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Climate and Physiographic Suitability Mapping System - AptClim: access, method, and example of use

Sistema de Mapeamento da Aptidão Climática e Fisiográfica – AptClim: acesso, método e exemplo de uso

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RESUMO

O Sistema de Mapeamento da Aptidão Climática e Fisiográfica (AptClim) tem como principal objetivo permitir ao usuário avaliar a aptidão climática e fisiográfica de uma área de interesse utilizando diferentes critérios e períodos climáticos. O AptClim foi desenvolvido na plataforma Google Earth Engine (GEE) e está disponível em https://ciram.epagri.sc.gov.br/aptclim/. Através do AptClim é possível mapear e avaliar a aptidão climática e fisiográfica considerando a climatologia mensal das temperaturas mínimas e máximas e da precipitação pluviométrica, além da declividade do relevo. Neste artigo apresentamos o AptClim, a forma de acessá-lo, o método utilizado no cálculo da aptidão e um estudo de caso para analisar a variação da aptidão climática para a palmeira juçara (*Euterpe edulis*) nas últimas quatro décadas. Foi percebido um aumento de 133% nas áreas com 100% de aptidão climática para a *E. edulis* entre as décadas de 1980 e 2010. No caso avaliado o AptClim se mostrou uma ferramenta acessível, prática e ágil para analisar a aptidão climática, gerar mapas de aptidão, calcular áreas por classe de aptidão e gerar séries históricas climáticas.

PALAVRAS-CHAVE: google earth engine; climatologia; mudanças climáticas; agrometeorologia.

ABSTRACT

The main objective of the Climate and Physiographic Suitability Mapping System (AptClim) is to allow the user to assess the climate and physiographic suitability of an area of interest using different criteria and climatic periods. AptClim was developed on the Google Earth Engine (GEE) platform and is available at https://ciram.epagri.sc.gov.br/aptclim/. Using AptClim, it is possible to map and evaluate the climatic and physiographic suitability considering the monthly climatology of minimum and maximum temperatures and rainfall, as well as the slope of the relief. In this article we present AptClim, how to access it, the method used to calculate suitability and a case study to analyze the variation in climate suitability for the juçara palm (Euterpe edulis) over the last four decades. There was a 133% increase in areas with 100% of climatic suitability for *E. edulis* between the 1980s and 2010s. In the case evaluated, AptClim proved to be an accessible, practical and agile tool for analyzing climate suitability, generating suitability maps, calculating areas by suitability class and generating historical climate series.

KEYWORDS: google earth engine; climatology; climate change; agrometeorology.

INTRODUCTION

The Agricultural Zoning of Climatic Risk (AZCR) is an agricultural policy and risk management tool in agriculture under the operational and technical responsibility of the Brazilian Agricultural Research Corporation - Embrapa (BRAZIL 2019). Access to AZCR information is available through the AZCR Plantio Certo app, which provides users with risk assessments for crop losses due to climate events. The query can be performed for various crops at the municipal level.

The AZCR is limited to Brazil's major crops, excluding those of lesser economic significance or with regional specificities. The AZCR Plantio Certo system does not allow for the assessment of climatic suitability for crops that have not yet been evaluated by Embrapa. The system also fails to account for the physiographic factors influencing crop suitability. In addition to being a municipalized system, it fails to capture the climatic and physiographic variability within a municipality.

Spatiotemporal mapping systems for crops are being developed to assist agricultural technicians and agronomists in assessing climatic potential. An example is the Global Agro-Ecological Zones (GAEZ) data portal of the Food and Agriculture Organization of the United Nations - FAO (FAO & IIASA 2021), a web-based application designed to provide free access to databases on current conditions and future trends in global agricultural production and suitability.

Each system has its own specific goals, tailored to meet the demands and needs of its target audience. The main purpose of the Climate and Physiographic Suitability Mapping System (AptClim) is to allow users to assess the climate and physiographic suitability of an area of interest using different criteria and climatic periods. Its versatility enables the assessment of various climate suitability scenarios across different time periods. Alternatively, assess the climatic impact on crop failure for a specific location and year.

AptClim was developed on the Google Earth Engine (GEE) platform and can be accessed at https://ciram.epagri.sc.gov.br/aptclim/. Access is available via any web browser. APTClim evolved from the space-time climate mapping system for crops (PETER et al. 2019), with some adaptations and the implementation of physiographic analysis.

The AptClim tool can be used to map and assess climatic and physiographic suitability, considering the monthly climatology of minimum and maximum temperatures and rainfall, as well as the slope of the terrain.

Fitness is determined based on user-defined criteria. The criteria include the area of interest (AI), climatic period (start and end years), species or species group cycle (start and end month/day), and optimal value ranges for key variables: mean minimum temperature, mean maximum temperature, average precipitation during the period, and slope. The areas of focus encompass Brazil's state and municipal boundaries. The system interface allows users to manually delineate their area of interest.

The fitness outcome is depicted in two maps. The default map displays the combined suitability based on three variables: temperature, precipitation, and slope. The combined suitability map illustrates the percentage compliance with user-defined criteria for the three variables (suitability classes). In addition to the combined suitability map, an area chart (in hectares) is generated for each suitability class. Additionally, a comprehensive suitability map illustrates areas that fully satisfy all criteria across the three variables.

In addition to fitness maps, the user can view ten more maps: limit of the area of interest; agricultural areas (SOUZA et al. 2020); average rainfall, average minimum temperature, average maximum temperature, average temperature, slope, suitability for the precipitation interval, suitability for the temperature range, and suitability for the slope interval.

AptClim also generates six monthly climate graphs for the specified area of interest and climate period: average sea surface temperature anomaly in the El Niño region (ENSO), monthly mean maximum temperature, monthly mean minimum temperature, average monthly precipitation, monthly average Palmer Drought Severity Index, and average monthly water deficit.

If the user is working with species or groups of agricultural crops, APTClim also allows assessment of suitability only in the agricultural areas defined in the MapBiomas use and coverage map (SOUZA et al. 2020).

This paper introduces AptClim, detailing its accessibility, the methodology employed for calculating suitability, and a case study demonstrating its application in analyzing the climatic suitability variations for the juçara palm (*Euterpe edulis*) over the past four decades. Recognized as a species of significant ecological and economic importance, it was once among the most abundant tree species in the Dense Ombrophilous Forest (KLEIN 1978, SILVA & REIS 2018). Over the past two decades, Santa Catarina has initiated research and rural extension efforts aimed at developing sustainable production systems for the economic exploitation of juçara palm fruits in açaí production. Its significance lies in both economic production and environmental restoration of regions suitable for agricultural use with a history of forest loss (VIANNA et al. 2023).

This article aims to introduce the system and make its code available for other developers to utilize. We also anticipate that agricultural researchers and technicians will find this tool valuable for conducting swift climate suitability assessments across various locations in Brazil.

MATERIAL AND METHODS

The APTClim calculation system was developed on the Google Earth Engine (GEE) platform (GORELICK et al. 2017), using the Java-Script language. The dataset is open-source, publicly accessible, and can be found in the Google Earth Engine data catalog (https://developers.google.com/earth-engine/datasets).

The Java Script code for AptClim is available at https://doi.org/10.5281/zenodo.10804870.

As input data, APTClim uses the political maps from FAO GAUL (GRITA 2016), containing the state and municipal boundaries of Brazil; the land use and land cover maps from the MapBiomas project (SOUZA et al. 2020); the digital elevation model of the Shuttle Radar Topographic Mission — SRTM, with 30 m resolution (FARR & KOBRICK 2007) and the climate data from TerraClimate, with 4,638.3 m resolution (ABATZOGLOU et al. 2018).

Figure 1 illustrates the fitness calculation method and the generation of time series graphs.

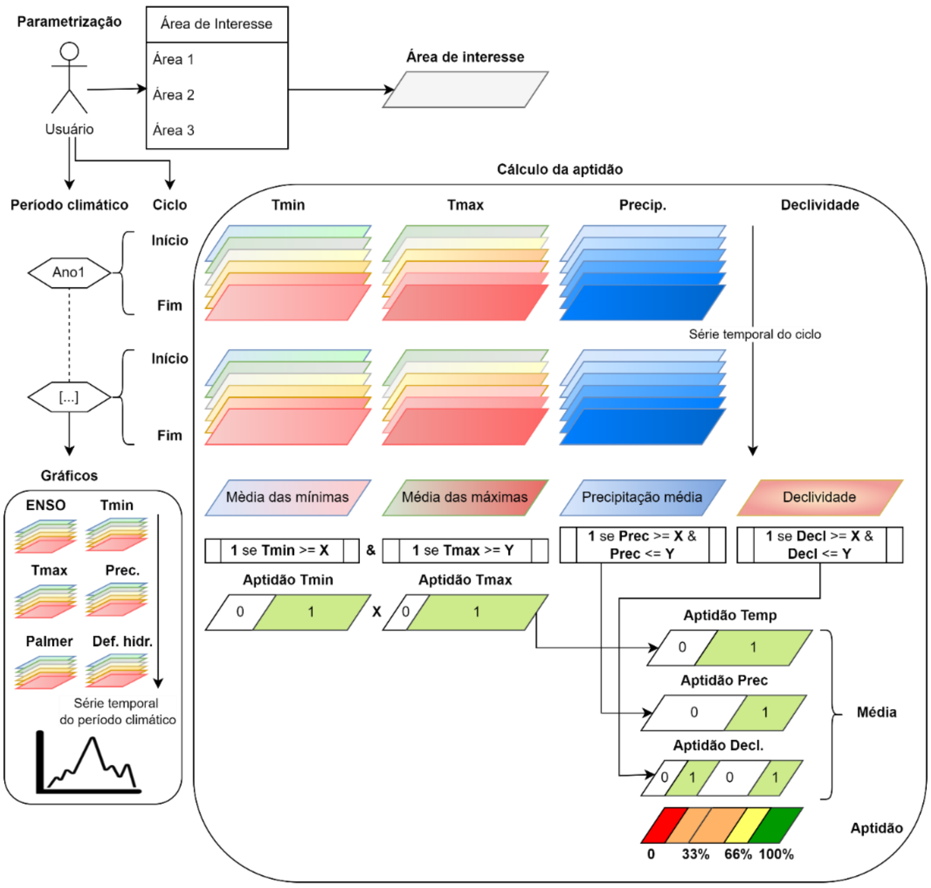

Figure 1. Diagram of the method for calculating suitability and generating time series graphs.

Fitness calculation is performed following user-defined parameters (Figure 1) for a single area of interest, which may be a Brazilian state, municipality, or a custom-drawn region within the system interface. The climatological period can be defined as spanning from September 1981 to the most recent complete year prior to the current year.

Based on the climatic period, AptClim generates climatological graphs of monthly averages (Figure 1 - Graphs). These graphs represent the monthly average of each variable within the area of interest. Monthly averages are computed in GEE using grouped reductions and zonal statistics (https://developers.google.com/earth-engine/guides/reducers_grouping).

To calculate fitness, in addition to the area of interest and climate period, the species or species group cycle must be defined, specifying the start and end month and day. Climatological means of variables are then computed for the area of interest, climatic period, and species or group cycle (Figure 1 - Fitness calculation). This calculation is performed using grouped reductions and zonal statistics (https://developers.google.com/earth-engine/guides/reducers_grouping).

Fitness is determined using map algebra, following the methodology employed by VIANNA et al. (2023), but here using the optimal temperature, precipitation, and slope ranges defined by the user. These ranges establish the fitness reclassification thresholds. Values within the threshold are reclassified as 1, while those outside the threshold are reclassified as 0 (Figure 1).

Temperature suitability is determined by combining the suitability maps for average minimum and maximum temperatures. Precipitation suitability is derived from reclassifying the average precipitation map, while slope suitability is obtained by reclassifying the slope map. The final suitability map is derived from the average temperature, precipitation, and slope suitability maps.

When the region meets none of the criteria, the suitability is 0%; when it meets one criterion, the suitability is 33%; when it meets two criteria, the suitability is 66%; and when it meets all criteria, the suitability is 100% (Figure 1).

Parametrization of APTClim to analyze the variation in climate fitness for the Juçara palm (*Euterpe edulis*) over the last four decades.

Access to the system must be done through the link https://ciram.epagri.sc.gov.br/aptclim/. The AptClim website features two panels. On the left (main panel) are the tools for selecting the area of interest, fields for defining the climate calculation period, species or species group cycle, and optimal variable value ranges. In addition to the button for calculating fitness and cleaning the map. Climate graphs are displayed on the right panel (Figure 2).

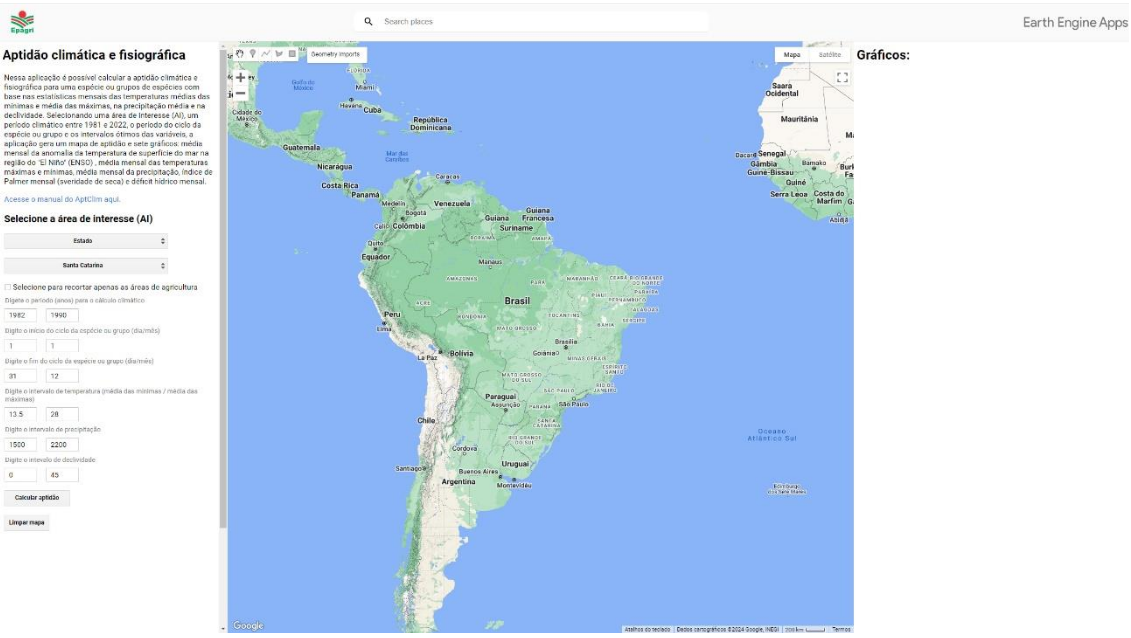

Figure 2. AptClim layout with parameterization for calculating the climatic suitability of Santa Catarina state for juçara palm (*Euterpe edulis*) for the 1980s.

The AptClim parameterization for the juçara palm (*Euterpe edulis*) was based on temperature, precipitation, and slope values established by VIANNA et al. (2023). Given the perennial nature of the species, the researchers examined the complete annual cycle. The average temperature of the minimums must not be lower than 13.5 ºC, while the average temperature of the highs must not be higher than 28 ºC. The optimal range for average annual rainfall should be between 1,500mm and 2,200mm, with ideal terrain slopes ranging from 0 to 45º (VIANNA et al. 2023). To assess the variation in climatic suitability for the juçara palm (*Euterpe edulis*) over the past four decades, it was necessary to perform four suitability calculations, one for each decade.

The initial fitness calculation was conducted for the 1982-1989 period (e2), as 1982 marks the first complete year in the historical series. To calculate the aptitude for the other decades, only the periods for 1990-1999; 2000-2009 and 2010-2019 were changed.

The climate time series maps and graphs were exported as figures. The area data (in hectares) categorized by suitability class per decade and the monthly climate data were exported as tables. Climate data were exported from individual graphs as outlined in the user manual available on the AptClim website. The files were exported in CSV format and named according to the variable, start year, and end year of the series, following the pattern "VAR_YEAR1_YEAR2.csv".

Climate data were processed and analyzed using R software, employing custom scripts to automate the import of AptClim-exported tables and subsequent analyses. A multivariate analysis was conducted to compare climate patterns across decades. MANOVA-ANOVA; multivariate dispersion homogeneity test based on distance (ANDERSON 2006) and principal component analysis (PCA).

RESULTS AND DISCUSSION

The lack of climate data for the first two years of the 1980s may have influenced the presented results, but it does not invalidate the analytical capability of AptClim or the discussion regarding the spatiotemporal variation of climatic and physiographic suitability for the juçara palm in Santa Catarina between the 1980s and 2010s.

Figure 3 illustrates a shift in areas with optimal climatic and physiographic suitability (depicted in green) between the 1980s and 2010s. This transformation unfolded progressively in the western region, while coastal areas experienced a northward to southward expansion.

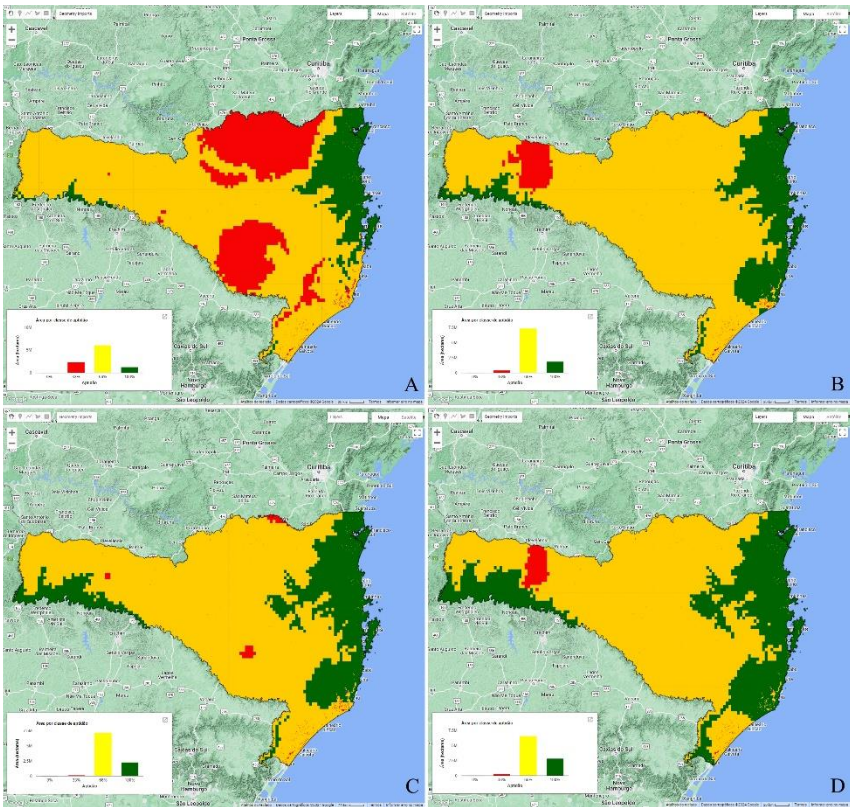

Figure 3. Spatio-temporal variation of the climatic and physiographic suitability classes for the juçara palm (*Euterpe edulis*) in Santa Catarina between the 1980s (A), 1990s (B), 2000s (C) and 2010s (D), according to AptClim.

According to AptClim, Santa Catarina experienced a 133% increase (1,590,543 hectares) in areas with optimal suitability for *Euterpe edulis* cultivation between the 1980s and 2010 (Table 1).

Table 1. Area (in hectares) of the climatic and physiographic suitability classes for the juçara palm *(Euterpe edulis*) in Santa Catarina between the 1980s, 1990s, 2000s and 2010s, according to AptClim.

Fitness class	Area 1982-1989	Area 1990-1999	Area 2000-2009	Area 2010-2019
0%	0	0	0	0
33%	2,251,003	395.426	112,867	219.624
66%	6,054,818	7,294,934	7.123.546	6,503,947
100%	1,187,977	1.811.513	2,265,745	2,778,520

Analysis of climate graphs generated by AptClim revealed distinct patterns in variable behavior across historical data series. An illustrative case is the Palmer Drought Severity Index (Figure 4), which exhibited a marked decline in the 1980s, with negative values observed from 1985 to 1989, before returning to positive levels in subsequent decades.

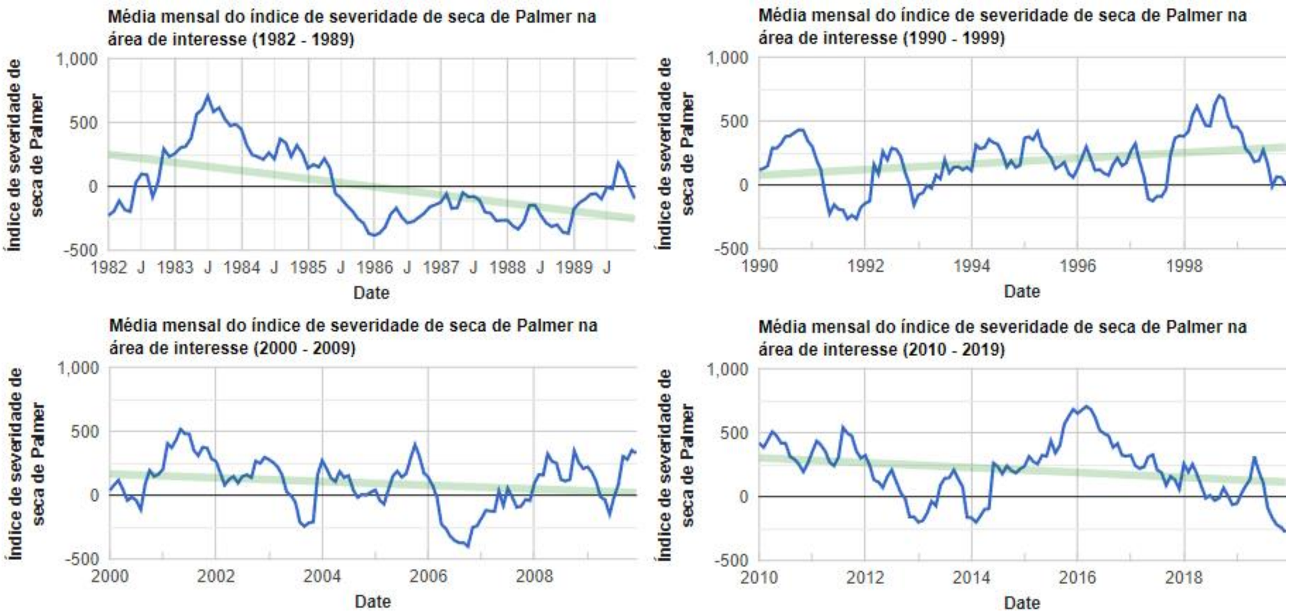

Figure 4. Monthly average variation of the Palmer drought severity index in Santa Catarina in the 1980s, 1990s, 2000s and 2010s, according to AptClim.

The shift in areas with optimal suitability can be attributed to climatic variations between decade (Tabela 2). The analyses conducted using R software supported these findings. The MANOVA result indicated a Pr(>F) value of 8.782^{-09} for a significance level of 0.001, confirming that there are significant climatic differences between the decades. Analyzing the variables individually using ANOVA, the Palmer drought index (Pr(>F) = 1.129^{-11}), water deficit (Pr(>F) = 0.02398) and the ocean surface temperature anomaly in the “El Niño” region (Pr(>F) = 0.03939) were the ones that best explained the difference between the decades.

The multivariate dispersion homogeneity test based on Euclidean distance (Table 3) revealed that the 1980s were climatically distinct from other decades. This discrepancy can be partially attributed to the lack of data for two years in the 1980s series. However, both the Palmer Drought Severity Index and the sea surface temperature anomaly in the El Niño region indicate increased climate variability, with extreme drought events linked to La Niña conditions (Table 2, Figure 5).

Table 2. Descriptive statistics of climate variables by decade.

Variable	Decade	Minimum	Q1	Mediana	Average	Q3	Maximum
dh	1980	0,00	0,00	1.17	54.99	39.09	656.72
dh	1990	0,00	0,00	0,00	29.03	18.94	600.91
dh	2000	0,00	0,00	1.15	26.49	26.18	463.47
dh	2010	0,00	0,00	0.20	26.11	13.99	468.79
en	1980	-1.82	-0.89	-0.32	-0.11	0.67	2.64
en	1990	-1.55	-0.50	-0.06	0.08	0.43	2.94
en	2000	-1.73	-0.50	0,00	-0.02	0.38	1.50
en	2010	-1.37	-0.37	0.19	0.20	0.66	2.83
ISP	1980	-383.74	-212.58	-88.39	-1.31	220.49	705.74
ISP	1990	-266.39	76.26	184.07	185.39	319.94	699.89
ISP	2000	-402.21	-23.81	122.36	92.51	228.09	515.13
ISP	2010	-280.56	68.92	225.72	208.13	342.70	705.29
prec	1980	10.05	92.71	126.42	132.88	166.65	299.34
prec	1990	26.64	100.73	142.40	147.24	180.66	318.16
prec	2000	29.97	103.33	141.21	141.38	173.20	322.88
prec	2010	28.52	106.50	143.23	147.98	182.39	346.91
tmax	1980	16.47	19.55	22.16	22.36	25.36	28.42
tmax	1990	15.25	19.81	22.48	22.48	25.75	27.47
tmax	2000	15.97	20.19	23.07	22.87	25.92	28.09
tmax	2010	16.17	20.51	22.96	23.04	26.01	28.69
tmin	1980	5.05	8.99	11.74	11.85	14.74	17.90
tmin	1990	4.69	9.33	12.50	12.14	15.18	17.45
tmin	2000	4.02	9.53	13.32	12.58	15.49	18.34
tmin	2010	5.58	10.11	13.01	12.84	15.66	18.38

Dh (mm) — average water deficit; en — average sea surface temperature anomaly in the “El Niño” region (o C); isp — average of the Palmer drought severity index; prec — average rainfall (mm); tmax — average temperature of the highs (ºC); tmin — average temperature of the lows (ºC).

Table 3. Paired comparison between the decades: p-value observed on the lower diagonal, p-value permuted on the upper diagonal.

	1980	1990	2000	2010
1980		0.002	0.001	0.012
1990	0.00109099		0.541	0.470
2000	0.00014936	0.53322127		0.176
2010	0.00951344	0.45858310	0.17617816	

The remaining variables also exhibited an increasing trend from the 1980s to the 2010s, with the exception of water deficit. In Santa Catarina, a trend of increasing average precipitation and average temperature has been observed over the past four decades, corroborating findings from previous studies conducted in the state (MENDES & CRISTINA 2016, PANDOLFO et al. 2015).

The principal component analysis revealed that dimensions 1 and 2 account for 73.5% of the data variability (Figure 6. A). This variability is primarily linked to precipitation (0.83), water deficit (-0.78), and the Palmer Drought Severity Index (0.75) (Figure 6. B). The 1980s stood out for its exceptional precipitation variability, alternating between extremely wet and dry years, and for its lower average temperatures. Subsequent decades exhibited reduced rainfall variability and a gradual trend towards increased temperatures and precipitation (Figure 6. C).

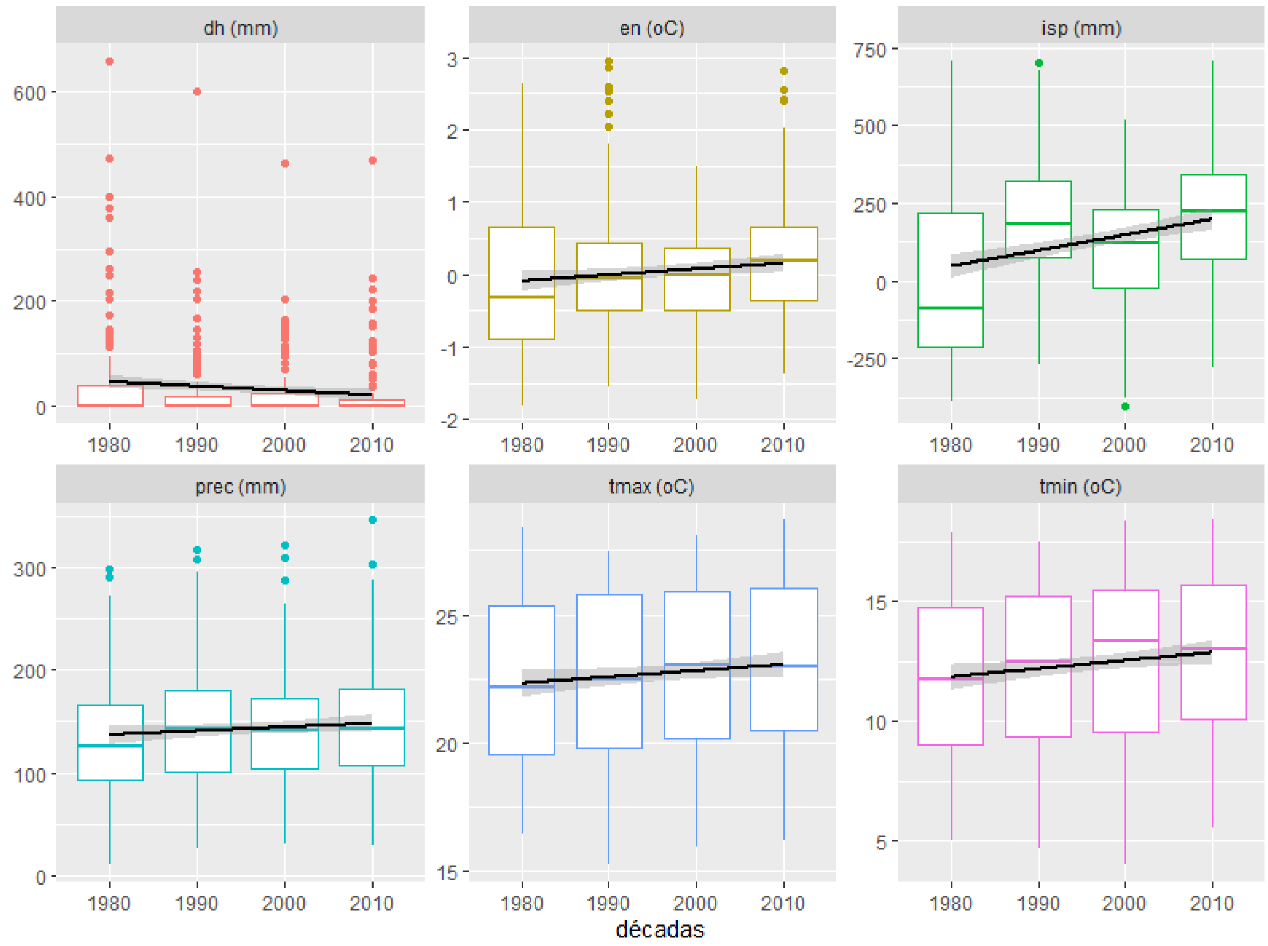

Figure 5. Boxplot of meteorological variables by decade in Santa Catarina. dh - average water deficit; en - average sea surface temperature anomaly in the "El Niño" region; isp - average Palmer drought severity index; prec - average precipitation; tmax - average maximum temperature; tmin - average minimum temperature.

AptClim-generated maps revealed an expansion of areas with optimal suitability for juçara palm cultivation in Santa Catarina between 1982 and 2019. This expansion occurred most significantly in the western region of the state, where the species was only recently catalogued in forest fragments (SZCZYGEL et al. 2021), and on the south-central coast (Figure 3). Similarly, climate data revealed that the 1980s exhibited greater climatic variability and was, on average, the driest decade among the four analyzed. Climatically, a gradual increase in temperatures and precipitation was observed during the study period (Figure 5).

To assess the relationship between the expansion of highly suitable areas and increases in temperature and precipitation, regional studies are needed, particularly focusing on the western region and southern coast where the most significant changes in area were observed. In this regard, AptClim can be applied using the same methodology presented in this study, simply by modifying the area of interest.

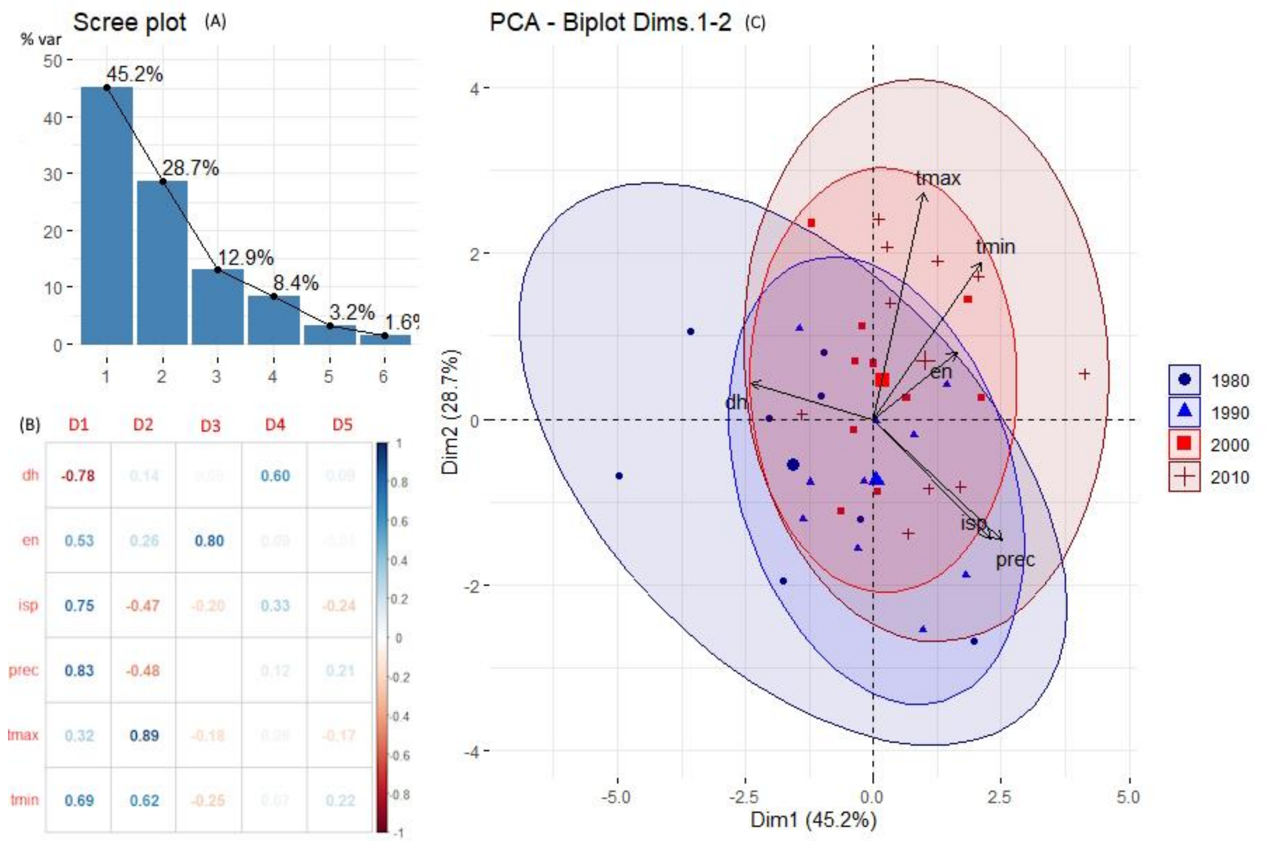

Figure 6. Results of the principal component analysis (PCA). (A) Scree plot with percentage of variance explained by each dimension (Component). (B) Range of each variable within each dimension: dh - average water deficit; en - average sea surface temperature anomaly in the "El Niño" region; isp - average Palmer drought severity index; prec - average rainfall; tmax - average maximum temperature; tmin - average minimum temperature. (C) Biplot of years (cases) and variables in dimensions (components) 1 and 2.

CONCLUSION

In the face of climate change, AptClim proved to be an efficient tool for assessing the climatic suitability of the juçara palm in Santa Catarina. The AptClim tool enabled the generation of maps and datasets, revealing significant variations in suitability across the territory over decadal timescales.

AptClim enables users to access climate maps and data for their specific areas of interest. As a preliminary step, suitability maps and time series graphs can be generated. If more in-depth analyses are required, data can be exported for examination using external applications.

As a continuously evolving tool, future versions could incorporate additional critical variables for climate suitability analyses, such as chilling hours, frost probability, and growing degree days.

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