

ECOLOGICAL LIFE ZONES OF BRAZIL

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Resumo

Zonas de vida ecológicas do Brasil. Muitos sistemas de classificação foram desenvolvidos para auxiliar na missão de descrever o clima, mas nenhum é capaz de atender a todas as atividades humanas. O sistema desenvolvido por Holdridge em 1947, chamado de “zonas de vida”, é considerado o sistema de classificação climática mais ecológico pelo uso da biotemperatura. Diversos países já possuem um mapa das suas zonas de vida e o objetivo deste estudo é classificar cada município brasileiro de acordo com esse sistema. Dados de temperatura, precipitação, altitude e latitude, cedidos por Alvares *et al.*, (2013), foram aplicados na metodologia descrita em Holdridge (2000). O mapa das zonas de vida foi comparado com o mapa de vegetação por meio de matrizes de correlação, que geraram índices de correspondência de 0 a 100%. Os resultados mostraram que o Brasil tem 35 zonas de vida. As mais comuns são floresta úmida tropical e floresta úmida tropical premontana, cobrindo quase 50% do território. Após as análises de correlação, foi possível identificar que 21 zonas de vida têm mais de 80% das suas superfícies explicadas por dois tipos de vegetação ou menos. A distribuição das zonas de vida foi consistente com as características de cada região, em termos de vegetação e clima; desta forma, o sistema de classificação de Holdridge pode ser considerado uma opção relevante e específica para tomadas de decisão na agricultura e silvicultura.

Palavras-chave: Holdridge; ecossistemas; clima; vegetação; biotemperatura

Abstract

Many classification systems were developed to help in the mission of describing climate, but none of them is able to meet all areas of human activity. A system developed by Holdridge in 1947, called “life zones”, is considered the most ecological climate classification system because of the use of biotemperature. Several countries already have a life zones map and the purpose of this study is to classify each Brazilian municipalities according to this system. Temperature, precipitation, altitude and latitude data, provided by Alvares *et al.* (2013), were applied according to the methodology described by Holdridge (2000). The ecological life zones map was compared with the vegetation map through correlation matrices, which generated indices ranging from 0 to 100%. The results showed that Brazil has 35 life zones. The most common are tropical moist forest and tropical premontane moist forest, covering almost 50% of the country's area. After the analysis of correlations, we could see that 21 LZs have more than 80% of their surfaces covered by two or less types of vegetation. The LZs distribution was consistent to the characteristics of each region, in terms of vegetation and climate; therefore, the Holdridge system can be considered a relevant and specific option for decision making related to agricultural and forestry activities.

Keywords: Holdridge; ecosystems; climate; vegetation; biotemperature

INTRODUCTION

The distribution of vegetation can hardly be justified or understood if we consider them isolated from the climate in which they are influenced, since this is one of the determining factors in the geographic distribution of natural vegetation. Each vegetal species lives between extreme limits of different climatic factors and elements, beyond which its development would not be possible.

Among the resources that plants need in order to grow, water is often the most limiting resource (TAIZ; ZEIGER, 2009). However, in addition to the availability of water, temperature also plays an essential role in vegetation growth, as it controls the rates of metabolic reactions in cells (MOLLO *et al.*, 2011). Thus, among the

climatic factors that determine the vegetal ecology, temperature and rainfall are probably the most active (MOLLO *et al.*, 2011; ALVARES *et al.*; 2012). In agriculture and forestry, these factors can be useful to define crop zoning, sowing dates, and the expected yield levels (ALVARES *et al.*; 2012). These two factors are the most used in several climate classification systems.

Holdridge (2000) proposed a bioclimatic classification system that is based on climatic parameters (biotemperature and precipitation) and non-climatic parameters (latitude and altitude). This climate classification system is called life zones (LZs) and it aims to group similar ecological associations (HOLDRIDGE, 2000). Instead of using air temperature, as other climate classifications, Holdridge (2000) suggests the use of biotemperature to represent the 'heat' factor in the LZs system. Biotemperature is the temperature range in which the effective growth of plants occurs, i.e., 0 to 30°C. Below this interval, the plant would paralyze its processes, and above it, the photosynthesis would be zero due to high rates of respiration. The use of biotemperature, as well as the information of latitude and altitude, is the reason why some authors consider LZs an ecological system of climate classification.

Many countries already have a national map based on the LZs of Holdridge. Some examples of countries in Latin America include Colombia (HINCAPIÉ; CAICEDO, 2013), Costa Rica, Honduras, Guatemala, Panama, Nicaragua, El Salvador, Belize (KHATUN; IMBACH; ZAMORA, 2013; IRUNGARAY *et al.*, 2016), Mexico (DURÁN *et al.*, 2014), Bolivia (MINISTERIO DE PLANIFICACIÓN DEL DESARROLLO, 2016), Puerto Rico (KHALYANI *et al.*, 2016) and Argentina (DERGUY, 2017).

Even though this classification is better adapted for the tropics, China (LI *et al.*, 2015), Pakistan (NASIR; AFRASIYAB; ATHAR, 2015), Turkey (TATLI; DALFES, 2016) and India (CHAKRABORTY *et al.*, 2013; SINGH; CHATURVEDI, 2017) are also using this system to relate to the ecosystem mapping and to compare with others climate classifications.

Considering that Brazil is a megadiverse country with a variety of agricultural and forestry activities, a map of Brazilian LZs is essential as a way to subsidize public policies and agricultural and forestry planning and as a tool for territorial management of natural resources. Life zones, as previously mentioned, include geographic (latitude and altitude), climatic (precipitation and temperature) and ecological (biotemperature) data. This wealth of information should be considered as a detailed alternative to, in some cases, replace the use of biomes, which, although necessary in a country of continental proportions, end up generalizing some important peculiarities of ecosystems.

Therefore, the objective of our study was to classify the Brazilian municipalities according to the Holdridge's life zone system and to compare it to the Brazilian vegetation map.

MATERIALS AND METHODS

Study site

Brazil is located in central-eastern South America, between the latitudes 5° 16' 20"N; 33° 45' 04"S and the longitudes 34° 47' 35"; 73° 59' 27"W, and has a total area of 8.515.759,09 km² (Brazilian Institute of Geography and Statistics - IBGE, 2011). Altitudes in Brazil vary from 2.93 m to 1,601.42 m at sea level (Figure 1A); annual precipitation ranges from 421.28 mm to 3,619.62 mm (Figure 1B). The mean annual temperature is 22.22 °C, ranging from 13.08 to 28.0 °C (Figure 1C).

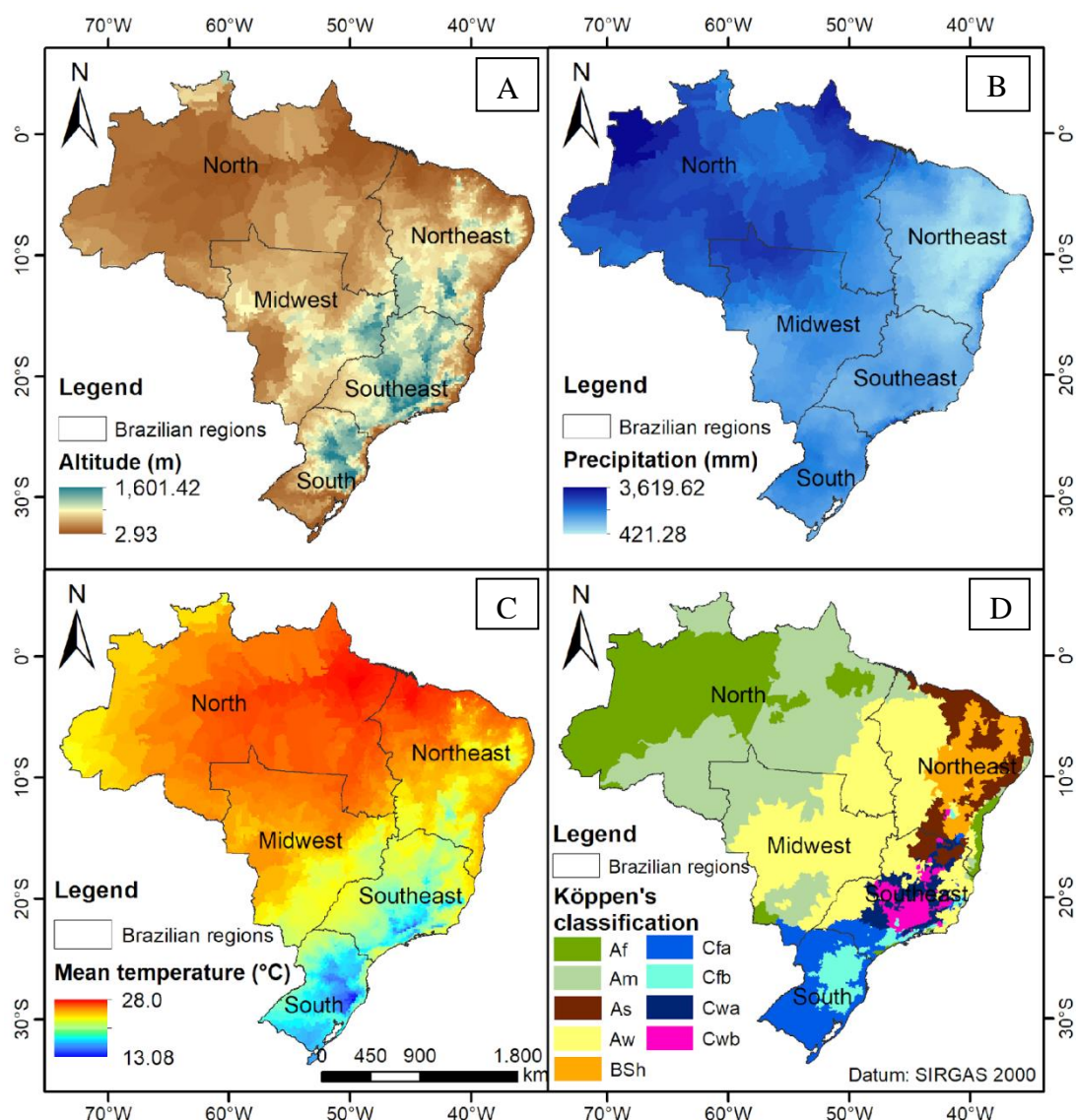


Figure 1. Characterization of the study site. Source: created by the authors based on Alvares *et al.* (2013).
 Figura 1. Caracterização da área de estudo. Fonte: elaborado pelos autores baseado em Alvares *et al.* (2013).

Figure 1D presents nine Brazilian Köppen climatic types, according to Alvares *et al.* (2013). The surface representativeness of each climate is within parentheses. Four of them are tropical climates: Am (28.2%) is a monsoon tropical climate; Aw (26.4%) is a tropical climate with dry winter; Af (21.0%) is a tropical climate without dry season; and As (5.5%) is a tropical climate with dry summer. Cfa and Cfb are subtropical climates without a defined dry season: Cfa (6.8%) is a humid subtropical climate with hot summer; and Cfb (2.7%) is a humid subtropical climate with temperate summer. Brazil also presents other two subtropical climates, but these, in turn, have a defined dry season: Cwa (2.6%) is a humid subtropical climate with dry winter and hot summer; and Cwb (1.8%) is a humid subtropical climate with dry winter and temperate summer (1.8%). Present only in the northeast region, BSh (5.0%) is a dry semi-arid climate.

Holdridge's life zones system

Holdridge proposed a bioclimatic classification system called life zones (LZs) that aims to group similar ecological associations (HOLDRIDGE, 2000). The author believes that the species of plants, which have adapted to a certain ecological niche, are similar from the point of view of physiognomy, even if they are not taxonomically related.

This methodology needs as input data the mean monthly temperature, annual precipitation, latitude and altitude values. Having this data, we can calculate the mean annual biotemperature and the corrected mean annual biotemperature, which will be used to determine the life zone, the latitudinal region and the altitudinal level.

Data obtention

Climatic data used in this study were provided by Alvares *et al.* (2013). They are composed of at least 25 years of records, between the years 1950 and 1990, based on 2,950 weather stations for rainfall data and 2,400 for temperature data. This data was obtained from the following sources: Brazilian National Institute of Meteorology (INMET), Brazilian National Department of Works Against Droughts (DNOCS) and Food and Agriculture Organization of the United Nations (FAO/UN).

The database presented the mean monthly temperature, monthly precipitation, mean altitude and Köppen's climate classification for each one of the 5,564 Brazilian municipalities.

Altitude data used by Alvares *et al.* (2013) were obtained from a Digital Elevation Model (DEM) provided by the Shuttle Radar Topography Mission (SRTM), with a spatial resolution of 90 m. Then, we calculated an average altitude for each municipality.

Data processing and analysis

A program developed in the FoxPro software (Figure 4) performed the calculations of mean annual biotemperature (T_{bio}), relation of potential evapotranspiration (R_{etp}) annual rainfall and the classification according to Holdridge's life zone system for the 5,564 Brazilian municipalities. After having the classification, we elaborated a map in the ArcGIS 10.0 program to see the LZs distribution in the country. The surface of each municipality was represented in the map with its respective life zone. Life zones map was superimposed on a vegetation map using the zonal histogram tool. The results were expressed as a percentage of the total LZ area.

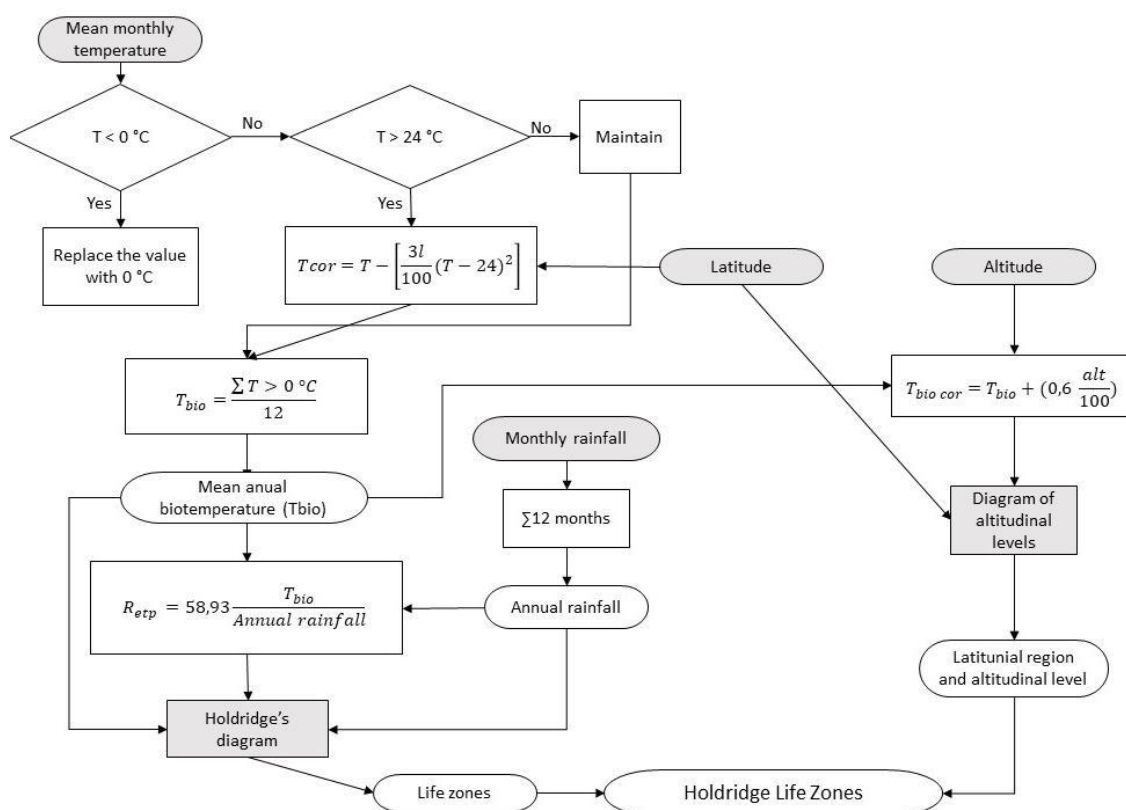


Figure 2. Flowchart of processes performed by the Foxpro software.

Figura 2. Fluxograma dos processos realizados no software Foxpro.

RESULTS

Figure 3 presents the spatial distribution of Brazilian annual biotemperatures, altitudinal levels, relation of potential evapotranspiration and latitudinal regions.

The mean annual biotemperature was 21.86°C, varying from 13.08°C to 27.69°C. There was a difference of 0.36°C between the mean annual temperature and the biotemperature. Biotemperatures were within three altitudinal levels: lower montane, premontane and basal.

The lower montane altitudinal level was distributed in two regions: southeast and south. In the southeast region, the altitudinal level is presented in the area corresponding to the “Serra da Mantiqueira”, whereas in the south region, it is established at the second plateau of Paraná and Santa Catarina states and in the area known as central depression in the state of Rio Grande do Sul.

Clearly, Retp (relation of potential evapotranspiration) had higher values in the northeast region owing to elevated temperatures and low precipitation rates.

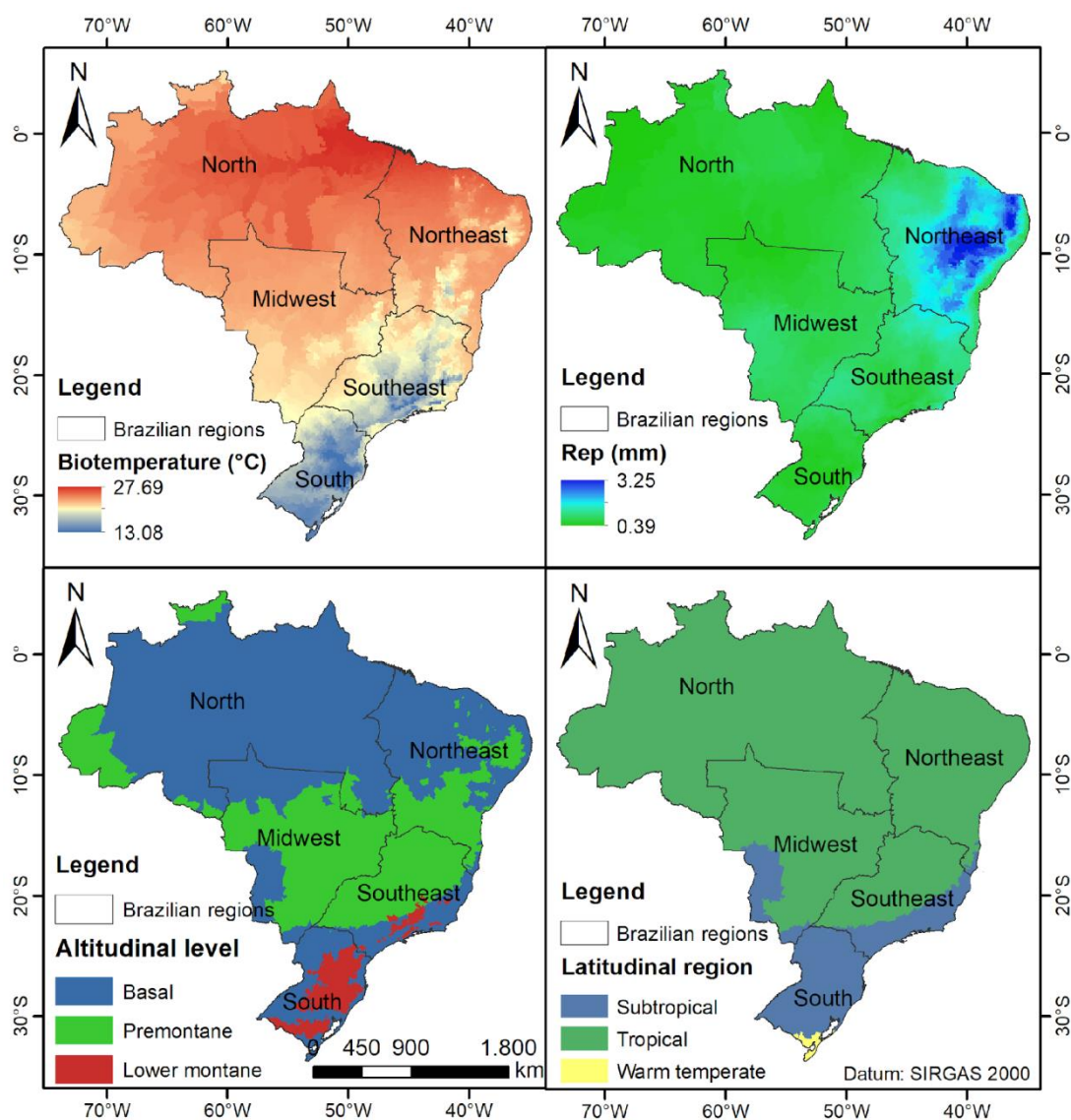


Figure 3. Distribution of biotemperature (°C), relation of evapotranspiration (mm), altitudinal level, and latitudinal region according to Holdridge life zones classification.

Figura 3. Distribuição da biotemperatura (°C), relação de evapotranspiração (mm), piso altitudinal e região latitudinal de acordo com a classificação das zonas de vida de Holdridge.

We found 35 LZs in Brazil (Table 1), most of them (60.23%) classified as moist forest. The largest Brazilian LZ was a tropical moist forest and together with the second largest LZ, they cover almost 50% of the country's area.

Table 1. Representativeness of Holdridge life zones by area (km²) and percentage (%) in Brazil.

Tabela 1. Representatividade das zonas de vida de Holdridge por área (km²) e porcentagem (%) no Brasil.

Holdridge life zones	Area (km ²)	%
Tropical moist forest	2,857,146.01	33.55
Tropical premontane moist forest	1,324,414.95	15.55
Subtropical moist forest	648,947.75	7.62
Tropical moist/wet forest	496,070.64	5.83
Tropical dry forest	378,232.87	4.44
Tropical premontane moist/wet forest	371,392.95	4.36
Tropical premontane dry forest	310,674.14	3.65
Tropical dry/moist forest	268,434.95	3.15
Subtropical lower montane moist forest	260,635.11	3.06
Tropical very dry/dry forest	184,076.56	2.16
Tropical premontane moist/dry forest	178,196.60	2.09
Tropical very dry forest	177,836.64	2.09
Tropical premontane wet/moist forest	158,996.95	1.87
Tropical moist/dry forest	151,917.14	1.78
Tropical premontane dry/moist forest	130,197.53	1.53
Tropical wet/moist forest	108,597.96	1.28
Tropical premontane wet forest	75,838.54	0.89
Tropical dry/very dry forest	63,718.83	0.75
Subtropical wet/moist forest	57,958.94	0.68
Tropical premontane dry/very dry forest/thorn woodland	55,318.95	0.65
Tropical premontane thorn woodland/dry/very dry forest	41,399.19	0.49
Subtropical moist/dry forest	38,519.25	0.45
Subtropical lower montane moist/wet forest	29,759.43	0.35
Warm temperate moist forest	28,319.50	0.33
Tropical premontane thorn woodland	25,439.54	0.30
Tropical premontane very dry forest/thorn woodland/dry forest	24,599.56	0.29
Tropical very dry forest/thorn woodland	17,639.63	0.21
Subtropical dry/moist forest	14,519.71	0.17
Subtropical lower montane wet/moist forest	9,959.76	0.12
Tropical lower montane moist forest	9,839.77	0.12
Subtropical lower montane wet forest	7,679.85	0.09
Subtropical moist/wet forest	4,319.95	0.05
Subtropical wet forest	2,879.94	0.03
Tropical thorn woodland/very dry forest	1,560.00	0.02
Subtropical dry forest	720.01	0.01
Total	8,515,759.09	100.00

Only the two smallest life zones presented complete correspondence with just one type of vegetation (Table 2) but we can say that 19 LZs have more than 80% of their surfaces covered by two types of vegetation. This includes the two biggest Brazilian LZs: tropical moist forest and tropical premontane moist forest. The first one was best correlated with Ombrophilous forests and the second one with savanna.

Table 2. Percentage of correspondence between Holdridge life zones and Brazilian vegetation.
Tabela 2. Porcentagem de correspondência entre as zonas de vida de Holdridge e a vegetação brasileira.

Holdridge life zones	Index 1	Vegetation	Index 2	Vegetation	Index 1+2
Subtropical dry forest	100.0	ODF	-	-	100.0
Tropical thorn woodland/very dry forest	100.0	N-SAV	-	-	100.0
Tropical very dry forest/thorn woodland	98.2	N-SAV	1.8	SAV/N-SAV/SF	100.0
Tropical premontane wet forest	94.6	OOF	5.4	ODF	100.0
Trop. premont. very dry forest/thorn woodland/dry forest	91.2	N-SAV	5.0	N-SAV/SF	96.2
Tropical very dry forest	91.1	N-SAV	6.3	N-SAV/SF	97.4
Subtropical wet forest	85.7	ODF	14.3	MOF	100.0
Subtropical moist/wet forest	75.0	ODF	25.0	ODF/MOF	100.0
Tropical premontane thorn woodland	74.4	N-SAV	11.6	SAV/SF	86.0
Tropical premontane dry/very dry forest/thorn woodland	73.3	N-SAV	16.1	N-SAV/SF	89.4
Tropical premontane thorn woodland/dry/very dry forest	72.3	N-SAV	11.5	SAV/SF	83.8
Tropical very dry/dry forest	70.7	N-SAV	9.8	N-SAV/SF	80.5
Subtropical moist/dry forest	61.8	ODF	35.0	SSF	96.8
Subtropical lower montane moist/wet forest	61.7	Steppe	31.9	MOF	93.6
Tropical premontane moist forest	60.8	SAV	20.8	SAV/SF	81.6
Tropical moist forest	59.9	ODF	20.5	OOF	80.4
Subtropical lower montane wet forest	59.1	MOF	40.9	Steppe	100.0
Tropical lower montane moist forest	55.6	SSF	25.0	SF/MOF	80.6
Tropical wet/moist forest	55.3	Campi./OF	33.4	Campinarana	88.7
Warm temperate moist forest	55.2	PF	40.2	Steppe	95.4
Tropical dry/moist forest	53.3	SAV	11.8	SAV/SF	65.1
Subtropical lower montane wet/moist forest	53.1	Steppe	40.6	MOF	93.7
Tropical premontane wet/moist forest	50.3	OOF	25.7	ODF	76.0
Tropical dry forest	47.7	SAV	10.9	N-SAV/SF	58.6
Tropical moist/wet forest	47.3	ODF	22.0	OOF	69.3
Tropical premontane dry/moist forest	44.5	SAV	28.9	SSF	73.4
Subtropical wet/moist forest	42.0	SDF	27.1	Steppe	69.1
Subtropical dry/moist forest	40.5	SSF	31.0	ODF	71.5
Tropical premontane moist/dry forest	38.9	SSF	34.4	SAV	73.3
Subtropical lower montane moist forest	38.8	MOF	32.4	Steppe	71.2
Tropical moist/dry forest	33.8	SAV	32.2	ODF	66.0
Tropical dry/very dry forest	32.3	N-SAV	19.6	N-SAV/SF	51.9
Tropical premontane dry forest	27.5	SDF	22.0	N-SAV/SF	49.5
Subtropical moist forest	27.4	SSF	21.6	SAV	49.0
Tropical premontane moist/wet forest	26.7	SAV	25.3	OOF	52.0

Note: Campi. – Campinarana; MOF – Mixed Ombrophilous Forest; N-SAV – northeast-savanna; ODF – Ombrophilous Dense Forest; OF – Ombrophilous Forest; OOF – Ombrophilous Open Forest; PF – pioneer forest; SAV – Savanna; SDF – Seasonal Deciduous Forest; SF – Seasonal Forest; SSF – Seasonal Semideciduous Forest.

Regarding LZs distribution (Figure 5), the most humid LZ found was the wet forest, located mainly in the state of Amazonas, and the driest LZ was the thorn woodland, located in the central area of the northeast region.

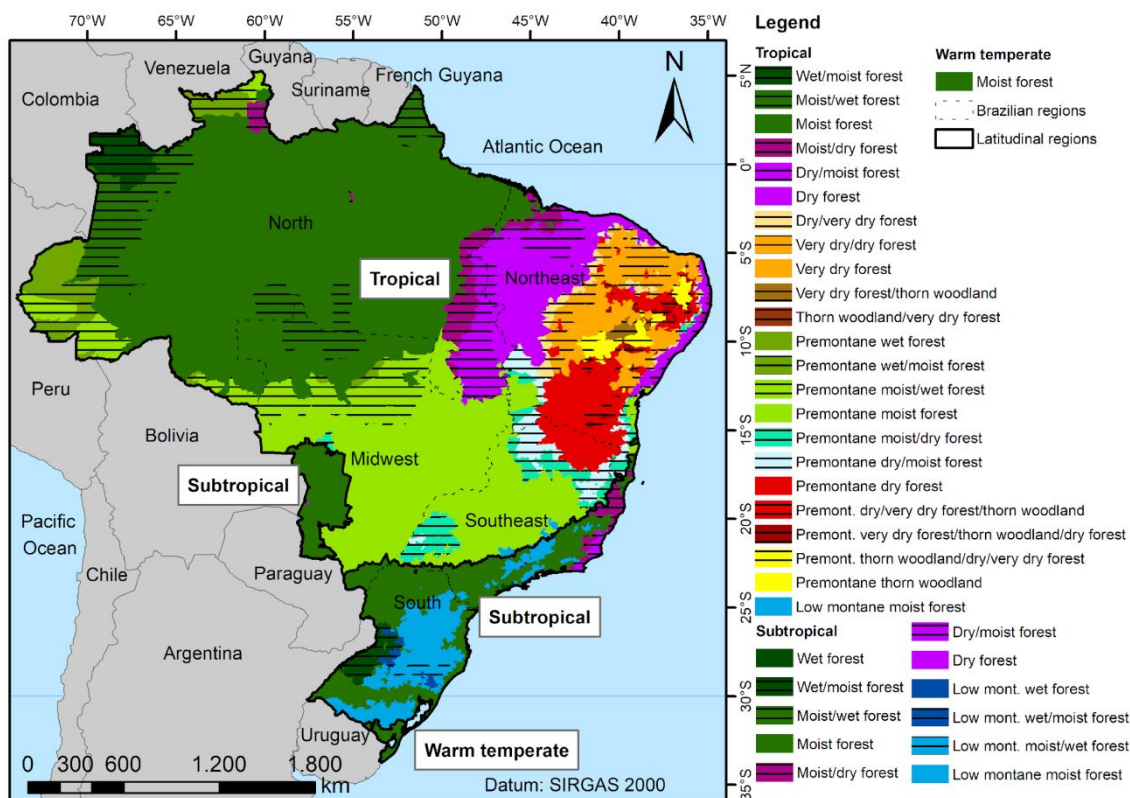


Figure 5. Holdridge life zones distribution in Brazil.
 Figura 5. Distribuição das zonas de vida de Holdridge no Brasil.

Of the nine LZs found in the Brazilian midwest region, the tropical premontane moist forest was the most expressive, covering 50.86% of the midwest region area and practically the entire state of Goiás. Transition zones with wet forests were concentrated in the northern portion of this region, where the Amazon biome occurs.

Northeast was the most heterogeneous region of Brazil, where 21 LZs were identified. In general, the most humid life zones were located in the northern area of Maranhão state and the south coast of Bahia state. The tropical dry forest was the most common life zone in that region (23.29%), whereas the thorn woodland, the driest life zone in Brazil, only occurred in the northeast of Brazil.

The northern region presented 10 LZs, and the tropical moist forest was the predominant type, with 67.81% of the total area. In the western portion of this region, the transition zones tended to be wet forests, such as tropical moist/wet forest and tropical wet/moist forest; in the eastern portion, the driest transition zones predominated in the border of the northeast region.

Premontane tropical moist forest is the most common life zone in southeast Brazil, covering 40.79% of the region's area. This life zone changes its latitudinal region and altitudinal level according to the area's proximity to the ocean, which creates the subtropical moist forest, representing 18.10% of the region. All four life zones with a lower montane altitudinal level are concentrated in the area corresponding to the "Serra da Mantiqueira", where altitudes are more elevated.

In the southern region, subtropical moist forest was the most abundant (42.77%). Subtropical lower montane moist forest (35.71%), the second largest life zones in the southern region, was found in the second plateau of Paraná state and in the central part of Santa Catarina and Rio Grande do Sul states.

DISCUSSION

The results of our study show, for the first time, a detailed map of Holdridge life zones in Brazil.

Moist forest, the LZ found in most of the Brazilian territory, is present in all geographic regions, but mainly in the north, center-west, southeast and south areas. In the northeast region, moist forest was found only in northern state of Maranhão and in the west and south coast of Bahia state, due to the higher humidity in those areas, compared to the center of the region.

As expected, the driest LZs were found in the northeast region. It was interesting to see how transitions were established in this area. They gradually became drier up to the central portion.

Vergara *et al.* (2013), in a study about how Holdridge LZs could change in a scenario with double CO₂ in Latin America, obtained similar results in Brazil although not as detailed. According to them, the moist forest was also the most recurrent LZ in Brazil and the northeast region was classified as dry forest.

In Colombia, as in Brazil, tropical moist forest was the most abundant LZ (HINCAPIÉ; CAICEDO, 2013). In the northern and eastern Bolivia, LZs are similar to those found in Brazil: moist forest, wet forest, rain forest and dry forest. However, the other areas in Bolivia are covered by desert, steppe, thorn steppe, desert shrub, thorn woodland, nival, moist tundra, wet tundra, rain tundra and dry tundra (*MINISTERIO DE PLANIFICACIÓN DEL DESARROLLO*, 2016).

The analysis of correlation between vegetation and ecological life zones is important as a way to validate the classification according to the characteristics of the study area. Isaac and Bourque (2001), studying the life zones of Saint Lucia, and Szelepcsényi, Breuer and Sümegi (2014), in the Carpathian Region, also approached this relation.

Some limitations of our study are: life zones were calculated for each municipality, where mean values of altitude, temperature and precipitation were considered, which may have disregarded some particularities of each location; some municipalities are much larger than others, i.e., in the northern area, the municipalities are larger than in the southern region. In this case, as we considered mean values, bigger municipalities can be treated as less precise than the smallest ones.

It is important to say that this map responds as a first approximation of Brazilian LZs and came to fulfill the lack of this information for the country. Future research may expand upon these results considering details and particularities of each region.

CONCLUSIONS

It was possible to conclude that:

- This first approach found 35 LZs for the Brazilian territory. However, considering the size of the country, futures studies are encouraged in local scales.
- The LZs distribution was consistent with the characteristics of each region, in terms of vegetation and climate; therefore, the Holdridge system can be considered a relevant and specific option for decision making related to agricultural and forestry activities.

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