Environment, Development and Sustainability
https://doi.org/10.1007/s10668-020-01201-2

Suitable environmental areas for commercial timber in the state of Rio de Janeiro, Southeastern Brazil

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Received: 29 March 2019 / Accepted: 26 December 2020

Abstract

In state of Rio de Janeiro, the Southeast Region of Brazil, 97.91% of the reforested areas contain exclusively species of *Pinus* and *Eucalyptus*. Due to the growing demand for raw forest materials, and low diversity of planted species, the market needs to explore new ones. Paricá (*Schizolobium amazonicum* Huber ex Ducke), Brazilian firetree (*Schizolobium parahyba*), Cedar (*Toona ciliate*), and Teak (*Tectona grandis*) are species with high economic value and are already found in small reforestation areas in the state of Rio de Janeiro. The goal of this study was to find the suitable environmental areas to good productivity each of these four forest species in the State of Rio de Janeiro. Suitable environmental areas were determined by classifying climate maps (water deficit, rainfall, and air temperature) and digital elevation models (DEM) of the State of Rio de Janeiro, based on the climatic and altitude demands of each species. Maps of suitable areas were generated using spatial analysis as raster map algebra and raster map reclassification. The species under study showed great potential for growth throughout the State of Rio de Janeiro. Brazilian firetree (known as Guapuruvu in Brazil) presented the largest environmentally suitable area for planting in the state (47%), especially in regions of low maximum rainfall, associated with high temperatures and low altitudes in Rio de Janeiro (e.g., *Baixadas Litorâneas* with 36.9% of suitable area). Paricá presented the smallest environmentally suitable area (19%), with suitable areas in regions of altitude less than 700 m (e.g., *Médio Paraíba* and *Serrana*, within 27.4% and 20.8% of the suitability area, respectively.). Future studies could refine the suitable areas by examining the soil conditions of each area and researching the economic and social factors that are unique to each region.

Keywords Commercial timber · Environment suitable · Geoprocessing · Forestry · QGis · Zoning

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Published online: 07 January 2021

1 Introduction

Current projections indicate that the world's population is on track to reach 9.8 billion people by 2050 (United Nations 2017), which will boost the demand for commodities and bioenergy. To meet this demand (amid a scenario featuring low carbon, renewable energy, and net zero deforestation), studies show that an additional 250 million hectares of planted forests will be needed around the world (IBÁ 2017).

In Brazil, commercial forest plantation operations have been carried out since the 1960s (FAO 2004), and according to Garlip (2001), Assis (2003) and Valverde et al. (2003), the social, economic and environmental relevance of the forest sector is important for the development of Brazil. Currently, the Brazilian forestry sector is responsible for generating about 4.4 million jobs, including direct and indirect jobs (ABRAF 2013).

There are 9.85 million hectares of planted forest in Brazil (IBGE 2017), which represents about 1% of the total area of the country, but supplies 96% of the total demand for wood for several purposes, and also contributes approximately 6.2% to the GDP (Gross Domestic Product) (IBÁ 2017). The planted forests in Brazil have 7.4 million hectares of *Eucalyptus* and 2.0 million hectares of *Pinus*. Together these species represent 95.7% of the planted forest area in this country (IBGE 2017). In the remaining areas, the crops are from plantations of non-conventional species such as Acacia (*Acacia sp*.), Paraná pine (*Araucaria angustifolia*), Teak (*Tectona grandis*), Rubber Tree (*Hevea brasiliensis*) and Paricá (*Schizolobium amazonicum* Huber ex Ducke) (IBÁ 2017). In the state of Rio de Janeiro, the scenario is similar, with 98.76% of the 18.4 thousand hectares of reforested land composed of *Eucalyptus* and *Pinus* (Barbosa Amorim et al. 2012).

Due to the increasing demand for forest raw materials and the low diversity of species normally planted, the market needs to explore new tree species. The commercial success of a species or, a group of species, is only possible when there is a joint development of technologies for its cultivation and market interest (CIFlorestas 2016).

Among the forest species with potential for commercial planting, Paricá (*Schizolobium amazonicum* Huber ex Ducke), Brazilian firetree (*Schizolobium parahybae*), Cedar (*Toona ciliata* M. Roem) and Teak (*Tectona grandis*) stand out due to multiple uses of their wood, rapid growth and adaptability to a diversity of climatic conditions. In addition, Brazilian firetree, Cedar and Teak were found in small reforestation areas in the state of Rio de Janeiro (Barbosa Amorim et al. 2012), demonstrating that local producers are interested in these species. Paricá is the Amazonian variety of Guapuruvu, and has interested producers because it has rapid growth (Leonard 2016) good quality, and is a competitive alternative to *Eucalyptus* and *Pinus* in the timber industry (Globo Rural 2011). The main uses of the timber of these species are for the manufacturing of plywood, panels, doors and windows (Brazilian firetree and Cedar), furniture (Brazilian firetree, Cedar and Teak), musical instruments (Cedar), and for construction in cities (Paricá, Brazilian firetree and Teak), ships (Cedar and Teak), and airplanes (Cedar) (Lorenzi 1992; Bortoletto and Belini Leandro 2003; Gomes 2002; Bygrave and Bygrave 2005; Carvalho 2007).

Paricá (*Leguminosae* family: *Caesalpinioideae*) and Brazilian firetree—also known as Guapuruvu—(*Leguminosae* family: *Caesalpinioideae*) are native to extensive Amazon and Atlantic forests, respectively, in Brazil. Cedar (*Meliaceae* family) and the Teak (*Verbenaceae* family) are native to rainy tropical regions between India and Malaysia to northern Australia (Lorenzi 2003), and Southeast Asia (Fonseca González 2004), respectively, which also gives them potential to be cultivated in the tropical climatic conditions of several regions in Brazil.

The state of Rio de Janeiro presents a great diversity of ecosystems due to the proximity of the coastal environment and varied topography. It has regions of lowland, coastal massifs and mountainous regions (*Serra do Mar and Mantiqueira*) and the meteorological systems acting in the Southeast region of Brazil (frontal systems, South Atlantic Convergence Zone, South Atlantic Subtropical High) (Dereczynski et al. 2009; Brito et al. 2017). These characteristics make the state of Rio de Janeiro favorable to the cultivation a large number of tree species.

The identification of the suitable areas for the cultivation of a specific species is critical for success in forestry and the process must include an evaluation of the suitable environment for the species. The suitable areas depend on the energy and water availability, which are the physical and climatic factors that determine the growth and development of the plants, and therefore, their productivity (Pereira et al. 2002). These areas can be defined by the locations where climatic conditions (air temperature, rainfall, water deficit) and elevation meet the bioclimatic requirements of forest species (Correia et al. 2019).

Thus, the objective of this work was to find suitable areas for good productivity of four forest species with economic potential for production in the state of Rio de Janeiro.

2 Methodology

2.1 Study area

The present study was carried out in the state of Rio de Janeiro, located at east of the Southeast region of Brazil, between latitudes 20°45′54″ and 23°21′57″ S, and longitudes 40°57′59″ and 44°53′18″ W. The total area of the State is 43,780.172 km^2 and is bounded to the northeast with the state of Espírito Santo (ES), east-south with the Atlantic Ocean, north and northwest with the state of Minas Gerais (MG) and southwest with the state of São Paulo (SP). The state is divided into eight geopolitical regions: *Metropolitana*, *Noroeste Fluminense*, *Norte Fluminense*, *Baixadas Litorâneas*, *Serrana*, *Centro-Sul Fluminense*, *Médio Paraíba*, and *Costa Verde* (Fig. 1).

2.2 Ranges of environmental requirements for the studied forest species

The forest species evaluated in this study were chosen based on the criteria of economic potential and occurrence in the state of Rio de Janeiro. The following species were selected: Brazilian firetree (*Schizolobium parahybae* Vell, S.F. Blake), Paricá (*Schizolobium amazonicum* Huber ex Ducke), Cedar (*Toona ciliata* M.Roem) and Teak (*Tectona grandis* L.f.). The environmental requirements of each species were obtained from the literature (Table 1). Soil data were not included because the species requirements for soil type, and corresponding high-resolution soil data, was not available at the time of the study.

2.3 Meteorological data

Data were obtained from the meteorological and rainfall stations located in the state of Rio de Janeiro (RJ) and those located in the states of São Paulo (SP), Minas Gerais (MG) and Espírito Santo (ES), up to 20 km from the state of RJ. The analyzed stations are well distributed throughout and around Rio de Janeiro State (Fig. 2). The inclusion of the climatic

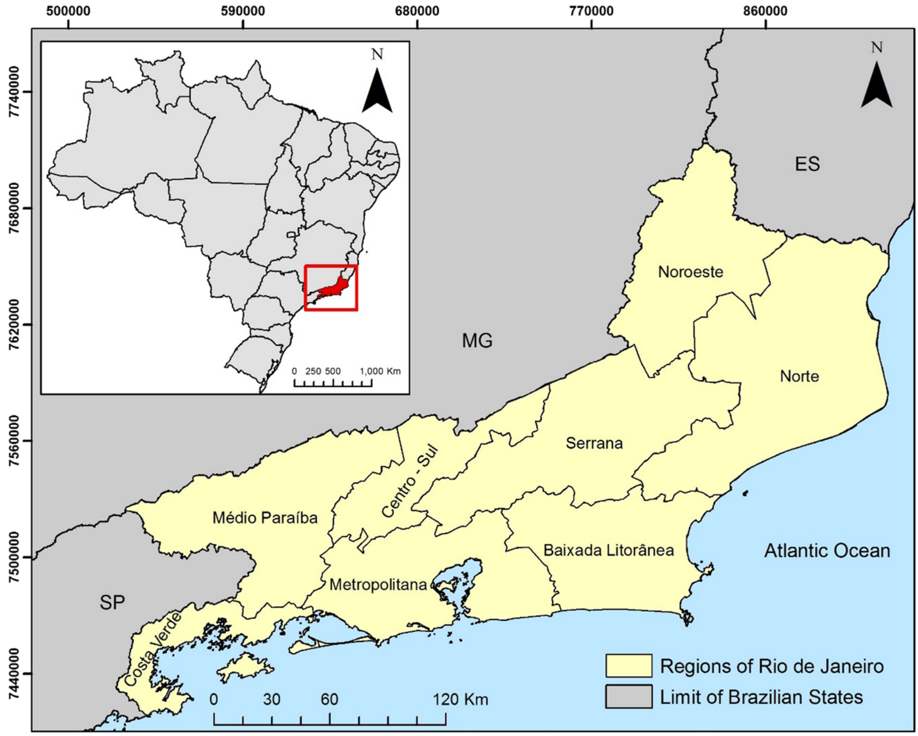

Fig. 1 Location of Rio de Janeiro and the eight geopolitical regions

Table 1 Species climate requirements to Paricá, Brazilian firetree, Cedar and Teak

Species	Altitude (m)	Annual air temperature (°C)	Annual precipitation (mm)	Annual water deficit (mm)
Paricá	0–700[a,b]	20.0–26.5[a,b,d]	1600–3000[b,c]	≤ 180[b,c]
Brazilian firetree	0–900[e]	18.8–24.3[e]	1100–2400[e]	< 150[e]
Cedar	0–1700[f]	20.0–26.0[f]	800–1800[g]	≤ 100[g]
Teak	0–1300[h]	22.0–46.0[h]	800–2500[h]	< 150[h]

[a]Carvalho (2005); [b]Martorano et al. (2010); [c]Crespo et al. (1995); [d]Carpanezzi et al. (1988); [e]Carvalho (2007); [f]Souza et al. (2010); [g]Campos (2007); [h]Nappo et al. (2005)

series of the stations of the states of SP, MG and ES sought to avoid the edge effect in rainfall interpolation and water deficit (Lyra et al. 2018) and in the case of air temperature, to improve the global deterministic model used in interpolation (Correia et al. 2019).

2.3.1 Rainfall

The rainfall series datasets from the weather stations were obtained from the Agência Nacional de Aguas (ANA) and the Instituto Nacional de Meteorologia (INMET), through the HIDROWEB tool (http://hidroweb.ana.gov.br).

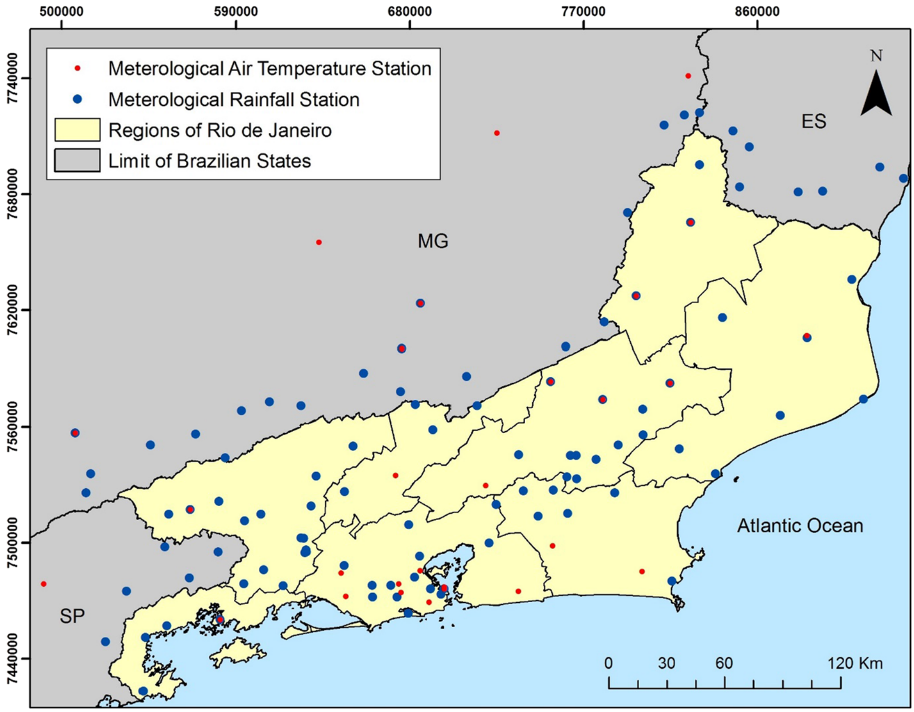

Fig. 2 Spatial distribution of the meteorological stations in the state of Rio de Janeiro, Espírito Santo (ES), Minas Gerais (MG) and São Paulo (SP), Southeast of Brazil

The rainfall series datasets of some stations were not continuous. To avoid the datasets with gaps, it was established that only continuous series over 20 years and starting from 1960 to 2010 was analyzed. These criteria were designed to select rainfall series that may represent part of the influence of the main modes of climatic variability in the Southeast region of Brazil (Correia 2014). Based on these criteria, 110 weather stations with rainfall series were selected (Lyra et al. 2018; Correia et al. 2019).

The monthly rainfall series were submitted to a data quality and gap filling process as recommended by the World Meteorological Organization (WMO 2006) and described in detail in Lyra et al. (2018). Then, the monthly and annual averages of rainfall for each weather station were stored in a vector format. The vector format in GIS (Geographic Information System) is a representation of the world using points, lines and polygons (Wise 2014).

2.3.1.1 Spatial rainfall interpolation Model The annual rainfall raster was obtained by means of spatial interpolation using the regularized spline with tension module (v.surf.rst) of the GIS—Geographic Resources Analysis Support System (GRASS). The raster format in GIS is a representation of the world as a surface divided into a regular grid of cells (Wise 2014).

The spline tension method was chosen because it gives better precision and accuracy for rainfall interpolation in the state of Rio de Janeiro and to consistently represent the expected spatial patterns of rainfall in the State (Lyra et al. 2018). The region considered in the interpolation was delimited by latitudes 20°45′54″ and 23°21′57″ S and longitudes 40°57′59″ and 44°53′18″ W and with spatial resolution of 90 m.

2.3.2 Air temperature

The air temperature climate normal data series came from stations belonging to the *Instituto Nacional de Meteorologia* (INMET) and the *Rede de Meteorologia do Comando da Aeronáutica* (REDEMET), and was downloaded from web sites belonging to Food and Agriculture Organization (FAO), the National Climatic Data Center of the National Oceanic and Atmospheric Administration (NCDC/NOAA) and INMET.

As with some rainfall stations, some meteorological stations contain gaps in their data measurements. Stations were selected that contained over 15 years of contiguous temperature measurements within the range from 1960 to 2010. Based on these criteria, 22 meteorological stations with air temperature series were selected (Correia et al. 2019). As the rainfall series, the air temperature series were submitted to the World Meteorological Organization (WMO 2006) quality process, and the monthly and annual averages of air temperature for each weather station were.

2.3.2.1 Spatial air temperature model To estimated air temperature for all of RJ, we first fitted the monthly air temperature values (dependent variable) with the independent variables: latitude, longitude and altitude in a multiple linear regression model (Eq 1). Studies in other Brazilian states have used the same model of air temperature estimation (Lima and Ribeiro1998; Correia et al. 2019).

$$T_i = \beta_0 + \beta_1 \mathrm{LAT}_i + \beta_2 \mathrm{LONG}_i + \beta_3 \mathrm{ALT}_i + \varepsilon_i \tag{1}$$

where T_i (°C) is the average monthly or annual air temperature; LAT_i (degrees) is the latitude; $\mathrm{LONG_i}$ (degrees) is the longitude; ALT_i (m) is the altitude; ε_i is the random error, considered independent, of normal distribution and constant variance $N[0, 1]$, and β_0, β_1, β_2 and β_3 are the fitted regression coefficients. The term i represents the i-th meteorological station ($i = 1, 2, \ldots, 22$).

In the spatial interpolation of the air temperature, the model fitted to air temperature (Eq. 1) and a digital elevation model (DEM) were used (Correia et al. 2019). The DEM horizontal resolution was obtained from the grid with spatial coverage equal to that considered in the rainfall interpolation and the annual water deficit; and the DEM from Shuttle Radar Topography Mission (SRTM) with the aid of the GRASS map calculator module (r.mapcalc).

2.3.3 Water deficit

The determination of the annual water deficit (WD) was made based on the soil water balance (SWB) of Thornthwaite and Mather (1955). In Thornthwaite-Mather' SWB, WD is the amount by which the actual evapotranspiration differs from potential evapotranspiration. Thornthwaite–Mather' SWB is computed using monthly air temperature, rainfall and the available water capacity (AWC). The AWC is the water held in soil between its field capacity (θ_{fc}) and permanent wilting point (θ_{pwp}) at root effective zone. The SWB was calculated with the aid of the "BHorm" program, in Excel® worksheet by Rolim et al. (1998). AWC (= AW Z_r, mm) in the soil was estimated from the product of the Available Water

[AW = 1000 ($\theta_{fc} - \theta_{pwp}$), mm/m] map, available from FAO, and derived from Soil Map of the World, produced by FAO-UNESCO (FAO 2007), and the effective depth of the root system (Z_r, m) for forest species, considered 2 m in this work (Pereira et al. 2002).

Monthly averages of air temperature and rainfall are required to compute SWB. Since some stations did not have complete data for monthly air temperature, it was necessary to estimate the missing monthly air temperature values for these stations. The monthly air temperatures were estimated by a multiple linear regression model (Eq. 1) previously fitted according to the geographical coordinates (latitude and longitude) and the altitude for each month and weather station.

2.3.3.1 Spatial water deficit interpolation model The water deficit raster map was obtained following the same steps as the annual rainfall map, by means of spatial interpolation using the regularized spline with tension module (v.surf.rst) of the GIS GRASS.

2.4 Elevation

To represent the altitude in the study area, the 90 m Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) was used. The DEM -SRTM used in the present study was treated by EMBRAPA (*Empresa Brasileira de Agricultura e Pecuária*) researchers to eliminate flaws and distortions (Miranda 2006).

2.5 Determining environmentally suitable area for the forest species

For the four forest species, the rainfall, air temperature, water deficit and elevation maps were reclassified (r.reclass - GRASS) to suitable and unsuitable areas considering the ranges of requirements presented in Table 1. In the reclassification, an area received value 1 when an attribute was within the requirement range and value 0 when outside the requirement range. Only areas with all 1 s (i.e., areas that fit all criteria) were considered suitable for cultivation of the evaluated species. This analysis was performed in GRASS, through the raster calculator module. Figure 3 presents the flowchart with all the steps taken to elaborate the suitable areas map of the evaluated species.

3 Results and discussion

3.1 Average annual distribution of climate and elevation in the State of Rio de Janeiro

Significant differences were observed regarding the spatial distribution of annual rainfall in the state of Rio de Janeiro (Fig. 4), mainly due to the influence of the topography associated with mesoscale meteorological systems, particularly in summer (Brito et al. 2017; Lyra et al. 2018). The coastal area of the Norte region has the lowest accumulated precipitation values (< 800 mm), while the highest values (> 2100 mm) occur near the border of the *Metropolitana*, *Serrana and Baixada Litorânea* regions, and in the region of *Costa Verde*, in the southern state.

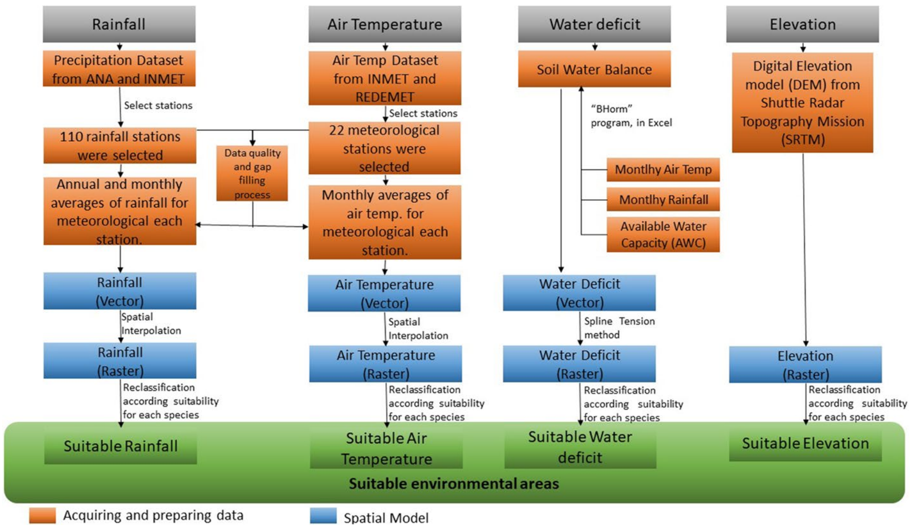

Fig. 3 Flowchart with steps referring to each stage of the suitable environmental areas, adapted from Correia et al. (2019)

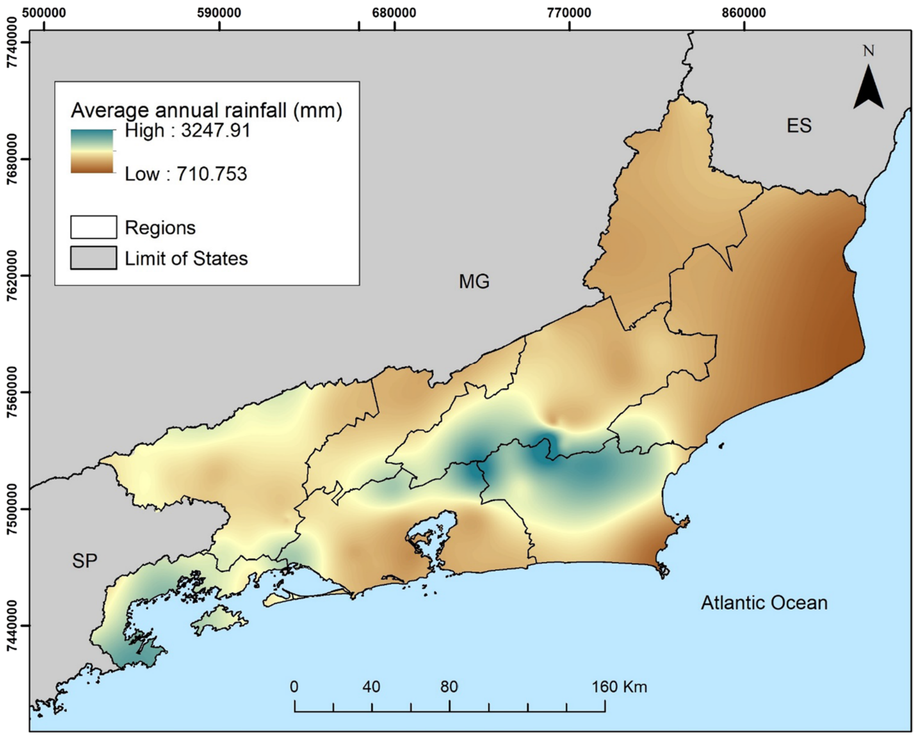

Fig. 4 Average annual rainfall for the state of Rio de Janeiro

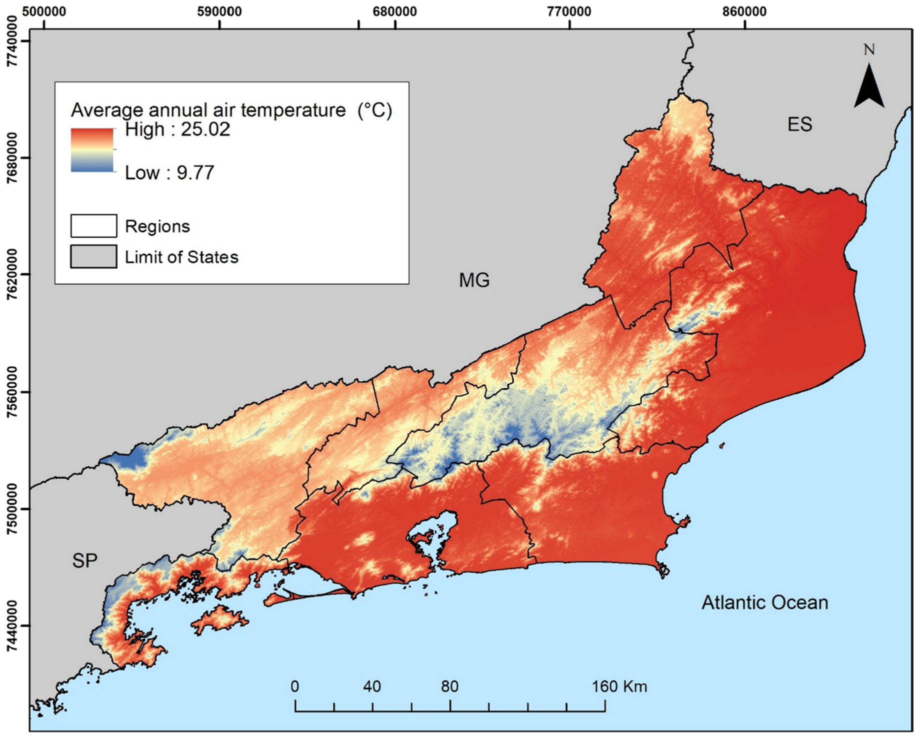

Fig. 5 Average annual air temperature for the state of Rio de Janeiro

The average annual air temperature distribution in the State is shown in Fig. 5. The highest temperatures occurred in the regions of lower altitudes, referring to coastal lowlands; in the *Metropolitana* region of Rio de Janeiro, and in Norte, on the border with Espírito Santo, with temperatures above 24 °C (Correia et al. 2019).

The elevation of the regions of Rio de Janeiro is shown in Fig. 6. Approximately half of Rio de Janeiro's territory (49%) has altitudes below 200 m, mainly observed in the coastal plain. Toward the interior of the state, the elevation increases, mainly in the Southeast-Northwest direction, with the highest altitudes (> 1200 m) observed in three extensive mountain ranges: the Serra da Bocaina (region of *Costa Verde*), the Serra da Mantiqueira (region of the *Médio Paraíba*) and the Serra dos Órgãos (region of *Serrana*) (Santos et al. 2018).

3.2 Suitable environmental areas for the forest species

The environmental zoning for forest species in the state of Rio de Janeiro indicated that Paricá was the species with the lowest suitability, with 19.25% (8403.64 km^2) of the total area of the state. The Brazilian firetree was the species with the largest suitable area for planting and can be planted in 47.17% (20,589.15 km^2) of the state. The Cedar and Teak species presented, respectively, 18,634 (42.69%) and 18,048 km^2 (41.35%) of areas identified as environmental suitable for cultivation (Table 2).

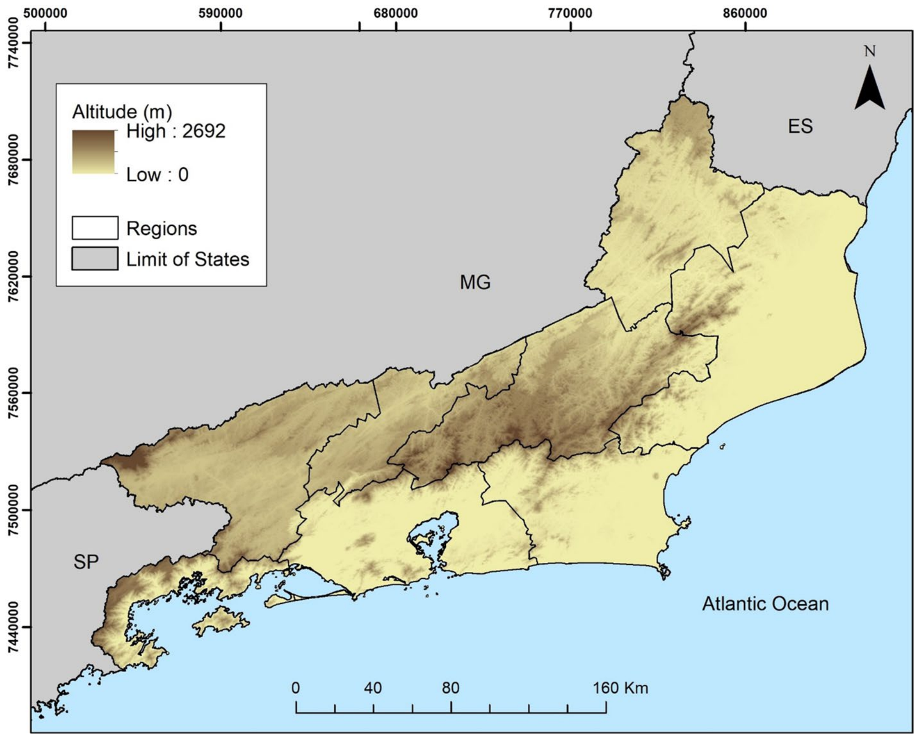

Fig. 6 Elevation for the state of Rio de Janeiro

Table 2 Area (km^2) suitable for the species in the State of Rio de Janeiro

Regions	Paricá	Brazilian firetree	Cedar	Teak
Baixadas Litorâneas[a]	3100.66	1301.92	251.86	2667.14
Centro Sul[b]	218.61	2923.08	2596.04	1323.00
Costa Verde[c]	1424.41	1374.26	357.96	1146.10
Médio Paraiba[d]	1684.32	5671.02	5432.80	1915.85
Metropolitana[e]	1473.39	1507.99	2683.11	3612.88
Noroeste[f]	0.00	2476.67	1542.30	2417.75
Norte[g]	404.01	1045.94	2078.12	2903.29
Serrana[h]	98.24	4288.27	3691.84	2062.65
Rio de Janeiro[i]	8403.64	20,589.15	18,634.02	18,048.66

Total region area and state area (km^2) [a]5055.55, [b]3046.24, [c]2000.78, [d]6197.26, [e]5321.07, [f]5360.33, [g]9714.12, [h]6952.97, [i]43,648.32

The areas eligible for Paricá cultivation were mainly at sites with annual rainfall above 1600 mm and annual water deficit (WD) of less than 120 mm, this configuration was found in the coastal regions of *Baixada Litorânea*, *Costa Verde* and *Meio Paraíba*, on the border with the state of Minas Gerais. Most regions of the Centro *Sul*, *Norte*, *Serrana*, *Metropolitana* and all of the *Noroeste* regions were environmentally unsuitable to the cultivation of this species, the main restriction of these regions being the annual water deficit above 150 mm and rainfall of less than 1500 mm. The results obtained for the state of Rio de Janeiro were similar to the zoning carried out for the Paricá plantation in the Amazon (North of Brazil), where the growth dynamics of this species is correlated with the seasonal variation of water availability (Lima et al. 1999). Elevations above 700 m and air temperatures below 20 °C were restrictive in some areas of the *Serrana* regions, in the border with the *Metropolitana* and *Baixada*, and part of the *Centro Sul*, in the SP and MG borders.

The largest suitable areas for Brazilian firetree cultivation were observed in regions with annual rainfall between 1100 and 2400 mm and air temperatures between 18.8 and 22 °C. These areas mainly covered the *Centro Sul* (95.96%) and *Médio Paraíba* (91.53%) regions, as well as being 61.68% of the *Serrana* Region and 46.20% of the *Noroeste* (Fig. 7). These regions present similar climatic characteristics to potential sites for the implantation of Brazilian firetree in the state of Santa Catarina, South of Brazil (Carpanezzi et al. 1988). Most of the *Metropolitana* and *Norte* regions showed a restriction on Brazilian firetree cultivation, due to lower total annual rainfall (< 1100 mm) and high annual water deficit (> 120 mm), and air temperatures above 25 °C, particularly in areas close to the coastal environment. According to Amorim et al. (2012), in the state of Rio de Janeiro, there is only 2.13 ha of reforestation planting with Brazilian firetree, which represents 0.012% of the silvicultural area of the State.

In the case of the Cedar, 5432.8 km^2 in the *Médio Paraíba*, 2683.11 km^2 in the *Metropolitana*, 2596.03 km^2 *Centro Sul* and 251.86 km^2 in the *Baixada* are suitable areas for cultivation. The *Norte*, *Noroeste*, and *Serrana* regions present smaller area of suitability. Klippel et al. (2013) observed suitable areas to Cedar in high elevation places in the State of Espírito Santo were, mainly, greater annual rainfall and, consequently, less water deficiency. According to Souza et al. (2010), Cedar is moderately tolerant to lack of water, but highly responsive to the amount of water available.

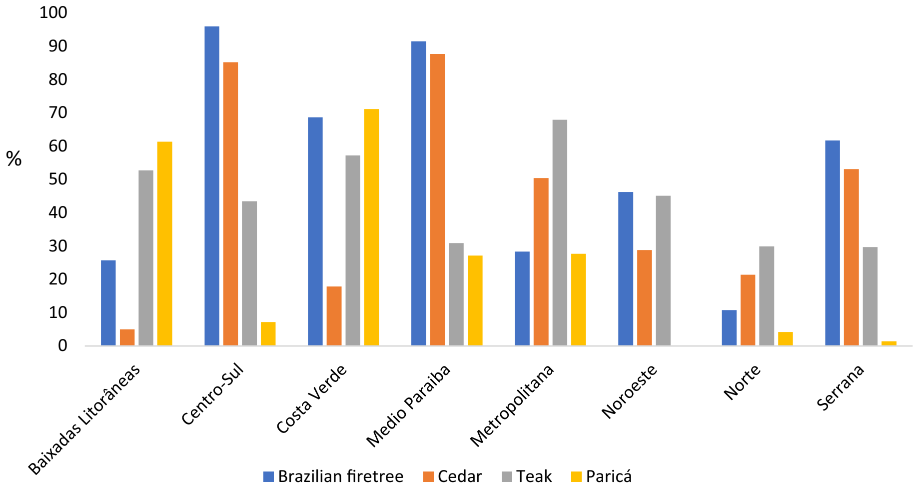

Fig. 7 Percentage of suitable area per species and region

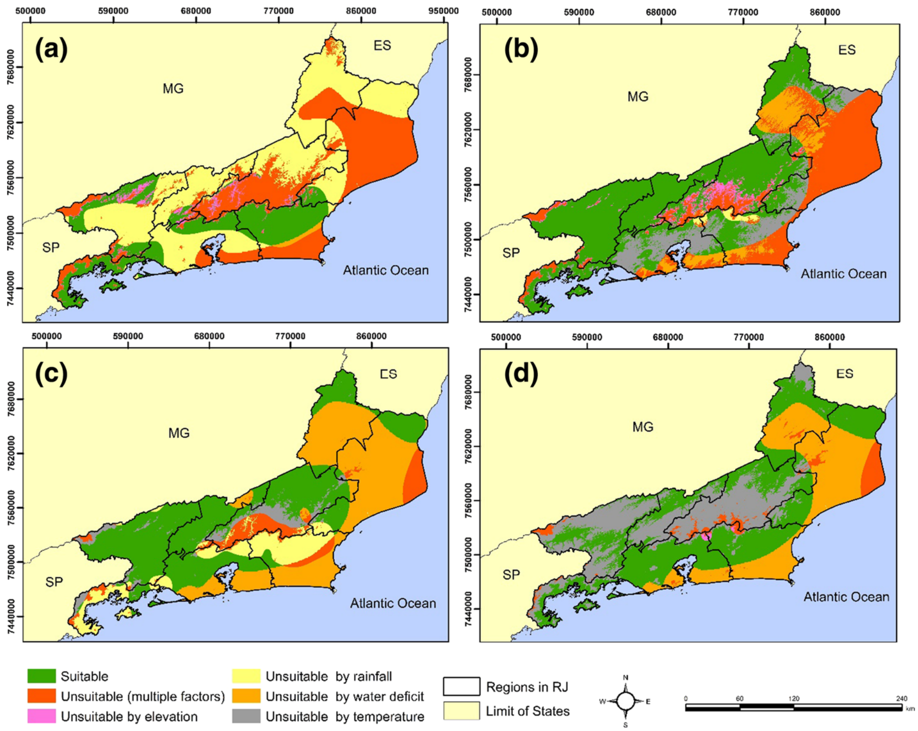

Fig. 8 Suitable environmental areas and unsuitable areas for each limiting factor. The unsuitable area for more than one factor is delimited in red. **a** *Schizolobium amazonicum* (Paricá), **b** *Schizolobium parahybae* (Brazilian firetree), **c** *Toona ciliata* (Cedar) and, **d** *Tectona grandis* (Teak)

Figure 8 illustrates the suitable areas of each species in each region of the State of Rio de Janeiro and the unsuitable areas, according to elevation, rainfall, water deficit, temperature, and their combination (multiple factors).

The *Metropolitana* region (3612.87 km^2), *Norte* (2903.28 km^2), *Baixada Litorânea* (2667.14 km^2) and *Noroeste* (2417.75 km^2) presented the largest extensions with ability to plant Teak. These regions are characterized by higher rainfall and lower water deficit (Fig. 9). These are similar conditions to the suitable areas mapped in the state of Espírito Santo, in the coastal region, where high average temperature values are found (Klippel et al. 2013). The regions that presented lower aptitude for Teak planting were *Costa Verde*, *Centro Sul*, *Meio Paraíba* and the *Noroeste* region. Annual low annual rainfall and high DW of these areas restrict teak cultivation. This was also observed by Klippel et al. (2013), where the main factor restricting the planting of the crop was the water deficit.

According to Cordeiro et al. (2009), the production system of Paricá as a monoculture, in the first four years, is not economically viable. Thus, a crop combination is needed to amortize the initial investment. The same study concluded that the use of Paricá in Agroforestry Systems is an economic possibility, as well as being an alternative for the recovery of altered pasture areas, and suppressed from the demand for wood for the production of laminates, plywood and fiberboard. Lima and Ribeiro (1998) emphasize that Paricá is a potential species for intensive silviculture programs, provided they are respected as soil and climatic constraints.

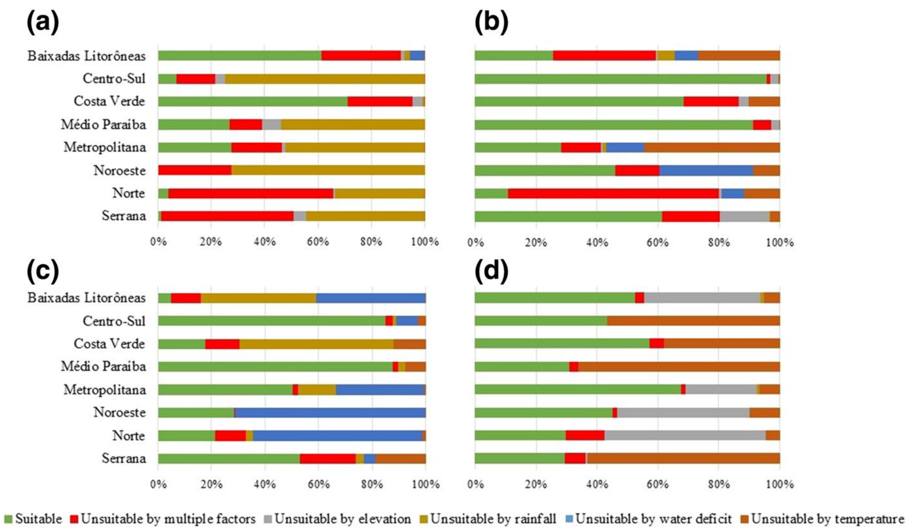

Fig. 9 Percentage of suitable and unsuitable environmental areas for each limiting factor. The unsuitable area for more than one factor is delimited in red. **a** *Schizolobium amazonicum* (Paricá), **b** *Schizolobium parahybae* (Brazilian firetree), **c** *Toona ciliata* (Cedar) and, **d** *Tectona grandis* (Teak)

Cedar, which has environmental requirements very favorable to the state of Rio de Janeiro, is harvested at approximately 12 years, but can be harvested at 10 years or postponed, depending on the specific conditions of the stand and the purpose of the wood. Its average productivity, at 10 years, is 150 m^3 ha^{-1}, after thinning for sawn wood production. The planting of the species is currently estimated at $1641.68 per hectare (R$ 3088.00 Brazilian currency in 2010), depending on the location of the property and especially the soil conditions (Souza et al. 2010). The wood can also be sold before 12 years, since there is ready acceptance of the young wood of Cedar. Currently, there are uses for wood from the age of 7, with the expected prices for 12-year-old wood. This demand makes it possible to use the thinning wood and shows that the value added in trees of larger diameter (15 years) may be higher than expected.

Cedar is a species that attracts the attention of forest industry investors because timber has a purpose for expensive uses in the market (Bufalino et al. 2012). The commercial Cedar's plantation has a positive impact in the environment, since the timber produces high-quality furniture pieces with potential chance to replace traditional native trees in the furniture sector, which are often from illegal harvesting (Ferreira et al. 2012). About the aspect of sustainability, the origin of wood is a major market strategy, mainly to meet export requirements (IBÁ 2017).

Cedar can also be used to enrich agroforestry systems in a consortium of crops such as coffee. Oliosi et al. (2016) evaluated the development of microclimate and coffee (*Coffea canephora cv.* Conilon Clone 02) under different levels of shading, provided by Cedar and concluded within the study that *Conilon coffee* planted with Cedar showed good production potential.

The value of the Teak forest, in the state of Mato Grosso (in the western part of Brazil), ranges from the $5000 to $ 14,000 US per hectare at the age of 25 years (Ângelo et al. 2009).

Financial maturity occurs between 14 and 20 years, depending on the interest rate. The minimum price of one m^3 of standing timber at the age of 25 is in the range of US $ 19.49 to US $ 44.36, demonstrating its viability.

4 Conclusions

The Brazilian firetree presents the greatest environment suitability for cultivation in the state of Rio de Janeiro (36.9%), while Paricá shows the smallest (19%). The areas close to the coastal environment of the *Metropolitana*, *Baixada* and *Norte* regions; and the central part of the *Noroeste* region, is unsuitable for the cultivation of all evaluated species. Part of the *Serrana*, *Metropolitana* and *Centro Sul* regions, with altitudes above 700 m, air temperatures between 18 and 22 °C, are also unsuitable for all species.

The cultivation restrictions of the evaluated species are mainly due to the failure to meet their water needs (rainfall and water deficit). The thermal demand is particularly restrictive in the case of low air temperatures, observed in the regions of highest altitude in the state of Rio de Janeiro (*Serras do Mar*, *Mantiqueira* and *Órgãos*).

The identification of suitable areas for planting determined species from the evaluation of multiple environmental factors be done with geoprocessing tools. This approach could support public policies and producers in defining better forest areas and species with the highest production potential. The validation was not made since there are not available data on the large-scale occurrences of the studied species in the State of Rio de Janeiro. However, the identification of the suitable areas for planting serve as a tool for decision making.

While this study identifies areas to be reforested according to climatic and elevation demands, it is important to emphasize the need for additional studies that take into account economic and social factors before planting crops. The inclusion of other species if future is recommended, and the exclusion of improper areas for planting, such as urban areas and environmental protection areas like the Conservation Units (UC) and Permanent Protection Areas (APP). Soil analysis could refine the areas of suitability for each species and could include soil treatment expenses. Climate change could also be analyzed in future studies, especially for long-cycle forest species.

Acknowledegments We thank the Instituto Nacional de Meteorologia (INMET), the Rede de Meteorologia do Comando da Aeronáutica (REDEMET), the Food and Agriculture Organization of the United Nations (FAO) and the Agência Nacional de Águas (ANA) for the availability of climatic and elevation data used in the analyzes.

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