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Prediction of the natural distribution and conservation of *Urena lobata* L. in Brazil[1]

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ABSTRACT

Urena lobata L. is a commercial species used for fiber extraction in the Brazilian states of Amazonas and Pará that presents relevant socioeconomic importance for the Amazon region. Despite its importance and wide distribution throughout Brazil, there are no data on the species response to global climate change. This study aimed to present the potential geographical distribution of *U. lobata* in the current period (2009-2019) and predict areas of climatic suitability for its occurrence in two future scenarios (RCP 4.5 and RCP 8.5), at two time intervals (2020-2050 and 2051-2070), in the face of global climate change. A total of 19 bioclimatic variables were obtained from the WorldClim database and four algorithms (Climate Space Model, Envelope Score, Niche Mosaic and Environmental Distance), from which the Envelope Score was the most representative model for the species to verify its occurrence along the Brazilian phytogeographic domains (Amazon, Caatinga, Cerrado, Pantanal, Atlantic Forest and Pampa). Vulnerability was observed for the species, since there were losses of favorable areas in the Amazon, Pantanal, Atlantic Forest, Cerrado and Caatinga, becoming practically extinct in the worst scenario (RCP 8.5), in the year 2070. However, for this same scenario and year, there was a significant area increase in the Pampa.

KEYWORDS: Caesar weed, Malvaceae, climate change, vulnerability of plant species.

RESUMO

Predição da distribuição natural e conservação de *Urena lobata* L. no Brasil

Urena lobata L. é uma espécie comercial, utilizada para a extração de fibras nos estados do Amazonas e Pará, que apresenta relevante importância socioeconômica para a região Amazônica. Apesar de sua importância e vasta distribuição pelo Brasil, não existem dados sobre a resposta da espécie às mudanças climáticas globais. Objetivou-se apresentar a distribuição geográfica potencial de *U. lobata* no período atual (2009-2019) e prever áreas de adequabilidade climática para sua ocorrência em dois cenários futuros (RCP 4.5 e RCP 8.5), em dois intervalos de tempo (2020-2050 e 2051-2070), diante das mudanças climáticas globais. Foram utilizadas 19 variáveis bioclimáticas obtidas do WorldClim e quatro algoritmos (Climate Space Model, Envelope Score, Niche Mosaic e Environmental Distance), dos quais o Envelope Score foi o modelo mais representativo para a espécie, para verificar sua ocorrência ao longo dos domínios fitogeográficos brasileiros (Amazônia, Caatinga, Cerrado, Pantanal, Mata Atlântica e Pampa). Observou-se vulnerabilidade para a espécie, já que houve perdas de áreas favoráveis na Amazônia, Pantanal, Mata Atlântica, Cerrado e Caatinga, tornando-se praticamente extinta no pior cenário (RCP 8.5), no ano de 2070. Entretanto, para esse mesmo cenário e ano, observou-se aumento significativo de área no Pampa.

PALAVRAS-CHAVE: Malva, Malvaceae, mudanças climáticas, vulnerabilidade de espécies vegetais.

INTRODUCTION

Caesar weed (*Urena lobata* L.) is a perennial shrub species belonging to the Malvaceae family. Its good adaptation to floodplain soils made it the most cultivated fibrous species in the Amazonas state and one of the main sources of income for riverside families (Maciel et al. 2019). It is estimated that, directly and indirectly, the *U. lobata* production chain involves about 20,000 jobs in Brazil (Gomes et al. 2019).

In addition, the species is considered a ruderal plant (Bovini 2015) and may be found in different regions (Fleppc 2011, PIER 2022). *U. lobata* presents a mechanism of dispersion that can help to increase its distribution in diverse regions, due to its high seed production and because its fruits are covered by trichomes (dispersed in the shape of small hooks).

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The dispersal of the species is then facilitated with the fruits sticking to animals and humans, when they touch the plant (Awan et al. 2014).

U. lobata is highly adaptable to different environments and can grow from sea level to altitudes of 1,500 m, in areas that receive about 1,400 to 3,000 mm of accumulated rainfall per year (Francis 2004).

Although it has a greater relevance in the northern region, its rusticity facilitates its dispersion and adaptation to different Brazilian environments. So, it is important to know its current and future distribution, when considering which regions will suffer the most from climate change (Marengo 2014, Marengo & Souza Junior 2018), in order to plan its use and the conservation of its genetic resources, thereby reducing future cultivation losses.

The ecological niche modeling is a method that has been used to analyze the adaptation and conservation of plant species (Loyola et al. 2013). It allows the evaluation of environmental conditions responsible for species distribution, and the obtained results can be extrapolated when assessing future climatic conditions and reaching predictions of where these events may be repeated (Elith et al. 2011, Silva et al. 2021). These results may also indicate whether the region is suitable for the development of the species (Giannini et al. 2012).

This study aimed to present the geographical distribution of *U. lobata* L. in the present period and predict favorable areas for its occurrence in future climatic scenarios.

MATERIAL AND METHODS

Urena lobata data were obtained in 2021, from open access databases of the Embrapa Florestas. The points of occurrence, with their respective geographic coordinates, were obtained from the SpeciesLink (CRIA 2019), Reflora virtual herbarium (Reflora 2021) and from surveying geographical coordinates of scientific articles on the species available in the literature. All data was restricted to Brazilian phytogeographic domains. This procedure was done using the geographic information system (GIS), in the ArcMap software (Esri 2011).

A total of 19 bioclimatic variables obtained from the Worldclim (Hijmans et al. 2005), including air temperatures (minimum and maximum) and rainfall (Kumar & Stohlgren 2009, Fick & Hijmans 2017), were used. To identify the contribution of each variable, the Principal Component Analysis (PCA) was performed from the R software (R Development Core Team 2021) and its complement RStudio Team (2020). Of the 19 main components generated from the PCA, the first six were used in the modeling process of the species, which, together, represented about 97 % of the total variability of the data. The most important climatic variables (with higher eigenvector values) were related to air temperatures [minimum temperature in the coldest month (Bio 6), average temperature in the driest quarter (Bio 9) and average temperature in the coldest quarter (Bio 11)] and rainfall [rainfall accumulated in the driest quarter (Bio 17) and in the driest month (Bio 14), and rainfall seasonality (Bio 15)].

The maps were elaborated using multiple linear regression, relating the bioclimatic variables with the numerical models of latitude, longitude and altitude. According to the Intergovernmental Panel on Climate Change (IPCC 2021), the maps were generated considering two scenarios [RCP 4.5 (less pessimistic) and RCP 8.5 (more pessimistic)], two periods (2020-2050 and 2051-2070), in addition to the current period (2009-2019), and six Brazilian phytogeographic domains (Amazon, Caatinga, Cerrado, Pantanal, Atlantic Forest and Pampa). For the RCP 8.5 scenario, it is admitted that strategies that reduce the greenhouse effect will not be considered (Li et al. 2020).

To predict the species distribution, four algorithm models were used (Climate Space Model, Envelope Score, Niche Mosaic and Environmental Distance), each obtained by integrating the receiver operating characteristic (ROC) curve. To evaluate the model that presented the best performance, the area under the curve (AUC) was calculated. Remaining consistent, Envelope Score was the algorithm that presented the best distribution of the species, because its AUC value was equal to 1.0, indicating a perfect discrimination, while values less than 0.5 mean low modeling performance.

Maps created in OpenModeller, in American Standard Code for Information Interchange (ASCII) text format, containing binary values, were transformed to 'raster' format (Esri 2011). Categories were created with a gradient ranging from 0 to 1, where 0 corresponded to areas with no possibility of occurrence and 1 to areas with maximum possibility of occurrence (Muñoz et al. 2011).

RESULTS AND DISCUSSION

The number of occurrence points (282) found after the consistency evaluation (removal of outliers) was sufficient for the modeling study and for obtaining the maps of the current period and future climate scenarios (RCP 4.5 and RCP 8.5). Figure 1 shows the distribution of the species through the points of occurrence in the Brazilian territory.

The map generated for the environmental conditions of the current period evidenced a high climatic suitability for the species (Figure 2), whose distribution occurs practically throughout Brazil, except for the Pampa, where no points were observed. In fact, according to Bovini (2015) and Fernandes-Júnior & Gonçalez (2020), the species has a wide distribution in the country. Thus, the prediction of the distribution made by using the Envelope Score method is consistent with the distribution patterns of the species described by the authors.

Figure 1. Points of occurrence of *Urena lobata* in the Brazilian phytogeographic domains, corresponding to the current period (2009-2019), using the Envelope Score model.

The projections for 2020-2050, for the less pessimistic scenario (RCP 4.5), showed a reduction of areas of occurrence of *U. lobata* in all phytogeographic domains, with significant losses for the Amazon and Pampa (Figure 2).

For 2051-2070, the loss of areas followed the same behavior, also with significant losses for the Amazon and Pampa (Figure 2). The considerable loss in the Pampa, when compared to the Amazon, can be observed by reducing the coverage of the graphical distribution of the species, showing the greater sensitivity of the Pampa to environmental climate change.

The *U. lobata* distribution in the Amazon has a higher probability of occurrence in the current distribution. In the 2020-2050 period of the RCP 4.5 scenario, there will be reductions in area for the Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa and Pantanal by 7.38, 0.34, 0.34, 0.34, 98.94 and 0.34 %, respectively (Table 1). The Amazon and Pampa presented the highest total area loss (14,991,781.83 km² and 15,515,373.48 km², respectively) in the 2020-2050 period (Table 1).

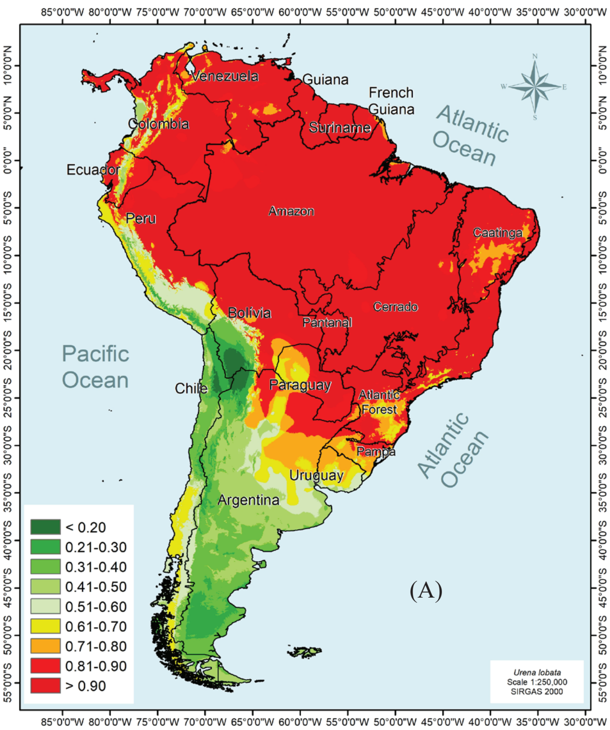
Regarding the 2051-2070 period, there were area reductions for the Amazon, Caatinga, Cerrado, Atlantic Forest, Pampa and Pantanal by 7.86, 0.52, 0.52, 0.52, 98.93 and 0.52 %, respectively (Table 1). Similarly, the Amazon and Pampa presented the highest total area losses (15,973,205.78 km² and 15,513,353.44 km², respectively).

The future projections for the less pessimistic scenario (RCP 4.5), in the 2020-2050 and 2051-2070 periods, showed climatic suitability for the

Table 1. Distribution area (km^2) of *Urena lobata* in the projection of the RCP 4.5 scenario (less pessimistic) for the current period (2009-2019), 2020-2050 and 2051-2070 and percentages of area change.

Phytogeographic domains	Currrent period (2009-2019)	2020-2050	Area loss (km²)	%	2051-2070	Area loss (km²)	%
Amazon	203,177,085.20	188,185,303.40	14,991,781.83	7.38	187,203,879.50	15,973,205.78	7.86
Caatinga	15,681,200.00	15,628,200.00	53,000.00	0.34	15,599,400.00	81,800.00	0.52
Cerrado	15,681,214.86	15,628,214.86	53,000.00	0.34	15,599,414.86	81,800.00	0.52
Atlantic Forest	203,856,591.50	203,167,591.50	689,000.00	0.34	202,793,191.50	1,063,400.00	0.52
Pampa	15,681,285.31	165,911.83	15,515,373.48	98.94	167,931.87	15,513,353.44	98.93
Pantanal	15,681,200.00	15,628,200.00	53,000.00	0.34	15,599,400.00	81,800.00	0.52
Total	469,758,576.90	438,403,421.60	31,355,155.31	6.67	436,963,217.70	32,795,359.22	6.98

occurrence of *U. Lobata* in the Amazon and Atlantic Forest, while, in the Pampa, the species presented a greater vulnerability to ongoing climate change (Figure 3).



For the more pessimistic scenario (RCP 8.5), a reduction in species suitability areas was observed for the current period (Figure 4). In the 2020-2050 period, there were percentages of favorable area reduction for the development of the species equivalent to 98.6, 99.5 and 99 %, respectively for the Amazon, Atlantic Forest and Pantanal (Table 2). For the Caatinga and Cerrado, the area loss was 95.3

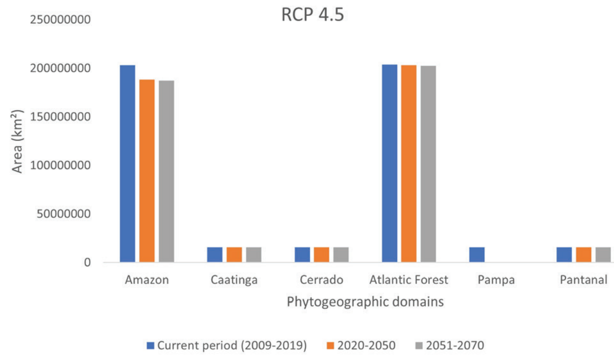


Figure 3. Distribution area of *Urena lobata* by Brazilian phytogeographic domain, using the Envelope Score model, for the current period (2009-2019), 2020-2050 and 2051-2070, in the less pessimistic scenario (RCP 4.5).

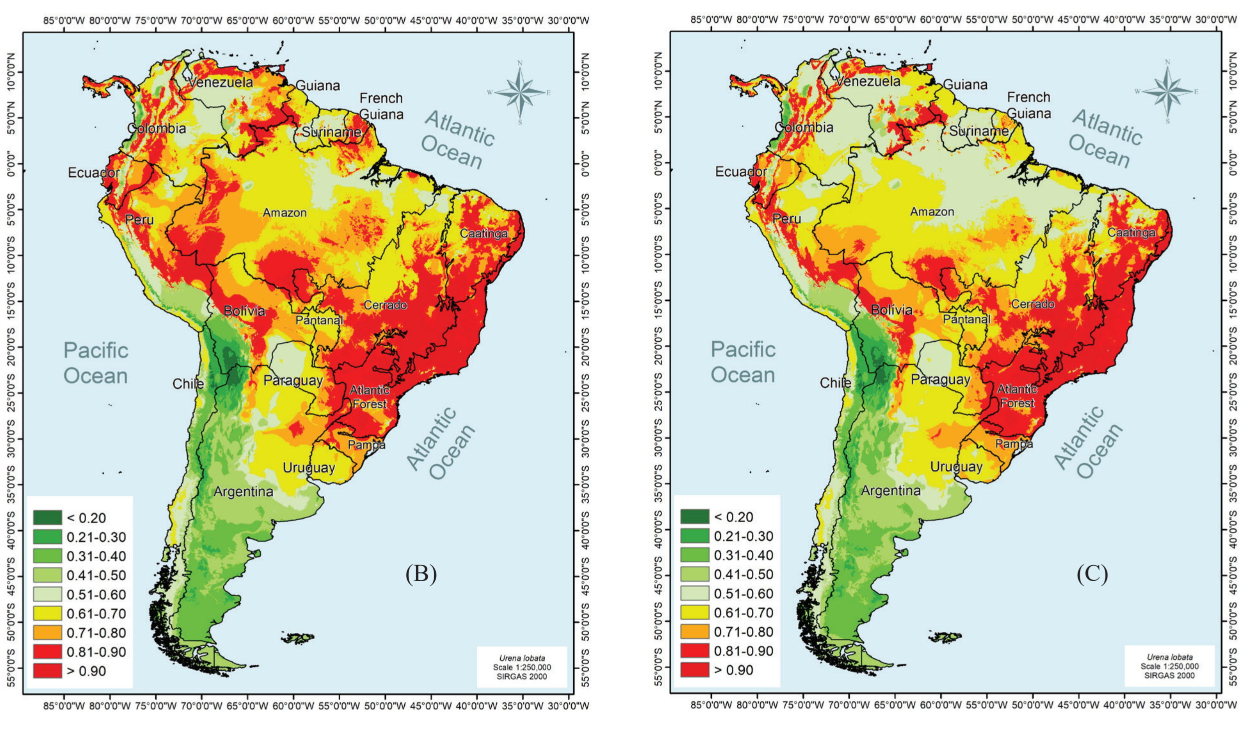


Figure 2. Distribution of *Urena lobata* in the Brazilian phytogeographic domains, using the Envelope Score model: A) current period (2009-2019); B) RCP 4.5 scenario (less pessimistic) and 2020-2050 period; C) RCP 4.5 scenario and 2051-2070 period.

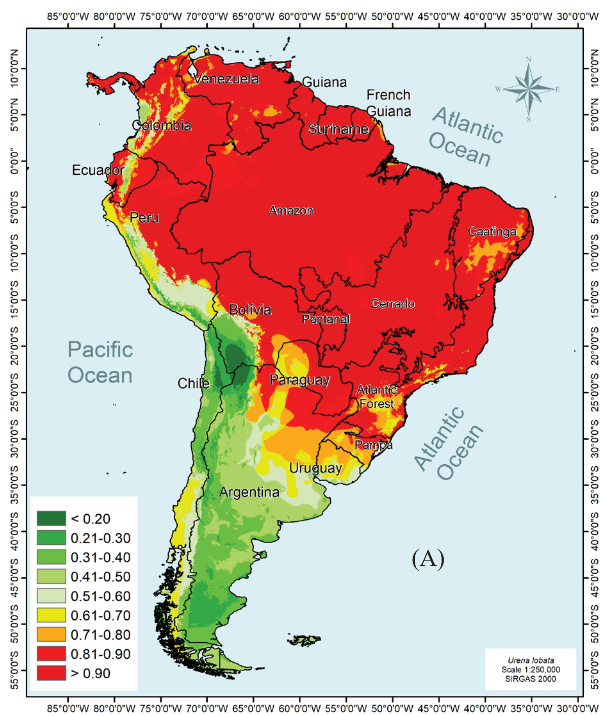
and 89.3 %, respectively, while the Pampa showed an area loss of less than 1 %, indicating that it may be a favorable area in the future for *U. lobata* (Table 2).

It is also noted that intertropical areas will be more affected in the RCP 8.5 scenario (Marengo 2014, Marengo & Souza Junior 2018), ergo the species is more favored in adaptation in the Pampa, if compared to the other Brazilian phytogeographic domains. In a study of the effects of climate change in the Peru's intertropical area (2035-2050 projections), the forecast is that approximately 6 % of the forest cover in the region will experience a change to an area of lower humidity (Zevallos & Lavado-Casimiro 2021).

For the 2051-2070 period, a scenario of near extinction of the species is observed in the Amazon, Pantanal and Atlantic Forest, since the area loss for these regions was 99.9 %. The Caatinga and Cerrado also expressed a severe area loss (97.2 and 93.3 %, respectively). However, the Pampa showed an increase in area favorable to the species by more than 200 % (Table 2).

The behavior of increase in favorable area for *U. lobata* in the Pampa may be justified by the fact that these changes in the distribution and displacement of the species to a more favorable climatic space is an expected effect arising from climate change (Lemes & Loyola 2014, Matos et al. 2017).

Changes in the distribution of plant species projected in future scenarios have been cited in the literature by several authors (Matos et al. 2017,



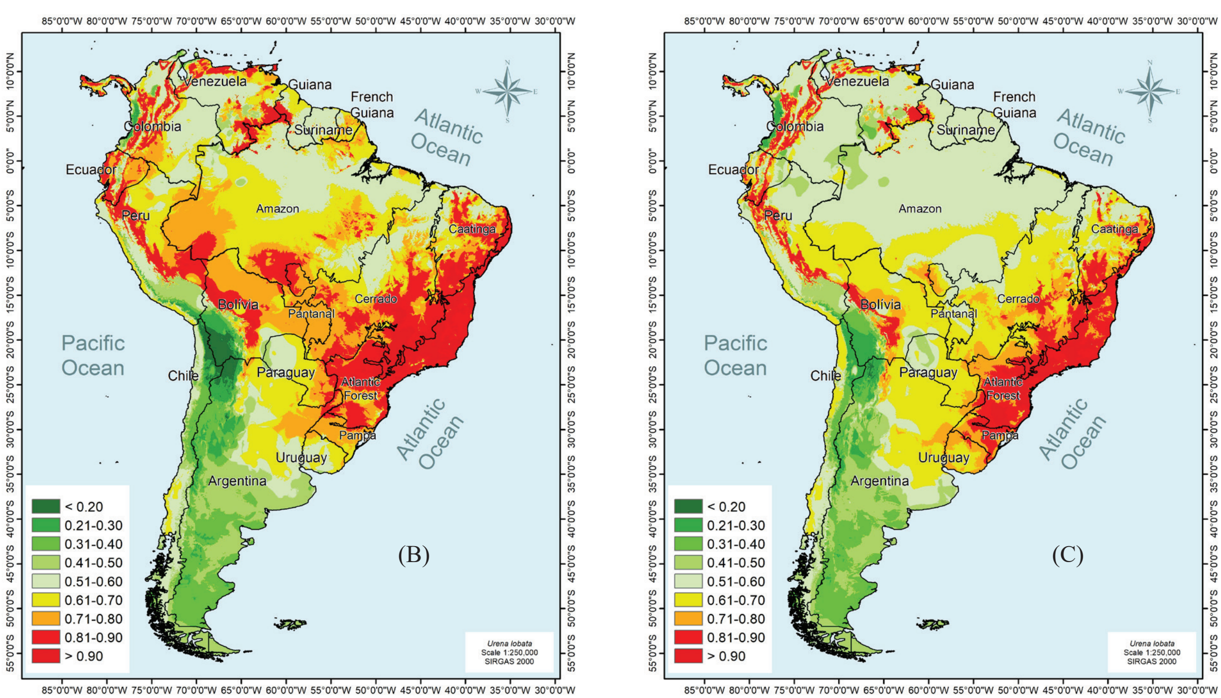


Figure 4. Distribution of *Urena lobata* in the Brazilian phytogeographic domains, using the Envelope Score model: A) current period (2009-2019); B) RCP 8.5 scenario (more pessimistic) and 2020-2050 period; C) RCP 8.5 scenario and 2051-2070 period.

Table 2. Distribution area (km^2) of *Urena lobata* in the projection of the more pessimistic scenario (RCP 8.5) for the current period (2009-2019), 2020-2050 and 2051-2070 and percentage of area change.

Phytogeographic domains	Current period (2009-2019)	2020-2050	Área loss (%)	2051-2070	Area loss (%)
Amazon	203,177,085.20	2,864,737.83	98.60	125,586.90	99.9
Caatinga	15,681,200.00	7,373,872.18	95.30	453,898.49	97.2
Cerrado	15,681,214.86	1,687,496.15	89.30	1,049,693.58	93.3
Atlantic Forest	203,856,591.50	1,142,759.10	99.50	1,135,673.46	99.4
Pampa	15,681,285.31	15,628,285.31	0.34	62,397,600.00	0.0
Pantanal	15,681,200.00	151,233.00	99.00	18,733.59	99.9
Total	469,758,576.90	22,211,898,62	80.30	65,181,186,04	65.5

Silva et al. 2018, Castro et al. 2019, Cintra et al. 2020), indicating the possibility of decrease, or even extinction, in sites of natural occurrence, as well as the species may "migrate" to more favorable regions (Guitérrez & Trejo 2014). Such is the case of *U. lobata*, showing a greater distribution in the Pampa, in the 2051-2070 period, in the more pessimistic scenario.

Urena lobata will still be able to grow in most of Brazil in the 2051-2070 period, in the RCP 4.5 scenario. Nonetheless, in the RCP 8.5 scenario, there will be a significant reduction in favorable areas in all the Brazilian phytogeographic domains (Figure 5). The reduction in the favorable area of the species in the Amazon is a cause of concern for the population and public agents, regarding environmental and economic consequences, due to the risk of decline in the production of fiber and seeds in Amazonas and Pará, which are currently the largest Brazilian producers (Idam 2020).

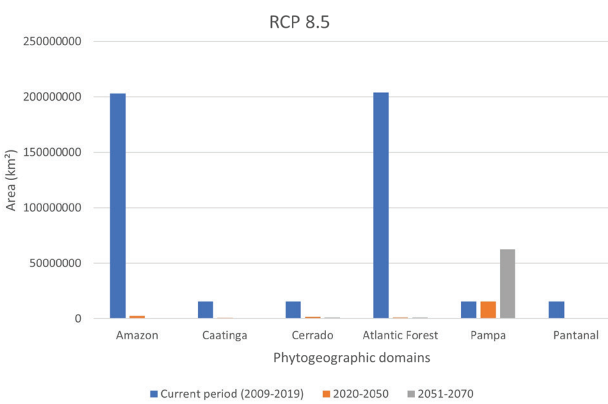


Figure 5. Distribution area of *Urena lobata* by Brazilian phytogeographic domain, using the Envelope Score model, for the current period (2009-2019), 2020-2050 and 2051-2070, in the more pessimistic scenario (RCP 8.5).

The Amazon is one of the phytogeographic domains with the greatest vulnerability to climate threats, right after semi-arid regions, with a serious risk of suffering "savannization" (PBMC 2014). The possibility of periods of intense drought in the Amazon region, such as that of 2005, may increase the average percentage of current occurrence from 5 % (a strong drought every 20 years) to 50 % in 2030, and up to 90 % in 2100 (Cox et al. 2008). This may represent an elongation of the dry season, thus affecting the hydrology and ecosystems of the region (Marengo 2014).

From the economic point of view, the cultivation of the species, regarding fiber production, will be challenging, since the species is cultivated in floodplain soils, requiring water cycles. Furthermore, producers make use of river waters at the time of harvest for the process of maceration and washing the fibers removed from plants. Besides the maturation cycle of *U. lobata* being dependent on the water regime (flooding, ebb and drought), its economic and adaptive potential to the floodplain areas of the region is remarkable (Gomes et al. 2019).

Water scarcity and temperature increase may contribute to the change of the preferential zone of *U. lobata* to areas with milder climates, such as the higher altitude areas in the South and Southeast regions of the country. To evaluate the Thornthwaite water balance in Brazil from the IPCC-AR5 projections, Marcos-Junior et al. (2018) verified the possibility of increased wet climates in the southern region of the country under both the RCP 4.5 and 8.5 scenarios. Changes may also mean increased water supply in these regions and may be taken into consideration for this present study.

From an environmental point-of-view, regions of milder climate, such as the Pampa, may function as climatic refuges in a scenario of global warming for

U. lobata. They may serve well as an alternative for the management of the species. The literature reports other species, such as *Handroanthus impetiginosus* (Mart ex. Dc) (Matos et al. 2017), *Ilex paraguariensis* A. St.-Hill. (Silva et al. 2018) and *Stryphnodendron pulcherrimum* (Willd.) Hochr. (Tomaz et al. 2022), which are sensitive to climate change, contributing to their migration to milder climate regions, such as in the southern part of the country.

The analysis performed in this study provides evidence of the need of conservation studies for *U. lobata*, in view of the risks of climate change in future scenarios on the distribution of the species. The induction of artificial mutation could be a process to generate genetic variability in the short term to seek a source of genes for tolerance to high temperatures and rainfall. This will aim to ensure the adaptability of the species to climatic conditions related to the worst-case scenario in northern Brazil. Populations from various locations may be collected for the study of genetic diversity with molecular markers for *ex situ* conservation, which will make allowances for a greater variability to be gathered and avoid duplication of genotypes. The *in situ* conservation of the species should be directed to areas of greater adaptation.

The results of the modeling may also be used to establish appropriate locations for the cultivation and development of the species, facilitating the use of its products, since *U. lobata* is of commercial interest. The adoption of conservation measures, either *in situ* or *ex situ*, are necessary to avoid the loss of further genetic variability.

CONCLUSION

Global climate change may severely affect the occurrence of *Urena lobata* in the Brazilian phytogeographic domains, mainly in the Amazon, Atlantic Forest and Pantanal, where the species may become completely extinct in the more pessimistic scenario (RCP 8.5). The populations present in these domains, especially in the Amazon, which is regarded as the area of greatest current distribution and region of cultivation relevance, should be considered in conservation studies on genetic resources of the species.

REFERENCES

AWAN, T. H.; CHAUHAN, B. S.; CRUZ, P. C. S. Influence of environmental factors on the germination of *Urena lobata* L. and its response to herbicides. *Plos One*, v. 9, n. 3, e90305, 2014.

BOVINI, M. G. *Urena na lista de espécies da Flora do Brasil*. 2015. Available at: http://floradobrasil2015.jbrj.gov.br/FB9269. Access on: Nov. 10, 2021.

CASTRO, F. À. B.; CONCEIÇÃO, F. G. da; COSTA, O. A. D.; LONGHI, S. J. Pinheiros antigos podem entrar em declínio devido ao efeito de mudanças climáticas. *BIOFIX Scientific Journal*, v. 4, n. 1, p. 16-25, 2019.

CENTRO DE REFERÊNCIA E INFORMAÇÃO AMBIENTAL (CRIA). *SinBiota*: sistema de informação ambiental do Programa Biota/FAPESP. 2019. Available at: https://specieslink.net/. Access on: Dec. 07, 2020.

CINTRA, P. H. N.; MELO, O. F. P. de; MENEZES, J. O. S. de. Produção agrícola: uma revisão bibliográfica sobre as mudanças climáticas e produtividade de plantas graníferas no Brasil. *Revista Agrotecnologia*, v. 11, n. 1, p. 87-94, 2020.

COX, P. M.; HARRIS, P. P.; HUNTINGFORD, C.; BETTS, R. A.; COLLINS, M.; JONES, C. D.; JUPP, T. E.; MARENGO, J. A.; NOBRE, C. A. Increasing risk of Amazonian drought due to decreasing aerosol pollution. *Nature*, v. 453, n. 7192, p. 212-215, 2008.

ELITH, J.; PHILLIPS, S. J.; HASTIE, T.; DUDÍK, M.; CHEE, Y. E.; YATES, C. J. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*, v. 17, n. 1, p. 43-57, 2011.

ESRI, D. A. *Release 10*. Redlands: Environmental Systems Research Institute, 2011.

FERNANDES-JÚNIOR, A. J.; GONÇALEZ, V. M. *Urena na Flora do Brasil*. 2020. Available at: https://floradobrasil2020.jbrj.gov.br/FB9269. Access on: Oct. 06, 2021.

FICK, S. E.; HIJMANS, R. J. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, v. 37, n. 12, p. 4302-4315, 2017.

FLORIDA EXOTIC PEST PLANT COUNCIL (FLEPPC). List of invasive plant species. *Wildland Weeds*, v. 14, n. 3, p. 11-14, 2011.

FRANCIS, J. K. *Wildland shrubs of the United States, and its territories*: thamnic descriptions. Washington, DC: USDA, 2004.

GIANNINI, T. C.; SIQUEIRA, M. F.; ACOSTA, A. L.; BARRETO, F. C. C.; SARAIVA, A. M.; ALVES-DOS-SANTOS, I. Desafios atuais da modelagem preditiva de distribuição de espécies. *Rodriguésia*, v. 63, n. 3, p. 733-749, 2012.

GOMES, L. M.; CASTRO, A. P. de; FRAXE, T. J. P.; COSTA NETO, P. Q.; SILVA MENDES, A. M. da;

VALENTE, M. S.; FEREIRRA, C. C.; PEREIRA, M. L. A. Genetic divergence *in Urena lobata* accessions to quantitative traits. *Journal of Agricultural Science*, v. 11, n. 11, p. 81-92, 2019.

GUITÉRREZ, E.; TREJO, I. Efecto del cambio climático en la distribución potencial de cinco espécies arbóreas de bosque templado en México. *Revista Mexicana de Biodiversidad*, v. 85, n. 1, p. 179-188, 2014.

HIJMANS, R. J.; CAMERON, S. E.; PARRA, J. L.; JONES, P. G.; JARVIS, A. Very high-resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, v. 25, n. 15, p. 1965-1978, 2005.

INSTITUTO DE DESENVOLVIMENTO AGROPECUÁRIO E FLORESTAL SUSTENTÁVEL DO ESTADO DO AMAZONAS (IDAM). *Relatório de acompanhamento trimestral da cultura da malva, Manaus, AM*. 2020. Available at: http://www.idam.am.gov.br/wp-content/uploads/2021/09/RAIDAM2020_web_vfinal.pdf. Access on: Oct. 24, 2021.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). *The physical science basis*. 2021. Available at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCCAR6WGIFullReport.pdf. Access on: Feb. 22, 2021.

KUMAR, R. S.; STOHLGREN, T. J. Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. *Journal of Ecology and Natural Environment*, v. 1, n. 4, p. 94-98, 2009.

LEMES, P.; LOYOLA, R. D. Mudanças climáticas e prioridades para a conservação da biodiversidade. *Revista de Biologia Neotropical*, v. 11, n. 1, p. 47-57, 2014.

LI, F.; LIU, Y.; YAN, W.; ZHAO, Y.; JIANG, R. Effects of future climate change on summer maize growth in Shijin irrigation district. *Theoretical and Applied Climatology*, v. 139, n. 1, p. 33-44, 2020.

LOYOLA, R. D.; LEMES, P.; NABOUT, J. C.; TRINDADE FILHO, J.; SAGNORI, M. D.; DOBROVOLSKI, R.; DINIZ FILHO, J. A. F. A straightforward conceptual approach for evaluating spatial conservation priorities under climate change. *Biodiversity and Conservation*, v. 22, n. 2, p. 483-495, 2013.

MACIEL, A. C.; FRAXE, T. J. P.; CASTRO, A. P. Agricultura familiar e o cultivo da malva na Amazônia. *Scientia Naturalis*, v. 1, n. 5, p. 92-107, 2019.

MARCOS-JUNIOR, A. D.; SILVA, S. C. da; CHAGAS, V. J. F. das; GUIMARÃES, S. O.; COSTA, J. M. F. da. Classificação climática de Thornthwaite para o Brasil com base em cenários de mudanças climáticas do IPCC-AR5. *Revista Brasileira de Meteorologia*, v. 33, n. 4, p. 647-664, 2018.

MARENGO, J. A. O futuro clima do Brasil. *Revista USP*, n. 103, p. 25-32, 2014.

MARENGO, J. A.; SOUZA JUNIOR, C. *Mudanças climáticas*: impactos e cenários para a Amazônia. São Paulo: ALANA, 2018.

MATOS, M. F. S.; SCARANTE, A.; SOARES, M. T. S.; BOGNOLA, I. A.; WREGE, M. S. *Distribuição de Handroanthus impetiginosus no Brasil e as projeções futuras conforme as mudanças climáticas globais*. 2017. Available at: http://www.alice.cnptia.embrapa.br/alice/handle/doc/1076242. Access on: June 21, 2021.

MUÑOZ, M. E. S.; GIOVANNI, R.; SIQUEIRA, M. F.; SUTTON, T.; BREWER, P.; PEREIRA, R. S.; CANHOS, D. A. L.; CANHOS, V. P. OpenModeller: a generic approach to species' potential distribution modelling. *GeoInformatica*, v. 15, n. 1, p. 111-135, 2011.

PACIFIC ISLANDS ECOSYSTEMS AT RISK (PIER). *Plant threats to Pacific ecosystems*. 2022. Available at: http://www.hear.org/pier/. Access on: Aug. 25, 2022.

PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS (PBMC). *Base científica das mudanças climáticas*: primeiro relatório da avaliação nacional sobre mudanças climáticas. Rio de Janeiro: COPPE, 2014.

R DEVELOPMENT CORE TEAM. *R*: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2021.

REFLORA. *Herbário virtual*. 2021. Available at: https://reflora.jbrj.gov.br/reflora/herbario Virtual/. Access on: Jan. 19, 2021.

RSTUDIO TEAM. *RStudio*: integrated development for R. Boston: RStudio, 2020.

SILVA, M. A. F. da; HIGUCHI, P.; SILVA, A. C. da. Mudanças no clima e a distribuição potencial futura de *Mimosa scabrella* Benth: influência das mudanças climáticas na bracatinga. *Revista Acta Ambiental Catarinense*, v. 18, n. 1, p. 116-128, 2021.

SILVA, M. A. F.; HIGUCHI, P.; SILVA, A. C. Impacto de mudanças climáticas sobre a distribuição geográfica potencial de *Ilex paraguariensis*. *Rodriguésia*, v. 69, n. 4, p. 2069-2079, 2018.

TOMAZ, J. S.; BEZERRA, C. de S.; AGUIAR, A. V. de; WREGE, M. S.; LOPES, M. T. G. Predição da distribuição natural, habitat e conservação de *Stryphnodendron pulcherrimum* (Willd.) Hochr. frente às mudanças climáticas globais. *Pesquisa Agropecuária Tropical*, v. 52, e72422, 2022.

ZEVALLOS, J.; LAVADO-CASIMIRO, W. Climate change impact on Peruvian biomes. *Forests*, v. 13, n. 2, e238, 2022.