Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Suitable areas for Juçara palm (*Euterpe edulis* Martius) cultivation in Rio de Janeiro state, Brazil: proposal to encourage agro-ecological practices and non-timber products

ARTICLES doi:10.4136/ambi-agua.3033

Received: 12 Sep. 2024; Accepted: 23 Jan. 2025

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ABSTRACT

The Juçara palm (Euterpe edulis Mart.) is a native species of the Atlantic Forest biome, with high commercial value due to, among other uses, the extraction of the palm heart and pulp. This species has essential ecological interaction with fauna, providing food for many frugivorous species. However, it is on the list of endangered species, mainly due to the disorderly exploration of the palm tree for the extraction of the palm heart, but also due to climate change, habitat fragmentation, and defaunation. In this context, understanding which areas are suitable to grow this species is important for planning and supporting decision-making, as well as delimiting areas environmentally suitable according to the optimal requirements of species and land-use occupation. Our aim was to identify the suitable areas to cultivate Juçara palm in the State of Rio de Janeiro and provide a set of supporting maps and

information for this productive sector, to increase agroforestry systems, or even for forest conservation and restoration purposes. Environmental parameters for the species (soil, elevation, air temperature and rainfall), and land use and land cover were assessed in order to perform the mapping of the optimal areas. The results indicate a potential for cultivation of Juçara palm in the State of Rio de Janeiro. All regions of the State have suitable areas, especially the Médio Vale do Paraíba, Centro–Sul, and Baixadas Litorâneas. The most restrictive variables to grow Juçara Palm in Rio de Janeiro State were rainfall and inadequate land use/cover for planting.

Keywords: environmentally suitable areas, geoprocessing, Juçara palm, planning.

Áreas adequadas para o cultivo da palmeira Juçara (*Euterpe edulis* Martius) no estado do Rio de Janeiro, Brasil: proposta de incentivo às práticas agroecológicas e aos produtos não madeireiros

RESUMO

A palmeira Juçara (*Euterpe edulis* Mart.) é uma espécie nativa do bioma Mata Atlântica, com alto valor comercial devido, entre outros usos, à extração do palmito e da polpa. Essa espécie tem interação ecológica essencial com a fauna, fornecendo alimento para muitas espécies frugívoras. No entanto, está na lista de espécies ameaçadas de extinção, principalmente devido à exploração desordenada da palmeira para extração do palmito, mas também devido às mudanças climáticas, fragmentação de habitat e defaunação. Nesse contexto, entender quais áreas são adequadas para o cultivo dessa espécie é importante para o planejamento e apoio à tomada de decisões, bem como delimitar áreas com adequação ambiental de acordo com as exigências óptimas da espécie e a ocupação do solo. Nosso objetivo foi identificar as áreas adequadas para o cultivo da palmeira Juçara no Estado do Rio de Janeiro e fornecer um conjunto de mapas e informações de suporte para esse setor produtivo, para incremento de sistemas agroflorestais, ou mesmo para fins de conservação e restauração florestal. Para realizar o mapeamento das áreas ótimas foram avaliados os parâmetros ambientais para a espécie (solo, altitude, temperatura do ar e precipitação), e uso e cobertura do solo. Os resultados indicam um grande potencial para o cultivo da palmeira Juçara no Estado do Rio de Janeiro. Todas as regiões do Estado apresentam áreas adequadas, especialmente o Médio Vale do Paraíba, Centro – Sul e Baixadas Litorâneas. As variáveis mais restritivas ao cultivo da Palmeira Juçara no Estado do Rio de Janeiro foram precipitação e uso/cobertura do solo inadequados para o plantio (por exemplo, urbano e rochoso).

Palavras-chave: áreas ambientalmente adequadas, geoprocessamento, palmeira Juçara, planejamento.

1. INTRODUCTION

One of the most used tools for environmental, agricultural and forest planning is the identification of optimal areas for planting a given species, supporting land zoning policy (Camba Sans *et al.*, 2018). Land zoning consists of the delimitation of suitable areas for growth and identifies optimal environmental and soil conditions for given crops (Giannini Kurina *et al.*, 2018).

The Atlantic Forest is a tropical forest biome, located on the eastern and southern coast of Brazil, eastern Paraguay and the province of Misiones (Argentina). It is one of the existing tropical forests of greater biodiversity currently classified as one of the hotspots in the world (Carvalho *et al.*, 2017).

TheBrazilian Atlantic Forest biome is an enormous economic engine, corresponding to

70% of the Brazilian gross domestic product (GDP). However, due to urbanization and industrialization, 60% of the endangered species of fauna and flora on the Brazilian national list are species native to the Atlantic Forest biome (Rother *et al.,* 2018).

Among the native species of the Atlantic Forest biome with great environmental and socio-economic interest, the Euterpe edulis Mart stands out. (Muler *et al.*, 2014). This species is also popularly known as "palmito juçara", "sweet palmetto", "palmetto", "ensarova", "içara" and "ripeira" (Lorenzi, 2010). Euterpe edulis Mart. has high commercial value and is endangered due to the intense exploitation and deforestation of the Atlantic Forest (Carvalho *et al.,* 2017; Parron *et al.,* 2015).

Palm hearts from the Juçara Palm are a valued product in both the Brazilian and the foreign market, where Brazil stands out as the largest consumer, and at the same time, the largest producer, responsible for 85% of all palm hearts available in the world (Sousa *et al.*, 2011). The timber from the palm tree is exploited for building bridges, furniture and houses; the leaves are used for fodder; the fruits to extract the pulp, known as "juçai"; and the seeds are used to manufacture bio-jewelry and handcrafts (dos Reis *et al.,* 2000).

The Juçara palm tree has great ecological relevance because the fruits are consumed abundantly by frugivorous vertebrates, especially in the time of food scarcity in the forest (Fadini *et al.,* 2009). However, this species is on the red list of threatened native species in Brazil (CNCFlora, 2012). In addition to uncontrolled exploitation, other factors, such as climate change, habitat fragmentation, and defaunation, especially the extinction of seed dispersal birds, have contributed to the disappearance of the species (Carvalho *et al.,* 2017).

In 2015, a program was created that serves the pulp from the Juçara palm in schools in the State of Rio de Janeiro (Law no. 591/2015) with the objective of supplementing meals in public schools. In order to encourage the planting of the species, resources from the State Fund for Environmental Conservation and Urban Development (FECAM) were released to financially support the family farmers in the purchase of machinery and equipment; to organize cooperatives; to reforest palm trees primarily in areas of environmental protection; and, to support the city halls in the State of Rio de Janeiro (RJ) in the purchase of juçai pulp for school meals. As justification, the law points out that, in addition to the juçai being appreciated gastronomically by the Brazilian population, it has high nutritional value, and helps to economically stimulate extractive activity, without harvesting the palm hearts. The palm heart is obtained from the inner core and growing bud of the palm trees; to get it is necessary to cut down the palm tree. Beyond the encouragement of this law in the state of Rio de Janeiro, there are others programs that support family farmers, such as the Food Acquisition Program (PAA), the National School Nutrition Program (PNAE), National Program for the Strengthening of Family Agriculture (Pronaf), and specific guidelines in the National Plan for Agroecology and Organic Production (PNAPO and PLANAPO) which provide subsidies for profitable activities and are in line with principles of sustainability (Moura *et al.,* 2017).

The environmental and preservation recovery, combined with income from the sale of Juçaras'pulp, makes the felling of palm trees for harvesting the palm heart unattractive. There are references that indicate the commercialization of edible pulp is more profitable than the palm hearts themselves. About one meter of palm heart in natural form is sold on average for US$ 0.53, whereas the pulp from the fruit of only one bunch is sold for between US$ 2.60 to US$ 3.20 (Nogueira *et al.,* 2013).

Introducing the palm trees in areas with high levels of biodiversity has a direct relationship to greater pulp yield, since the variety and quality of the dispersers directly influence the size of the fruit (Galetti *et al.,* 2013). Therefore, it is interesting to cultivate the species in Areas of Permanent Preservation (APPs), Legal Reserve (RL) and Conservation Units of Sustainable Use (UCUS), since the activity has low environmental impact and has social interest, according to the Brazilian forest code (BRASIL, 2012).

The optimal sites to invest in Juçara palm plantation is defined by land use, land cover and the environmentally suitable areas, as evaluated by means of overlaps of layers of soil, climate, and topography that are the main factors affecting maximum crop production, thus determining environmental suitability and informing appropriate management. The determination of these areas as optimal sites has a positive result on the producer's profitability (Giannini Kurina *et al.*, 2018). It is important to highlight the relevance of Geographic Information Systems (GIS) for predicting optimal sites, as a fundamental step in the processes of economic, territorial, environmental and ecological research and planning, and in the generation of synthesis maps (Naveen Kishore and Rekha, 2018).

It is important to establish strategies that involve cultural, ecological and socioeconomic aspects, as well as to map areas with high potential for species development. These, combined with sustainable management and conservation of biodiversity, mainly in areas with traditional populations, are fundamental elements for sustainable development (Oliveira *et al.*, 2007).

In view of the above, the present work identifies the suitable áreas to grow Euterpe edulis Mart. in the State of Rio de Janeiro, in order to support actions at micro and macro scale, according to the socioeconomic and environmental assessments in different regions of the state.

2. MATERIAL AND METHODS

The study was conducted at the State of Rio de Janeiro, in the east of the Southeast region of Brazil, between latitudes 20º45'54" S and 23º21'57" S and longitudes 40º57'59'W and 44º53'18" W. The state has a north-eastern border with the state of Espírito Santo, east-south with the Atlantic Ocean, north and northwest with the state of Minas Gerais, and southwest with the state of São Paulo (Figure 1).

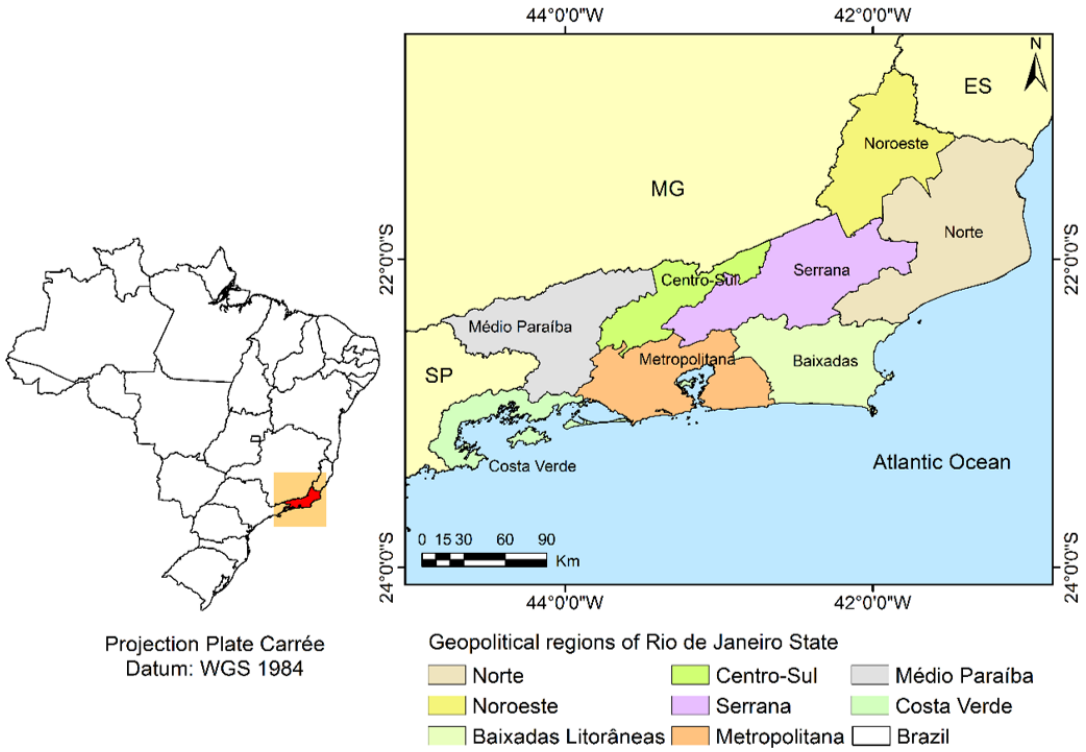

Figure 1. Location of the State of Rio de Janeiro and the eight geopolitical regions.

The state of Rio de Janeiro is divided into eight geopolitical regions: Noroeste Fluminense, Norte, Baixadas Litorâneas, Serrana, Centro-Sul Fluminense, Metropolitana, Vale Paraíba and Costa Verde. Each region has particular characteristics related to economic activities, relief,

population density and industrialization (INEA, 2017).

The state of Rio de Janeiro presents predominance of humid tropical climate, with the rainy season in the summer and the dry season in the winter, classified as Aw in the Köppen-Geiger climate classification (Alvares *et al.,* 2013). Variations in rainfall and air temperature are diversified in the spatial and temporal scale, mainly due to the complex relief (elevation), and the meteorological systems: Frontal Systems (SFs), South Atlantic Subtropical High (ASAS) and South Atlantic Convergence Zone (ZCAS), and ocean influence (maritime / continental). The predominant biome in the State of Rio de Janeiro is the Atlantic Forest (Figueiredo *et al.,* 2016; Lyra *et al.,* 2018).

To determine the suitable areas to cultivate Juçara Palm, environmental- and land-attribute components were considered. The environmental aspects analyzed were: soil, average annual rainfall (mm / year), mean annual air temperature (°C) and elevation (m). The land-use and land-cover attributes components were the current occupation, excluding inappropriate areas, urban areas or Conservation Units with integral protection.

The species *Euterpe edulis* Mart belongs to the family *Arecaceae* (*Palmae*) and naturally occurs in the Brazilian states of Bahia, Espírito Santo, Rio de Janeiro, Minas Gerais, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul (Lorenzi, 2010). According to literature, the optimal climate interval, altitude, and soil for the studied species was sought (Table 1).

Table 1. Suitable environment requirements for *Euterpe edulis* Mart.

Average Elevation (m)	Annual Average Air Temperature (°C)	Annual Rainfall (mm)	Type of Soil	
			World Reference Base (WRB) from Food and Agriculture Organization (FAO) (2014)	Soil Taxonomy (1999)
< 1600	17 a 26	1000 a 1500 (Restricted) and > 1500 (Suitable)	Lixisols, Ferralsols Arenosols, Nitosols and Cambisols	Ultisols, Oxisols, Quartzipsamments, Alfisols, Inceptisols

Source: Bovi *et al.* (1987); Carvalho (1994); IUSS (2014).

The identification of the areas with suitable soil for the palm tree planting was carried out according to the environmental requirements in the literature and based on soil datasets from the state of Rio de Janeiro done by the Brazilian Agricultural Research Corporation – EMBRAPA (Santos *et al.,* 2006).

The Brazilian soil data (scale of 1: 250,000) was clipped to embrace the state of Rio de Janeiro, it was transformed into the raster format, and resampled for spatial resolution of 90 m. Subsequently, reclassification (reclassify tool) was performed, according to the suitability of the species. All these analyses were done using ArcGIS 10.6®.

The daily rainfall series (mm) of the State of Rio de Janeiro, and the regions near its border, in the States of São Paulo (SP), Minas Gerais (MG) and Espírito Santo (ES), was obtained from the database of the National Water Agency (ANA) and the National Institute of Meteorology (INMET). The selected stations obeyed a minimum criterion of the size of the series, with series above or equal to 20 years, from 1960 until 2010.

The rainfall dataset was submitted to rigorous quality control, fault filling (simple linear regression method) and consistency analysis (accumulated waste method). The rainfall raster was obtained from the interpolation performed for the region between latitudes 20º45’54” S and 23º21’57” S and longitudes 40º57’59’W and 44º53’18” W (Lyra *et al.,* 2018), through the minimum curvature, in SURFER® software. The map with the mean annual rainfall was reclassified as “suitable”, “restricted” (areas with the possibility of achieving maximum productivity, through irrigation) and “unsuitable” areas, according to the Suitable environment

requirements for *Euterpe edulis* Mart. (Table 1), with the reclassify command in ArcGIS 10.6®.

The daily air temperature series (°C) were obtained from the National Meteorological Institute (INMET) and the Aeronautical Command Meteorological Network (REDEMET) databases, available from the National Climatic Data Center of the National Oceanic and Atmospheric Administration (NCDC / NOAA) for the State of Rio de Janeiro, and for the bordering areas of the States of São Paulo, Minas Gerais and Espírito Santo (Correia *et al.*, 2019). The station selection criteria were: time series of at least 15 years and starting in 1960 up to 2010. Subsequently, the monthly and annual averages of the air temperature were obtained, and data quality control was performed, in accordance with the guidelines of the World Meteorological Organization (WMO).

The global deterministic model was fitted based on multiple linear regression (Equation 1), as a function of latitude, longitude and altitude, for monthly and annual air temperature averages for the State of Rio de Janeiro, and then was used for spatial interpolation of the annual air temperature (Correia *et al.*, 2019):

$$T_{ar,i} = \beta_0 + \beta_1 \varphi_i + \beta_2 \lambda_i + \beta_3 Z_i + \varepsilon_i \quad (1)$$

Where: T_{ar} *(°C)* = monthly or annual air temperature (dependent variable) and the independent variables; φ = latitude (degrees); λ = longitude (degrees); Z = (m) elevation, being ε_i the random error, assumed to be independent and with normal distribution of mean and constant variance. The term *i* represents the i-th meteorological station.

The map with the estimated and spatialized data of the average annual air temperature variable was reclassified (reclassifying tool) to "suitable" or "unsuitable" according to *Euterpe edulis* Mart. optimal requirements.

The Digital Elevation Model (DEM) came from the SRTM (Shuttle Radar Topographic Mission) project, with an original spatial resolution of 30 m. After pretreatment (elaboration of the mosaic, elimination of systematic errors of the SRTM images by removing cells without data, and conversion of the coordinate system), reclassification was performed according to the requirements of the species under study (Table 1) and resampled to a spatial resolution of 90 meters.

The raw land-use and land-cover data were acquired from the database of the State Institute of Environment of Rio de Janeiro (INEA, 2017), published in 2018, with 1:100.00 scale, in shapefile (shp) format. The areas with the current use and land cover of the land that were not reconciled with the cultivation and development of *Euterpe edulis* Mart., were disregarded. These areas, which were excluded to perform the overlap were: rock outcrops; bodies of water; sandy areas; dunes; mangroves; urban occupation; areas of beach plants and saline areas. These areas were exported, and transformed into a new Shapefile, called "Inappropriate areas". Then, the land-use and occupation maps were transformed into the raster format (tiff), with spatial resolution of 90 meters.

The dataset of Conservation Units of Integral Protection (areas for ecosystem maintenance, free from changes caused by human interference), and of Conservation Units of Sustainable Use (areas that allow exploitation of the environment, provided that it ensures the sustainability of renewable environmental resources) (law No 9.985, of July 18, 2000) of the State of Rio de Janeiro, in the 1: 100,000 scale, was obtained from INEA - database (INEA, 2017), available in the shapefile (shp) format. The Conservation Units of Integral Protection were exported in the shapefile (shp) format and added to the class of "Inappropriate areas", extracted from the land-use and land-cover map; the merging was performed with the ArcGIS 10.6® software.

Conservation Units for Sustainable Use were considered suitable areas to grow Jucara Palm. As mentioned before, the cultivation of the species is classified as a low environmental

impact activity, and by the Brazilian forest code, these activities are permitted even in Permanent Preservation Areas and Conservation Units of Sustainable Use.

Each raster map of the environmental variable was reclassified in 1 (for suitable area to grow Juçara tree), 2 (for restricted area) and 3 (for unsuitable area) according to the species requirements (Table 1). The determination of potentially suitable areas for planting Juçara were obtained from the combination of maps of environmental variables in raster (tiff) format, through the combine tool in ArcGIS 10.6® software. The input maps were: soil, rainfall, air temperature, and altitude; the output map was the environmentally suitable areas.

The environmentally suitable areas map to cultivate Juçara Palm was converted into the shapefile format, making the attribute table editable, being possible to name each variable. Areas in the output map with the combination result equal to 1 for all variables was designated as “suitable”; on the other hand, combination result equal to 3 for all variables was designated as “unsuitable”. The areas that presented 2 for rainfall (restricted by rainfall) and 1 for all the other variables, were designated “restricted”. If any area received a 3 for a variable and received a 1 for all others, it was designated “unsuitable” by the variable that received 3, so the classes were named “unsuitable” by soil, elevation, air temperature and rainfall. Table 2 exemplifies.

Table 2. Example of how areas were classified according to environmental suitability.

	Soil	Temperature	Precipitation	Elevation	
Area 1	1	1	1	3	Unsuitable by elevation
Area 2	1	1	3	3	Unsuitable
Area 3	1	1	1	1	Suitable
Area 4	1	2	1	1	Restricted
Area 5	3	3	3	3	Unsuitable

After editing the attribute table, the update tool was used. This command updated the classes, overlapping with the inappropriate areas (rock outcrops; bodies of water; sandy areas; dunes; mangroves; urban occupation; areas of beach plants, saline areas and Conservation Units of Integral Protection), constituting a new class in the attribute table. In order to calculate the area of each class we used the intersect tool, in the final zoning map, and the shapefile of the government regions. The final suitable area map to grow Juçara has a spatial resolution of 90 meters.

3. RESULTS

3.1 Suitable areas according to environmental and land attributes

The variables: Soil, Temperature and Elevation were classified as “Suitable” or “Unsuitable” areas. Rainfall was classified as “Suitable”, "Restricted” and “Unsuitable”, according to the species demand. The resulting maps of each environmental Variable classified in accordance with the demands of Juçara Palm (Table 1) are illustrated in Figure 2.

Rio de Janeiro State presented 10,160 km² (23.3%) of an environmentally suitable área with no land use restriction; 7,491.8 km² (17.2%) of an environmentally suitable area with land use restriction and; 25,916.4 km² (59.5%) of the environmentally unsuitable area. Among the environmentally unsuitable areas, 5,765.1 km² (13.2%) were due to the incomparability of all analyzed variables; 17,199.1 km² (39.6%) just due to rainfall restriction; 212.5 km² (0.5%) just due to altitude; 1,540.1 km² (3.5%) just due to rainfall; 1,049.1 km² (2.5%) just due to soil; and 116.4 km² (0.2%) just due to temperature (Figure 3).

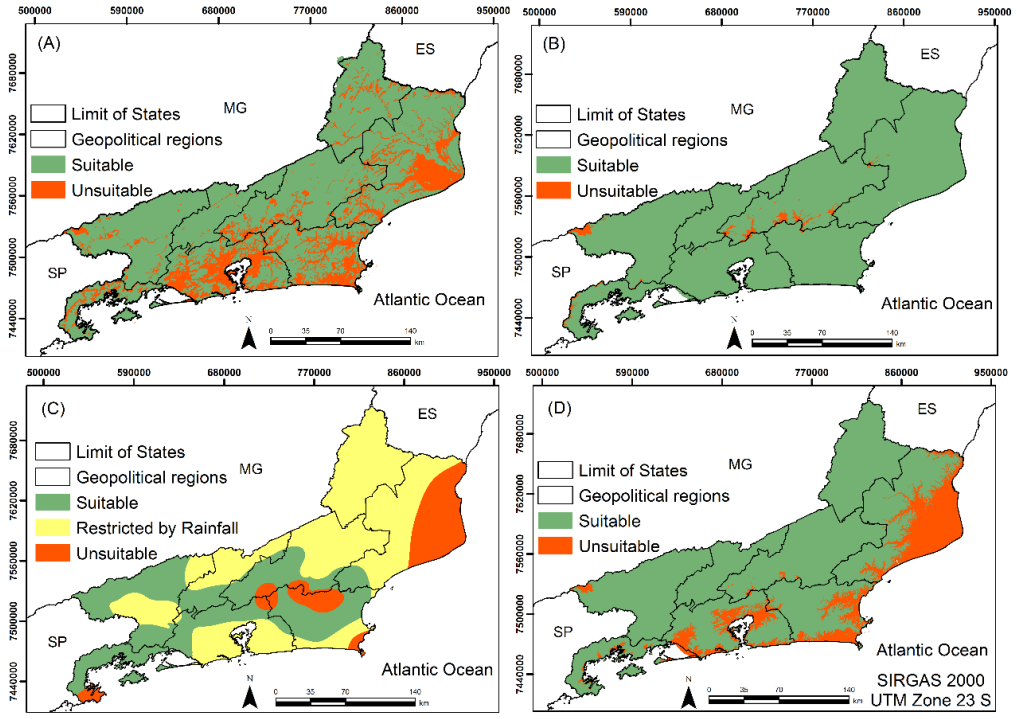

Figure 2. Classification in suitable, restricted and unsuitable areas of environmental variables: A) Soil, B) Air Temperature, C) Rainfall and D) Elevation, according to the demand required for the *Euterpe edulis*, in the State of Rio de Janeiro, Brazil.

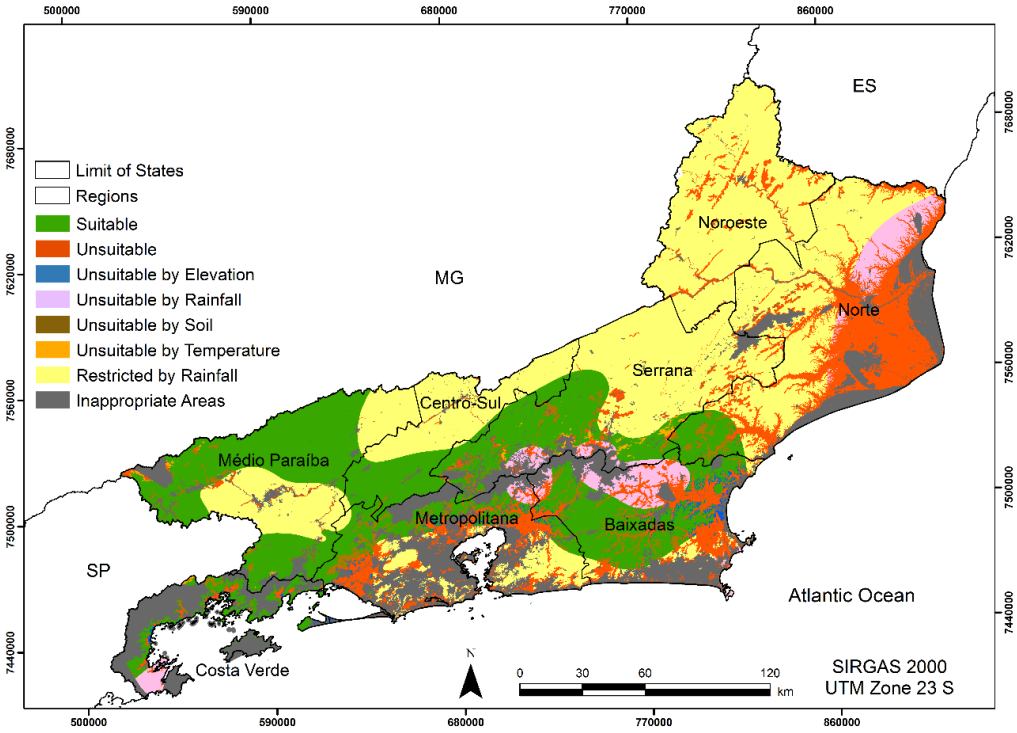

Figure 3. Environmental and land-use classification for *Euterpe edulis* planting in the State of Rio de Janeiro, Brazil.

Among the geopolitical regions of the RJ state, the Médio Vale do Paraíba, presented the highest percentage of suitable areas with 3496.3 km², that represented 56.9% of this region; followed by the Centro-Sul region with 1071.2 km² (35.4%); Baixadas Litorâneas with 1762.94 km² (34.9%); Serrana with 1937.0 km² (27.9%); Costa Verde with 459.4 km² (23.1%);

metropolitana with 944.9 km² (17.8%); and Norte with 488.3 km² (5.0%). The Noroeste Fluminense and Centro-Sul Fluminense regions, presented 90.1% and 60.6%, respectively, of restricted areas related to rainfall (Figure 4).

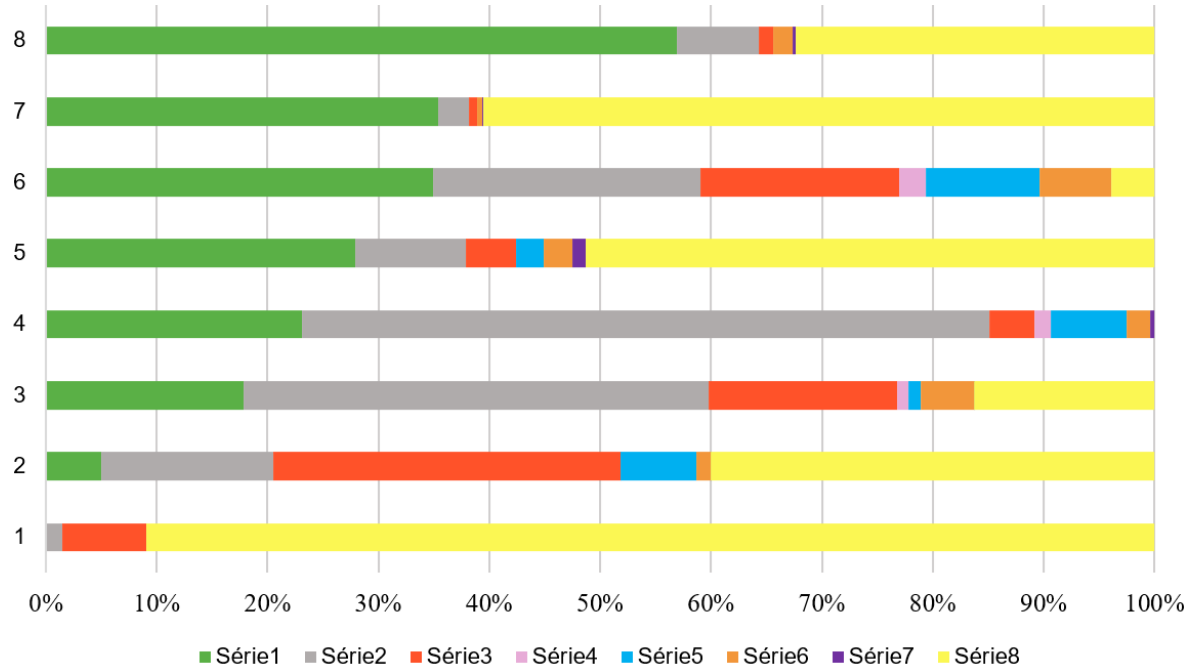

Figure 4. Percentage of suitable, restricted and unsuitable for each limiting factor, in each geopolitical region of the RJ state. The unsuitable area for more than one factor is shown in red.

In Médio Vale do Paraíba, most of the unsuitable areas were due to the restricted values of rainfall, representing 32.3% (1985.8 km²) of this region. The percentage of unsuitability for more than one was only 1.2%; the inadequacy for the soil variable was 1.7%; and for the temperature it was only 0.3% of the total area. The altitude has not influenced since the whole region is below 1600 m. The land-use restriction was equal to 7.3% in this region.

For the Centro-Sul region, the rainfall restriction also was the main variable to the environmental unsuitability for the species, restricting 60.5% (1832.3 km²) of the area to cultivate Palm. Many areas in this region are located in a rainfall shadow area, in the face of Serra do Mar towards the mainland, with low rainfall totals (Lyra *et al.*, 2018). The unsuitability area for all variables corresponded 0.7% of the total area in the Centro-Sul region, the inadequacy for the soil variable was 0.4% and the land use restriction was 2.7% in this region. Elevation, Rainfall, and Temperature were suitable for the cultivation of the species throughout the region.

In the Baixadas Litorâneas region, the most limiting factors were inappropriate areas related to land-use restriction, making it impossible to manage Juçara palm in 24% (1215.5 km²) of the total area. In this region, the unsuitability areas for all variables was 17.9%, exclusively by rain, 10.2%, by soil, 6.5%, and areas restricted by rain were 3.9%. The region does not have unsuitable areas according to temperature.

The Serrana region presents a high elevation range, with an altitude between 10 and 2240 m. Due to this factor, rainfall was the most restrictive element of the species' suitability in this region, with 51.3% of the area restricting rain values (between the optimum and unsuitable values for the cultivation of the species). The unsuitability for all variable classes was 4.5%. Inappropriate land use areas accounted for 9.2%. The classes of unsuitability by rain and soil were 2.5% each, while temperature resulted in 1.9% of unsuitable area. The region does not have unsuitable areas according to elevation.

In the Costa Verde region, the greatest restriction is Inappropriate land-use areas (62% of the area in the region), related to the numerous Conservation Units present in the region, especially the Cunhambebe State Park, considered the second largest State Park in the State of Rio de Janeiro (Assumpção and Carvalho, 2015). The city of Paraty, one of the most important and touristic cities in this Region, is two-thirds covered by Conservation Units, mostly full protection (INEA, 2017). The unsuitable area for all variables corresponds to 4%, and for each variable: altitude (1.4%), rain (6.8%), soil (2.1%) and temperature (0.4%).

The Metropolitana region is the most populous of the State and presents areas with high urban density. The region presented 41.8% (1473.2 km²) of areas classified as inappropriate land-use areas to manage Juçara Palms. The city of Rio de Janeiro, the capital of the RJ State, located in the Metropolitana region, owns approximately 50% of the urban areas and 30% of the Conservation Units (Pereira *et al.*, 2002). Despite presenting few suitable areas, the city was first to commercialize Juçai and also stands out as the largest consumer of Juçara pulp in the State (de Souza *et al.*, 2016). Relevant environmental areas include Tijuca National Park and Pedra Branca State Park (Pereira *et al.*, 2002). The region presented 17% of unsuitable areas for all variables, 4.7% unsuitable for soil only and 1% for altitude. The region does not have unsuitable áreas according to the temperature. Rain-restricted areas accounted for 16.3% of the total area.

In the Norte region, unsuitable areas totaled 15.4%, mainly due to environmental protection areas, such as the Restinga de Jurubatiba National Park, which occupies 13% of the State territory (Alves *et al.*, 2007). This region also contains the largest Private Conservation Unit of restinga of Brazil - RPPN Caruara (INEA / RJ / PRES nº357 / 2012). The rain-restricted areas totaled 40%, while the unsuitable class for all variables was 31.3%. The unsuitability for each variable was: 6.7% for rainfall and 1.3% for soil. The unsuitability for altitude and temperature were not significant.

The Noroeste region was the only one that did not present suitable areas. Rainfall was the most restrictive factor in the species; suitability, since it presents low rainfall indexes (700 mm per year); the rain restricted area corresponds to 90.1% (5340.3 km²) of unsuitable areas for cultivating Juçara Palm. The unsuitability class for all variables was 7.5%, and inappropriate land-use areas was 1.4%.

In general, the rainfall variable was the most incapacitating factor to the development of the species in the Rio de Janeiro State. About 3.5% (1540.12 km²) of the State was unsuitable to grow the Juçara Palm due to the rainfall, and 39.50% (17199.10 km²) presented rainfall restrictions for the planting and development of the species. However, the unsuitability for the soil variable was 1049.09 km² (2.40%) of the total area of the State, and by temperature was only 0.26% (116.46 km²) (Figure 2B).

In the coastal areas of the RJ State, that include parts of the regions of Norte, Baixadas Litorâneas, Metropolitana and Costa Verde, altitude was the most limiting element; unsuitability corresponded 0.48% of the area (212.5 km²) (Figure 2D).

About 50% of the RJ State is located below 200 m altitude, 32% between 200 and 600m, 11% between 600 and 900m, 6% between 900 and 1,500m and 1% above 1,500 m. In the reclassified altitude map for Juçara palm suitability, it can be seen that on the coastal area present below 15 meters in altitude, and in the Serrana region, some áreas are above 1,600 meters of altitude, extrapolating the optimal tolerance limit for species.

Part of the Norte and Baixadas regions that are in the coastal area of RJ State present the lowest accumulated annual rainfall (700 mm). The highest rainfall indexes occur close to the border of the Metropolitana, Serrana and Central regions. The maximum values found in the RJ State were approximately 2900 mm/year in the Serrana region and values above 2500 mm/year in Costa Verde.

4. DISCUSSION

The rainfall presents significant variation among the regions in the State of Rio de Janeiro, mainly due to the influence of the relief. The predominant type of rain in the State is the orographic rainfall and the rainfall caused due to the interactions of large-scale systems (ex.: Frontal Systems and Atlantic Convergence Zone South) with relief (Lyra *et al.*, 2018). The rain-restricted areas have a high potential for cultivation of the Juçara Palm, since it could reach maximum yield through irrigation, which is an option for economic analysis for producers who wish to make the investment.

Due to the complex relief, many areas of the Serrana region are located in parts of rainfall shadows, in the face of Serra do Mar, facing the interior of the continent (North face). Regions with North face are characterized by low rainfall; there is also an occurrence of dry winds in relation to the area facing the coastal environment (Atlantic Ocean - South face) and higher temperatures (Pereira *et al.*, 2002).

Marques and Marques (2002) evaluated the irrigation conditions in areas with environmental characteristics favorable to the Pupunha Palm (*Bactris gasipaes* H.B.K.), but with water deficit. The Pupunha and Juçara Palm are from the same botanic family, and both require high rainfall rates in order to obtain the planned economic production. The authors observed that in some places in the São Paulo State, the irrigation is mandatory in the Pupunha Palm plantations to have an optimal development, and the irrigation by sprinkler, micro-sprinkler, and drip irrigation are the most used systems among the producers. The study done at Fazenda Castanheira with the management plan of the Juçara Palm, in the State of São Paulo, showed that Palm trees with the highest diameter at breast height values (DBH) were from irrigated areas, presented positive investment in relation to non-irrigated areas (Fazenda Castanheiras, 2013).

Altitude is the variable that best explains the behavior of the air temperature, since the higher or lower temperatures are associated with higher or lower altitudes. In the geopolitical regions in the RJ State, the highest temperatures occur in the lower altitudes, referring to Baixada Litorânea (average elevation = 127 m), Metropolitana region (average elevation = 126 m), and Norte region (average elevation = 105 m) with annual average temperatures above 24°C (75.2°F). The lowest temperatures occur mainly in areas of higher altitude (> 500 m), as in the Serra do Mar (a long system of mountain ranges and escarpments) which includes part of the regions Costa Verde (average elevation = 507 m), Serrana (average elevation = 727 m) and Centro-Sul (average elevation = 544 m); and at Serra da Mantiqueira (a mountain range) which includes part of the region Médio Paraíba (average elevation = 608 m) with Monthly minimum air temperatures of up to 9°C (48.2F). For the Juçara Palm, practically all areas of the state cover the range considered adequate to grow it, with an annual average ranging from 17 to 26°C (62.6 to 78.8 °F), as observed in the reclassified map (Figure 2).

The region of Baixadas Litorâneas is composed of areas of environmental relevance, with extremely sensitive environments, such as the specific type of mangrove found in this region; there are only three in the world, two in Brazil (Recife and Armação dos Búzios) and the other in Japan (Mangue de Pedra) (Alves *et al.*, 2007). In addition to the mangrove, the region also presents many areas of restingas (type of coastal tropical and subtropical forest), sandy areas, rocky shores and wet areas (marsh, ponds and lagoons) and rare vegetation types (Pereira *et al.*, 2002).

In the State of Rio de Janeiro, the Norte, Noroeste, Centro-Sul and Médio Paraíba regions present great degraded land areas, with low carbon stock capacity since they were devastated by intensive techniques of monocultures such as coffee, sugar cane, pineapple, and pasture (Cunha *et al.*, 2009; Da Gama-Rodrigues *et al.*, 2008). The Norte is the region with the largest areas of exposed soil, degraded pasture (Geluda and May, 2005) and elevated fires occurrence;

because of that, this region has been the target of desertification-process studies, with the intensification of climate change (Caúla *et al.*, 2017).

Otherwise, in addition to the visual impact of areas in advanced erosion processes, soil loss may be irreversible, since poor soil, compacted with low moisture retention capacity and low albedo coefficients could initiate microclimates with characteristics of desert environments, and the introduction of the native Atlantic Forest species would be difficult (EC, 2015). In these regions, it is urgent to develop projects that offer opportunities for income sources and employment for the local population, while at the same time fulfilling the functions of reestablishing ecosystem services (Novello *et al.*, 2018).

There are environmental initiatives with the implementation of Agroforestry Systems in the Norte and Noroeste regions of the State (Geluda and May, 2005), enrichment of forest consortium, and inclusion of the Juçara Palm, which provide great benefits in soil enrichment, fauna attraction and great economic return. The incentives to manage species with great environmental relevance and economic returns are crucial factors in motivating local farmers.

Also, there is an important initiative to increase the Juçara Palm's population as an income source for the local producers in the Médio Paraíba. One of them is the "Amável - A Mata Atlântica Sustentável" project in the Environmental Protection Area of Serrinha, in the Itatiaia National Park. In this area, due to the simplified Community management plan for the sustainable and organic collection of Juçara pulp, producers have already implemented the stamp of "Atlantic Forest Market -Biosphere Reserve of the Atlantic Forest"; ("Mercado Mata Atlântica- RBMA", in Portuguese). This stamp is an important tool for the marketing of the products because they assure that the products were managed with respect to the conservation and development laws.

In The Itatiaia National Park, the first national park created in Brazil, and of great importance due to the springs of rivers that supply much of the State of RJ (Ramos *et al.*, 1982), studies indicate that illegal exploitation of juçara palm heart is responsible for the extinction of animals that feed on its fruits, such as the muriqui (Brachyteles Spix), which is one of the most endangered primates in the world (Aximoff, 2015).

According to the Brazilian Forest Code (BRASIL, 2012), the landowner in the Atlantic Forest biome must reserve 20% of the area in the property as a Legal Reserve, that is an area with native forest vegetation, in which some management practices are allowed. The Agroforestry System (SAF's) could be adopted in the Legal Reserve área with the Juçara Palm plantations, allowing the sustainable use of the natural resources in the rural property.

Another positive aspect to growing Juçara Palm on the private property is the maintenance of the ecological function, beyond the spaces delimited by the areas of environmental preservation and conservation (Geluda and May, 2005). The drastic change in landscape through unsustainable substitution of land use has been one of the most alarming concerns at the global level, due to the intensification of climate change, the occurrence of extreme events, loss of biodiversity and large forest fires (Levy and Patz, 2017).

In addition to the importance of its ecological interactions, the Juçara Palm also has great potential to generate non-timber forest products (Barroso *et al.*, 2010). Based on this, many associations, research institutions, and government agencies have been working with rural producers and traditional local people in order to intensify the áreas of implementation and management of this species. An example is the Rede Juçara that is a producer organization that works with the sustainable use of Juçara Palm, supporting and assisting the elaboration of public policies and projects to consolidate the production chain of Juçara Pulp, in Atlantic Forest biome, that extends along the Atlantic coast of Brazil. The Rede Juçara is supported by the Demonstration Projects Program (PDA, in Portuguese) of the Ministry of the Environment (MMA, in Portuguese) in Brazil; it is also financed by the German International Cooperation Agency (GIZ, in Portuguese), and it has a strong presence in the State of Rio de Janeiro (de

Souza *et al.*, 2016).

The fruit of the Jucara Palm tree is an excellent non-timber product. In the scientific milieu, numerous articles were recently published describing the nutritional properties of the fruit of the Juçara Palm trees, among the benefits are its large amount of oxidants, anti-inflammatory and cardio protectors. Cardoso *et al.* (2018) has compiled recent scientific papers on the phytochemical properties and biological activities of the Juçara Palm tree. The authors emphasize that Juçara pulp is attractive due to a set of factors that goes beyond nutritional benefits, as it is also due to the sustainable production model, with great environmental significance and economic return.

Novello *et al.* (2018) evaluated whether community management of non-timber forest products the from Juçara Palm, in agroforestry systems in second-growth forest, is sustainable at the point of view of genetic conservation of the species, parallel to the functions of ecosystem protection. Simple Sequence Repeats (SSR) markers were used for comparing the genetic diversity of individuals growing in conserved native forests and in agroforestry systems. The results indicated high levels of genetic diversity in both systems, with no significant differences. Therefore, it is important to note that rural producers, when it is a resource that generates direct benefits and an impact on income, have the potential to fulfill an important role in biodiversity conservation and ecological balance.

There are many relevant works with species in multiple biases, with a range of possibilities to be developed in partnership with rural farmers and local traditional people (Rother *et al.*, 2018). In addition to the economic topic, important environmental education activities can be triggered, such as hydrologic issues, the role of vegetation in capturing and filtering the water in the watersheds, the importance of fauna as a pollinating and dispersing agent of the species, and the wellness that can be generated in place with the presence of vegetation and fauna (Parron *et al.*, 2015).

The sustainable management of Juçara is the key element for farmers who want to produce and export their products, besides being able to develop and support ecological tourism, bringing another source of income to local producers. Rio de Janeiro State is an international tourist attraction in Brazil, and there is a growing market for native fruits from tropical countries due to its rich nutritional composition (Cardoso *et al.*, 2018).

The best strategy for implementing Juçara Palm populations is through Agroforestry Systems (AFSs), but attention must be paid to the design of the system to better optimize the Juçara production chain. In addition to agrifood production, AFSs restore landscapes, contribute to the recovery of degraded areas, and generate income for families. This is the best management scenario for the areas indicated as suitable on the zoning map of this study, since most of these areas are located in areas of extensive livestock farming or close to environmental protection units. After planting the first seedlings, some of them should be chosen to form a seedling bank, since the population structure of the Juçara Palm is naturally pyramidal, with many young individuals. After about nine years, with a seedling bank formed, these younger individuals can be transplanted to other areas, and these seedlings can even be sold. AFSs are already a practice among quilombola communities, family farmers, and caiçaras in the state of Rio de Janeiro. Supporting and encouraging this technique contributes greatly to the preservation of the Atlantic Forest biome.

5. CONCLUSIONS

The State of Rio de Janeiro has areas with great potential for the cultivation of the Juçara Palm. All regions of the State present suitable areas to grow this palm, totaling 101, 60.10 km² (23.3%) of optimal area for the species. Among the regions, the Vale do Paraíba (56.9%), Center-South (35.4%) and Baixadas Litorâneas (34.9%) stand out with the highest percentage of suitable areas.

This work contributes to the advancement of socio-environmental development practices, presents the survey of potential areas for maximum productivity for implantation of the Juçara Palm, which has potential to generate non-timber forest products (pulp and seed for handicrafts), and it is unnecessary to harvest the Juçara Palm tree itself.

The sustainable cultivation of Juçara, besides being a strategy for the conservation of a native species, is in great demand in the State of Rio de Janeiro, which has been attempting to expand the productive chain, mainly through the use of Juçara pulp.

6. ACKNOWLEDGMENTS

Coordination of Improvement of Higher Level Personnel (CAPES) – Postgraduate Scholarship.

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