The use of RapidEye images and vegetation index to discriminate mangrove and tidal flat areas: applications to climate change monitoring

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Abstract. Mangroves and tidal flats are intrinsic coastal ecosystems high venerable to impacts due to climate changes. This highlights the need for remote sensing tools and techniques to map and monitor these ecosystems. This study investigated the potential of different vegetation index applied in RadidEye images to discriminate mangrove and tidal flats areas, and the correlation among vegetation index and structural vegetation parameters of these environments. In the present study we found that the application of qualitative and quantitative remote sensing techniques using RapidEye images are suitable tools and techniques for mapping and discriminating mangrove and tidal flats physiognomies. With the advantage of the red edge band presented by the RapidEye images, the calculation of the NDVI Red Edge showed the best result for discriminating these vegetations. We conclude that RapidEye images are potential high resolution remote sensing tools for mapping mangrove and tidal areas, thus it can be applied for monitoring spatial temporal changes in this vegetation caused by climate changes, as sea level rise, using standard range values of NDVI Red Edge index for these physiognomies, as calculated and indicated in this study.

Keywords: mangrove, tidal flat, RapidEye.

1. Introduction

Mangroves are coastal forests that inhabit saline tidal areas along sheltered bays, estuaries, and inlets in the tropics and subtropics throughout the world (FAO, 2007). The mangrove vegetation is characterized by facultative halophytes of woody angiosperm plants, which colonizes mostly muddy sediments under tidal influence (Schaeffer-Novelli et al., 2016). Tidal flats are transition zones found between mangroves forests and the adjoining dry upland coastal areas, as well as within mangrove coverage (Albuquerque et al., 2014). Thus, tidal flats are always associated with mangrove ecosystems, and their limits are set by the mean level of the spring tides (Albuquerque et al., 2014). These areas are subjected to much less frequent tidal flooding periods, which coupled with high evaporation and low precipitation rates causes the formation of hypersaline soils (Albuquerque et al., 2014). Therefore, tidal flats are primarily vegetated by extreme halophytes which herbaceous habit, and/or small spread shrubs of mangrove plants or devoid of vegetation (Albuquerque et al., 2014).

Although mangroves and tidal flats occur in the same coastal environment and integer a unique ecosystem, they are characterized by distinct vegetation composition and structure and soil features. Exposure and sensitivity of mangrove species and ecosystems make them extremely vulnerable to environmental impacts and potential indicators of sea level and climate-driven environmental change (Schaeffer-Novelli et al., 2016). In this context, mapping and monitoring mangroves and tidal flats are extremely important to assess climate changes effects on coastal areas.

Analysis of vegetation and detection of changes in vegetation patterns are keys to natural resource assessment and monitoring (Eastman, 2012), and can aid in mitigating environmental impacts, as those cause by climate changes. For this purpose, remote sensing techniques as vegetation index have been used in a variety of contexts to assess green biomass and have also been used as a proxy to overall environmental change. As a consequence, special interest has been focused on the assessment of green biomass in environments where soil background becomes a significant component of the signal detected (Eastman, 2012). Therefore this remote sensing technique has a potential applicability to distinguish between mangrove and tidal flat vegetation in coastal landscapes. This is very relevant, when we consider that with climate changes, as the sea level rise, it is expect to occur changes among these habitat extent, as the replacement of tidal flats by mangroves, and the inland intrusion of tidal flats.

This study aims to investigate the potential of different vegetation index applied in RadidEye images to discriminate mangrove and tidal flats areas, and the correlation among vegetation index and structural vegetation parameters of these environments. The potential of the methodology and results achieved were discussed in the view of monitoring coastal environments in the context of climatic changes.

2. Methodology

2.1 Study Area

The study area is located in the State of São Paulo, and is part of the south most part of the Baixada Santista, integrating the municipality of Peruíbe It corresponds to the coastal area associated to River Ulna (Figure 1). The study area is part of a conservation unit of integral protection called Juréia-Itatins Ecological Station (ESEC). In this area mangrove and the coastal landscape show high conservation state, thus they are under legal protection.

Figure 1. Study Area: coastal area associated to River Ulna, in Peruíbe, São Paulo.

2.2. Remote Sensing

The image RapidEye (Table 1) was acquired on the GeoCatalogo website, as part of an agreement between the CRUSTA laboratory and the MMA (Brazilian Environmental Ministry). The image was processed using the IDRISI software. Firstly, it was geometrically correct, using the IDRISI function *Resample*, based on GPS points collected on field. After that, the image was subject to an atmospheric correction using the Chavez's Cos(t) model by the module *Atmosc* (Eastman, 2012). The Cos(t) model was developed by Chavez (1996) as a technique for approximation that works well in these instances. It incorporates all of the elements of the Dark Object Subtraction model plus a procedure for estimating the effects of absorption by atmospheric gases and Rayleigh scattering. It requires no additional parameters over the Dark Object Subtraction model and estimates these additional elements based on the cosine of the solar zenith angle (Eastman, 2012). This operation performs together the atmospheric and radiometric corrections. For the radiometric calibration we used the option offset/gain, with a gain of 0.00099999999776482582, according the image metadata. All the data necessary for the Cos(t) model correction, was obtained in the RapidEye metadata.

Then we performed different color compositions with the different image's bands (Table 1), using the IDRISI function *Composite* and applying a contrast stretch type linear with saturation points. We selected the best color composite for visual interpretation, which was carried out based on color, texture, shape, size, structure and position attributes (e.g. Santos et al., 2014). In the visual interpretation we discriminated the classes: 1) tidal flat with sandy soil influence, 2) tidal flat without sandy soil influence, 3) mangrove and 4) Atlantic forest.

With the aim to evaluate the best quantitative method to discriminate between mangrove and intertidal flat vegetations, we calculated different vegetation index (Table 2). Then the different vegetation index images were generated using IDRISI module *image processing*, *vegindex*. Only the EVI index was calculated using the IDRISI *Image Calculator*, because its function was not implemented in the software. Finally, each vegetation index image was reclassified using an interval of index values typical of each vegetation classes: 1) tidal flat with sandy soil influence, 2) tidal flat without sandy soil influence, 3) mangrove and 4) Atlantic forest. Since our focus was in mangrove and tidal flat vegetation, these classes were supported by field data about the vegetation structure.

Table 1. Characteristics of the satellite images used in the present study.

Satellite/ Sensor	**Spatial Resolution (m)**	**Band**	**Wavelength (nm)**	**Date**	**Radiometric Resolution**
REIS (RapidEye Earth Imaging System)	5	Blue (1)	440-510	2015-06-09	12 bites
		Green (2)	520-590		
		Red (3)	630-685		
		Red Edge (4)	690-730		
		Infra-red (5)	760-850		

Table 2. Different vegetation index applied in the present study.

Vegetation Index	Band used in the calculation	Function
$NDVI_{Red}$	Red and Infra-red	$NDVI_{Red} = \rho nir - \rho red / \rho nir + \rho red$
$NDVI_{RedEdge}$	Red and Red Edge	$NDVI_{RedEdge} = \rho nir - \rho_{RedEdge} / \rho nir + \rho_{RedEdge}$
SAVI	Red and Infra-red	$SAVI = (1 + L)(\rho nir - \rho red)/(\rho nir + \rho red + L)$
EVI	Red, Infra-red and blue	$EVI = G(\rho_{nir} - \rho_{red})/(L + \rho_{nir} + C_1\rho_{red} - C_2\rho_{blue})$

2.3. Field work: vegetation structure

In order to support the data generating by the remote sensing techniques, we carried out a field work to characterize the vegetation structure in mangrove and tidal flat without sand, where was possible to sample the tree vegetation. For this, we applied the methodology describe on Schaeffer-Novelli *et al.* (2015). Therefore, plots of 5 m x 5 m were delimitated in mangrove and tidal flat without sand, where the vegetation composition, tree height and diameter were recorded. Then, these data were tabulated in Excel in order to calculate the stand density, diameter and height. A t-student test was carried out to verify significant differences of these parameters among mangrove and tidal flat.

3. Results and Dicussion

The color composite generated by the bands red (3), red edge (4) and infra-red (5) of the RapidEye image (Figure 2) showed a spatial resolution of 5 m, and a clear discrimination among the vegetation targets, therefore a good product for visual discrimination. In this composite mangroves showed light orange color, medium texture and were located along the river channels which present black in black color and curvilinear shape (Figure 2). By contrast, it was possible to discriminate two types of tidal flat physiognomies, one without influence of sand soil, where the shrub vegetation predominates, which showed dark grey color and fine texture, and another which showed a high influence of the sand soil, exhibiting fine texture and blue/light grey color (Figure 2). Both tidal flat physiognomies are located among the mangrove vegetation, mainly in the transition with the uplands. The Atlantic forest vegetation was also clearly discriminated due to its coarse texture and dark orange color (Figure 2). Here we found a high potential of the qualitative analysis of high-resolution color composite of RapidEye images for mangrove and tidal flat discrimination, despite this images is still scarce in mangrove studies (e.g. Roslani et al., 2014). Images of optical systems of high spatial resolution are recent products of remote sensing and sources of large-scale and detailed information about mangrove vegetation (Santos & Bitencourt, 2016). These tools allow the discrimination and mapping of mangrove plant species or assembly of plant species, detailed characterization of the canopy structure, estimation of green biomass and leaf area index at high spatial detail (Santos & Bitencourt, 2016).

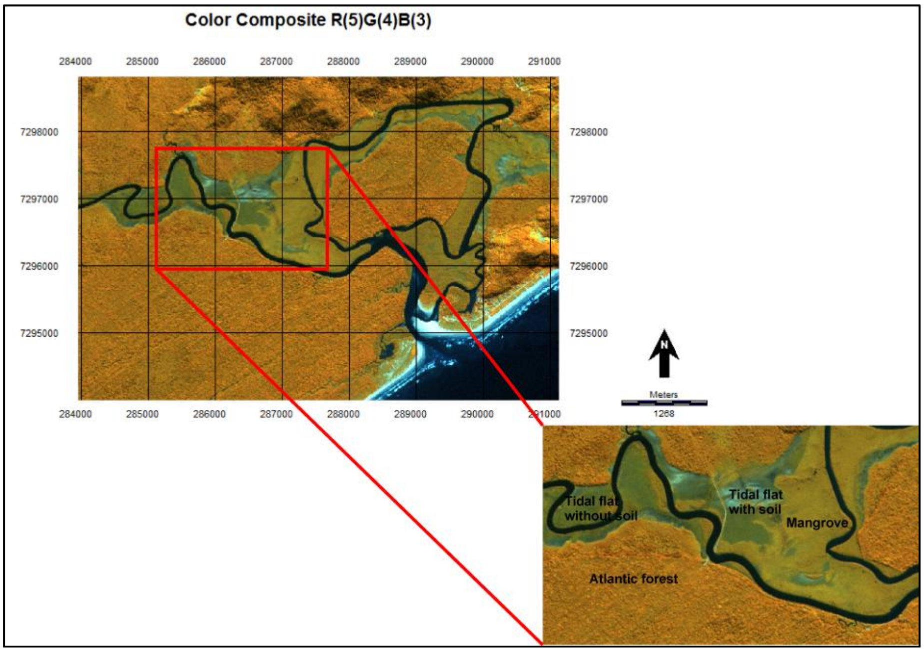

Figure 2. Color composite of Rapid Eye images.

By the application of the quantitative analysis of vegetation index, we also discriminated the mangrove and tidal flat physiognomies (Figures 3 and 4). In all vegetation index, the index values were crescent from tidal flat with soil to Atlantic forest, indicating the degree development and green biomass of the vegetation (Table 2). For example, the lowest vegetation index values were recorded for tidal flat with soil (Table 3), indicating the features of this physiognomy which is characterized by areas with exposed sand soil and grass vegetation. Higher crescent values of vegetation index were recorded for the other vegetation types. For the tidal flat without soil, higher index values (Table 3) indicated its vegetation structure, where is found a higher stand height and density, most due to the high abundance of tress with low diameter (Figures 5a, 5b, 5c). For mangrove, higher vegetation index values were registered (Table 3), indicating its typical vegetation coverage, with higher stand height, and more development stands evidence by lower density due to the occurrence of trees with higher diameters (Figures 5a, 5b, 5c). Moreover, we found differences in the vegetation composition between mangrove and tidal flat without soil. While mangrove is dominated by *Rhizophora mangle*, tidal flat without soil is dominated by *Laguncularia racemosa* (Figure 5c, 5d). This difference in vegetation composition can also be detected by the different pattern color exhibited by each vegetation type in the color composite (Figure 2). Finally, the highest index values were recorded for Atlantic forest, as it is a more dense and developed vegetation than mangroves.

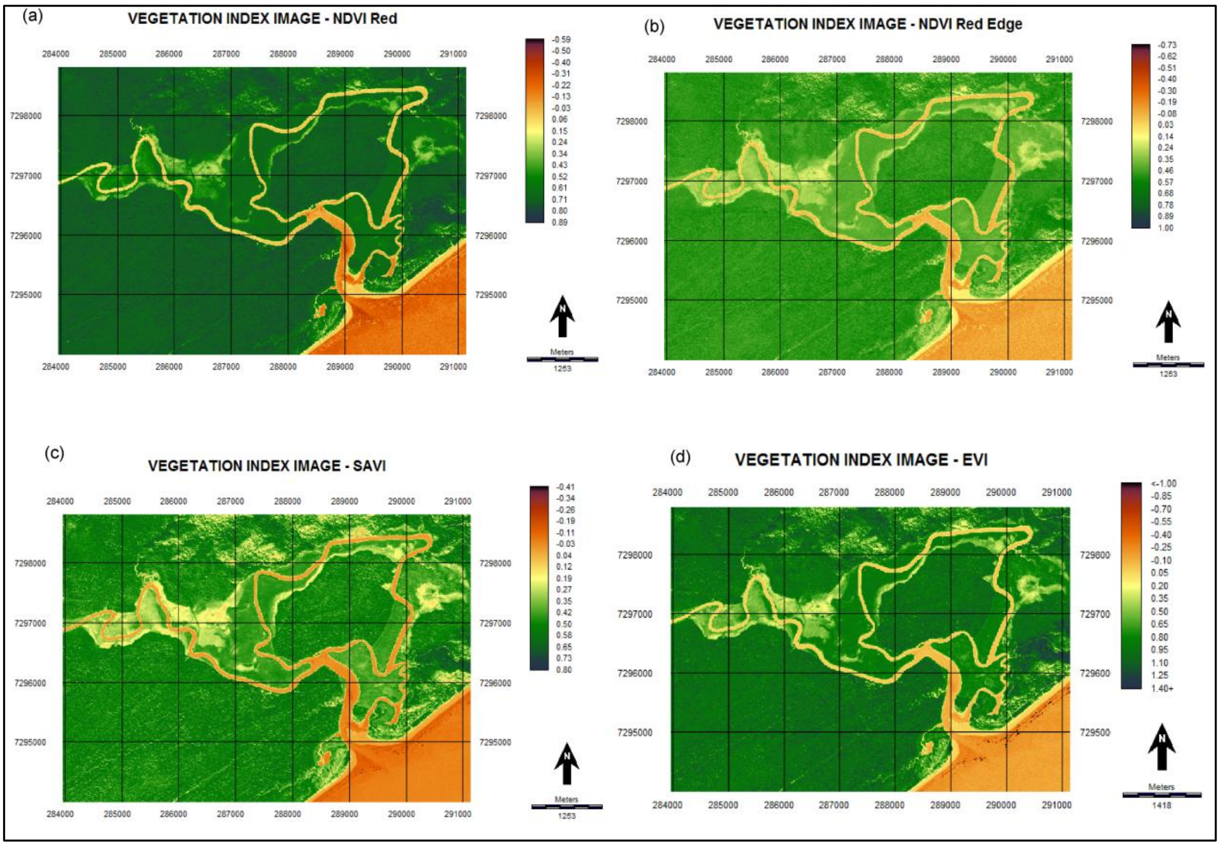

Figure 3. Different vegetation index calculated for the RapidEye images.

We applied different vegetation indices, with the aim to identify the best to discriminate these vegetations types (Figure 2). Our results indicated that in overall, all the indices applied were effective in discriminating these vegetation types, based on the index range values showed by each vegetation. The NDVI Red and NDVI Red Edge, showed the best results to discriminate these vegetation types (Figures 3a, 4a and 4a, 4b). The NDVI index is based on the spectral properties of green vegetation and is an indicator of primary productivity, vegetation biomass, health condition and canopy closure (Giri et al. 2007). The difference among them is that the NDVI Red Edge uses the red edge band instead of the red, used in the classic NDVI. Here we found that mangroves and tidal flats showed lower values of NDVI Red Edge than the NDVI Red Edge (Table 3). This difference can be attributed due to the features of the red edge band which represents the region of abrupt change in leaf reflectance between 680 nm and 780 nm caused by the combined effects of strong chlorophyll absorption in the red and leaf internal scattering in the near infra-red (Gates et al. 1965, Horler et al. 1983). Another difference detected among these indices is that NDVI Red Edge was more effective in discriminating tidal flat with soil from tidal flat without soil and in discriminating mangrove from Atlantic forest (Figures 4a, 4b). This can be due to the lower range values for each class, excepted for Atlantic forest (Table 3), which make this index more precise to discriminate these vegetation types.

We applied the SAVI index with the aim to minimize the effects of soil background on the vegetation signal, specially for the physiognomy tidal flat with soil, which has a high contribution of the soil in the vegetation reflectance. Despite this, in this index, the tidal flat with soil clearly showed the lowest index value, thus indicating the high influence and presence of the sand soil typical of this physiognomy. Nevertheless, it was less precise in discriminating tidal flat with soil from tidal flat without soil (Figure 4d) than the NDVI Red Edge (Figure 4b). The EVI index recorded the highest amplitude range for the vegetation, and the highest values for tidal flat without soil, mangrove and Atlantic forest, demonstrating that this index is more sensitive to vegetation with high density coverage. Nevertheless, it was not higher precise to discriminate mangrove from Atlantic forest (Figure 4d) than the NDVI Red Edge (Figure 4b).

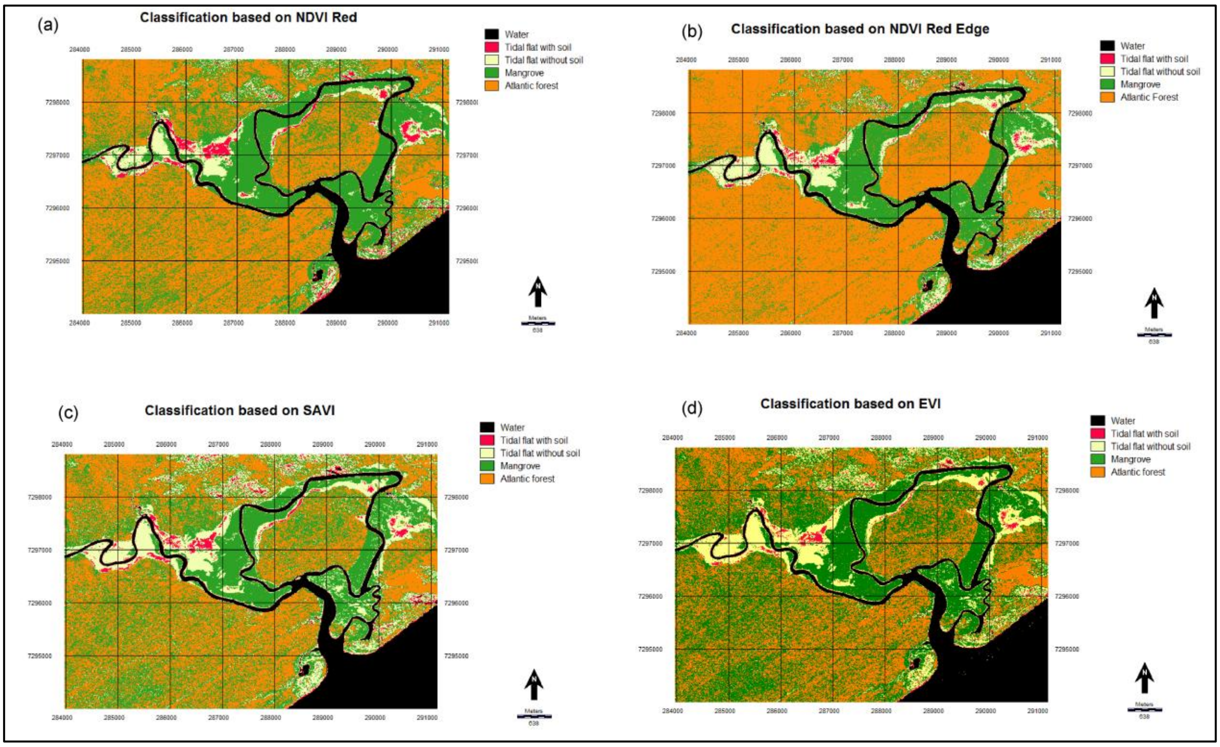

Figure 4. Reclassification of de vegetation index images.

Table 3. Range values of vegetation index for each vegetation classes.

	$NDVI_{Red}$	**$NDVI_{Red\ Edge}$**	**SAVI**	**EVI**
Tidal flat with soil	0.2 - 0.4	0.14 to 0.23	0.10 - 0.20	0.17-0.34
Tidal flat without soil	0.4 to 0.56	0.23 - 0.36	0.20- 0.38	0.34 - 0.72
Mangrove	0.56 - 0.69	0.36 - 0.46	0.38 - 0.49	0.72 -0.98
Atlantic forest	0.69 to 0.89	0.46 - 1	0.49 - 0.80	0.98- 1.40

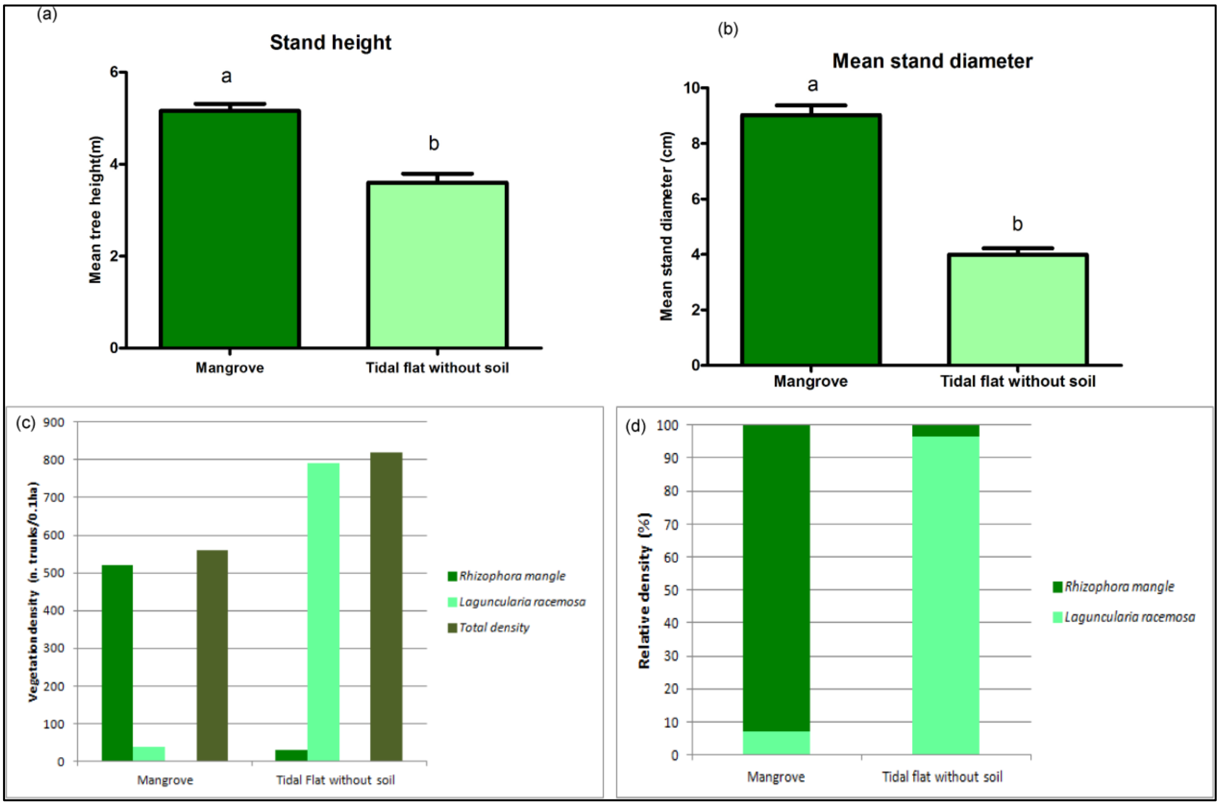

Figure 5. Vegetation structure of mangrove and tidal flat obtained by field work. Differences letters in the figures a and b indicate statistical difference (t-student).

4. Conclusions

In the present study we found that the application of qualitative and quantitative remote sensing techniques using RapidEye images are suitable tools and techniques for mapping and discriminating mangrove and tidal flats physiognomies. With the advantage of the red edge band presented by the RapidEye images, the calculation of the NDVI Red Edge showed the best result for discriminating tidal flats without soil from tidal flats with soil as well as, mangrove from Atlantic forest, than others vegetation indices as NDVI Red, SAVI e EVI. We conclude that RapidEye images are potential high resolution remote sensing tools for mapping mangrove and tidal areas, thus it can be applied for monitoring spatial temporal changes in this vegetation caused by climate changes, as sea level rise, using standard range values of NDVI Red Edge index for these physiognomies, as calculated and indicated in this study.

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