

Agroclimatic zoning for eucalyptus in the state of Paraná and the new scenarios defined by global climate change

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ABSTRACT

Brazil is a country with one the largest areas of forest plantations in the world. The state of Paraná (PR) has the largest area of designated plantations in the country. The main cultivated species belong to the genus *Eucalyptus*. In this work, the areas of better favorability for planting the main species of commercial value eucalyptus were defined. Additionally, changes may also occur in these zones in the coming decades, due to global climate change. For this purpose, future scenarios were elaborated using a stochastic time series simulation software, to assess the possible changes of the climate and indicate potential consequences regarding the changes of eucalyptus plantation zones. The results show that there will be an increase in areas favorable to the commercial plantations of *E. grandis* and *E. urograndis*, species cultivated in the Cfa climate zone (subtropical zones). For *E. benthamii*, a species cultivated mostly in the Cfb climate zone (temperate zones), there will be a reduction of suitable areas for commercial plantations in Paraná, with displacement to areas located to the south and at higher altitudes, where edaphic limitations may occur.

Keywords: global warming, rural credit, agricultural insurance, reforestation, agricultural risk

Introduction

Brazil has one of the largest areas planted with forests in the world. The cultivation of eucalyptus is mainly used for the production of pulp and paper. The state of Paraná (PR) is the 3rd largest producer, with 13% of the planted area (846,860 ha), after the state of Minas Gerais, with 22.7% of the area (1,477,195 ha) and the state of São Paulo, with 18.2% of the area (1,188,403 ha) (ANUÁRIO ESTATÍSTICO DA ABRAF, 2012).

Species of the genus *Eucalyptus* are grown in more than 100 subtropical and tropical countries. However, few species have commercial value. In total, there are less than 20 species used commercially along with some hybrids. The total area planted with eucalyptus in the world is 20.6 million hectares, distributed in Asia (40.78%), in the Americas (36.41%), Africa (11.65%), Europe (6.31%),

and Oceania (4.85%) (GLOBAL, 2009; PALUDZYSZYN FILHO, 2010).

Eucalyptus productivity is dependent on many aspects of the environment, such as climate and soil composition, species, provenance and efficient breeding programs. Furthermore, quality management and the choice of the best site for the development of that provenance can also be contributing factors.

In Brazil, commercial eucalyptus plantations have grown 3% a year between 2005 and 2011. It has expanded to new regions with no tradition of eucalyptus production. This expansion is largely due to its ability to adapt to the different climates and soils of Brazil, as well as its rapid vegetative development (short cycle) and technological advances in the processes of industrialization. All of this is the result of the investments by companies in the timber sector together with support from public

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research institutions, promoting the multiplicity of uses of wood (ANUÁRIO ESTATÍSTICO DA ABRAF, 2010). Currently, eucalyptus is one of the best options for use in commercial plantations in Brazil and in the state of Paraná.

Among all species of Eucalyptus, a genus of Australian origin, less than 2% come from regions with an altitude above 1,000 meters and more than 39% from altitude below 200 meters, which suggests that most species are best adapted to warm climate areas and few species are adapted to the cold climate. Therefore, they are suitable for planting in regions with subtropical or tropical climates and are not tolerant to frost. There are few of them that survive temperatures below -15 °C to -18 °C (TURNBULL, ELDRIDGE et al., 1994), but with damages when the temperature remains for a few hours below 0 °C (HIGA et al., 2000, FRANKLIN; MESKIMEN, 1983).

In subtropical temperate regions, eucalyptus can be more productive with maximum temperatures of 24-32°C and average minimum temperatures of 3 - 17 °C. The average annual ideal temperature should remain between 14-22°C (BOOTH; PRYOR, 1991; POYTON, 1979).

There are three species of Eucalyptus that stand out commercially in Paraná: Eucalyptus grandis, E. urograndis and E. benthamii. E. grandis is the most planted species in Brazil and in Paraná, due to its high yield potential and adaptability to different climatic and soil conditions.

The largest planted area of E. grandis in the world is in Brazil, but it can also be found in other countries such as Sri Lanka, India, South Africa, Tanzania, Uganda, Zambia, Zimbabwe and the United States. It is especially prevalent in the states of California, Florida and Hawaii (ELDRIDGE et al., 1994). E. urograndis, which is an E. grandis hybrid, is also widely planted.

The species E. benthamii has a higher tolerance to frost than E. grandis. It originated in Australia, in a subtropical region with an average of 20 frosts per year, with minimum screen temperature between 0 and 3°C.

The state of Paraná is located between 22 and 27 degrees of latitude south, in a transitional zone between tropical and subtropical climates. The climate types according to Koeppen's classification are Cfa (subtropical) and Cfb (warm temperate). The relief with varying altitude intensifies the climatic differences between the north of the state, where the average altitude is low (less than 700 meters), and the south, where the average altitude is mostly above 700 m.

The coastal region also has a different situation, with an Af (tropical) climate, with higher temperatures and a more intense rainfall regimen, which reaches more than 3,500 mm / year, according to the region (WREGGE et al., 2011, 2015). The high pluviometric volume of the coastal region is due to the foothills of the Serra do Mar, which forces the elevation of the moisture from the

sea and increases the precipitation in that region. Higher temperatures occur because of very low altitude and high humidity.

Air temperature has an inverse correlation with altitude. The dry adiabatic lapse rate is 1°C per 100 m of elevation. The moist adiabatic lapse rate depends on air moisture. In the state of Paraná, MAACK (1981) reported, on average, the reduction of 0.5°C at each 100-meter increase in altitude, while OMETTO (1981) reported 0.6°C. In the mid-latitude regions, as in the case of Paraná, the large temperature differences in small geographic distances are mainly due to the effects of altitude and cloudiness (OMETTO, 1981; FRITZSONS et al., 2016).

On the other hand, the occurrence of frost has a direct correlation with the minimum screen temperature. As the minimum air temperature has increased in the last decades due to climate change, the risk of frost has diminished. In Londrina, PR, in the northern part of the state, for example, the minimum temperature increased by 1.5°C in the last 30 years (RICCE et al., 2008) and frosts are becoming less frequent.

Since most species of eucalyptus originated from warm regions of Australia with low risk of frost, global warming is likely to contribute to increase the suitable areas for commercial plantations of this genus.

The objective of this work was to map the favorable areas for eucalyptus commercial plantation in the state of Paraná and to design favorable areas, considering issues of global climate change for the next decades, with continued projections up to 2080.

Material and Methods

Climate database

The climatic data used in this work belong to the network of meteorological stations of the Agronomic Institute of Paraná (IAPAR). IAPAR has 33 meteorological stations that recorded and monitored all the climatic conditions of the state, and compiled them in a database from 1981 to 2010.

In addition to the database periods, the climate scenarios for the coming decades, represented by the periods 2011-2020, 2021-2030, 2031-2040, 2041-2050, 2051-2060, 2061-2070 and 2071-2080 were calculated. The future time series were calculated by using the average of five simulations, applying the program PGECLIMA_R: Stochastic Generator for Simulation of Brazilian Climatic Scenarios, developed by VIRGENS FILHO et al. (2011). The generated values are published in WREGGE et al. (2016).

The model considers the trend of the climatic series for the period and projects the trend over the next decades. Maps were generated for two distinct scenarios, one less pessimistic (B1) and

another more pessimistic (A2), using the means of minimum, maximum and average temperatures.

The same data used in defining the geographical distribution limits for each species were used in the time series elaborated for the future scenarios. This enabled us to begin defining new limit zones for the development of eucalyptus species.

Procedures for the mapping of climatic variables

We used the Geographic Information System (GIS) ArcGIS 10 to organize the data on geographic maps. Due to the direct correlation between temperature and altitude and temperature and latitude and longitude, we used for the mapping the tool Numerical Model of Terrain (MNT) (USGS, 1999) to analyze temperature variables, altitude, and latitude and longitude models, in the 1: 250,000 scale. The map with the MNT and the maps of latitude and longitude were in the Raster graphic format, with values corresponding, on the equator, every 90 meters.

WEBER et al. (2004) made adaptations and clippings of the MNT images from the United States Geological Survey (USGS) by employing the resources of a Brazilian government research agency. They corrected the existing gaps in the original radar images, when there was no information due to the presence of clouds or other types of image noise made by the Shuttle Radar Topographic Mission (SRTM).

The relationship between temperature and altitude (MNT, in meters), latitude and longitude (in decimal degrees) was established by a multiple linear regression equation, using the following formula:

$$\text{Temperature} = a + b \times \text{altitude} + c \times \text{latitude} + d \times \text{longitude} \text{ (equation 1)}$$

Values of Variables:

a: constant;

b: altitude coefficient;

c: latitude coefficient;

d: coefficient of the longitude.

The linear regression equation presented above (equation 1) was inserted into the mapping function of the ArcGIS program, where the temperature maps were obtained according to the altitude, latitude and longitude maps. The coefficients of the regression equations were published by WREGGE et al. (2016). A different equation was used for each period: base period and future decades, with projections continuing until 2080.

For each map generated, two or three development favoring classes were defined, depending on the case: favorable or preferential zone, when the region presented the necessary criteria for attending the species; marginal zone (or intermediate zone, in the transition between the

favorable and the unfavorable); and unfavorable zone, when the region did not present the necessary conditions for the development of the species.

Results and Discussion

There is very strong evidence that global climate change is due to anthropogenic causes. On most of the terrestrial earth, there has been a "warming", an increase of global temperatures. However, in some regions there has been a drop in temperature, due to changes in the behavior of the cold fronts. Changes in temperature and rainfall have affected grain production, livestock, fruit production and forestry.

The rapid changes in the climate that have occurred and those that are about to occur, will create a scenario of uncertainties about agricultural production worldwide in the medium and long term. A very strong crisis in global food security can occur in the coming decades if there is no minimal planning, to prepare the country's agriculture for the future. Thus, it becomes important to know what can happen to areas favorable for production in the coming decades, including those of eucalyptus.

The questions to be answered are: What will be the favorable zones for planting commercial eucalyptus species in Brazil in the next decades, from now until 2080? Also, in a scenario of uncertainties considering global climate change, what is actually happening and is about to happen?

Thus, the elaboration of future scenarios is important to allow planning for the forestry sector, in order to reduce the risks caused by extreme climatic events. The identification of new favorable areas for commercial plantations is important to prepare this sector and related disciplines for changes resulting from climate change. This is especially significant for eucalyptus, due to its capacity to adapt to environments with a warmer climate and frost free.

Eucalyptus is one of the genera whose species expected to benefit from global climate change, with predictions of expansion in the delimitations for the southern region of Brazil, starting with the state of Paraná,

The selected scenarios for the present study were A2 and B1. The A2 is the most pessimistic scenario, projecting the maintenance of the greenhouse gas (GHG) emission standards observed in the last decades. This would imply atmospheric CO₂ concentrations of about 850 parts per million by volume (ppmv) in the year 2100; On the other hand B1 is a scenario of lower emissions or a less pessimistic one, predicting the stabilization of GHG emissions, with CO₂ concentration at the end of this century of about 550 ppmv (NAKICENOVIC and SWART, 2000).

The distribution in the future scenarios encompasses the years 2011 to 2080, divided into seven periods: 2011-2020, 2021-2030, 2031-2040, 2041-2050, 2051-2060, 2061-2070 and 2071-2080.

Future scenario maps were prepared, foreseeing expansion of *E. grandis* and *E. urograndis* planting area and retraction for *E. benthamii*, according to the IPCC (2012) reports (Table 1 and Figures 1 to 6). In the worst case scenario, *E. urograndis* may increase by as much as 100% or more than 70% in the best scenario, or *E. grandis* may increase by 90% in the worst case and 85% in the best scenario.

The maps were classified into two zones: favorable and unfavorable for planting. Green areas are favorable for planting and white areas are unfavorable due to the occurrence of frost, considering that most of the favorable zone is located in the region classified as Cfa, with a subtropical climate. *E. grandis* and *E. urograndis*, differently from *E. benthamii*, which are frost tolerant and occur mostly in the area classified as Cfb, with a temperate climate.

The coastal region of Paraná, which is also in white, is unsuitable for eucalyptus due to high temperature, precipitation and humidity (WREGE et al., 2011). For this reason, the commercial plantation of eucalyptus is not feasible in this region (even when considering the future scenarios) due to the high probability of occurrence of fungal diseases that could benefit from the excess moisture, such as rust, caused by the fungus *Puccinia psidii* (BORA et al. Al., 2016).

WREGE et al. (2016) published the equations and values that were developed for use as a baseline for current and future climate scenarios.

The coefficients can be used in the regression equations applying climatic variables obtained as a function of the latitude, longitude and altitude of each site to achieve accurate mapping.

The advancement of the favorable zone in the colder areas occurs due to the increase of temperature, especially the minimum temperature, related to the occurrence of frosts. *E. grandis* and *E. urograndis* are species adapted to areas with low risk of frost, with higher temperatures. Thus, in the coming decades, with the reduction of frost risks, there will be a shift of the favorable zone to the south (Table 1). The reverse occurs for *E. benthamii*, a species of colder climate, adapted to areas with frost and low temperatures.

In the coming decades, if the progression of greenhouse gas emissions continues as it stands, there should be a significant increase in the areas most suitable for planting *E. grandis* in the state of Paraná, reaching the whole state by 2060's in the worst scenario, or by 2080's in the best scenario. *E. grandis* and *E. urograndis* may therefore be a viable alternative, replacing other species whose planting area may be reduced in the state, including *E. benthamii*.

It is important to consider that the analyses carried out in this work do not consider the soil conditions. *E. benthamii* may remain in areas with less favorable terrain, shallower, sandy and stony soils and in areas of greater slope, due to loss of area and displacement of areas of favorable climatic conditions to the south and to zones of higher altitude.

Table 1. Alteration of areas of agroclimatic zoning of eucalyptus in the state of Paraná for the coming decades, according to global climate change.

Scenario	decade	E. grandis		E. urograndis		E. benthamii	
		favorable area (ha)	area increase (%)	favorable area (ha)	area increase (%)	favorable area (ha)	area increase (%)
	atual	10.348.600	0,0	9.335.560	0,0	7.141.426	0,0
A2	2011-2020	14.923.400	44,2	13.156.235	40,9	6.485.330	9,1
	2021-2030	17.745.100	71,5	14.345.951	53,6	5.092.010	28,6
	2031-2040	18.959.300	83,2	15.737.033	68,5	3.574.105	49,9
	2041-2050	19.487.800	88,3	17.372.163	86,0	1.745.908	75,5
	2051-2060	19.770.200	91,0	18.717.265	100,4	859.526	87,9
	2061-2070	19.885.100	92,2	19.404.763	107,8	343.889	95,1
	2071-2080	19.919.854	92,5	19.713.486	111,1	141.520	98,0
B1	2011-2020	14.331.500	0,0	12.747.052	0,0	7.311.178	0,0
	2021-2030	16.085.300	55,4	13.214.606	41,5	6.793.785	4,8
	2031-2040	16.895.100	63,3	13.713.292	46,8	6.168.174	13,6
	2041-2050	17.541.100	69,5	14.230.747	52,4	5.542.564	22,3
	2051-2060	18.181.600	75,7	14.796.329	58,4	4.936.066	30,8
	2061-2070	18.739.400	81,1	15.389.802	64,8	4.329.567	39,3
	2071-2080	19.141.600	85,0	16.108.108	72,5	3.408.784	52,2

Figure 1. Agroclimatic zoning of *E. grandis* to the state of Paraná.

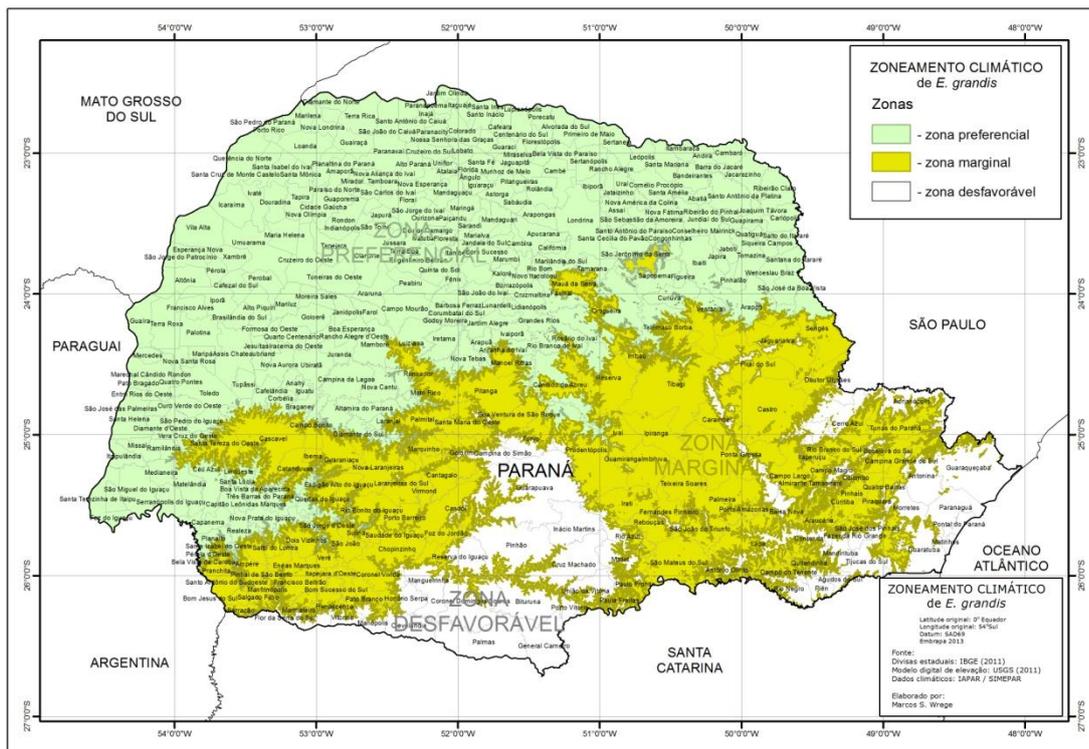


Figure 2a. New scenarios of *E. grandis* agroclimatic zoning for the state of Paraná.

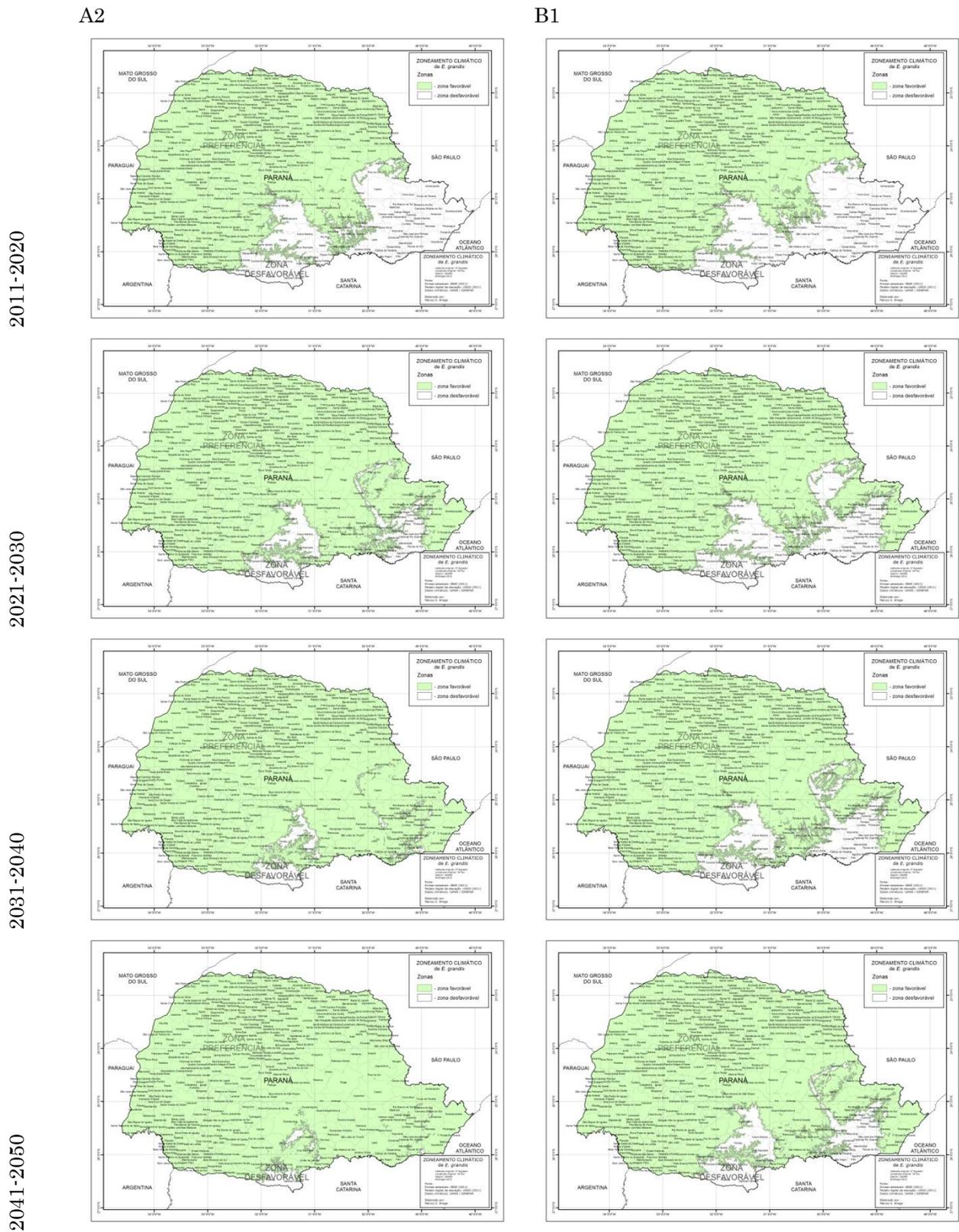


Figure 2b. New scenarios of *E. grandis* agroclimatic zoning for the state of Paraná.

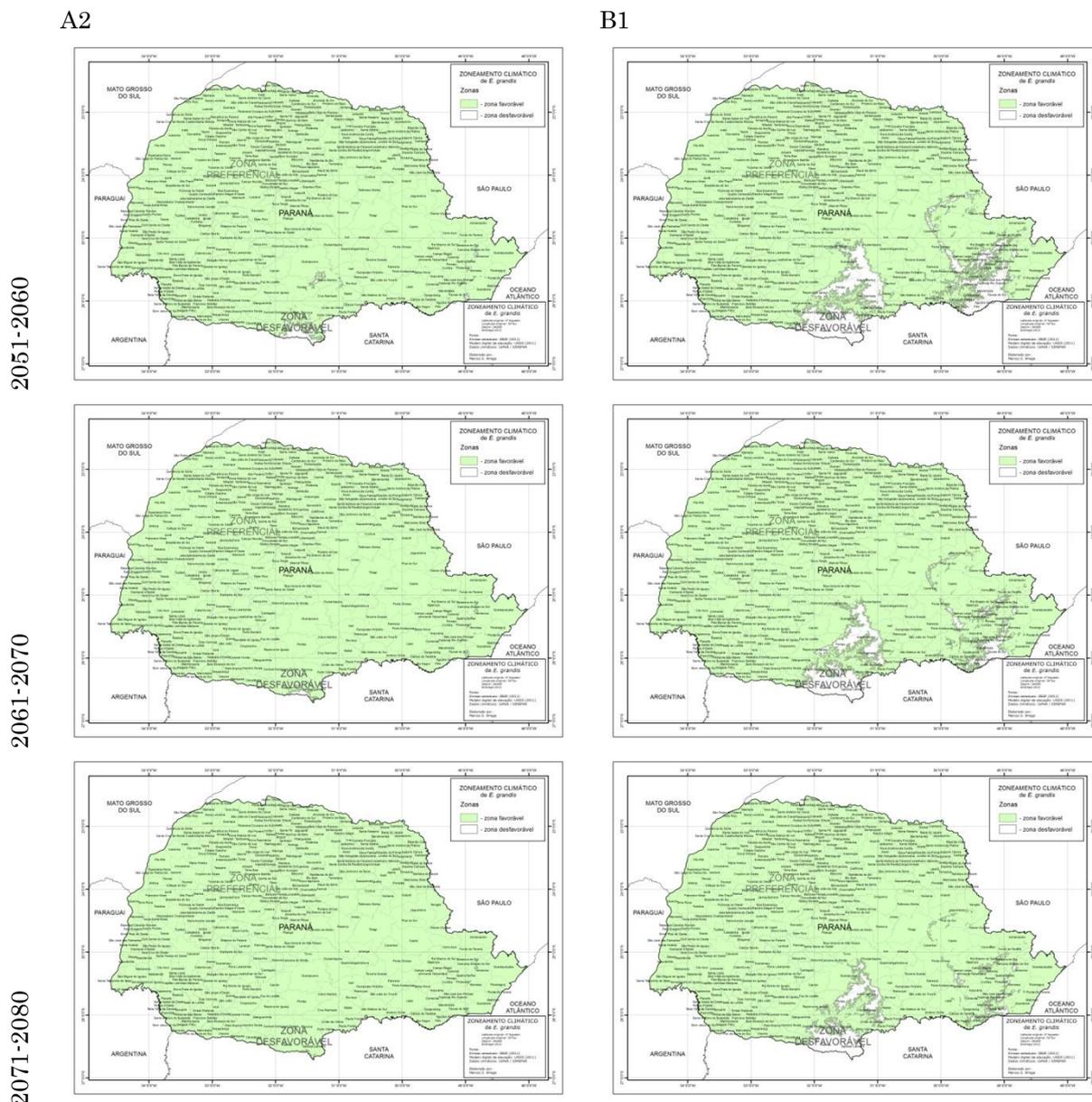


Figure 3. Agroclimatic zoning of *E. urograndis* to the state of Paraná.

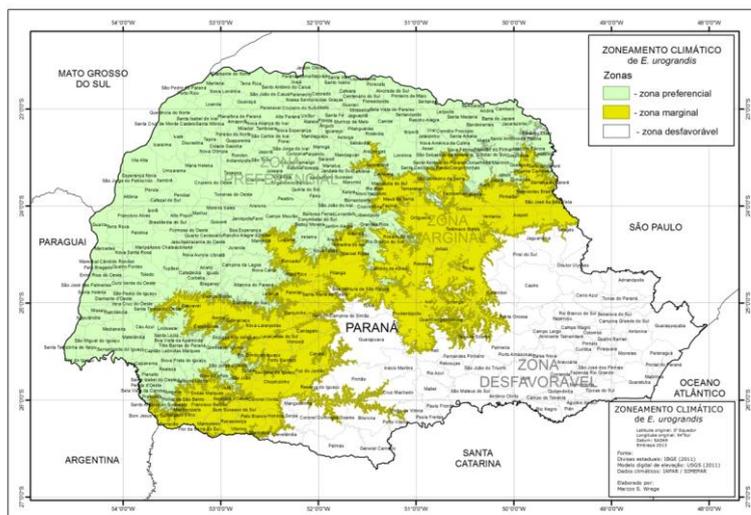
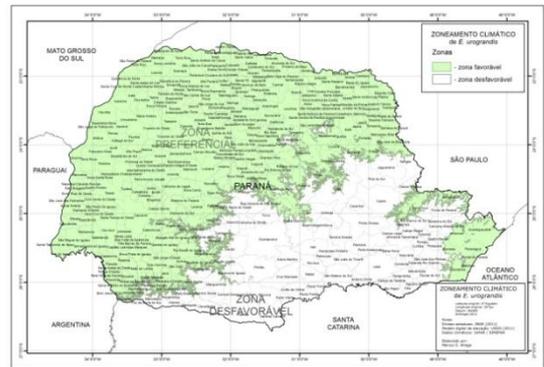
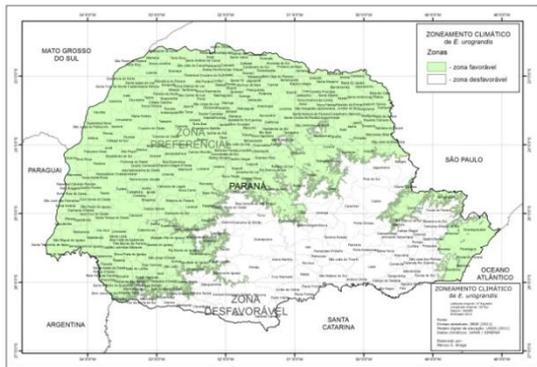


Figure 4a. New scenarios of the agroclimatic zoning of *E. urograndis* to the state of Paraná.

A2

B1

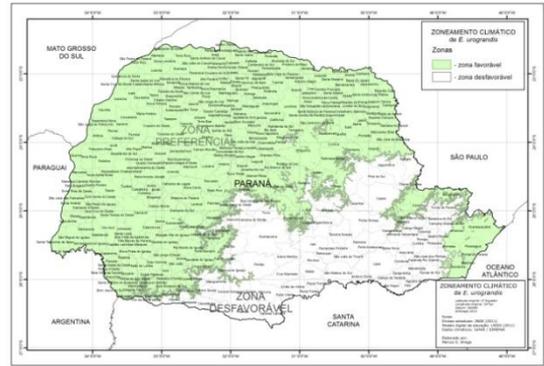
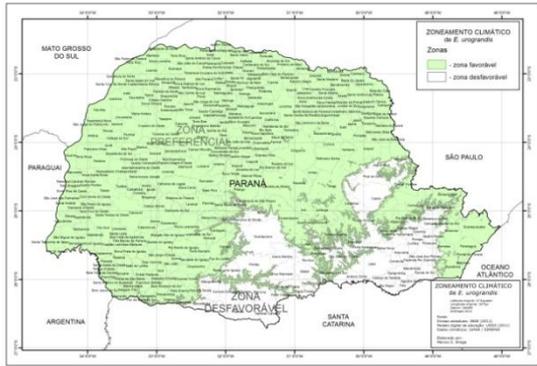
2011-2020



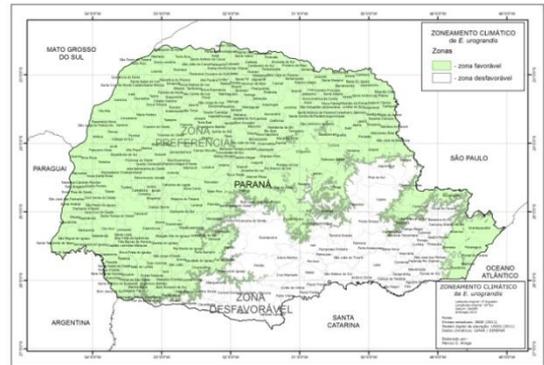
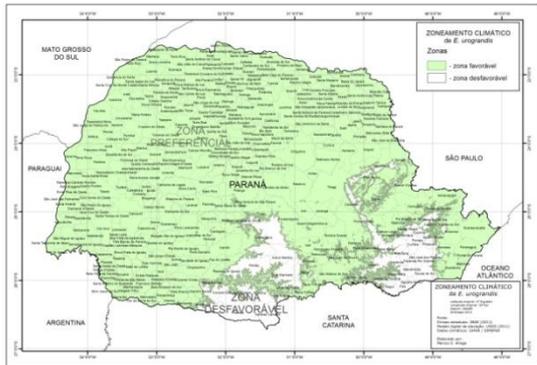
2021-2030



2031-2040



2041-2050



. Figure 4b. New scenarios of the agroclimatic zoning of *E. urograndis* to the state of Paraná.

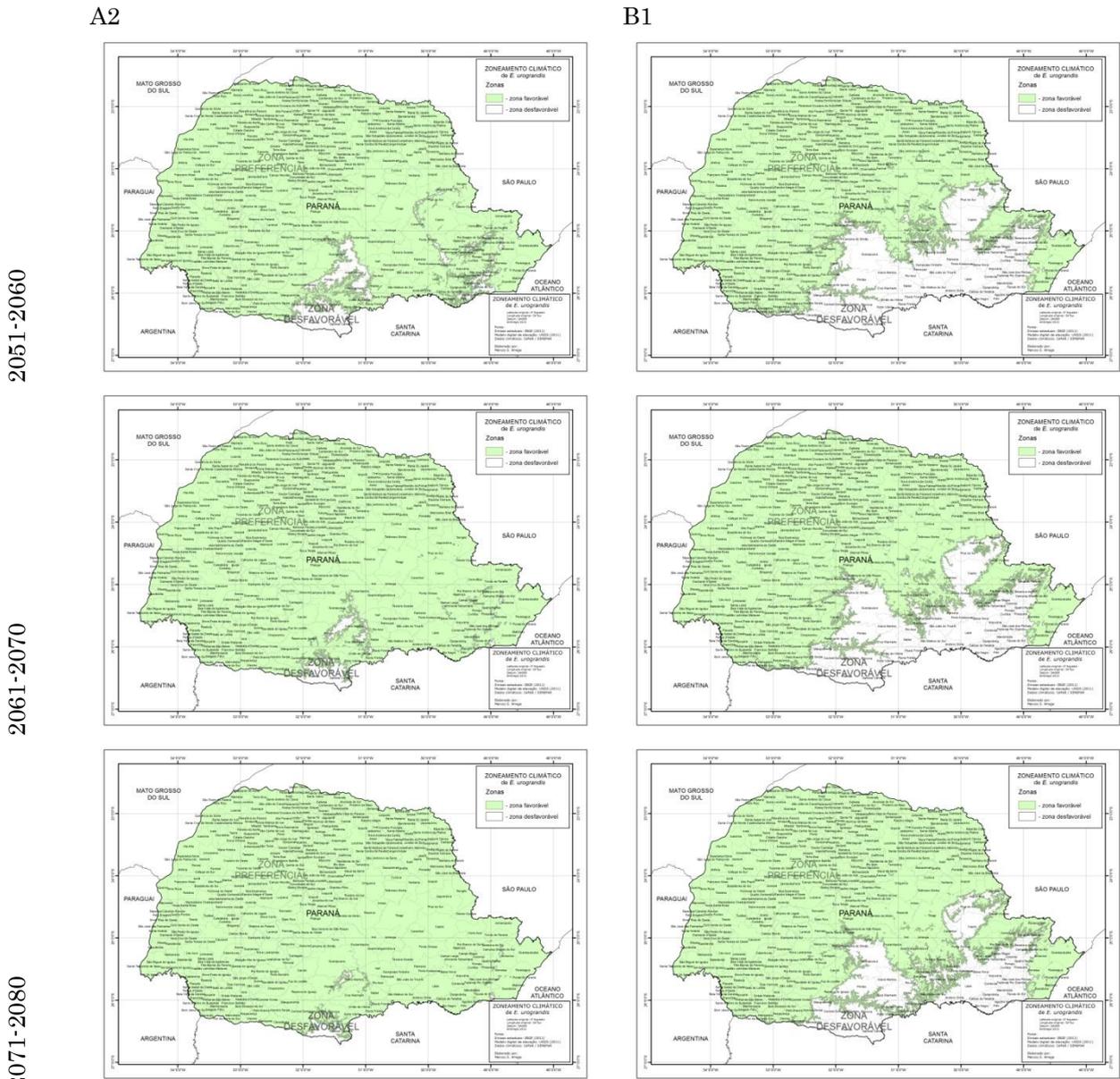


Figure 5. Agroclimatic zoning of *E. benthamii* to the state of Paraná.

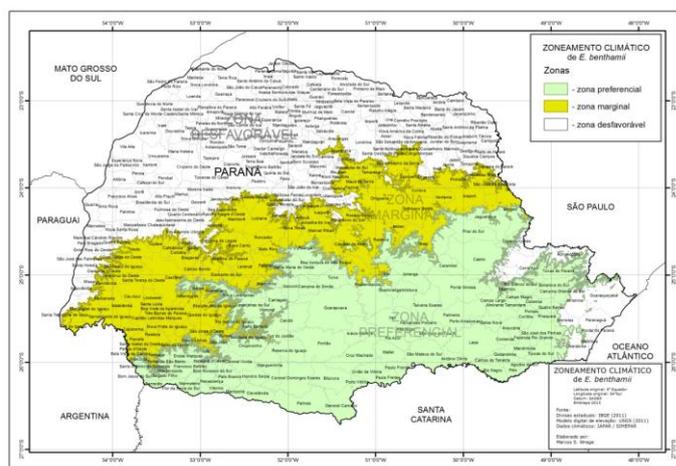
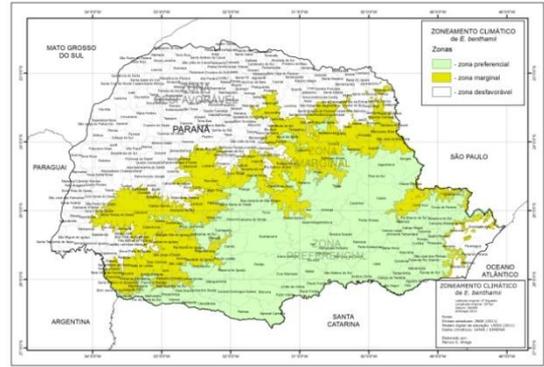
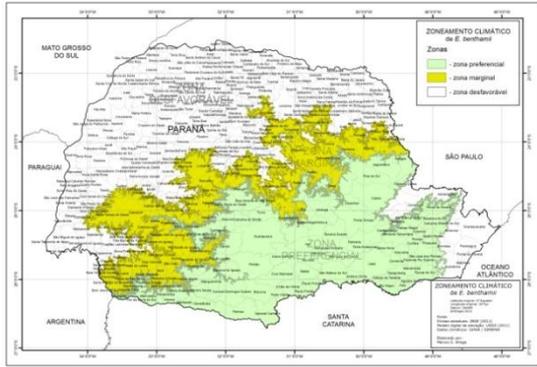
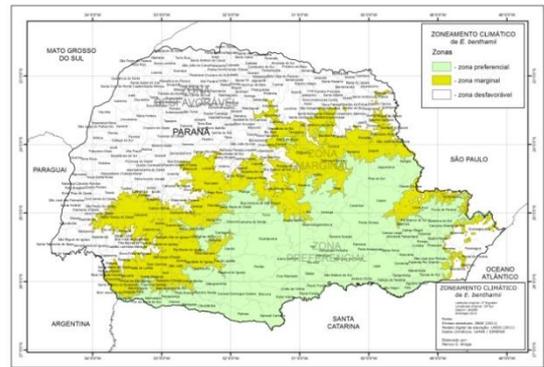
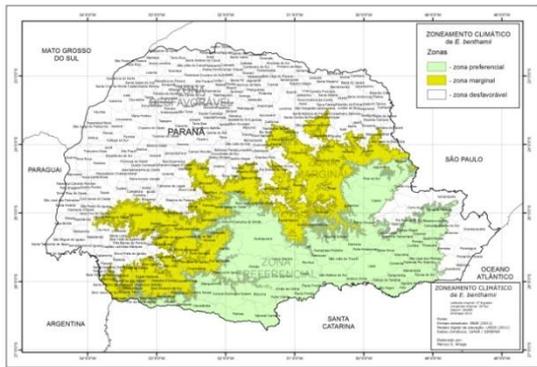


Figure 6a. New scenarios of the agroclimatic zoning of *E. benthamii* to the state of Paraná A2 B1

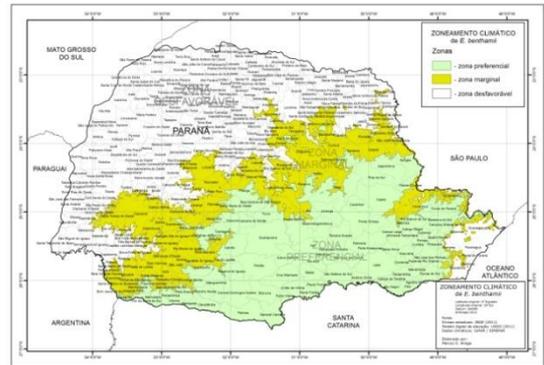
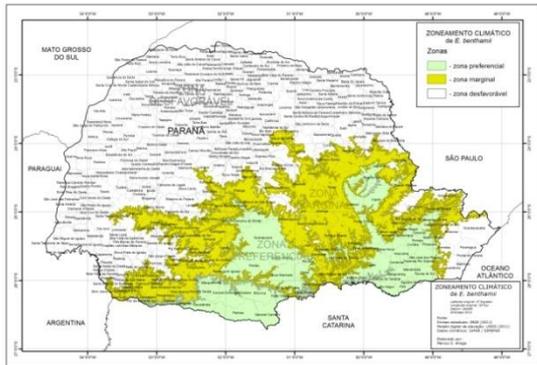
2011-2020



2021-2030



2031-2040



2041-2050

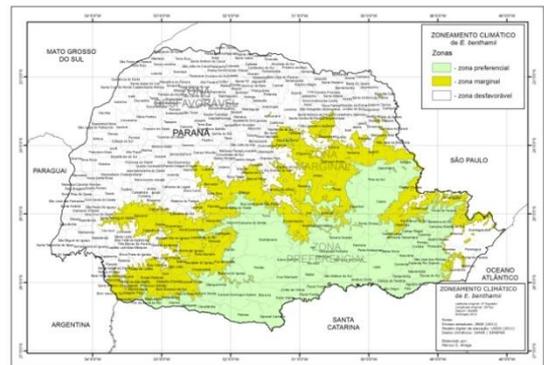
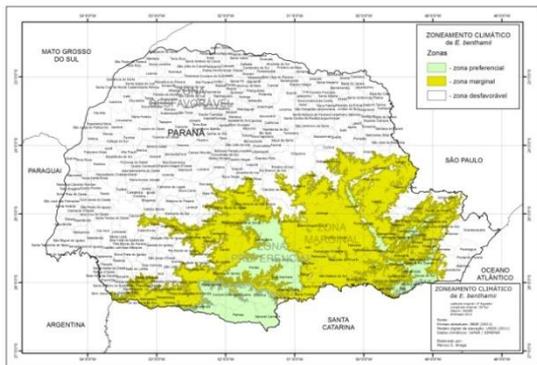
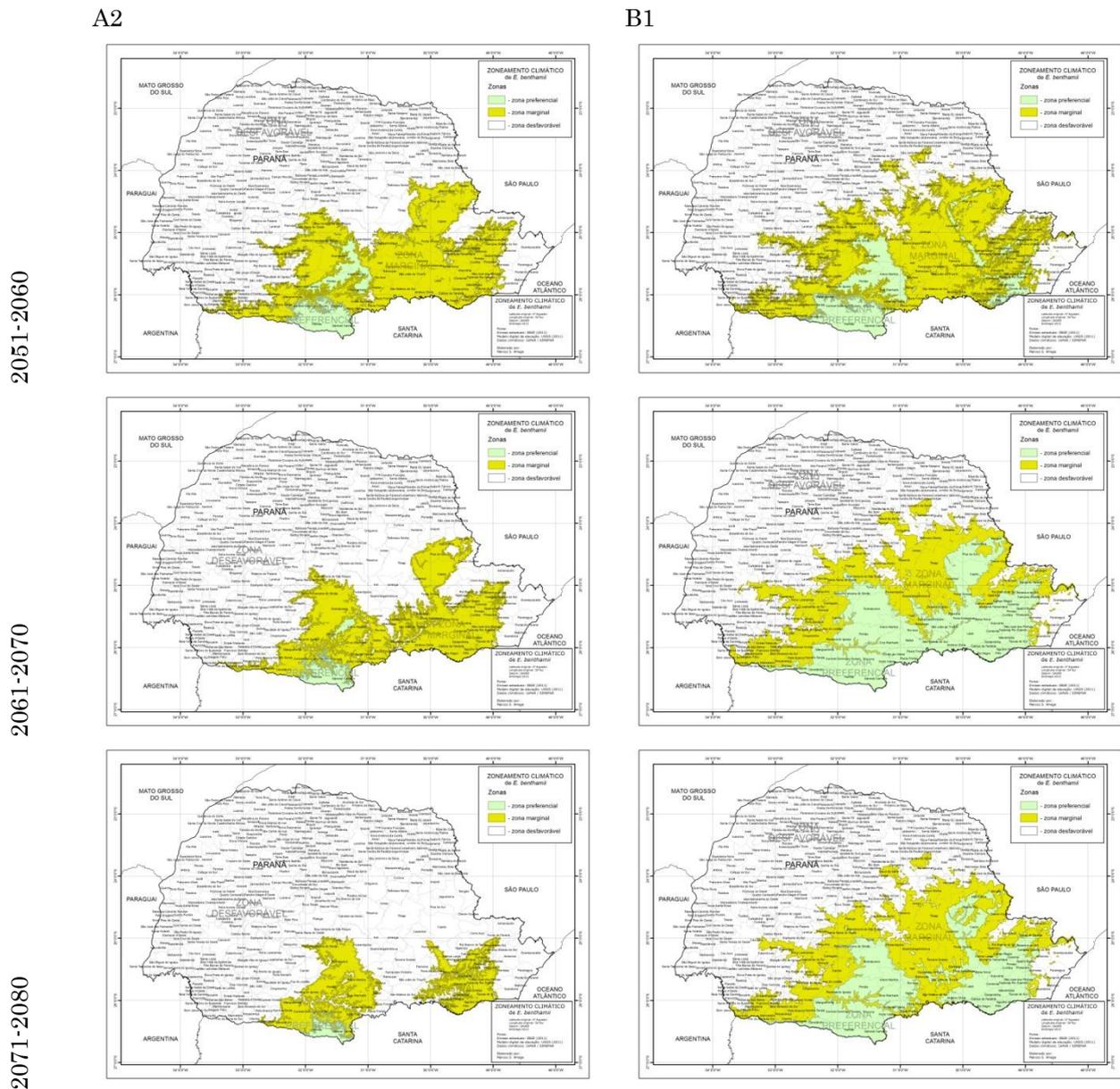


Figure 6b. New scenarios of the agroclimatic zoning of *E. benthamii* to the state of Paraná



Conclusions

Considering the trends in the coming decades related to global warming, there will be changes in the climatic transition zones of Paraná, with a rise in temperature throughout the state and reduction of frost risks;

The Climate changes will alter the delineation of climatic favorability zones for the various eucalyptus species in Paraná, moving them to areas with higher altitude and latitude, where temperatures are lower;

Favorable areas for plantations with *E. grandis* and *E. urograndis* tend to increase and advance southward, and to reduce areas for *E. benthamii*, which tends to move to areas with higher altitudes..

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