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ASSESSMENT OF BIOMASS POTENTIAL IN EUCALYPTUS FORESTS USING REMOTE SENSING

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ABSTRACT

The search for renewable energy combined with the socio-economic importance of Eucalyptus cultivation has opened new avenues for Eucalyptus application beyond the traditional uses. In this study, the Geographical Information System (GIS) was applied to evaluate the distribution of Eucalyptus stands in Botucatu SP, Brazil. The GIS also assisted in the calculation of the potential biomass with satellite images. Satellite images were captured by the Land Operational Imager (OLI), installed aboard the Landsat-8 satellite and made available by the United States Geological Survey (USGS) / Earth Resources Observation & Science Center (EROS). Results from this study showed that the area covered by the Eucalyptus forest in Botucatu corresponds to a maximum of 197.04 tons per hectare of biomass, representing more than 10% of its area. Therefore, it is possible to use remote sensing images to expand the capacity to generate information on forest registries. These results may be very useful to companies that use the raw materials from these planted forests.

Keywords: satellite images, geoprocessing, GIS.

AVALIAÇÃO DO POTENCIAL DE BIOMASSA EM FLORESTAS DE EUCALIPTO UTILIZANDO SENSORES REMOTOS

RESUMO

A busca por energia renovável, combinada com a importância socioeconômica do cultivo de eucalipto, abriu novas avenidas para a aplicação do eucalipto além dos usos tradicionais. Neste estudo, o Sistema de Informação Geográfica (SIG) foi aplicado para avaliar a distribuição dos talhões de eucalipto em Botucatu, SP, Brasil. O SIG também ajudou no cálculo do potencial de biomassa com imagens de satélite. As imagens de satélite foram capturadas pelo Land Operational Imager (OLI), instalado a bordo do satélite Landsat-8, e disponibilizadas pelo Serviço Geológico dos Estados Unidos (USGS) / Centro de Observação e Ciência de Recursos da Terra (EROS). Os resultados deste estudo mostraram que a área coberta pela floresta de eucalipto em Botucatu corresponde a um máximo de 197,04 toneladas por hectare de biomassa, representando mais de 10% de sua área. Portanto, é possível usar imagens de sensoriamento remoto para expandir a capacidade de gerar informações sobre os registros florestais. Esses resultados podem ser muito úteis para empresas que utilizam as matérias-primas dessas florestas plantadas.

Palavras-chave: imagens de satélite, geoprocessamento, SIG.

1 INTRODUCTION

The cultivation of Eucalyptus, native to Australia, was introduced in Brazil in the early twentieth century, established itself in the country in the 1950s, and its cultivation has increased since the 1970s, especially with the introduction of the pulp industry in the Botucatu region. Considering reforestation based on periodic inventories, the evaluation of

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the vegetation cover is an important planning tool for those who consider exporting crops, because accurate data allows for the identification and measurement of areas, characterization of Eucalyptus properties, reduction of Eucalyptus trees, and harnessing the potential of remaining small and medium properties within the municipality to expand this high-technology investment culture.

Given the socioeconomic importance of soil, its conservation is vital as it is highly susceptible to erosion. Furthermore, monoculture is conducted using agronomic techniques that favor the maintenance of soil structure and help prevent silting in streams and rivers. This silting could aggravate the situation if the region is used for grazing without noted conservation techniques, as is happening in the adjacent municipality.

In the search for renewable energy, Eucalyptus cultivation has become a new option, and applications beyond traditional ones, such as the production of plates and laminates, are being explored; i.e., planting aimed at biomass production for various applications in manufacturing industries is being evaluated.

The global forestry significant production of Eucalyptus and in Brazil is an important sector of economic because of some success characteristics associated. Stand out: great diversity of species; ease of propagation and adaptability; forestry improvement of species of this genus that provides its implementation in homogeneous plantations; and, mainly, the use for various purposes, from the manufacture of sleepers at the beginning of its historical participation, as well as today, to the industry with the manufacture of paper, cellulose, pressed wood fiber and even in the development of Eucalyptus trees transgenics for tissue manufacturing.

The productivity of Eucalyptus, given its rapid growth, can be considered as one of the main factors that determined its expansion in the pulp and paper market and also to sawmill. Although the average annual productivity, considered around thirty-five cubic meters per hectare is relatively low, there crops with use of adapted best Eucalyptus, using good technology that affect yields close to sixty cubic meters per hectare per year (Dossa *et al.*, 2002).

In a country of continental dimensions such as Brazil, with a great lack of adequate information for decision making on urban, rural and environmental problems, geoprocessing has enormous potential, especially if based on relatively low-cost technology, where the knowledge is acquired locally (Câmara; Davis; Monteiro, 2004).

The advantages of using remote sensing data in the surveys of the current use of lands are reaching large areas of difficult access to the imaging of high altitude, providing a synoptic view of the Earth's surface, with repeatability, enabling the monitoring of large areas (Campos *et al*., 2004a).

Remote sensing and GIS are in fundamental techniques for maintaining records of land use over time. The satellite images are very important and useful because it allows to evaluate changes in the landscape of a region and a given period, recording the vegetation cover at each time (Campos *et al*., 2004b).

The images obtained by sensors on board orbiting satellites have shown great potential to monitor or detect changes in forest cover over large geographic areas (Souza *et al*., 2007). Change detection algorithms have been developed, and the band ratio technique has been highlighted because of its simplicity of implementation and efficiency (Muchoney; Haack, 1994).

The management is the management of forest resources by developing and applying quantitative methods and ecophysiological knowledge aimed at generating products, services, and direct and indirect benefits, ensuring economic, social and environmental sustainability from a forest (Loëtsch; Haller; Zöhrer, 1973).

The Landsat program (Land Remote Sensing Satellite) was developed by NASA (National Aeronautics and Space Administration) in the late 1960s aiming to collect data on the natural renewable and nonrenewable resources of the earth's surface (Ribeiro; Petry; Limberger, 2018). Launched in February 2013, the Landsat-8 satellite has a polar orbit, positioning is sun-synchronous manner at an altitude of approximately 705 km. There are two sensors embedded in the Landsat-8 satellite the OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor). The sensors on board the Landsat-8 satellite have imaging range 170 km north-south by 185 km east-west, temporal resolution of approximately 16 days, spatial resolution of 30m for the bands of the visible, 15m for panchromatic band and 100m the hot bands (TIRS).

The Normalized Difference Vegetation Index (NDVI) allows monitoring of the density and the state of vegetation on the Earth's surface, being generated by the combination of bands (Tucker, 1977). The NDVI (Normalized Difference Vegetation Index) is calculated from the equation (1):

$$NDVI = (NIR - VIS)/(NIR + VIS) \quad (1)$$

Where NIR is near-infrared and VIS is red reflectance. The NDVI values range between -1 and +1. Negative values correspond to the presence of water and +1 represents a vegetation with large amounts of biomass allowing the identification of the presence of vegetation on the surface and the characterization of their spatial distribution, as well as their evolution over time (Bezerra; Moraes; Soares, 2018). The vegetation values are values between 0 and 1, so NDVI is directly related to the photosynthetic capacity and the energy absorption by the tree coverage.

The use of remote sensing techniques in forest areas is gradually more common. There are several works carried out, highlighting one of the techniques regularly used in monitoring forest cover, which is the multitemporal analysis of sensor observations (Foody *et al*., 1996; Lucas *et al*., 2002).

In Brazil, several authors have already used multitemporal analysis of sensor observations, for example, (Skole; Tucker, 1993), in a study of the temporal evolution of deforestation occurring in the Amazon Forest. Also for this same forest, (Mausel *et al*., 1993), the different phases that occurred during the deforestation process were studied.

Biomass can be defined as the amount of organic material that constitutes beings of an existing ecosystem in a particular area and can be expressed in weight, volume, area or number and calorific units. One of the advantages of biomass is the variability usage forms which can be in the form of gas, liquid or solid. Furthermore, the biomass has a short cycle as compared with other fossil energy sources. Another advantage is that works as long-term storage of carbon dioxide, thus playing an important role in sequestration (Mello, 2001).

The cultivation of Eucalyptus in the municipality of Botucatu, shows favorable due to its great suitability for the region’s soil and climate. In this context, it is worth highlighting that the improvement in the development and implementation of techniques and approaches for estimating biomass potential via remote sensing is necessary.

The goal is to develop a methodology to identify the model that best fits the calculation of the amount of biomass involved in planting Eucalyptus in Botucatu SP, Brazil, by using remote sensing techniques and making use of GIS tools.

In summary, this study is aimed at estimating the biomass potential of Eucalyptus in Botucatu.

2 MATERIALS AND METHODS

2.1 Study Area

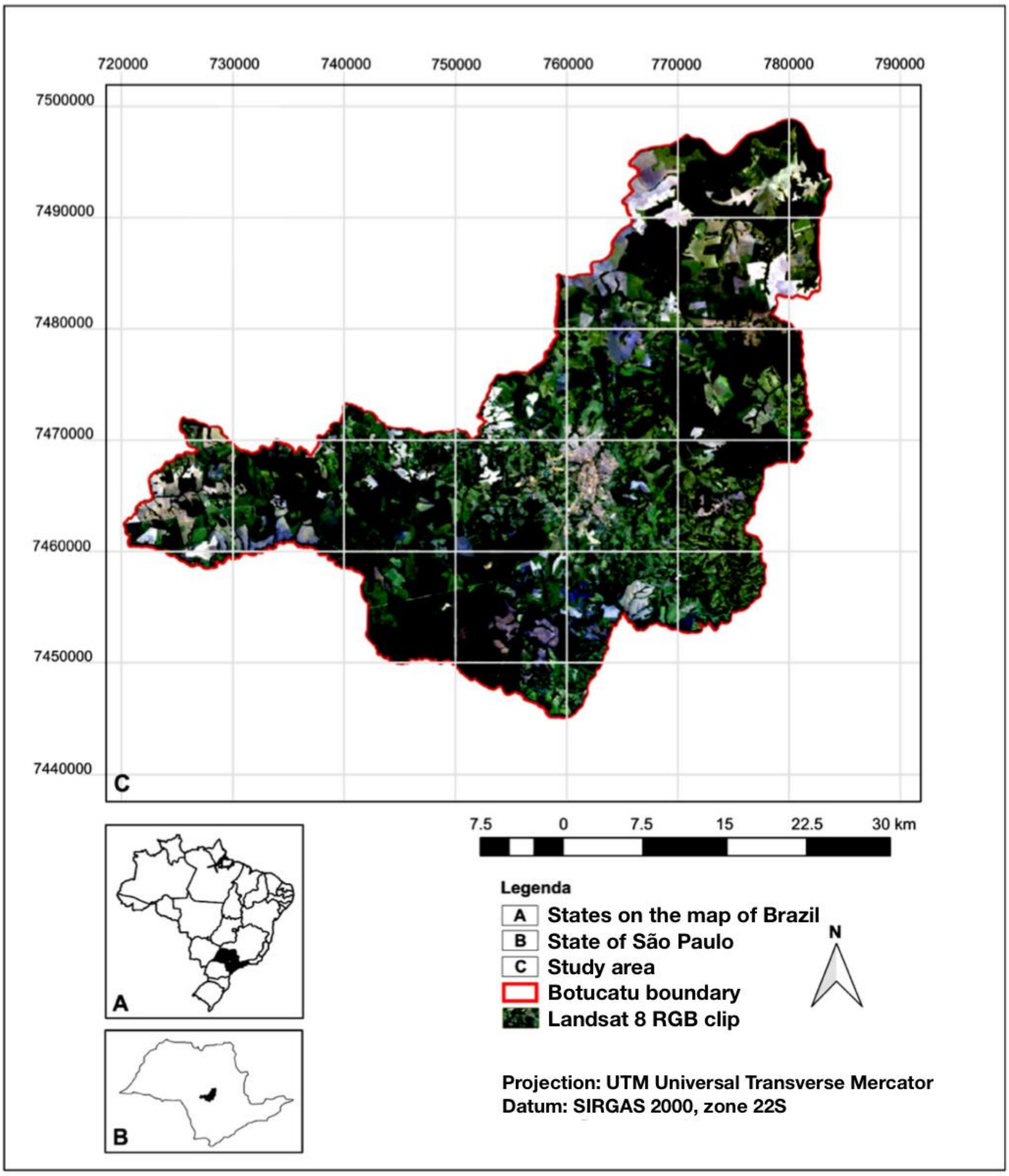
The municipality of Botucatu (Figure 1) is located at 22°53'03" south latitude 48°26'39" west longitude, in the midwestern state of São Paulo.

Among the neighboring municipalities are Anhembi, Bofete, Pardinho, Itatinga, Pratânia, Dois Córregos, Santa Maria da Serra, Avaré, and São Manuel.

With an altitude of approximately 865 m located in the areas of reverse "cuesta" and peripheral depression "cuesta", the municipality of Botucatu occupies the central-western portion of the state of São Paulo, where, according to the Pedological Map of the State of São Paulo (Oliveira *et al*., 1999), the predominant soil type is unit dystrophic RED Latosol (Oxisol) (LVd) and RED-YELLOW Latosol (LVA), classified as flat relief and undulated, respectively.

The climate in the region, according to the Köppen-Geiger system is type CFA, i.e., a rainy temperate climate, with a prevailing wind to the southeast (SE). The annual average temperature is around 20°C, with an average annual rainfall of 1447 mm.

Figure 1. Botucatu/SP



Source: Author (2024).

2.2 Data Acquisition

Satellite images were captured by the Land Operational Imager (OLI), installed aboard the Landsat-8 satellite and made available by the United States Geological Survey (USGS) / Earth Resources Observation & Science Center (EROS).

The images were captured on August 29, 2015. Based on the selection criteria, the amount and distribution of clouds were noted, so that the presence of this phenomenon did not damage the landscape sharpness.

The limit municipal vector file, a cartographic base provided by the Brazilian Institute of Geography and Statistics (IBGE), was also used for preparation of the location map.

2.3 Equipment and computing

In developing this work, we used a laptop Apple MacBook Pro computer with Intel Core i5 2.5 GHz processor, 4 Gigabytes memory, 500-Gigabyte hard disk, and OS X El Capitan operating system. The computer program used was QGIS 2.14.3-Essen, which is compatible with more recent versions, including the latest version for MacOS (QGIS 3.38.0-Grenoble).

2.4 Methods

The methodology described below aimed to establish a single model based on research developed by Barros *et al.* (2015), which correlated satellite imaging data and field data over time, in the form of forest inventories from the years 2007, 2008, 2009, and 2010, to estimate structural parameters of two local Eucalyptus plantations (Botucatu and Itatinga, SP).

According to Yang and Lo (2000), normalizing all images to a single epoch by removing the relative atmospheric effect between epochs for change detection from image differencing is a possible way to address the problem of non-random residuals over time. This technique involves acquiring radiometric values from areas that have not undergone changes over time and are present in both the reference image and the images to be normalized. Using these values and linear regression, normalization models are determined and subsequently applied to all images, except the reference epoch image.

Therefore, for this study, the calculation estimation technique was extrapolated to a new sensor aboard another satellite, with an image acquired on a different date and covering a larger area, to estimate the biomass potential of the entire municipality of Botucatu, thereby serving as a method to validate and reduce uncertainties in vegetation measurement using satellite indices.

After downloading the satellite image of the study area, spectral bands were selected. For LANDSAT-8, bands 4R, 3G, and 2B, corresponding to red, green, and blue bands, respectively, were used to form the RGB composition for natural color visualization of the landscape. The panchromatic band 8 (PAN) was added to improve spatial resolution from 30 to 15 meters. It is noteworthy that the projection used was Universal Transverse Mercator (UTM) and the Datum was SIRGAS 2000 (the official Datum of Brazil). The chosen zone was 22 S due to the geographical position of the study area (Southern Hemisphere).

The image was then cropped based on the vector file of the Botucatu county limit, which was also in the same reference system. The thematic classification was undertaken by the supervised method, with the allocation of polygons in regions where Eucalyptus exists in the field.

The purpose of atmospheric correction of the satellite image was to transform digital numbers into reflectance, eliminating atmospheric influences, seasonal variations of the solar zenith angle, and soil interferences in the spectral response of vegetation. This made the image suitable for applying the Normalized Difference Vegetation Index (NDVI). Bands 4R and 5NIR were used for the vegetation index (NDVI).

The equation (2) used was adjusted with the values that best fit the determination of biomass in the municipality of Botucatu, obtained by the Stepwise statistical regression procedure, derived from the logarithmic expression of Schumacher and Hall (1933) and adapted by Barros *et al.* (2015):

$$\text{Biomass} = 494.6741 - 498.1773 * \text{NDVI} - 860.8670 * \text{REF3} \quad (2)$$

Where NDVI is the normalized difference vegetation index, referring to the use of bands 4R (red) and 5NIR (near-infrared), and REF3 refers to the reflectance of band 3.

The biomass can be detected for the areas of Botucatu SP where there is presence of Eucalyptus. The values in the equation are related to the work of Barros *et al.* (2015) for areas that served as controls because they had field data for comparison. In addition, REF3 references the reflectance of band 3, which, according to the same author, also responds best to the proposed objective.

Corroborating Barros *et al.* (2015), it is feasible to characterize Eucalyptus crop structures by integrating satellite imagery with field data. Using statistical procedures, through the correlation of the degree of linear dependence between biometric and digital variables obtained by the Normalized Difference Vegetation Index (NDVI) and reflectance for biomass determination, by multiple linear regression. After classifying land use, aiming to relate field data with the combined use of image data, multiple regression analyses are performed using the Stepwise method, thus determining the independent variable(s) that best explain the variation of the dependent variable.

The area covered by Eucalyptus in the municipality of Botucatu was calculated by QGIS, represented in km². Finally, process maps were generated and the computer program QGIS was used to demonstrate the raised areas.

3 RESULTS AND DISCUSSION

To locate the areas with biomass generated by the map, Landsat 8 satellite images, based on 2015 data, were used and processed through equation (2), developed based on NDVI and Reflectance Band 3 (REF3), along with field forest inventory data. This map refers to the existing biomass that year, being an approximation of reality, as the values of the equation were determined based on field forest inventory data from two farms in the region in question and extrapolated to the entire municipality.

The area demarcated by Eucalyptus cultivation in Botucatu was 20480 hectares in this research for the year 2015. Table 1 shows the soil occupation values provided by the Brazilian Institute of Geography and Statistics (IBGE), with Eucalyptus covering 15019 hectares in 2014. The total area of municipality of Botucatu is 1482.642 km2.

Therefore, one can see the importance of culture in the study of the region, since the Eucalyptus forest occupies more than 10% of its area and is useful for companies that use the raw materials from these planted forests.

Table 1. Eucalyptus area in Botucatu.

Municipality area	**1482.642 km^2**
Eucalyptus area in 2015	204.80 km^2
Eucalyptus area in 2014	150.19 km^2

Source: Research data (2024)

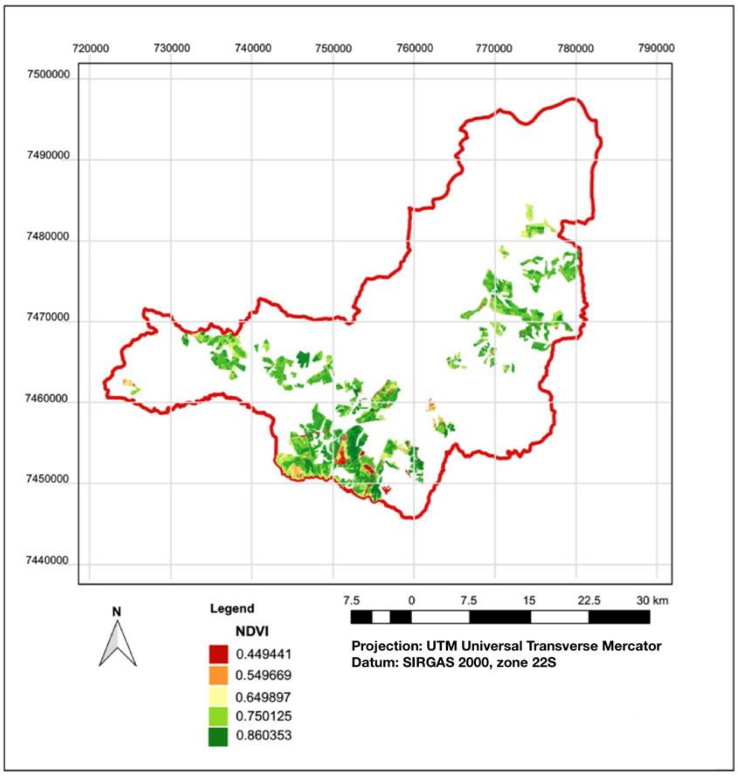
Table 2 shows the NDVI values and biomass found in this study. As for the NDVI, a minimum value of 0.44 and a maximum value of 0.85 (Figure 2) mean a good result for the combination of bands. As for the biomass values, the minimum and maximum, respectively, were 22.37 and 197.04 tons per hectare (Figure 3), similar to the real values for the region.

Table 2. Values of NDVI and Biomass.

	NDVI	**BIOMASS (t ha^{-1})**
Minimum	0.449441	22.378500
	0.549669	66.045375
	0.649897	109.712250
	0.750125	153.379125
Maximum	0.850353	197.046000

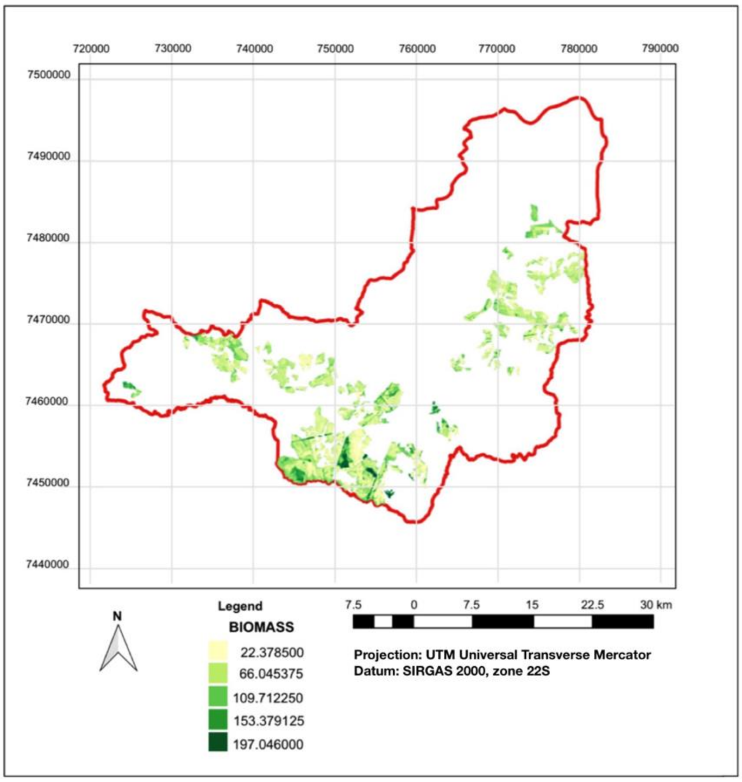
Source: Research data (2024)

Figure 2. NDVI of Eucalyptus in the studied areas of Botucatu



Source: Author (2024).

Figure 3. Biomass of Eucalyptus in the studied areas of Botucatu



Source: Author (2024).

Spectral information from Landsat satellite data can be used to estimate various forest biophysical variables, including biomass, basal area, volume, average diameter, average height, and structural attributes, as demonstrated by several studies (Adhikari *et al*., 2020; Astola *et al*., 2019; Bulut; Günlü; Çakir, 2023; Chen *et al*., 2018).

The study by Fassnacht *et al.* (2014) concluded that the type of sensor data is the most important factor for the accuracy of biomass estimates, and that the prediction method significantly affects accuracy, generally being more important than sample size. The same authors also suggested that choosing the appropriate statistical method may be more effective than obtaining additional field data for achieving accurate biomass estimates.

Macedo *et al.* (2021) indicates that data from satellite images significantly contribute to the estimation of the total biomass of Eucalyptus plantations, particularly through vegetation indices. According to the authors, the best performance was achieved using SAVI (Soil-Adjusted Vegetation Index) as an independent variable, with an R^2 of 64.6%, although the difference compared to NDVI (Normalized Difference Vegetation Index) was not substantial.

Soares and Hoffer (1996) used TM/LANDSAT images to monitor changes in Eucalyptus plantations through band differences in images taken at different times. Skidmore (1989) developed an expert system to classify forest types, incorporating LANDSAT Thematic Mapper data, digital elevation models, slope and aspect information, and field knowledge from area managers.

Values close to those calculated in this study were found by Santana *et al*. (2008), who determined the biomass observed and estimated by the use of the global equation for Eucalyptus in the Itapeva-SP region. These values were 172.4 and 130.4 tons per hectare, respectively.

It is noteworthy that in Botucatu, conventional tillage is the most common way of land preparation, contrary to the dense planting of trees. Also, Eucalyptus cultivation is very present in Botucatu, excluding some regions of Cuesta and areas with citrus and cane sugar. In this context, the GIS is characterized as an instrument to reduce subjectivity in the decision to implement culture in new areas and evaluate the fitness of the land. In this context, the GIS is an environmental planning tool.

4 CONCLUSIONS

The statistical analysis of data allowed an analytical estimation of the uncertainty associated with the final result, where, the evaluation the potential for using satellite images in estimating of this dendrometric variable with the appearance of vegetation cover in an orbital image is the consequence of a complex process that involves many parameters and environmental factors, according to Barros *et al.* (2015).

GIS QGIS proved to be a reliable and practical tool for all stages of the process. In order to validate the results, it is feasible to reapply this method. Remembering that with the restrictions to the planting of Eucalyptus forests, there is a possibility that the results may change for other species, locations, structures, or other methods used for determining the variables.

Corroborating Barros *et al.* (2015) and observing the restrictions, we conclude that it is possible to use remote sensing images to expand the capacity to generate information on forest registries.

With the increased availability of sensors offering enhanced spatial and spectral resolutions, this study underscores the utility of remote sensing techniques for facilitating more precise qualitative and quantitative forest assessments. Future objectives include acquiring recent high-resolution imagery and calibrating remote sensing data with ground observations to achieve classifications that increasingly reflect reality.

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