Discrimination of forest species using medium spatial resolution images

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ABSTRACT: This research aimed to evaluate the potential of orbital images from the Landsat-8/OLI and Sentinel-2/MSI sensors in the distinction of species from a forest stand located in Campo Belo do Sul, State of Santa Catarina, Brazil. A total of 53 plots were allocated in the field, in which the central coordinate of the plot was collected using GPS receivers. In SIG environment, two images were used, one from each sensor, closely dated to the field campaign and with no clouds and other atmospheric factors. Then, the images were processed, and 17 vegetation indices were calculated for each one. The indices were compared statistically by the t-Student test for independent samples. The indices that provided the best species differentiation were: CRI, GNDVI, NDI11, NDI12, NDVI, RDVI, SAVI, and SR. In addition, the species with greater prominence in the Landsat-8/OLI images was Eucalyptus spp. whereas Cunninghamia lanceolata (Lamb.) Hooker was easily distinguished in Sentinel-2 images. It was possible to differentiate the species from remote data derived from the Sentinel-2/MSI and Landsat-8/OLI sensors. However, further studies using other Remote Sensing data sources and other species are suggested.

RESUMO: Essa pesquisa objetivou avaliar as potencialidades de imagens orbitais dos sensores Landsat-8/OLI e Sentinel-2/MSI na distinção de espécies de alguns povoamentos florestais localizados em Campo Belo do Sul, Estado de Santa Catarina. Para tanto, foram alocadas 53 parcelas a campo, nas quais coletou-se a coordenada central da parcela com auxílio de receptores GPS e qual era o indivíduo predominante da parcela, com o maior número de indivíduos. Em ambiente SIG, foram utilizadas duas imagens, uma de cada sensor avaliado, de data próxima a avaliação realizada a campo e com ausência de nuvens e demais fatores atmosféricos. Em seguida, as imagens foram processadas e foram calculados 17 índices de vegetação para cada uma. Os índices foram comparados estatisticamente pelo teste t-Student para amostras independentes. Os índices que proporcionaram a melhor diferenciação das espécies foram: CRI, GNDVI, NDI11, NDI12, NDVI, RDVI, SAVI e SR. Além disso, foi possível perceber que a espécie mais destacada nas imagens Landsat-8/OLI foi o Eucalyptus spp. ao passo que a Cunninghamia lanceolata (Lamb.) Hooker se diferenciou com maior facilidade nas imagens Sentinel-2. Nesse contexto, foi possível diferenciar as espécies em questão a partir de dados remotamente situados derivados dos sensores Sentinel-2/MSI e Landsat-8/OLI. Contudo, sugere-se que novos estudos utilizando outras fontes de dados de Sensoriamento Remoto e outras espécies sejam avaliadas.
Introduction

The forest sector is an important economic activity in Brazil. It acts as a major supplier of raw material to the industrial sectors, and the high levels of productivity of the planted forests in Brazil make the country highly competitive in the foreign market. In addition, this sector also contributes to environmental issues, such as the protection and recovery of water and soil resources, which minimizes the effects caused by greenhouse gas (GHG) emissions and reduces the pressure on native forests (Coutinho et al., 2017).

The diversity of tree species can influence the provision of forest ecosystem services such as timber production, energy and food, carbon sequestration, and regulation of biogeochemical and climate cycles (Assessment, 2005; Gamfeldt et al., 2013). Iverson and McKenzie (2013) state that the complementarity between species can support such services simultaneously. In this sense, information about the diversity of tree species is essential to understand the characteristics and resilience of the forest, as well as the vulnerability to pathogens (Guyot et al., 2015).

Precise species discrimination is important for forest inventory, pest control, and species carbon sequestration assessment, according to Aardt & Wynne (2007). Therefore, Remote Sensing (SR) techniques have been highlighted in these studies, as orbital images can provide detailed information on the status of the forest, such as species distribution and differentiation, population density, forest extension, and operational monitoring (Purnamasayangkutasih et al., 2016).

The identification of tree species can be considered a classic topic of study within the scope of the optical SR (Holmgren and Thuresson, 1998; Boyd and Danson, 2005). The spectral reflectance values are used to characterize the stands and differentiate the ages of the species, as researched by Ponzoni et al. (2015) and Goergen et al. (2016).

Several multispectral sensors with different spatial, temporal, and spectral characteristics are available. However, images with lower spatial resolution and, consequently, a greater richness of details are associated with a high acquisition cost and smaller area imaged by the sensor, which restricts its use in analysis of large areas and requires greater periodicity (Alba et al., 2017).

In this sense, the use of the Landsat-8/OLI and Sentinel-2/MSI orbital sensors should be tested. Both enable the generation of free data, with medium spatial resolution and accessible temporal resolution. In the case of Sentinel-2/MSI, the spectral capacity is a strong point to be highlighted, due to the inclusion of four bands in the range of the red-edge (red edge), a region of the electromagnetic spectrum very sensitive to the characteristics of vegetation. Thus, these sensors must be studied to fill the gap in the use of high spatial resolution sensors to discriminate forest species.

Given this context, this research aimed to investigate the potential of using orbital images from the Landsat-8/OLI and Sentinel-2/MSI sensors to distinguish species from a forest stand located in Campo Belo do Sul, State of Santa Catarina.

Material and Methods

The research was carried out in a forest area formed by plantations of Cupressus spp., Pinus elliottii Engelm, Eucalyptus spp., Araucaria angustigolia Kuntze and Cunninghamia lanceolata (Lamb.) Hooker located in the municipality of Campo Belo do Sul, State of Santa Catarina (Figure 1). The area has an average altitude of 1017 m and the climate, according to the Köppen classification, fits as mesothermal, subtropical humid Cfb (subtropical), with an average temperature of 15.7°C and average annual rainfall is 1647 mm (Alvares et al., 2013).

![Figure 1. Location of the study area: A) Brazil, B) Santa Catarina and C) study area.](image-url)

In the stands of the five described species, 53 plots were allocated using GPS receivers (Global Positioning System) of the Garmin Etrex® model to obtain the central coordinate of each plot. Images from the Landsat-8 satellites were used, with the OLI sensor (Operational Land Imager) and Sentinel-2 with the MSI sensor (Multispectral Instrument). Landsat-8/OLI has a spatial resolution of 30 meters, a radiometric resolution of 16 bits and a spectral resolution of 8 bands (USGS, 2013). Sentinel-2/MSI has images with 10, 20 and 60 meters of spatial resolution, 12 bits of radiometric resolution and 13 spectral bands, with emphasis on the inclusion of red-edge bands (ESA, 2010).

The acquisition of the Landsat-8/OLI image was carried out on the United States Geological Survey website, dated 08/28/2018. The Sentinel-2 / MSI image was obtained from the Copernicus Open Access Hub, dated 9/22/2018. Both images were acquired in orbit 221 and point 79. The criterion for choosing the images was the absence and / or little
cloud cover and dates close to the installation of the field plots.

The first digital processing in the images involved the conversion of digital numbers to radiance at the top of the atmosphere and later to reflectance at the base of the Earth's surface using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) algorithm in the computational application ENVI (Environment for Visualizing Images) (EXELIS, 2018).

Then, the vegetation indices (IV) described in Table 1 were derived in the processed images:

<table>
<thead>
<tr>
<th>VI</th>
<th>Abbreviation</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carotenoid Reflectance Index</td>
<td>CRI</td>
<td>$\frac{\rho_{\text{GREEN}} + \rho_{\text{NIR}}}{\rho_{\text{GREEN}}} - 1$</td>
<td>Gitelson et al. (2002)</td>
</tr>
<tr>
<td>Green Chlorophyll Index</td>
<td>CL&lt;sub&gt;green&lt;/sub&gt;</td>
<td>$\frac{\rho_{\text{NIR}}}{\rho_{\text{GREEN}}} - 1$</td>
<td>Gitelson et al. (2003a,b)</td>
</tr>
<tr>
<td>Enhanced Vegetation Index 2</td>
<td>EVI&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$2.5\frac{\left(\rho_{\text{NIR}}+2.4\rho_{\text{RED}}+1\right)}{\rho_{\text{NIR}}-\rho_{\text{RED}}}$</td>
<td>Jiang et al. (2008)</td>
</tr>
<tr>
<td>Green Normalized Difference Vegetation Index</td>
<td>GNDVI</td>
<td>$\rho_{\text{NIR}} - \rho_{\text{RED}}$</td>
<td>Gitelson et al. (1996)</td>
</tr>
<tr>
<td>Infrared Simple Ratio</td>
<td>ISR</td>
<td>$\frac{\rho_{\text{NIR}}}{\rho_{\text{SWIR}1}}$</td>
<td>Fernandes et al. (2003)</td>
</tr>
<tr>
<td>Modified Soil Adjusted Vegetation Index</td>
<td>MSAVI</td>
<td>$\frac{\rho_{\text{NIR}} - \rho_{\text{RED}}}{\rho_{\text{NIR}} + \rho_{\text{RED}} + L}$</td>
<td>Qi et al. (1994)</td>
</tr>
<tr>
<td>Modified Soil Adjusted Vegetation Index 2</td>
<td>MSAVI&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$2\rho_{\text{NIR}} + 1 - \sqrt{2(\rho_{\text{NIR}} + 1)^2 - 8(\rho_{\text{NIR}} - \rho_{\text{RED}})}$</td>
<td>Qi et al. (1994)</td>
</tr>
<tr>
<td>Modified Simple Ratio Index</td>
<td>MSR</td>
<td>$\sqrt{\frac{\rho_{\text{NIR}}}{\rho_{\text{RED}}}} - 1$</td>
<td>Chen (1996)</td>
</tr>
<tr>
<td>Modified Triangular Vegetation Index Normalized Difference Infrared Index</td>
<td>NDI&lt;sub&gt;11&lt;/sub&gt;</td>
<td>$\rho_{\text{NIR}} - \rho_{\text{SWIR}1}$</td>
<td>Haboudane et al. (2004)</td>
</tr>
<tr>
<td>Normalized Burn Ratio</td>
<td>NDI&lt;sub&gt;12&lt;/sub&gt;</td>
<td>$\rho_{\text{NIR}} + \rho_{\text{SWIR}2}$</td>
<td>Key et al. (2002)</td>
</tr>
<tr>
<td>Normalized Difference Vegetation Index</td>
<td>NDVI</td>
<td>$\rho_{\text{NIR}} - \rho_{\text{RED}}$</td>
<td>Rouse et al. (1974)</td>
</tr>
<tr>
<td>Optimized Soil Adjusted Vegetation Index</td>
<td>OSAVI</td>
<td>$\rho_{\text{NIR}} - \rho_{\text{RED}}$</td>
<td>Rondeaux et al. (1996)</td>
</tr>
<tr>
<td>Plant Senescence Reflectance Index</td>
<td>PSRI</td>
<td>$\frac{\rho_{\text{RED}} - \rho_{\text{BLUE}}}{\rho_{\text{NIR}}}$</td>
<td>Merzyak et al. (1999)</td>
</tr>
<tr>
<td>Re-normalized Difference Vegetation Index Soil Adjusted</td>
<td>RDVI</td>
<td>$\sqrt{\rho_{\text{NIR}} + \rho_{\text{RED}}}$</td>
<td>Wang et al. (1998)</td>
</tr>
<tr>
<td>Vegetation Index</td>
<td>SAVI</td>
<td>$\frac{\left(1 + L\right)(\rho_{\text{NIR}} - \rho_{\text{RED}})}{\rho_{\text{NIR}} + \rho_{\text{RED}} + L}$</td>
<td>Huete (1988)</td>
</tr>
<tr>
<td>Simple Ratio</td>
<td>SR</td>
<td>$\frac{\rho_{\text{NIR}}}{\rho_{\text{RED}}}$</td>
<td>Jordan (1969)</td>
</tr>
</tbody>
</table>

Where: $\rho_{\text{BLUE}}$: Blue band reflectance; $\rho_{\text{GREEN}}$: Green band reflectance; $\rho_{\text{RED}}$: Red band reflectance; $\rho_{\text{NIR}}$: Reflectance of the near infrared band; $\rho_{\text{SWIR}}$: Reflectance of the short wave infrared band; L: constant that minimizes the effects of the soil, used in this study the value of 0.50; $\gamma$: slope of the ground line.
Statistical analyzes involved the normality test using the Shapiro-Wilk test at 5% probability. The design was completely randomized with four treatments (reflectance obtained from the visible and infrared bands of Landsat-8/OLI (T1), reflectance derived from the vegetation indices from Landsat-8/OLI (T2), reflectance obtained from the bands of the visible and infrared of Sentinel-2/MSI (T3), reflectance derived by vegetation indexes from Sentinel-2/MSI (T4) and 53 repetitions (plots installed in the field). Then, the data were submitted to the T-Student test for independent samples, in order to assess the differences between the mean values of the IVs and spectral bands derived from Landsat-8/OLI and Sentinel-2/MSI. All analyzes were performed using software R version 3.4.1. (R Core Team, 2020).

Table 2. Descriptive statistics and significance of the spectral values derived from the Landsat-8/OLI and Sentinel-2/MSI sensors.

<table>
<thead>
<tr>
<th>VI</th>
<th>Landsat-8/OLI</th>
<th>Sentinel-2/MSI</th>
</tr>
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<tbody>
<tr>
<td>Clgreen</td>
<td>0.7307+/-.0830</td>
<td>2.2512+/-.5109**</td>
</tr>
<tr>
<td>CRI</td>
<td>0.8861+/-.3876</td>
<td>0.0217+/-.0022**</td>
</tr>
<tr>
<td>EVI2</td>
<td>0.8341+/-.2166</td>
<td>0.0379+/-.0081**</td>
</tr>
<tr>
<td>GNDVI</td>
<td>0.2946+/-.0934</td>
<td>0.5220+/-.0573**</td>
</tr>
<tr>
<td>ISR</td>
<td>9.7349+/-.25120</td>
<td>1.8616+/-.4629**</td>
</tr>
<tr>
<td>MSAVI</td>
<td>0.2309+/-.0507</td>
<td>0.0298+/-.0062**</td>
</tr>
<tr>
<td>MSAVI2</td>
<td>-0.8643+/-.1095</td>
<td>-1.4690+/-.0067**</td>
</tr>
<tr>
<td>MSR</td>
<td>1.0573+/-.3134</td>
<td>1.5731+/-.3320**</td>
</tr>
<tr>
<td>MTVI</td>
<td>-2.2012+/-.16895</td>
<td>0.0044+/-2.0058**</td>
</tr>
<tr>
<td>NDI11</td>
<td>0.8011+/-.0572</td>
<td>0.2798+/-0.1222**</td>
</tr>
<tr>
<td>NDI12</td>
<td>0.9633+/-.0168</td>
<td>0.5684+/-.1260**</td>
</tr>
<tr>
<td>NDVI</td>
<td>0.5060+/-.1084</td>
<td>0.6440+/-0.0772**</td>
</tr>
<tr>
<td>OSAVI</td>
<td>0.4500+/-.1035</td>
<td>0.0112+/-0.0024**</td>
</tr>
<tr>
<td>PSRI</td>
<td>-0.4910+/-.1111</td>
<td>-0.1696+/-0.0433**</td>
</tr>
<tr>
<td>RDVI</td>
<td>1.1678+/-.2945</td>
<td>0.1000+/-1.0159**</td>
</tr>
<tr>
<td>SAVI</td>
<td>0.0005+/-.0001</td>
<td>0.0298+/-0.0062**</td>
</tr>
<tr>
<td>SR</td>
<td>3.1632+/-.9015</td>
<td>4.9210+/-.3166**</td>
</tr>
</tbody>
</table>

Where: ns: non significant; **: significant by the T-Student test for independent samples at 5% probability; IV: vegetation index.

Such results can be explained by the leaf characteristics of the species evaluated. Souza et al. (2020) point out that leaf structures are influencing factors on the spectral properties of plants. As a result, it is worth understanding the dynamics that occur between vegetation and electromagnetic radiation, resulting in the processes of absorption, reflection and transmission.

The CRI, GNDVI, NDI11, NDI12, NDVI, RDVI, SAVI and SR indices, which values differed between the two sensors tested, point to the direct relationship between the bands of the visible region (green and red), near infrared and medium infrared spectral phenomena mentioned above. The studies carried out by Goodwin et al. (2005) and Canavesi & Ponzoni (2010) also identified that the leaf area index, the understory, the canopy structure of the species, conditions of the anatomy and leaf architecture may be related to reflectance and, consequently, to the values of IVs.

Another influencing factor refers to the inclusion of native species (A. angustigollia and C. lanceolata) and another conifer, of the genus Cupressus spp in this study, in addition to the main genera planted in southern Brazil (Pinus elliotti Engelm and Eucalyptus spp.). In the case of plantations, the reflectance is more accentuated in the near infrared because they present more homogeneous canopies due to the similar growth of the trees. The native areas, in turn, show great

Results and discussion

The Table 2 illustrates the results obtained from the statistical tests performed. They demonstrate that the spectral data derived from Landat-8/OLI and Sentinel-2/MSI differed significantly, at 5% probability:

- Pertille et al.
heterogeneity, with individuals in different stages of
growth. This fact can be seen in Figure 2:

Figure 2. Reflectance of the species evaluated with data: A) Landsat-8/OLI and B) Sentinel-2/MSI.

Figure 2 highlights that, for the data derived from Sentinel-2/MSI, there was species
differentiation caused by the greater variation in the
reflectance values, with emphasis on the plots with a
predominance of individuals of *C. lanceolata*. The
commercial species also stood out from the others,
since the genus *Cupressus* spp. differed slightly from
*A. angustigolia*. The spectral responses of Landsat-
8/OLI showed more uniform values and greater
distinction between the genera *Cupressus* spp. and
*Eucalyptus* spp., as shown in Figure 3:

In general, it is noticed that the results
(reflectance and coefficient of variation) of the
Sentinel-2/MSI sensor present higher values than the
Landsat-8/OLI data. This can be explained by the
differences in the technical properties of the tested
sensors, especially in the resolutions (temporal,
spatial, radiometric and spectral), modes of image
acquisition and other specific factors. In addition,
these values reflect only the date of image
acquisition (08/28/2018 and 09/22/2018) and
indicate that a temporal evolution could assist in
differentiating species from images of medium
spatial resolution.

Sheeren et al. (2016) studied the potential of
Sentinel-2/MSI images for the distinction of species
in temperate forests and concluded that the dominant
trees showed greater accuracy in the classification
and that the inclusion of phenological factors can
improve the identification of species.

In this theme, the vegetation indices
combined with the spectral attributes of the image
can contribute to the distinction of species using
images of medium spatial resolution, since the plots
with predominance of *P. elliottii* and *Eucalyptus* spp.
had a greater relationship with vegetation indexes
with significant results in statistical tests. However,
the discrimination of the other species was not
assertive and showed several built-in errors,
especially due to the structural and biophysical
conditions of these individuals.

The level of differentiation by image is also a
factor of interest, since the differentiation of species of
distinct genera and characteristics can be more
complex than the identification of species of the
same genus. Goergen et al. (2016) evaluated the
possibility of using Landsat-5/TM images to
differentiate species of *Eucalyptus dunnii* and
*Eucalyptus urograndis* with different ages and
concluded that such data were successful in
distinguishing the species tested and also of the same
species in equi-plantations. Similar analysis was
performed by Alba et al. (2017), in which the *E.
grandis* growth stages were differentiated using data
from Landsat-8/OLI.
Conclusions

It was possible to differentiate tree species from remotely located data derived from the Sentinel-2/MSI and Landsat-8/OLI sensors. The greatest assertiveness was in the differentiation of commercial species (Pinus spp. and Eucalyptus spp.) of the other species evaluated.

References


It is important to highlight the importance of conducting tests with sensor images with higher spatial resolution and other vegetation indexes to contribute to the identification of forest species using data remotely located.


Rouse JW, Haas RH, Schell JA (1974) Monitoring the Vernal Advancement of Retrogradation (Green Wave Effect) of Natural Vegetation, Remote Sensing Center, Texas A&M University College Station, USA.


