INTEGRATING VERY HIGH AND HIGH RESOLUTION IMAGERY FOR DETECTING SECONDARY GROWTH IN A NEOTROPICAL DRY FOREST ECOSYSTEM: A VEGETATION INDICES APPROACH

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Abstract. Neotropical dry forests have been understudied not only from the ecological point of view but also by means of remote sensing techniques. Characteristics of Neotropical dry forest such as seasonality, high historical anthropogenic disturbance and patchiness through the landscape have made them a difficult ecosystem to map using remotely sensed imagery. In addition, an even harder task is to map secondary succession in dry forests, something that has been fairly successful in Neotropical rain forests (i.e. Amazonian forest). In this paper we propose a technique to detect four different successional stages of tropical dry forest in an area of 49 km^2 in the Santa Rosa National Park (Guanacaste, Costa Rica). We combined very high-resolution imagery (IKONOS) with high-resolution imagery (Landsat ETM+) and tested four vegetations indices: single ratio (SR), normalized difference vegetation index (NDVI), infrared index (IRI) and, mid-infrared index (MIRI). This allowed us to define thresholds for the successional stages based on the tested indices.

Keywords: tropical dry forests, secondary forests, vegetation indices, IKONOS/Landsat ETM+.

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1. Introduction

Most of the remote sensing studies of vegetation (including secondary growth detection) in the last 20 years have focused in tropical rain or wet forest ecosystems (Sanchez-Azofeifa et al., 2001). However, 42% of the vegetation of Mesoamerica and the Caribbean, along with 42% of all intra-tropical worldwide vegetation is considered dry forest (Murphy and Lugo, 1995). Seasonality of tropical dry forests (*T-dfs*) represents a challenge in knowing the real extent of dry forest at a large scale using remotely sensed imagery (Pfaff et al, 2000). In addition, climatic and topographic characteristics have made the *T-dfs* very appropriate areas for agricultural activities (Mass, 1995; Ewel, 1999). As a consequence, the *T-dfs* are among the most heavily utilized and perturbed ecosystems due to human activities; a far greater proportion of *T-dfs* have been degraded or converted than wet forest (Murphy and Lugo 1986). In Costa Rica for example, by 1960 the *T-dfs* mainly located in the Guanacaste province, had almost vanished from the landscape (Sader & Joyce, 1988). At a larger scale currently, only 0.08% of the *T-dfs* located in Mesoamerica (Southern Mexico and Central America) are under conservation status and only 2% of their original extent remains in relatively undisturbed areas (Janzen, 1986). Therefore, the *T-dfs* are considered to be one of the most threatened (Janzen, 1988) and least studied (Mooney *et al*., 1995) ecosystems in the tropics.

The main objective of this study is the detection and mapping of different successional stages in a *T-df* ecosystem within the Santa Rosa National Park, Costa Rica combining very high and high spatial resolution imagery (IKONOS and Landsat ETM+). As well, we attempt to link basic ecological characteristics of the forest stand (i.e. horizontal and vertical structure) with the remotely sensed data based on vegetation indices. Vegetation indices have been commonly used for change detection (Sader et al., 2001), forest age detection (Lucas et al., 2000) and general forest mapping (Purevdorj et al., 1998). The advantage of vegetation indices (spectral ratios) is that they enhance compositional information, while topographic and illumination effects are diminished (Vincent, 1997). As an alternative test to a supervised classification (Arroyo et al., 2002) in the present study, various vegetation indices were evaluated for the separation of different successional stages in a *T-df* ecosystem. The vegetation indices tested were: (1) Simple ratio (SR), (2) Normalized Difference Vegetation Index (NDVI), (3) Infrared Index (IRI), and (4) Mid-Infrared Index (MIRI).

3. Methods

3.1 Study area

Our study area corresponds to a 49 km^2 within the Santa Rosa National Park (Guanacaste Conservation Area) located in the northwestern province of Guanacaste, Costa Rica (between 85° 38' and 85° 34' west longitude and 10° 52' and 10° 48' north latitude). This National Park covers a large remnant of tropical dry forest, which has been under protection since 1971 (Janzen, 1983). The forest in Santa Rosa is a mosaic of various ages of secondary succession that ranges from abandoned grass pastures to 400-year-old forests. It is also possible to find remnants of forest almost intact where only a few individual trees have been removed (Janzen, 1988). The vegetation within the *T-df* located in the Santa Rosa National Park ranges from forest stands that are almost completely deciduous found in young successions (2 m tall) to semi-evergreen forests in old successions (nearly 30-meter tall) (Janzen, 1988).

3.2 Interpretation of ecological variables related with IKONOS data

An IKONOS image was acquired during the dry season (March, 2000) in order to identify secondary growth in the Santa Rosa National Park. Since this image was the base for the interpretation of the different successional stages, only basic preprocessing steps were applied to the image (i.e. enhancement and rectification). Based on field observations and a literature review (Holdridge, 1967; Ewel, 1977; Hubbel1, 1979; Hartshorn, 1993; Pacheco, 1998), we characterized four-successional stages within the tropical dry forest located in the Santa Rosa National Park: pastures, early succession, intermediate succession and late or mature succession. Ecological variables such as vertical structure of the forest stand, leaf phenology at the time of image acquisition and, canopy distribution and density (patchiness) were used to define the aforementioned successional stages. Pasture areas were represented in the field by open areas with a low density of trees with different levels of deciduousness at the time of image acquisition. Pastures were depicted in a 4:3:2 "false color" IKONOS image as light blue areas with dark blue pixels representing the low density of trees (Figure 1a). A much higher density of trees and only one vertical layer (stratum) of vegetation represent early successional stages. Although most of the species present in early successional stages are deciduous in March, the degree to which the species begin to lose their leaves varies in time. In IKONOS this successional stage (Figure 1b) is represented by dark bluish clusters of pixels (mix of bark, branches, green leaves and litter), reddish areas (green canopies) and, some light blue regions (open areas with tall grasses).

The intermediate successional stage is characterized by a taller layer of trees than the early successional stage. As well, in this successional stage we find a thicker canopy (up to two strata) with some evergreen species and a complex combination of green leaf biomass and exposed branch and bark material, with little soil and litter exposure. In IKONOS the intermediate successional stage is shown by red groups of pixels (green canopies) and dark blue areas, which represent trees with variable degrees of deciduousness (Figure 1c). The late or mature successional stage (Figure 1d) has a two-layer canopy structure with a higher presence of evergreen species than the other three successional stages. In addition, these late or mature forest areas form an almost continuous canopy with low patchiness, very similar to those found in tropical rain forests. In the IKONOS image, almost continuous clusters of red pixels represent the late or mature successional stage. A more detailed explanation of the ecological linkage between successional stages and the IKONOS image can be found in Arroyo et al. (2002).

3.2 Landsat ETM+ processing and successional stages extraction base on vegetation indices

A Landsat ETM+ image (30 x 30 meters resolution) was acquired during the transition from the rainy to the dry season (January, 2000). The Landsat image was rectified to a previously corrected Landsat image (P15R53/1997/TM5). A second order polynomial and nearest neighbor method were chosen for the rectification and resampling processes respectively. Fifty well-distributed ground control points were acquired from the reference image, resulting in an RMSE of 0.6 pixels (≅ 18 meters). Since vegetation indices were calculated using bands 3, 4, 5 and, 7 of the Landsat ETM+ image (Conghe *et al*., 2001) the image was atmospherically corrected. The first step in the atmospheric correction process was to convert digital numbers to at sensor radiance values using the gain and offset values for the Landsat ETM+ sensor. Then, the radiance values were converted to surface reflectance using the ACORN module in ENVI 3.4.

We tested four vegetation indices used in remote sensing studies: Simple Ratio (Jordan, 1969), Normalized Difference Vegetation Index (Jordan, 1969), Infrared Index (Bohlman *et al*. 1998) and, Mid-infrared index (McMorrow, 2001). Single Ratio and NDVI are commonly used indices in vegetation studies. The rational behind the Infrared Index was to combine the ability of band 4 for biomass detection (Tucker, 1979) with the ability of band 5 to detect vegetation moisture (Knipling, 1970), as reported by Bolhman et al. (1998). The Mid-Infrared Index has been used as a measure of relative greenness (Rouse et al., 1973). In order to define the thresholds for each vegetation index using the Landsat ETM+ image, we extract 25 points per successional stage from IKONOS. Then, we created scatter plots of band combinations (4,3; 4,5; 5,7) based on a three pixels by three pixels window from Landsat. In addition for every cluster of points corresponding to a successional stage, an ellipse was defined based on the mean and the standard deviation of the reflectance values for each band. The scatter plots and the ellipses were then overlain on top of a contour plot of each vegetation index using Mathematica 4.0 (Wolfram Research, 2002). Based on the ellipses position over the contour plot the threshold for each successional stage was determined.

4. Results

Values of SR and NDVI for pastures range between 2.52 – 1.85 and 0.43 – 0.22, respectively. Open pasture areas cause high reflectance values in both the infrared and red portions of the spectrum (Figures 1a and 1b). A higher amount of green biomass in the early successional stage than in pasture caused a decrease in reflectance in both Band 4 (NIR) and Band 3 (red) ($\bar{x} = 0.09$, $s =$ 0.02) and ($\bar{x} = 0.25$, $s =$ 0.02). Therefore, values of SR and NDVI for early successional stages range between 4.16 – 2.52 and 0.58 – 0.53, respectively. The same pattern of increasing biomass is followed by intermediate and late or mature successional stages at the time of image acquisition (January, 2000). Consequently, the intermediate successional stage is found in the NDVI range 0.58 – 0.7 and 3.76 – 5.6 for SR. The late or mature successional stage is found in the NDVI range of 0.70 to 0.83, and in the range of 5.6 to 10.7 for SR. At an approximate NDVI value of 0.70 (SR = 4.16) there is an overlap in the ellipses for intermediate and late or mature successional stages, which is explained by the inability of Landsat to separate the physical canopy boundaries between them, due to its limited spatial resolution (30 meters by 30 meters). However, results from an ANOVA (not shown here) demonstrate that there were no significant differences ($p<0.01$) between these two successional stages for bands 4 and 3.

The third band ratio (IRI) using near and mid infrared portions of the spectra (Landsat bands 4 and 5, respectively) was also analyzed. The use of these bands for the detection of stand canopy phenology was studied in Brazil (Bohlman et al. 1998). The results show that this vegetation index does not separate the different successional stages (Figure 2c) as well as NDVI. Using IRI, it is possible to define only three succession stages: later or mature (0.24 to 0.48), intermediate (0.08 to 0.24), and a single class for pastures and early successional stage (-0.13 to 0.08). The fourth vegetation index (MIRI) studied, did not allow the definition of thresholds for the different successional stages (Figure 2d). The portion of the spectra used by MIRI is not sensitive to biomass (Gates et al., 1965). Moreover, MIRI shows a linear behavior, explained by the inverse relationship of Band 5 with total leaf area index and the inverse relationship of Band 7 to total stand biomass (McMorrow, 2001). Pastures with large areas of soil exposure do not show MIRI values different from late or mature successional stages (0.14 to 0.45).

5. Final considerations

Based on our analysis of vegetation indices for detection of successional stages in tropical dry forest we conclude:

- The ecological interpretation of successional stages based on stand characteristics represents and advantage when this information is linked to very high resolution imagery (IKONOS).
- The next step would be the classification of the image from the study area based on the thresholds for the different indices and the actual validation based on field data. This will also allow a stronger validation of our interpretation of the ecological parameters.
- Topography, forest fires and date of image acquisition could cause potential outliers in the interpretation of the satellite image data.
- This study presents an advance in tropical dry forest studies, mainly in the Mesoamerican Corridor area, where dynamics of secondary succession have been understudied from both ecology and remote sensing sciences.

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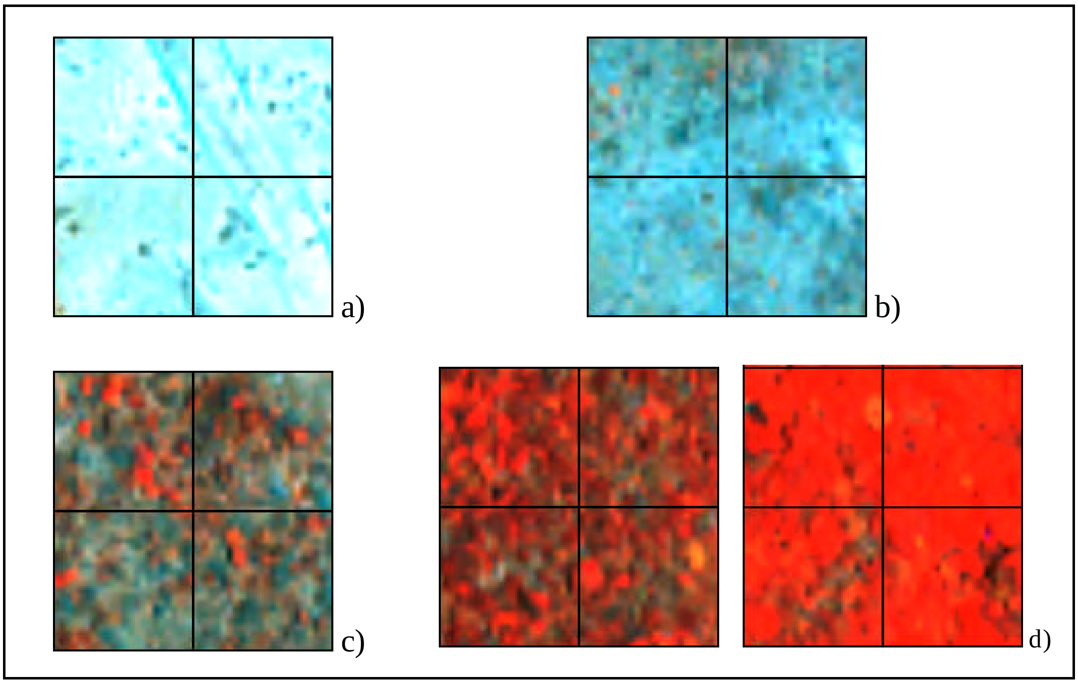

Figure 1. Representation of four successional stages in a tropical dry forest based on a 4:3:2 “false color” IKONOS image (4 meters spatial resolution) acquired during the dry season (March, 2000). Each area represents 90 meters by 90 meters on the ground. a) Pastures .b) Early successional stage. c) Intermediate successional stage. d) Late or mature successional stage.

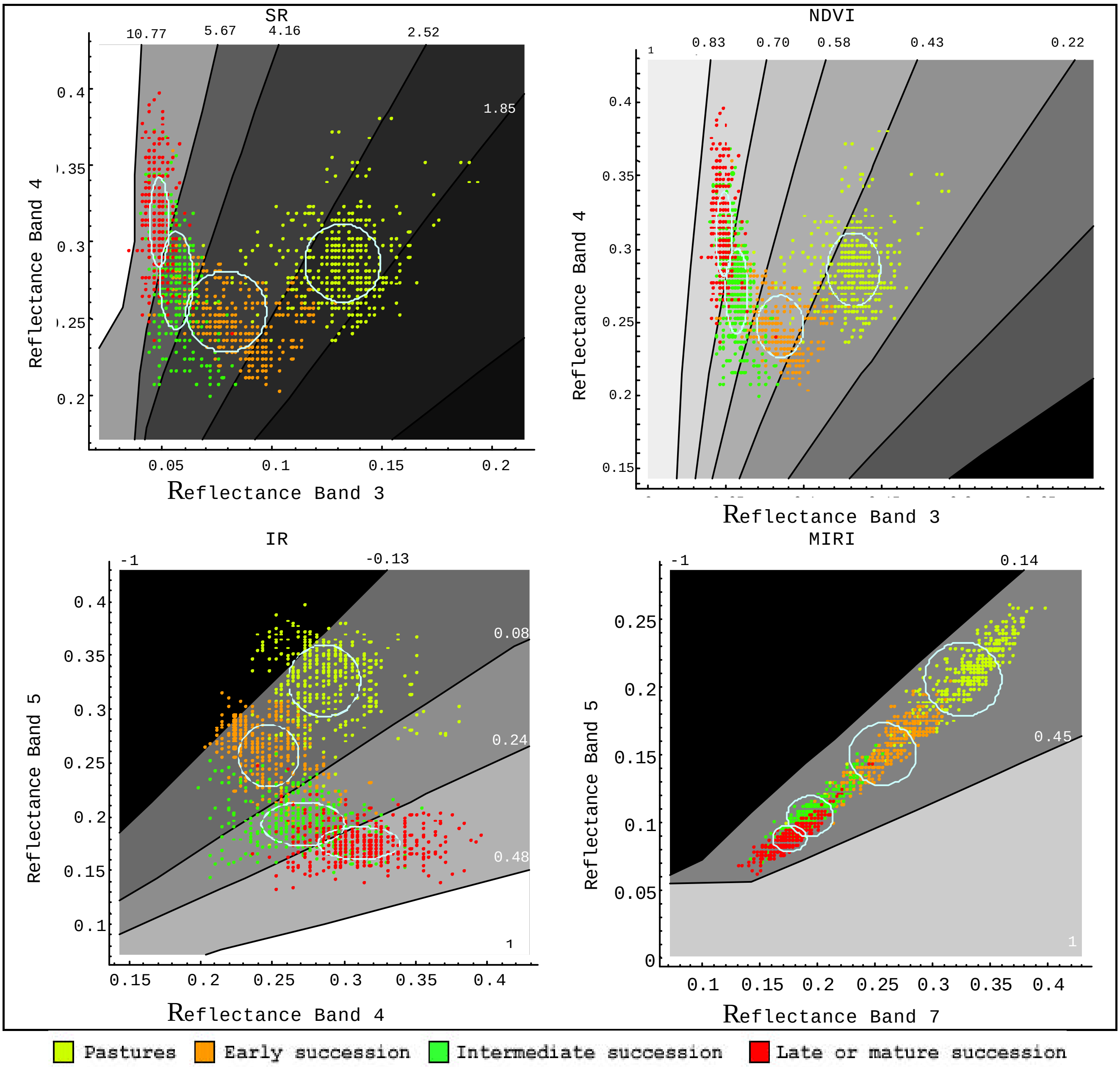

Figure 2. Vegetation index thresholds for Landsat ETM+ imagery based on data for four successional stages extracted from a 25 x 25 pixels window in IKONOS. a) SR. b) NDVI. c) IRI. d) MIRI