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Original Article

Demography and spatial distribution of a threatened species from the Atlantic Forest in southern Brazil: differences between urban and rural remnants

Demografia e distribuição espacial de uma espécie ameaçada da Floresta Atlântica no sul do Brasil: diferenças entre remanescentes urbano e rural

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Abstract

Logging and agricultural exploitation have led to the degradation of Araucaria Forest remnants and the alteration of its last preserved patches. This forest typology contains many endangered plant species, as is the case of the tree *Oreopanax fulvus* Marchal. To support conservation of this species and understand how different landscape matrices can influence its populations, we evaluated the demographic structure and spatial distribution of *O. fulvus* in two Araucaria Forest remnants in Paraná state. We delimited two plots (urban and rural population), each with 1 ha, subdivided them into 100 subplots (10 x 10 m), and recorded diameter at ground level (DGL), height, and coordinates of two post-germinative developmental stage of individuals. In each subplot, we measured slope, luminosity, and canopy height. We used Ripley's K function analysis to describe distribution patterns of the species and the spatial relationship between mature and juvenile trees. We performed correlations between abundance and environmental and structural variables of the *O. fulvus* populations. Abundance varied between remnants, from 183 individuals/ha (12 mature and 171 juvenile) to 1306 individuals/ha (10 and 1296). The remnants varied in abundance and plant frequency. The species showed an investment in seedling banks. Most juvenile had DGL up to 3.0 cm and height up to 1.0 m and presented aggregated spatial distribution, while adults had random distribution. In the rural population juvenile abundance were correlated with canopy height (positively) and distance to mature trees (negatively). The slope was correlated for both sites, but oppositely, indicating that other factors might have interfered in the regeneration abundance. The urban remnant showed a high abundance of this endangered species, calling attention for potential studies in urban arborization, management and conservation of these remnants.

Keywords: Araucaria Forest, *Oreopanax fulvus*, natural regeneration, abundance.

Resumo

A exploração madeireira e agrícola levou à degradação dos fragmentos de Floresta com Araucária e à alteração de seus últimos fragmentos preservados. Esta tipologia florestal contém muitas espécies de plantas ameaçadas, como é o caso de *Oreopanax fulvus* Marchal. Para apoiar a conservação desta espécie e entender como diferentes matrizes da paisagem podem influenciar suas populações, avaliamos a estrutura demográfica e a distribuição espacial de *O. fulvus* em dois remanescentes de Floresta com Araucária no estado do Paraná. Delimitamos duas parcelas (população urbana e rural), cada uma com 1 ha, subdivididas em 100 subparcelas (10 x 10 m), registrando-se o diâmetro ao nível do solo (DGL), a altura e as coordenadas de dois estágios de desenvolvimento pós-germinativo de indivíduos. Em cada subparcela, medimos declividade, luminosidade e altura do dossel. Utilizamos função K de Ripley para descrever os padrões espaciais da espécie e a relação espacial entre árvores maduras e juvenis. Realizamos análise de correlação entre a abundância e as variáveis ambientais e estruturais das populações de *O. fulvus*. A abundância variou entre os remanescentes, de 183 indivíduos/ha (12 maduros e 171 juvenis) a 1306 indivíduos/ha (10 e 1296). Os remanescentes apresentaram variações na abundância e frequência de indivíduos. A espécie demonstrou investimento na formação de banco de plântulas. A maioria dos juvenis tinha DGL até 3,0

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cm e altura até 1,0 m e apresentaram distribuição espacial agregada, enquanto os adultos tiveram distribuição aleatória. Na população rural a abundância de juvenis foi correlacionada com altura do dossel (positivamente) e com a distância de árvores maduras (negativamente). A declividade foi correlacionada em ambos os locais, mas de forma oposta, indicando que outros fatores podem ter interferido na abundância da regeneração. O remanescente urbano mostrou elevada abundância desta espécie ameaçada, demonstrando um potencial para estudos de arborização urbana, manejo e conservação destes remanescentes.

Palavras-chave: Floresta com Araucária, *Oreopanax fulvus*, regeneração natural, abundância.

1. Introduction

Human interventions such as logging and agriculture contribute to forest fragmentation. The Araucaria Forest originally comprised 250,000 km^2, distributed in Brazil, Paraguay, and Argentina (Ribeiro et al., 2009). However, it is now one of the most fragmented forests landscapes in Brazil, encompassing only 12.6% of its original area remaining (Ribeiro et al., 2009). Forest fragmentation generally results in disturbed landscapes (*e.g.,* agricultural or urban areas), which hamper seed dispersion and gene exchange (Costa et al., 2019), negatively affecting the persistence of rare tree species (Silva et al., 2017; Zanella et al., 2022). However, recent studies have shown that urban forest remnants can contribute with environmental services and public health (Diener and Mudu, 2021).

Urban forests are prone to anthropogenic changes, such as alien species invasion and air pollution, which negatively influence such places (Groffman et al., 2017; Doroski et al., 2018). However, some authors have defended the conservation value of urban forests, for instance its considerable biological richness (Kowarik and von der Lippe, 2018; Planchuelo et al., 2019). In rural forest remnants the occurrence of threatened tree species can be facilitated by the edaphoclimatic conditions and less anthropic influence, such characteristics could guarantee these species in the environment. However, despite the suitable conditions for plant assemblages, Templeton et al. (2019) have described rural landscapes as being less resilient than urban areas. Usually, the main concern about any forest patch is the remnant size, which is not always the main factor to explain the rare species occurrence (Planchuelo et al., 2019). Understanding the differences between rural and urban forest remnants ecology can contribute to creating policies to protect and manage such places.

New policies can represent opportunities for species' conservation, such as, *Oreopanax fulvus* Marchal (Araliaceae) which is a woody forest species included in regional threatened species lists (Paraná, 1995; Rio Grande do Sul, 2003). This species is endemic to the southern and southeastern regions of the Brazilian Atlantic Forest biome (Fiaschi, 2015). It grows under the canopy of well-preserved forests (Fockink et al., 2020; Pscheidt et al., 2018) in moderately drained soils (Higuchi et al., 2014) and is considered a late secondary species (Grings and Brack, 2009; Araujo et al., 2010). *O. fulvus* has rapid growth and a well-developed crown (Fockink et al., 2020). It has inflorescences in terminal panicles containing c.15 flowers with 6 to 8 mm in diameter (Carvalho, 2014) and fruits with fleshy and purplish-colored mesocarp (Pinto et al., 2016). Therefore, it has an important role as a food source for frugivorous birds in montane forests (Parrini et al., 2017).

Brazilian rare species are generally poorly studied. To our knowledge, *O. fulvus* is not mentioned in spatial patterns and demographics studies, which are needed to support conservation programs (Volis and Deng, 2020). The assessment of distributional patterns of rare species is important to understand demographic dynamics and discover whether natural regeneration is occurring. This information is relevant, as to be successful in conservation activities, populations need to be able to maintain themselves over the years (Burgess et al., 2020). *O. fulvus* is rarely recorded in Atlantic Forest surveys (Higuchi et al., 2016; Higuchi et al., 2018; Pscheidt et al., 2018). Here, we aimed to evaluate the population structure and spatial pattern of individuals in two populations of *O. fulvus* in two remnants (urban and rural) to answer the following questions: *i*. Is there a difference in structural and spatial pattern of the species between urban affectand rural remnants? *ii.* Is there any potential of urban places to support *O. fulvus*' population? *iii.* Is the abundance of juvenile determined by environmental factors? Our results can contribute to strategies for conservation of *O. fulvus* and other species with similar ecological niches.

2. Materials and Methods

2.1. Study areas

The study was carried out in two advanced succession stage remnants of Araucaria Forest, 130 km from each other, in distinct forest remnants (Figure 1). According to Köppen's classification, the local climate of both sites is *Cfb,* humid subtropical mesothermal (Alvares et al., 2013), and both sites are located on Cambissols (EMBRAPA, 2013). The first remnant has 101 ha, is located in the municipality of Fernandes Pinheiro (25º32'49" S and 50º28'37" W), c.900 m.a.s.l., surrounded by an agricultural landscape and nearby forest remnants (hereafter rural landscape). The second remnant has 19 ha, is located in Curitiba city, capital of Paraná state (25º26'53" S and 49º14'25" W) c.920 m.a.s.l, in an urban area, surrounded by few nearby forest remnants and isolated by the road network (hereafter urban landscape).

2.2. Data collection

We set out one 1 ha plot (100 x 100 m) in each forest stand. We selected the places based on the following criteria: same forest succession stage in both areas, homogeneous topography and soil type, *O. fulvus* presence, and same distance to the forest edge. To facilitate the location and measurement of mature and juvenile trees, we split the plot into 100 subplots, each with 100 m^2.

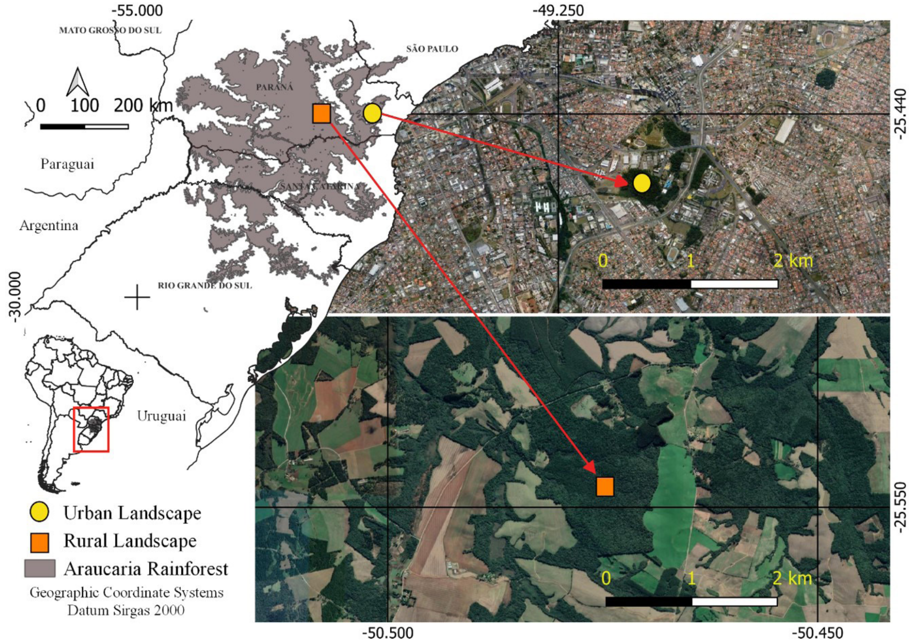

Figure 1. Study areas in rural (Fernandes Pinheiro) and urban (Curitiba) landscapes in remnants of Araucaria Forest, Paraná state, Brazil.

In each subplot, we assessed canopy height using a telescopic ruler, slope using a clinometer, and the luminosity using a lux meter. Three readings were done in each subplot to calculate the luminosity, always on cloudless days, and the average luminosity was obtained by calculating the percentage of light retention with the reading taken in open areas adjacent to the studied forest remnants (Mazuchowski et al., 2007). All individuals of *O. fulvus* were measured, being considered mature with a diameter at breast height (DBH) ≥10 cm, and otherwise were classified as juveniles. The diameter at ground height (DGH) and total height were also measured, with total height obtained from the stem base above the soil to the apical meristem in small size plants while in adults we measured considering the crown height. Finally, coordinates of individuals were mapped (x, y) using a tape measure and ruler in relation to the corner of the subplot.

2.3. Data analysis

Populations of different remnants were compared concerning frequency and abundance of individuals, mean diameter, and height. The population size structure was represented employing frequency distribution graphs in diameter and height classes. To verify the difference between plots we applied Tukey test at 95% confidence level, based on linear or generalized linear models (GLM) with the Poisson error distribution. The *p*-values were adjusted using the single-step method.

We used Ripley's K function to perform spatial analysis of mature and juvenile individuals separately (Ripley, 1977). Complete spatial randomness (CSR) was tested using the univariate function to ascertain whether the spatial distribution pattern was aggregate, random, or regular. The spatial relationship between mature and juvenile trees was evaluated with the bivariate Ripley's K function, and the complete spatial independence (CSI) was tested. CSR and CSI were tested using confidence envelopes constructed with 999 Monte Carlo simulations, with isotropic edge effect correction (Silva et al., 2009).

Spearman correlations were used to analyze the relationship of juveniles abundance to slope, canopy height, luminosity, and distance to mature individuals. Spatial and distribution analyses were performed in the R environment v.3.2.2 (R Core Team, 2022) through the packages *multcomp*, *spatstat*, *Hmisc*, and *flexclust* (Leisch, 2006; Hothorn et al., 2008; Baddeley et al., 2015; Harrell Junior, 2020).

3. Results

We recorded 183 and 1,306 *O. fulvus* individuals in the rural and urban plots, respectively (Table 1). No significant difference was observed in the abundance of mature individuals, but the number of juveniles in the urban remnant was 7.6 times higher than in the rural one. In both sites, the number of juveniles was higher than adults (Table 1; Figure 2). The mature class in the urban remnant represented <1% of the individuals.

We observed *O. fulvus* presence in 56% and 97% of rural and urban subplots, respectively (Table 1). However, the frequency of adults was similar in both areas (Table 1).

Regarding height classes, 81% of the individuals in the rural remnant and 98% in the urban remnant had values up to 1 m. Furthermore, there was low representation or absence of individuals in some height classes (Figure 2a). The diameter distribution of the population indicated concentrations of 92 and 99% in the 0.07 to 3.0 cm class in the rural and urban population, respectively (Figure 2b).

Table 1. Demographic parameters, diameter, and height of two studied populations of *Oreopanax fulvus* in rural and urban landscapes.

Parameter	Category	Rural	Urban
Abundance (plant/ha)	Mature	12	10
	Juvenile	171	1296
Abundance proportion (%)	Mature	6.56	0.77
	Juvenile	93.44	99.23
Mean of plants/subplot (100 m^2)	Mature	0.12 ± 0.38 a*	0.12 ± 0.36 a
	Juvenile	1.71 ± 2.99 b	12.96 ± 19.42 a
Plant frequency in each subplot (%)	Mature	10	9
	Juvenile	55	96
DBH Mature (cm)	Minimum	14.01	10.66
	Average	23.95 ± 10.63 a	18.83 ± 6.46 a
	Maximum	46.47	31.51
DGH Mature (cm)	Minimum	19.10	14.26
	Average	26.2 ± 19.58 a	24.68 ± 18.72 a
	Maximum	61.75	40.43
DGH Juvenile (cm)	Minimum	0.35	0.07
	Average	4.69 ± 2.07 a	2.83 ± 1.80 b
	Maximum	18.24	9.61
Mature Height (m)	Minimum	7.00	8.20
	Average	11.26 ± 9.00 a	9.81 ± 8.50 a
	Maximum	22.00	12.00
Juvenile Height (m)	Minimum	0.019	0.008
	Average	20.91 ± 4.11 a	8.87 ± 4.09 b
	Maximum	216.00	750.00

*Means with the same letter do not differ according to the Tukey test ($p < 0.05$) between the study areas within the same category.
DBH: diameter at breast height; DGH: diameter at ground height.

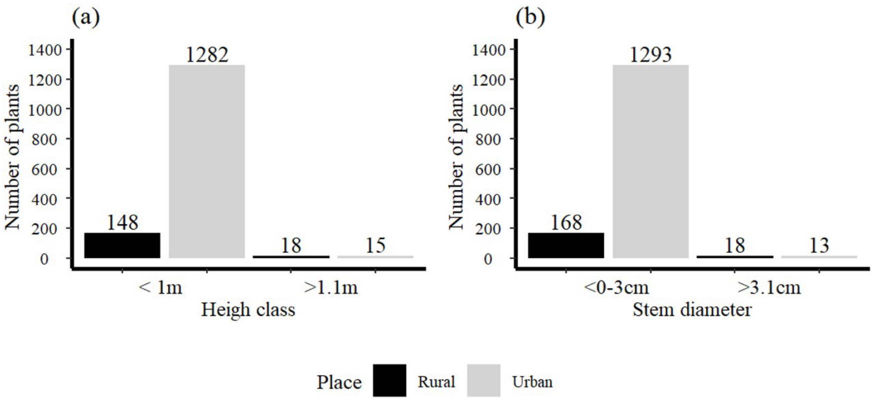

Figure 2. Distribution of *Oreopanax fulvus* individuals in height classes (a) and diameter at ground level (b) in the urban and rural landscape.

The population of the urban remnant showed regular spatial distribution of adults and random distribution of juveniles in the subplots. However, in the rural remnant, the distribution was more aggregated, with a greater number of subplots without the occurrence of the species, for both developmental stages (Figure 3).

The spatial distribution of mature individuals in the rural remnant showed a tendency towards aggregation, between 28-40 m (Figure 4a). For juveniles, an aggregated behavior was observed. The spatial pattern between mature and juvenile individuals showed a tendency of juveniles to aggregate with adults. All mature individuals were

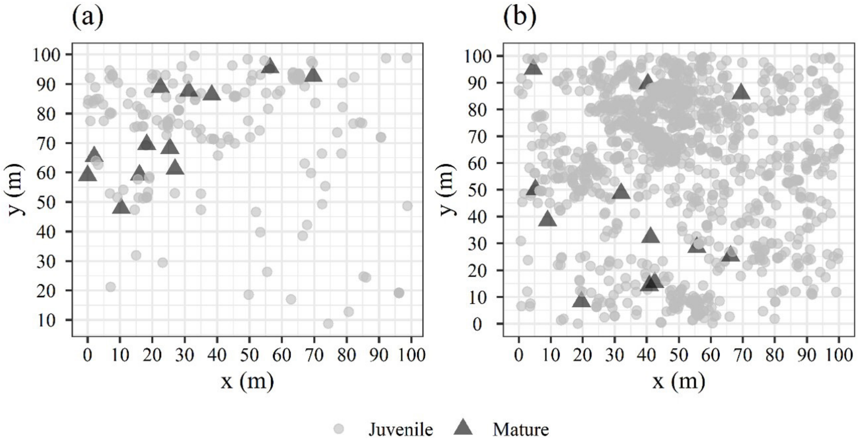

Figure 3. Spatial distribution of mature and juvenile individuals of *Oreopanax fulvus* in rural (a) and urban landscape (b).

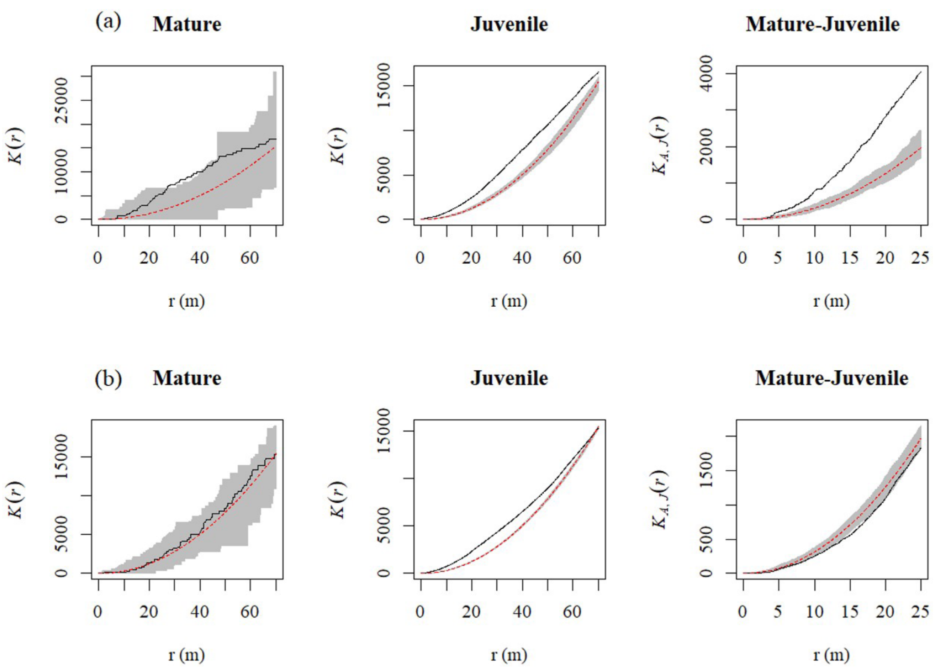

Figure 4. Spatial pattern of *Oreopanax fulvus* in rural (a) and urban landscape (b). Black lines indicate the spatial pattern, and red lines represent the mean value of randomizations. K(r): point pattern analysis function; r(m): domain radius in meters.

randomly distributed for the urban remnant, unlike the juvenile individuals, which showed aggregated distribution (Figure 4b). In contrast to the former area, the juveniles of the urban remnant showed repulsion to mature individuals in the range between 0 to 25 m.

Slope and canopy height were similar in both areas, while the distance to adults was about 4 m greater in the rural remnant. Regarding the light incidence in the forest understory, the rural remnant presented 4.3% and the urban remnant 3.0% averages in relation to the measurements taken in the respective open areas (Table 2). The abundance of juveniles in the rural remnant showed a positive correlation with slope and canopy height and a negative correlation with distance to adults (Table 2). In the urban area, the slope showed a negative correlation. The luminosity did not correlate with the abundance of juveniles.

4. Discussion

The abundance of *O. fulvus*' mature individuals in the remnants was similar to the values observed for this species in other phytosociological studies conducted in Araucaria Forest areas, ranging from 5 to 20 individuals/ha (Nascimento et al., 2007; Klauberg et al., 2010). The high

Table 2. Statistical parameters of the slope, canopy height, distance to adults, luminosity, and Spearman correlations between the abundance of juveniles and the variables for rural and urban landscape.

Variable	Landscape	Average	Spearman Correlation	*p*-value
Slope (%)	Rural	13.2 ± 6.1	0.314	< 0.01**
	Urban	12.4 ± 7.4	-0.252	0.01**
Canopy Height (m)	Rural	11.9 ± 3.2	0.453	< 0.01**
	Urban	11.6 ± 1.8	-0.043	0.67
Mature distance (m)	Rural	19.8	-0.431	< 0.01**
	Urban	15.5	0.083	0.41
Luminosity (%) *	Rural	4.6 ± 3.9	-0.159	0.11
	Urban	3.0 ±1.2	-0.160	0.11

*Percentage in relation to luminosity in adjacent open area. **Significant values at 95% confidence level ($p < 0.05$).

abundance of juveniles recorded in the urban remnant stood out, considerably higher than that observed in the rural remnant of the present study and then that recorded by Higuchi et al. (2015) in another rural remnant of Araucaria Forest, in Santa Catarina, Brazil. Some factors may influence differently the regeneration of the same species in different places. Whether related to the phenological pattern and efficiency in fruit production (Pinto et al., 2021) or genetic diversity to maintain gene flow (Carvalho et al., 2010).

Both remnants had expressive seedling banks, indicating that the species has good germination potential in the understory, even though with considerable variation in abundance of seedlings. At the community level, natural regeneration is prone to be influenced by edaphic characteristics and has a greater dependence on abiotic characteristics than other individuals of the tree stratum (Callegaro et al., 2017). Moreover, an expressive seedling bank usually is adapted to local edaphic conditions and has more individuals than the mature tree layer in preserved forests, this characteristic enables the process of forest succession (Turchetto et al., 2017).

Despite the adverse conditions related to the city environment (Groffman et al., 2017; Doroski et al., 2018), the urban population showed many juveniles, opening perspectives for studies targeting rare and endangered species in such places. In fact, urban areas can be more resilient to impacts than rural places (Templeton et al., 2019) and can be a source of seedlings for nearby reforestation projects (Turchetto et al., 2016). Our results suggest that new studies should be focused on urban remnants to describe better aspects like the genetic structure, pollution influence, and alien species damage on populations of rare and threatened species (Wodkiewicz and Gruszczynska, 2014).

The difference in the number of juvenile individuals of *O. fulvus* between remnants and the low number of adults recorded indicates difficulty in the demographic dynamics of the species (Higuchi et al., 2015). It is probably due to unmet environmental requirements, especially in the intermediate stages of development (Volis and Deng, 2020). Understory is a transitional environment that has a role as an ecological filter and selects the species that will compose the upper strata by determining which individuals and species will be able to survive in such conditions (Gomes-Westphalen et al., 2012). Hence, the abundance of young individuals will not necessarily guarantee the maintenance of the species in the community but will indicate the ability to compete within its ecological niche (Schaaf et al., 2006).

Mature individuals of zoochoric species tend to present a random distribution pattern (Negrini et al., 2012), as we observed in the urban population. However, in the rural population the matures' distribution pattern was aggregated, which may be related to the previous use and management of the area, as well as biotic interactions, dispersal, and environmental conditions (Silva et al., 2019). Regarding juveniles, the aggregated distribution may be related to a spatially limited distribution of propagules (Santos et al., 2018). This pattern has also been described for some other Araucaria Forest species, where microclimatic conditions, seed source, and dispersers may be the causal agents (Canalez et al., 2006). This tendency to aggregation interferes with the abundance of individuals, which is lower when a larger area is sampled (Klauberg et al., 2010).

The significant correlation of juveniles' abundance with canopy height in the rural population may be related to the level of community development, since an advanced stage forest provides more favorable conditions for late secondary or climactic species' growth (Passos et al., 2021), such as *O. fulvus* (Grings and Brack, 2009; Araujo et al., 2010). Furthermore, the negative correlation between juveniles and distance to adults in the rural remnant demonstrates the conditions verified of spatial pattern in the field and may indicate a dependence on regeneration in the vicinity of adults. Tree species populations are often geographically structured in patches due to seed dispersal near the matrix (Higuchi et al., 2010). However, this pattern can vary since different behavior was observed for the urban population. The absence of correlation with luminosity, and the weak correlations between the abundance of juveniles and slope, divergent among the areas, indicates that unknown factors are acting in the spatial structuring of the species.

Given the high density of juveniles, especially in the urban population, we recommend studies of genetic diversity of populations in urban patches, increasing the possibility of using those patches to obtain seedlings for nurseries for subsequent enrichment planting. Seedling rescue is feasible for secondary species and is a way to increase their availability for restoration (Turchetto et al., 2016).

5. Conclusion

Based on our results, the *O. fulvus* populations demonstrated differences in the structural and spatial pattern between urban and rural remnants. The expressive number of juveniles in the urban population calls attention to these environments, while the rural landscape showed more developed juveniles (greater average height and diameter). The concentration of juvenile plants indicated that the species is prone to seedling bank formation, although an analysis of the soil seed bank is necessary to confirm this information.

O. fulvus tolerates urban forests environment, being a potential species for urban arborization plans increasing ex-situ conservation, such as the planting of streets and gardens. We also should highlight the importance of maintenance and management of urban forest remnants; such places can be unexpected sanctuaries for the rare endemic tree species.

The result also highlights the importance of the environmental variables on *O. fulvus* seedlings distribution, meaning that slope, canopy height and luminosity should be considered to ensure population renewal and maintenance, also in management plans.

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References

ALVARES, C.A., STAPE, J.L., SENTELHAS, P.C., GONÇALVES, J.L.M. and SPAROVEK, G., 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, vol. 22, no. 6, pp. 711-728. http://dx.doi.org/10.1127/0941-2948/2013/0507.

ARAUJO, M.M., CHAMI, L., LONGHI, S.J., AVILA, A.L. and BRENA, D.A., 2010. Análise de agrupamento em remanescente de floresta ombrófila mista. *Ciência Florestal*, vol. 20, no. 1, pp. 1-18. http://dx.doi.org/10.5902/198050981755.

BADDELEY, A., RUBAK, E. and TURNER, R., 2015. *Spatial point patterns: methodology and applications with R*. London: Chapman and Hall/CRC Press. http://dx.doi.org/10.1201/b19708.

BURGESS, M.D., EATON, M.A. and GREGORY, R.D., 2020. A review of spatial patterns across species ranges to aid the targeting of conservation interventions. *Biological Conservation*, vol. 251, p. 108755. http://dx.doi.org/10.1016/j.biocon.2020.108755.

CALLEGARO, R.M., ARAÚJO, M.M., LONGHI, S.J., ANDRZEJEWSKI, C., TURCHETTO, F. and GOMES, D.R., 2017. Fitossociologia e fatores ecológicos condicionantes da vegetação em uma floresta estacional na região central do Rio Grande do Sul, Brasil. *Iheringia. Série Botânica*, vol. 72, no. 1, pp. 33-43. http://dx.doi.org/10.21826/2446-8231201772104.

CANALEZ, G.G., CORTE, A.P.D. and SANQUETTA, C.R., 2006. Dinâmica da estrutura da comunidade de lauráceas no período 1995-2004 em uma floresta de araucária no sul do estado do Paraná, Brasil. *Ciência Florestal*, vol. 16, no. 4, pp. 357-367. http://dx.doi.org/10.5902/198050981917.

CARVALHO, A.C.M.D., MORAES, S.M.B.D., STRANGHETTI, V., ALZATE-MARIN, A.L. and SEBBENN, A.M., 2010. Diversidade genética, endogamia e fluxo gênico em pequena população fragmentada de Copaifera langsdorffii. *Brazilian Journal of Botany*, vol. 33, pp. 599-606.

CARVALHO, P.E.R., 2014. *Espécies arbóreas brasileiras*. Brasília: Embrapa Informação Tecnológica/Embrapa Florestas, 634 p. Coleção Espécies Arbóreas, vol. 5.

COSTA, A., GALVÃO, A. and SILVA, L.G., 2019. Mata Atlântica brasileira: análise do efeito de borda em fragmentos florestais remanescentes de um hotspot para conservação da biodiversidade. *Revista GEOMAE*, vol. 10, no. 1, pp. 112-123. http://dx.doi.org/10.17605/OSF.IO/8GS9Y.

DIENER, A. and MUDU, P., 2021. How can vegetation protect us from air pollution? A critical review on green spaces' mitigation abilities for air-borne particles from a public health perspective-with implications for urban planning. *The Science of the Total Environment*, vol. 796, p. 148605. http://dx.doi.org/10.1016/j.scitotenv.2021.148605. PMid:34271387.

DOROSKI, D.A., FELSON, A.J., BRADFORD, M.A., ASHTON, M.P., OLDFIELD, E.E., HALLETT, R.A. and KUEBBING, S.E., 2018. Factors driving natural regeneration beneath a planted urban forest. *Urban Forestry & Urban Greening*, vol. 29, pp. 238-247. http://dx.doi.org/10.1016/j.ufug.2017.11.019.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA, 2013. *Sistema brasileiro de classificação de solos*. Brasília: Embrapa Informação Tecnológica, 353 p.

FIASCHI, P., 2015 [viewed 30 September 2015]. *Araliaceae* [online]. Jardim Botânico do Rio de Janeiro. Available from: http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB52

FOCKINK, G.D., ZANGALLI, C., OLIVEIRA, E. and KANIESKI, M.R., 2020. Espécies prioritárias para restauração da Floresta Ombrófila Mista Montana e Altomontana na Bacia Hidrográfica do Rio Canoas. *Advances in Forestry Science*, vol. 7, no. 1, pp. 911-923. http://dx.doi.org/10.34062/afs.v7i1.8657.

GOMES-WESTPHALEN, J.S., LINS-E-SILVA, A.C. and ARAÚJO, F.S., 2012. Who is who in the understory: the contribution of resident and transitory groups of species to plant richness in forest assemblages. *Revista de Biología Tropical*, vol. 60, no. 3, pp. 1025-1040. http://dx.doi.org/10.15517/rbt.v60i3.1755. PMid:23025077.

GRINGS, M. and BRACK, P., 2009. Árvores na vegetação nativa de Nova Petrópolis, Rio Grande do Sul. *Iheringia. Série Botânica*, vol. 64, no. 1, pp. 5-22.

GROFFMAN, P.M., CADENASSO, M.L., CAVENDER-BARES, J., CHILDERS, D.L., GRIMM, N.B., GROVE, J.M., HOBBIE, S.E., HUTYRA, L.R., JENERETTE, G.D., MCPHEARSON, T., PATAKI, D.E., PICKETT, S.T.A., POUYAT, R.V., ROSI-MARSHALL, E. and RUDDELL, B.L., 2017. Moving towards a new urban systems science. *Ecosystems*, vol. 20, no. 1, pp. 38-43. http://dx.doi.org/10.1007/s10021-016-0053-4.

HARRELL JUNIOR, F., 2020 [viewed 5 June 2023]. *Hmisc: Harrell Miscellaneous. R package version 4.4-2*. Available from: https://CRAN.R-project.org/package=Hmisc

HIGUCHI, P., SILVA, A.C., AGUIAR, M.D., MAFRA, A.L., NEGRINI, M. and ZECH, D.F., 2014. Tree species community spatial partition in function of soil drainage in an araucaria forest fragment in southern Brazil. *Ciência Florestal*, vol. 24, no. 2, pp. 421-429. http://dx.doi.org/10.5902/1980509814580.

HIGUCHI, P., SILVA, A.C., BUZZI, F.J., NEGRINI, M., FERREIRA, T.S., SOUZA, S.T., SANTOS, K.F. and VEFAGO, M.B., 2015. Fatores determinantes da regeneração natural em um fragmento de Floresta com Araucária no Planalto Catarinense. *Scientia Forestalis*, vol. 43, no. 106, pp. 251-259.

HIGUCHI, P., SILVA, A.C., FERREIRA, T.S., SOUZA, S.T., GOMES, J.P., SILVA, K.M., SANTOS, K.F., BERNDT, E.J., SOUZA JUNIOR, J.O., GOIS, D.T. and WEIDUSCHAT, F., 2016. Florística e estrutura do componente arbóreo e relação com variáveis ambientais em um remanescente florestal em Campos Novos-SC. *Ciência Florestal*, vol. 26, no. 1, pp. 35-46. http://dx.doi.org/10.5902/1980509821089.

HIGUCHI, P., SILVA, A.C., LOUZADA, J.N.C. and MACHADO, E.L.M., 2010. Spatial patterns of a tropical tree species growing under an *Eucalyptus* plantation in South-East Brazil. *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 70, no. 2, pp. 271-277. http://dx.doi.org/10.1590/S1519-69842010000200006. PMid:20549060.

HIGUCHI, P., SILVA, A.C., SPIAZZI, F.R., NEGRINI, M., RAFAELI NETO, S.L., BENTO, M.A., MORÉS, D.F., AGUIAR, M.D., BUZZI JUNIOR, F. and SILVA, A.L., 2018. Elementos da paisagem como fonte de heterogeneidade florístico-estrutural do componente arbóreo em área de floresta ombrófila mista. *Ciência Florestal*, vol. 28, no. 2, pp. 661-673. http://dx.doi.org/10.5902/1980509832061.

HOTHORN, T., BRETZ, F. and WESTFALL, P., 2008. Simultaneous inference in general parametric models. *Biometrical Journal*, vol. 50, no. 3, pp. 346-363. http://dx.doi.org/10.1002/bimj.200810425. PMid:18481363.

KLAUBERG, C., PALUDO, G.F., BORTOLUZZI, R.L.C. and MANTOVANI, A., 2010. Florística e estrutura de um fragmento de Floresta Ombrófila Mista no Planalto Catarinense. *Biotemas*, vol. 23, no. 1, pp. 35-47. http://dx.doi.org/10.5007/2175-7925.2010v23n1p35.

KOWARIK, I. and VON DER LIPPE, M., 2018. Plant population success across urban ecosystems: a framework to inform biodiversity conservation in cities. *Journal of Applied Ecology*, vol. 55, no. 5, pp. 2354-2361. http://dx.doi.org/10.1111/1365-2664.13144.

LEISCH, F., 2006. A toolbox for K-centroids cluster analysis. *Computational Statistics & Data Analysis*, vol. 51, no. 2, pp. 526-544. http://dx.doi.org/10.1016/j.csda.2005.10.006.

MAZUCHOWSKI, J.Z., SILVA, E.T. and MACCARI JUNIOR, A., 2007. Efeito da luminosidade e da adição de nitrogênio no crescimento de plantas de *Ilex paraguariensis* St. Hil. *Revista Árvore*, vol. 31, no. 4, pp. 619-627. http://dx.doi.org/10.1590/S0100-67622007000400006.

NASCIMENTO, D.S., MARANHO, L.T. and HATSCHBACH, G., 2007. Fitossociologia da vegetação fanerogâmica do Jardim Botânico Municipal de Curitiba, PR, Brasil. *Revista Brasileira de Biociências*, vol. 5, no. 2, pp. 240-242.

NEGRINI, M., AGUIAR, M.D.D., VIEIRA, C.T., SILVA, A.C.D. and HIGUCHI, P., 2012. Dispersão, distribuição espacial e estratificação vertical da comunidade arbórea em um fragmento florestal no Planalto Catarinense. *Revista Árvore*, vol. 36, no. 5, pp. 919-930. http://dx.doi.org/10.1590/S0100-67622012000500014.

PARANÁ. SECRETARIA DE ESTADO DO MEIO AMBIENTE, 1995. *Lista vermelha de plantas ameaçadas de extinção no estado do Paraná*. Curitiba: SEMA/GTZ, 139 p.

PARRINI, R., PARDO, C.S. and PACHECO, J.F., 2017. Conhecendo as plantas cujos frutos e recursos florais são consumidos pelas aves na Mata Atlântica do Parque Nacional da Serra dos Órgãos. *Atualidades Ornitológicas*, vol. 199, pp. 38-136.

PASSOS, M.G., PRADO, G.P., FONTANA, C. and BIANCHINI, E., 2021. Structure and tree diversity in a Mixed Ombrophilous Forest remnant, southern Brazil. *Floresta e Ambiente*, vol. 28, no. 2, p. e20200064. http://dx.doi.org/10.1590/2179-8087-floram-2020-0064.

PINTO, M.B., GRABIAS, J., HOFFMANN, P.M., VELAZCO, S.J.E. and BLUM, C.T., 2016. Caracterização morfológica de frutos, sementes, plântulas e germinação de *Oreopanax fulvus* Marchal. *Revista Brasileira de Ciências Agrárias*, vol. 11, no. 2, pp. 111-116. http://dx.doi.org/10.5039/agraria.v11i2a5366.

PINTO, M.B., VELAZCO, S.J.E., BARBOSA, F.M., CHAGAS, K.P.T. and BLUM, C.T., 2021. Phenological patterns of *Oreopanax fulvus* (Araliaceae) in remnants of Araucaria Rainforest in Paraná, Brazil. *Rodriguésia*, vol. 72, p. e01092020. http://dx.doi.org/10.1590/2175-7860202172124.

PLANCHUELO, G., VON DER LIPPE, M. and KOWARIK, I., 2019. Untangling the role of urban ecosystems as habitats for endangered plant species. *Landscape and Urban Planning*, vol. 189, pp. 320-334. http://dx.doi.org/10.1016/j.landurbplan.2019.05.007.

PSCHEIDT, F., HIGUCHI, P., SILVA, A.C., RECH, T.D., SALAMI, B., FERREIRA, T.S., BONAZZA, M. and BENTO, M.A., 2018. Efeito de borda como fonte da heterogeneidade do componente arbóreo em uma Floresta com Araucárias no Sul do Brasil. *Ciência Florestal*, vol. 28, no. 2, pp. 601-612. http://dx.doi.org/10.5902/1980509832046.

R CORE TEAM, 2022 [viewed 5 June 2023]. *R: a language and environment for statistical computing* [software]. Vienna: R Foundation for Statistical Computing. Available from: https://www.R-project.org/

RIBEIRO, M.C., METZGER, J.P., MARTENSEN, A.C., PONZONI, F.J. and HIROTA, M.M., 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. *Biological Conservation*, vol. 142, no. 6, pp. 1141-1153. http://dx.doi.org/10.1016/j.biocon.2009.02.021.

RIO GRANDE DO SUL. FUNDAÇÃO ZOOBOTÂNICA, 2003 [viewed 28 May 2015]. *Decreto estadual no. 42.099. Lista final das espécies da flora ameaçadas* [online]. Diário Oficial do Estado do Rio Grande do Sul, Porto Alegre, 1 Jan. Available from: https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Decretos/2002/dec_rs_42099_2002_especies_floranativa_ameacadasdeextincao_rs.pdf

RIPLEY, B.D., 1977. Modeling spatial patterns. *Journal of the Royal Statistic Society*, vol. 39, no. 2, pp. 172-212.

SANTOS, G.N., HIGUCHI, P., SILVA, A.C., FARIAS, K.J., MACHADO, F.D., DUARTE, E., FERNANDES, C., VIEIRA, F., AMARAL, R.S., AGUIAR, V., WALTER, F.F., MORES, B. and REIS, M.A., 2018. Regeneração natural em uma Floresta com Araucária: inferências sobre o processo de construção da comunidade de espécies arbóreas. *Ciência Florestal*, vol. 28, no. 2, pp. 483-494. http://dx.doi.org/10.5902/1980509832029.

SCHAAF, L.B., FIGUEIREDO FILHO, A., GALVÃO, F. and SANQUETTA, C.R., 2006. Alteração na estrutura diamétrica de uma Floresta Ombrófila Mista no período entre 1979 e 2000. *Revista Árvore*, vol. 30, no. 2, pp. 283-295. http://dx.doi.org/10.1590/S0100-67622006000200016.

SILVA, D.P., BARBIERI, L.R. and FERREIRA, I.J., 2017. Efeitos da fragmentação florestal no município de Japurá – Paraná. *Revista GEOMAE*, vol. 8, pp. 186-195.

SILVA, K.E., MARTINS, S.V., SANTOS, N.T. and RIBEIRO, C.A.A.S., 2009. Padrões espaciais de espécies arbóreas tropicais. In: S.V. MARTINS, ed. *Ecologia de florestas tropicais do Brasil*. Viçosa: Editora UFV, pp. 216-244.

SILVA, R.A.R., MAZON, J.A. and WATZLAWICK, L.F., 2019. Distribuição espacial de táxons anemocóricos e zoocóricos em fragmentos de Floresta Ombrófila Mista. *Pesquisa Florestal Brasileira*, vol. 39, no. 1, pp. 1-10. http://dx.doi.org/10.4336/2019.pfb.39e201801700.

TEMPLETON, L.K., NEEL, M.C., GROFFMAN, P.M., CADENASSO, M.L. and SULLIVAN, J.H., 2019. Changes in vegetation structure and composition of urban and rural forest patches in Baltimore from 1998 to 2015. *Forest Ecology and Management*, vol. 454, p. 117665. http://dx.doi.org/10.1016/j.foreco.2019.117665.

TURCHETTO, F., ARAUJO, M.M., CALLEGARO, R.M., GRIEBELER, A.M., MEZZOMO, J.C., BERGHETTI, A.L. and RORATO, D.G., 2017. Phytosociology as a tool for forest restoration: a study case in the extreme south of Atlantic Forest Biome. *Biodiversity and Conservation*, vol. 26, no. 6, pp. 1463-1480. http://dx.doi.org/10.1007/s10531-017-1310-3.

TURCHETTO, F., ARAUJO, M.M., TABALDI, L.A., GRIEBELER, A.M., RORATO, D.G., AIMI, S.C., BERGHETTI, A.L. and GOMES, D.R., 2016. Can transplantation of forest seedlings be a strategy to enrich seedling production in plant nurseries? *Forest Ecology and Management*, vol. 375, pp. 96-104. http://dx.doi.org/10.1016/j.foreco.2016.05.029.

VOLIS, S. and DENG, T., 2020. Importance of a single population demographic census as a first step of threatened species conservation planning. *Biodiversity and Conservation*, vol. 29, no. 2, pp. 527-543. http://dx.doi.org/10.1007/s10531-019-01897-3.

WODKIEWICZ, M. and GRUSZCZYNSKA, B., 2014. Genetic diversity and spatial genetic structure of *Stellaria holostea* populations from urban forest islands. *Acta Biologica Cracoviensia. Series Botanica*, vol. 56, no. 1, pp. 42-53. http://dx.doi.org/10.2478/abcsb-2014-0004.

ZANELLA, A., BRUM, F.T., PETISCO-SOUZA, A.C., MACCORI, G.F. and CARLUCCI, M.B., 2022. Tree species of the Araucaria Mixed Forest: which, how many and how threatened are they? *Acta Botanica Brasílica*, vol. 36, p. e2021abb0021. http://dx.doi.org/10.1590/0102-33062021abb0021.