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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 indexes 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.

Discriminação de espécies florestais empregando imagens de média resolução espacial

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 com maior destaque 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 (Purnamasayangsukasih 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 Thuressopn, 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 elliotti* 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 15.7ºC and average annual rainfall is 1647 mm (Alvares et al., 2013).

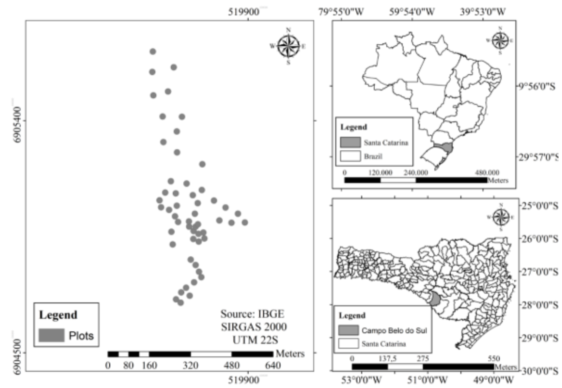


Figure 1. Location of the study area: A) Brazil, B) Santa Catarina and C) study area.

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 1. Vegetation indices calculated for the orbital images referring to the studied forest stands in Campo Belo do Sul/SC.

VI	Abbreviation	Formula	Reference
Carotenoid Reflectance Index	CRI	$\frac{1}{\rho GREEN} + \frac{1}{\rho NIR}$	Gitelson et al. (2002)
Green Chlorophyll Index	CL_{green}	$\left(\frac{\rho NIR}{\rho GREEN}\right) - 1$	Gitelson et al. (2003a,b)
Enhanced Vegetation Index 2	EVI_2	$2{,}5 * \frac{(\rho NIR - \rho RED)}{(\rho NIR + 2{,}4 * \rho RED + 1)}$	Jiang et al. (2008)
Green Normalized Difference Vegetation Index	GNDVI	$\frac{\rho NIR - \rho GREEN}{\rho NIR + \rho GREEN}$	Gitelson et al. (1996)
Infrared Simple Ratio	ISR	$\frac{\rho NIR}{\rho SWIR1}$	Fernandes et al. (2003)
Modified Soil Ajusted Vegetation Index	MSAVI	$\frac{\rho NIR - \rho RED}{\rho NIR + \rho RED + L}\ (1 + L)$	Qi et al. (1994)
Modified Soil Ajusted Vegetation Index 2	$MSAVI_2$	$\frac{2\rho NIR + 1 - \sqrt{2(\rho NIR + 1)^2 - 8(\rho NIR - \rho RED)}}{2}$	Qi et al. (1994)
Modified Simple Ratio Index	MSR	$\frac{(\rho NIR/\rho RED) - 1}{\sqrt{\rho NIR/\rho RED\ + 1}}$	Chen (1996)
Modified Triangular Vegetation Index	MTVI	$1{,}2 * (1{,}2 * \rho NIR - \rho GREEN) - 2{,}5 * \rho RED - \rho GREEN)$	Haboudane et al. (2004)
Normalized Difference Infrared Index	NDI11	$\frac{\rho NIR - \rho SWIR1}{\rho NIR + \rho SWIR1}$	Hardisky et al. (1983)
Normalized Burn Ratio	NDI12	$\frac{\rho NIR - \rho SWIR2}{\rho NIR + \rho SWIR2}$	Key et al. (2002)
Normalized Difference Vegetation Index	NDVI	$\frac{\rho NIR - \rho RED}{\rho NIR + \rho RED}$	Rouse et al. (1974)
Optimized Soil Adjusted Vegetation Index	OSAVI	$\frac{\rho NIR - \rho RED}{(\rho NIR + \rho RED + 1{,}6) * 1{,}16}$	Rondeaux et al. (1996)
Plant Senescence Reflectance Index	PSRI	$\frac{\rho RED - \rho BLUE}{\rho NIR}$	Merzyak et al. (1999)
Re-mormalized Difference Vegetation Index	RDVI	$\frac{\rho NIR - \rho RED}{\sqrt{\rho NIR + \rho RED}}$	Wang et al. (1998)
Soil Ajusted Vegetation Index	SAVI	$\frac{(1 + L)(\rho NIR - \rho RED)}{\rho NIR + \rho RED + L}$	Huete (1988)
Simple Ratio	SR	$\frac{\rho NIR}{\rho RED}$	Jordan (1969)

Where: ρBLUE: Blue band reflectance; ρGREEN: Green band reflectance; ρRED: Red band reflectance; ρNIR: Reflectance of the near infrared band; ρSWIR: 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; γ = 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).

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:

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

VI	**Landsat-8/OLI**	**Sentinel-2/MSI**
Clgreen	0.7307+/-0.0830	2.2512+/-0.5109^{ns}
CRI	0.8861+/-0.3876	0.0217+/-0.0022**
EVI2	0.8341+/-0.2166	0.0379+/-0.0081^{ns}
GNDVI	0.2946+/-0.0934	0.5220+/-0.0573**
ISR	9.7349+/-2.5120	1.8616+/-9.4629^{ns}
MSAVI	0.2309+/-0.0507	0.0298+/-0.0062^{ns}
MSAVI2	-0.8643+/-0.1095	-1.4690+/-0.0067^{ns}
MSR	1.0573+/-0.3134	1.5731+/-1.3320^{ns}
MTVI	-2.2012+/-1.6895	0.0044+/--2.0058^{ns}
NDI11	0.8011+/-0.0572	0.2798+/-0.1222**
NDI12	0.9633+/-0.0168	0.5684+/-0.1260**
NDVI	0.5060+/-0.1084	0.6440+/-0.0772**
OSAVI	0.4500+/-0.1035	0.0112+/-0.0024^{ns}
PSRI	-0.4910+/-0.1111	-0.1696+/-0.0433**
RDVI	1.1678+/-0.2945	0.1000+/-1.0159**
SAVI	0.0005+/-0.0001	0.0298+/-0.0062**
SR	3.1632+/-0.9015	4.9210+/-3.1666**

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 tha 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 understorey, 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. angustigolia* 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 heterogeneity, with individuals in different stages of growth. This fact can be seen in Figure 2:

A) B)

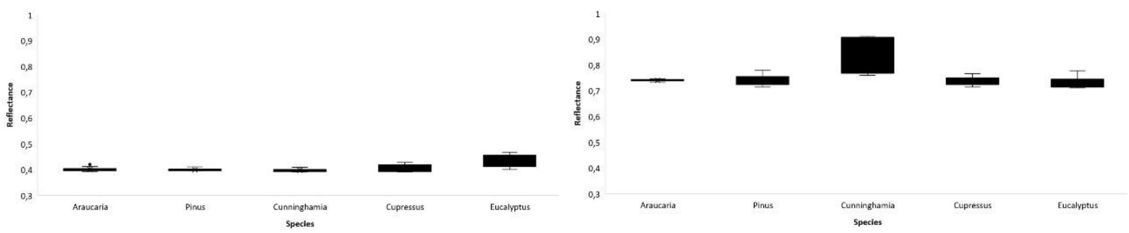
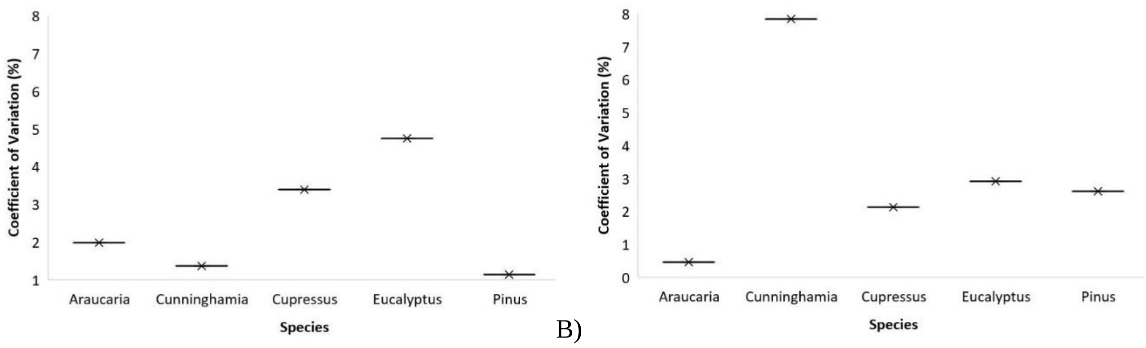


Figure 2. Reflectance of the species evaluated with data: A) Landsat-8/OLI and B) Sentinel-2/MSI.

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:



A) B)

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. elliotti* 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 Landat-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.

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.

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