Continuous	m	859.58 – 1087.0	INPE (2011)
bio.2	Slope	Continuous	º	0.178 – 68.709	INPE (2011)
bio.3	Fragment area	Continuous	m^2	900.0 – 7,113,600.0	IPPUC (2018)
bio.4	Fragment shape	Continuous	-	1.0 – 10.26	IPPUC (2018)
bio.5	Isolation between fragments	Continuous	m	60.0 – 4012.9	IPPUC (2018)

Source: Authors (2020)

In where: INPE - Instituto Nacional de Pesquisas Espaciais; IPPUC - Instituto de Pesquisa e Planejamento Urbano de Curitiba.

Altitude and slope were classified as a function of the value gradient, ranging from 1 for the lowest dimensions to 5 for the highest altitudes and slopes. These weights were determined by the fact that the collections of *Hovenia dulcis* were located mainly in the highest quotas of Curitiba, where the slope is also higher.

The calculation of landscape metrics was performed in the Software Fragstats® (MCGARIGAL; MARKS, 1995). The average pixel size was 30 m. Thereafter, the file was converted to a raster format, using the QGIS® 3.10 software (QGIS DEVELOPMENT TEAM, 2019).

The environmental layers were reclassified into five classes according to the amplitude of their respective values. For this, weights of importance were stipulated for each variable, with values from 1 to 5. For the reclassification of the values of the three landscape metrics, the following standardization was considered:

a) AREA (area) – decreasing values, due to the smaller areas providing better environmental conditions for the establishment and development of the species since they tend to be more altered and with greater edge effect;

b) SHAPE (shape) – increasing values, because by distancing themselves from 1, the shapes of the fragments become more irregular, which favors the edge effect and, consequently, the development of invasive species, which tend to be more generalistic;

c) ENN (isolation) – decreasing values because as the fragments approach each other, they favor the dispersion of the species.

The AHP (Analytic Hierarchy Process) method (SAATY, 2004) was used to verify the vulnerability to biological invasion by *Hovenia dulcis* in the urban green areas of Curitiba. Two forest engineers experts in landscape analysis and alien invasive species were selected for this research. The questionnaire for consulting specialists was constructed based on the comparison scale presented in Table 2, adapting the methodologies proposed by Mu and Pereyra-Rojas (2017) and Piri *et al*. (2019).

Table 2 – Comparison scale between pairs of criteria based on expert opinions

Numeric value	Preferences	Description
9	Absolute preference	The evidence favors one activity about the other, with the highest degree of safety
7	Very large preference	One activity is strongly favored compared to another
5	Large preference	Experience or judgment strongly favor one activity over the other
3	Little preference	Experience and judgment favor one activity over the other
1	Equal preferences	The two activities contribute equally to the objective
2, 4, 6 and 8	Preferences between the above intervals	Compromising condition between two settings

Source: Adapted from Mu and Pereyra-Rojas (2017) and Piri *et al*. (2019)

Before the AHP method was applied, the correlation between environmental factors was verified. Thus, Spearman correlation pairs that exceeded 0.8 had the variable with lower ecological value eliminated (SZYMURA *et al*., 2018). This analysis was performed in the Microsoft Excel 2016 software.

However, since the numerical values added to the calculation of the AHP method are derived from the subjective preferences of the specialists, inconsistencies may occur in the final weight assignment matrix, and it is necessary to establish a limit of acceptable inconsistency (MU; PEREYRA-ROJAS, 2017). Thus, after calculating the weights, it was verified whether they were consistent, as recommended by Saaty (2004).

The consistency analysis of the final matrix was performed through a consistency index (CI), calculated by an approximation of the self-value of the weights obtained (λmax) and the number of factors, or information, used through the Equation (1), proposed by Schmidt and Barbosa (2016).

$$CI = \frac{(\lambda max - n)}{(n-1)} \quad (1)$$

In where: n = number of factors used (number of columns or rows); λmax = self-value obtained from the results of the dominant matrix analysis.

Subsequently, the consistency ratio (CR) was calculated by comparing the consistency index (CI) of the elaborated matrix with the weights assigned to each variable and the consistency index of a random matrix (RI). The tabulated value of 1.25 for the IR was used, according to Saaty (2004) for the "n" of six criteria. The environmental layers in raster format were then multiplied by their respective weights obtained by the AHP method and integrated through the raster calculator tool in QGIS (QGIS DEVELOPMENT TEAM, 2019), generating the vulnerability map to biological invasion by *Hovenia dulcis.* The final vulnerability assessment of the invasion by the species was based on five vulnerability classes: 0 – 0.2 - very low; 0.21 – 0.4 - low; 0.41 – 0.6 - moderate; 0.61 – 0.8 - high and 0.81 – 1 - very high (PIRI *et al*., 2019). Subsequently, the areas covered by each vulnerability class were quantified.

3 RESULTS AND DISCUSSION

With the application of the AHP method, based on the weights assigned by the specialists, the weighting autovectors presented in Table 3 were reached. The value calculated for CI was 0.04542 and for CR was 0.03633, indicating that the calculated dominant matrix was consistent. Thus, the autovectors calculated in the AHP for spatial analysis can be used.

Table 3 – AHP method weighting autovectors

Criteria	Occurrence points	Altitude	Slope	Area	Shape	Isolation
Autovector	0.45004	0.04552	0.05094	0.11485	0.17695	0.16169

Source: Authors (2020)

The area around *Hovenia dulcis* specimens represented 45% of the AHP calculation. Nielsen and Fei (2015) also verified that the occurrence of the invasive species *Lonicera japonica* Thunb. was one of the weightiest factors in the AHP calculated for the prioritization of areas for species management in Kentucky, USA. In the aforementioned research, the available records of the occurrence of the species were used. However, the literature about the approach of the AHP method to estimate the distribution of species has little information regarding the minimum number of points of occurrence. As an example, Sarangthem, Talukdar and Thongam (2012) researched the geographical distribution of 11 species of the genus *Hedychium* in India and used from 1 to 19 occurrence points for the AHP method.

Regarding environmental factors, the most important for the occurrence of *Hovenia dulcis* was the shape of vegetation fragments, which corresponded to 17.7% of the general importance of the criteria, followed by the isolation between fragments (16.17%) and the area of the fragments (11.48%).

The shape of the fragments affects the potential for the invasion of more generalist species, such as alien invasive species, due to the edge effect, especially in those whose shape is more irregular due to the greater interaction with the landscape matrix. This phenomenon exerts greater pressure on the nucleus of the fragments, providing greater disturbances to the environment. The edge effect also is related to the fragment area, and the smaller the area is, the greater the disturbances tend to be, which favors the development of invasive species.

Furthermore, *Hovenia dulcis* is a heliophile species (DILLON *et al*., 2018), which indicates that its seedlings have a preference for clearings and edges of vegetation fragments, because they provide a higher incidence of insolation, leaving the smaller fragments even more vulnerable to their establishment. On the other hand, according to Dechoum *et al*. (2015), *Hovenia dulcis* seeds are relatively tolerant to shadow, being able to germinate and establish seedlings in all forest successional stages. These factors promote faster biotic homogenization of vegetation fragments (LOSOSOVÁ *et al*., 2012), demonstrating that these areas should require even more attention from those responsible for controlling the invasive flora.

Thus, the landscape metrics are the most important factors for the occurrence of *Hovenia dulcis* in Curitiba. This result corroborates that found by Basnou, Iguzquiza and Pino (2015), where the parameters related to the landscape indicated the greater vulnerability to the establishment of invasive plants in urban coastal habitats in the region near the Mediterranean Sea in Europe.

Altitude was the variable that least contributed to the vulnerability to invasion by *Hovenia dulcis,* representing 4.55% of the total environmental adequacy for the species. This is due to the generalist behavior of the species about environmental conditions in regions where it is not native (DILLON *et al*., 2018).

Considering the urban green areas selected for this research, the total area vulnerable to invasion by *Hovenia dulcis* within the moderate, high, and very high classes, corresponds to 1,877.85 ha (Table 4). The high vulnerability class covers the largest surface of the municipality, followed by the moderate class. The three classes together represent 89% of the total area evaluated, which covers 2,110.17 ha of the city. This factor is one of the most relevant to understand the behavior of invasive alien species. As an example, there is the research conducted by Szymura *et al*. (2018), where it was found that the most urbanized regions, due to their perturbation characteristics, represented 17.1% of the potential for biological invasion, among the categories of land use evaluated.

Table 4 – Areas corresponding to the classes of vulnerability to the biological invasion by *Hovenia dulcis* in Curitiba, Paraná

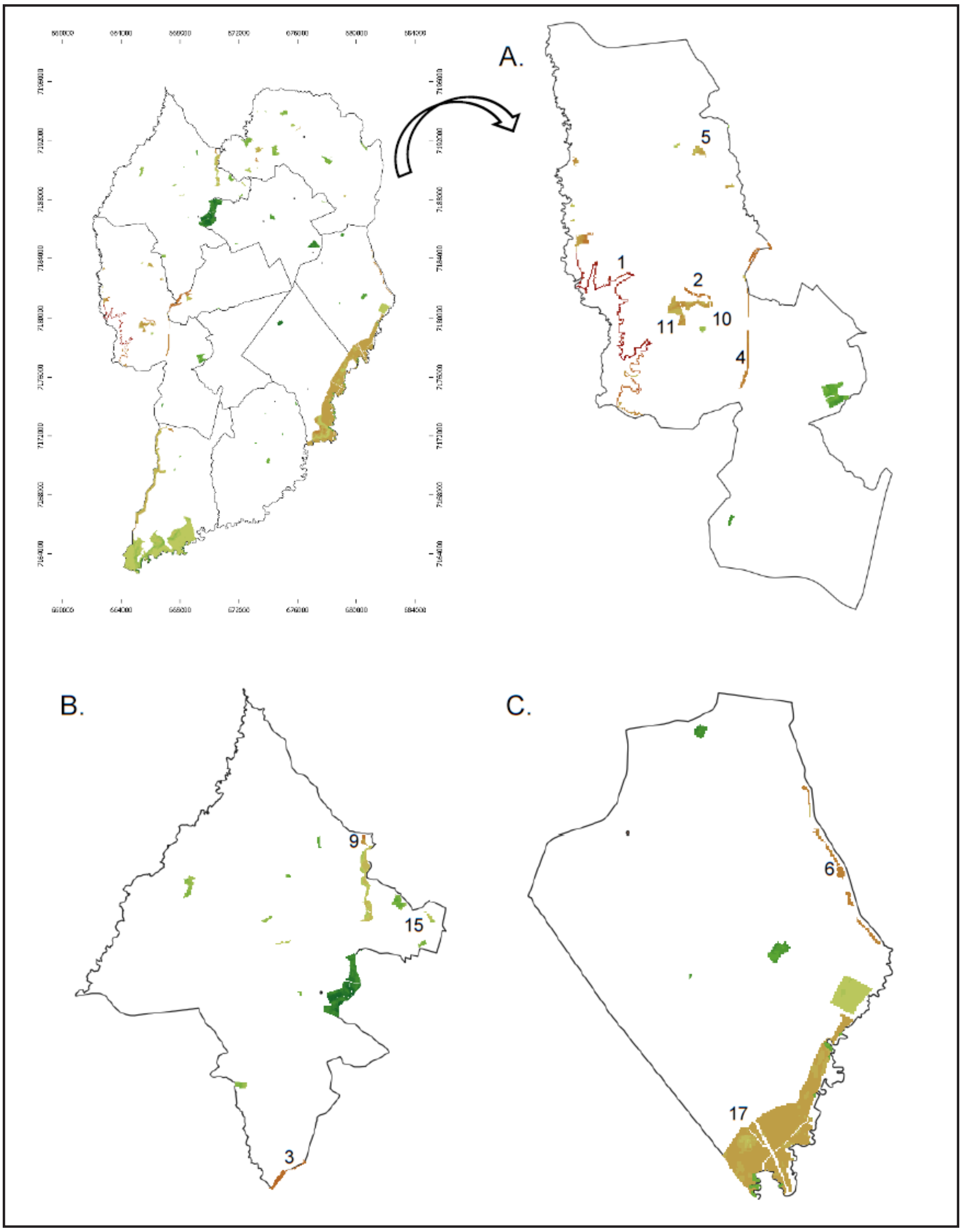
Classes of vulnerability	Area (ha)
1 (Very Low)	5.62
2 (Low)	226.7
3 (Moderate)	839.54
4 (High)	995.15
5 (Very High)	43.16
Total	2,110.17

Source: Authors (2020)

Thus, most of the 80 green areas of Curitiba selected presented moderate to high environmental vulnerability for *Hovenia dulcis* (Figure 2). These areas are mainly in the western (Regional CIC); southern (Regional Tatuquara and Boqueirão); and northern (Regional Santa Felicidade, Boa Vista, and Matriz) regionals of the municipality; besides the Cajuru Regional, in the eastern region. This indicates that, together with the high capacity of the species to spread, the characteristics related to the urban landscape of Curitiba favor its establishment.

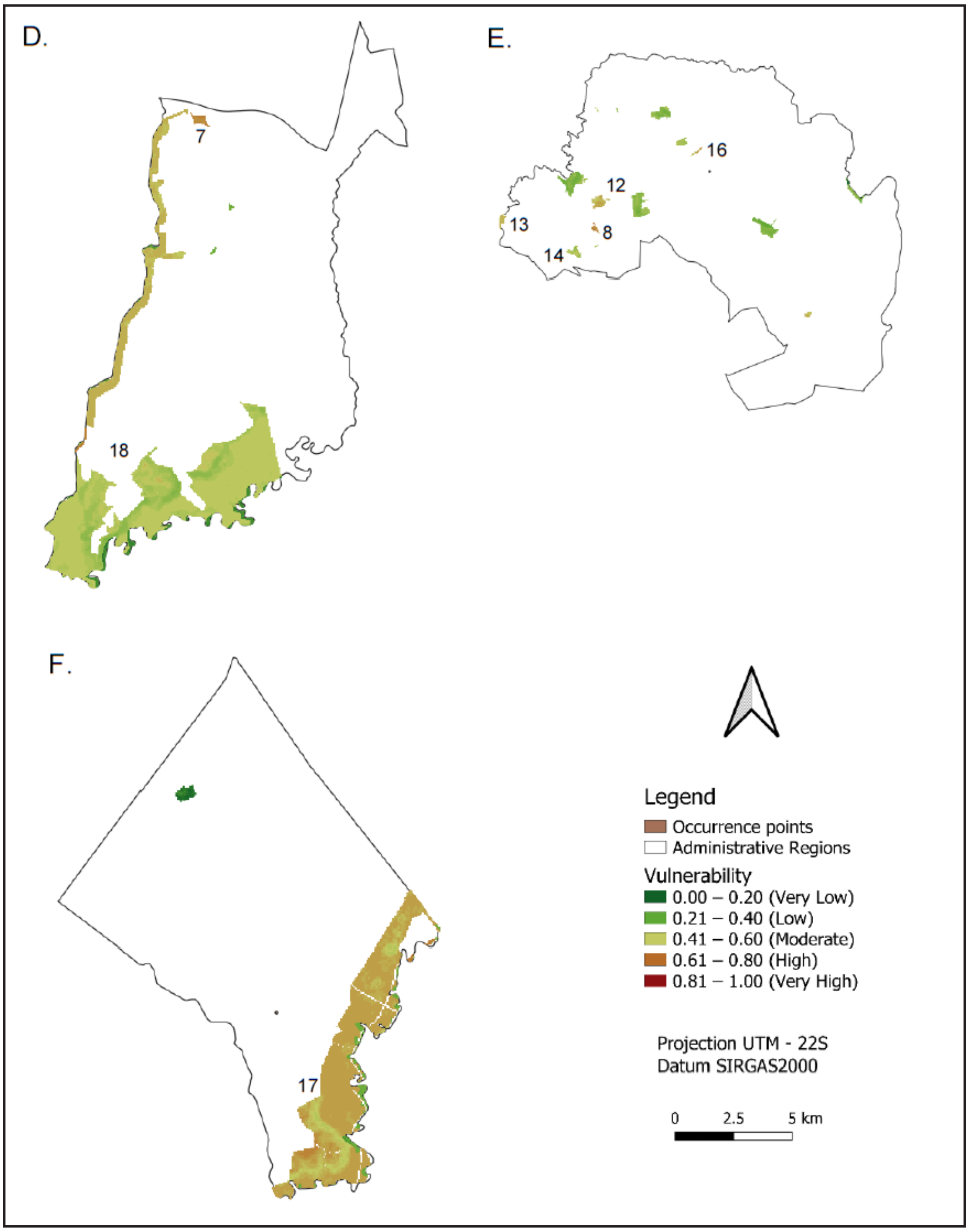
However, the result found should be considered as an approximation of the distribution potential of *Hovenia dulcis,* because according to Piri *et al*. (2019), due to the absence of specific factors on the autecology of the species in the model generated by the AHP method, such as competition between individuals, determining their real habitat is not possible. Moreover, Reis *et al*. (2019) state that the fact that a place presents individuals of a certain species may not constitute the best environment for its establishment, offering incomplete environmental conditions to meet the self-ecological demands of the species, thus the development of individuals tends not to be as efficient.

Figure 2 – Classification of vulnerability to biological invasion by *Hovenia dulcis* by the AHP method



To be continued ...

Figure 2 – Conclusion



Source: Authors (2020)

In where: Regionals: A. – CIC; B. – Santa Felicidade; C. – Cajuru; D. – Tatuquara; E. – Boa Vista; F. – Boqueirão. Urban green areas: 1 – Passaúna Park; 2 – Caiuá Park; 3 – Guairacá Park; 4 – Mané Garrincha Park; 5 – Túlio Vargas Park; 6 – Cajuru Linear Park; 7 – unnamed UBCF (Tatuquara neighborhood); 8 – Pilarzinho Woods; 9 – Name PRMNH; 10 – Diadema Park; 11 – Tropeiros Park; 12 – Pedreiras Park; 13 – Papa João Paulo II Woods; 14 – Zaninelli Woods; 15 – Alemão Woods; 16 – Vô Mantino e Amélia PRMNH; 17 – Iguaçú Park; 18 – Bugio ER.

The urban green area most susceptible to biological invasion by *Hovenia dulcis* in Curitiba is the Passaúna Park (Figure 2A), located in the western region of the municipality, presenting a very high risk of invasion by the species. The presence of specimens of this species has been recorded in the Passaúna Park, in addition to at least six other invasive species, such as *Eucalyptus* spp., *Pinus* spp., *Pittosporum undulatum* Vent., *Eriobotrya japonica* (Thunb.) Lind., *Morus nigra* L., and *Ligustrum lucidum* W. T. Aiton. (MIELKE, 2012; BIONDI; MULLER, 2013). Thus, the aptitude of this green area for biological invasion by plant species is confirmed.

Following the Passaúna Park are its neighbors Caiuá, Guairacá, Mané Garrincha and Túlio Vargas parks, all located in the CIC Regional; followed by the Cajuru Linear Park (Figure 2C), in the extreme east of Curitiba; the unnamed UBCF located in the Tatuquara neighborhood (Figure 2B), in the southwest region; and the Pilarzinho Woods and the Name PRMNH (Figure 2E), located in the northern region of the city. In common, these areas have the location close to the limits of the municipality, the relatively small dimensions, and their irregular forms, well above 1, on a scale ranging from 1 (regular form) to infinity (irregular shape). Smaller patches tend to have larger edge effects (WEIßHUHN, 2019).

The location of these sites near the limits of the municipality becomes an aggravating factor for the dissemination of *Hovenia dulcis,* helping the contact of propagules of the species with other fragments of vegetation nearby and suffering more anthropic disturbances. The landscape of the immediate surroundings is the most relevant for biological invasions, because it reflects the direct link between the disturbance and the dispersion of species, especially in urbanized regions (BASNOU; IGUZQUIZA; PINO, 2015). After all, they facilitate the introduction of ornamental (BASNOU; IGUZQUIZA; PINO, 2015) and food plants, as is the case of *Hovenia dulcis* (INSTITUTO HÓRUS, 2019). Lososová *et al*. (2012) add that the longer the length of stay of individuals of an invasive species in a location, the more likely it is to occupy sites in increasingly larger areas, thus contributing to biotic homogenization.

This finding also corroborates the location of other urban green areas near the Passaúna Park that are relevant to the occurrence of *Hovenia dulcis,* such as the Diadema and Tropeiros parks, which have a moderate vulnerability to the invasion by the species. Other areas in this category, located in the most urbanized region, are the Pedreiras Park, the Papa João Paulo II, Zaninelli and Alemão Woods and the Vô Mantino e Amélia PRMNH (Figure 2B and 2C). Areas such as these are important for the dispersion of invasive species, especially to places, even more, subject to recent disturbances, with soil revolving, such as abandoned land (LOSOSOVÁ *et al*., 2012).

Although this pattern is more related to urbanized regions, urban green areas were also verified in the south-central region of the city, such as the Iguaçú Park (Figure 2C and 2F) (located in the Cajuru and Boqueirão regionals) and the Bugio ER (Figure 2D) with the vulnerability of invasion by the species. These conservation units are the largest protected areas of Curitiba and with less altered vegetation. However, due to the existing risk, the impact of the invasion of *Hovenia dulcis* tends to be more intense on the native flora in these places, which is possibly not adapted to competition with invasive species.

The classes of vulnerability to the invasion by *Hovenia dulcis* in Curitiba was not evenly distributed in the study area, since the species can occupy areas located both to the north of the municipality, where the highest altitudes and slopes are and in the southern region, where the land quotas are lower. Thus, the results described in this research reinforce the statement that the species has generalist autecological characteristics.

The vulnerability assessment to invasion by *Hovenia dulcis* on a landscape scale, together with other alien invasive species, tends to make the prioritization of areas for their control more feasible, due to the greater detail of spatial parameters related to their occurrence. Moreover, prioritization at this level can facilitate targeting efforts to the most vulnerable areas, with less time and less spending (NIELSEN; FEI, 2015). Thus, it is expected that the results found in this research provide directions to the management actions of the species in the urban green areas of Curitiba most vulnerable to biological invasions.

4 CONCLUSION

Curitiba has a high vulnerability to biological invasion by *Hovenia dulcis* in its urban green areas, especially in those located in the most urbanized regions, mainly the northern portion of the municipality.

The factors related to the structure of the urban landscape, mostly the shape of the fragments, were the most relevant to estimate the occurrence of *Hovenia dulcis* in Curitiba and, consequently, the degree of vulnerability of the urban green areas to biological invasion by the species.

Passaúna Park is the most vulnerable green area to invasion by *Hovenia dulcis,* mainly due to its irregular shape. Other green areas near the northern and southern limits of the municipality, in addition to other parks near the Passaúna, also presented relevant degrees of vulnerability to the establishment of the species, serving as the first contact of the species with other protected areas of the city.

The use of factors related to the level of urbanization with high detailing by similar researchers is recommended, aiming to estimate more accurately the areas most vulnerable to species invasion. Furthermore, determining minimum amounts of occurrence points of a given species for analysis by the AHP method is also advised.

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