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Contents

1 Presentation

In 2009, the company Digital Globe launched the WorldView2 satellite, the first high spatial resolution satellite providing 8 spectral bands in the visible and near-infrared (VIS-NIR) regions of the electromagnetic spectrum. In order to investigate the potential of the new sensor for different environmental applications, Digital Globe organized in 2010 and 2011 a research competition: the '8-Band Research Challenge'. They granted the best proposals free WorldView2 imagery and a final price to the best five applications. The authors of this report presented a research proposal, and later a paper, entitled "Object-based analysis of 8-bands Worldview2 imagery for assessing health condition of desert trees" to the 8-Band Research Challenge, Phase 2. A total of 350 researchers from 70 countries participated in this contest, and the paper of Chávez and Clevers from the Center for Geo-Information of Wageningen University was awarded as one of the five winner papers. The price was formally announced in August 2012 during the Latin America Geospatial Forum in Rio de Janeiro, Brazil.

In this CGI report, we present the results of the research carried out by Chávez and Clevers in the framework of the Digital Globe 8-band challenge competition.

2 Abstract

High spatial resolution panchromatic and multispectral WorldView2 images were used to assess the health condition of Tamarugo (*Prosopis tamarugo* Phil.) trees in the hyperarid Atacama desert in Northern Chile. Tamarugo is a very valuable species for biodiversity conservation due to its endemic character and limited distribution range. An object-based analysis of a panchromatic WorldView2 image was carried out to identify single trees and to measure canopy area. The NIR/red-edge ratio index (NIR/Re) and Red-edge Normalized Difference Vegetation Index (ReNDVI) were calculated using the near-infrared band (772-890 nm) and the red-edge band (704-744 nm) of the 8-band multispectral WorldView2 image in order to assess health condition at the tree level. The widely used Normalized Difference Vegetation Index (NDVI) was also calculated as reference. Finally, the results were compared with field data taken over 48 trees.

The developed object-based algorithm worked out satisfactory with WorldView2 panchromatic data, especially in defining canopy contours and splitting overlapping trees. Within the study area - Bellavista plantation in Pampa del Tamarugal National Reserve- a total of 90,350 trees were automatically identified with a total canopy area of 5.2 km^2. The tree average canopy size was 57.6 m^2. Single canopy identification allowed an accurate assignment of average spectral values from vegetation index images to the object trees. This way single values of the three vegetation indices were used to evaluate vegetation condition at tree level. Correlation coefficients between vegetation index values and green canopy percentage (GC%) measured for 48 trees in the field were significant in all cases, with the highest one for the traditional NDVI.

Index Terms—object-based analysis, WorldView2, *Prosopis tamarugo*, vegetation indices, Atacama desert

3 Introduction

Conservation of biodiversity in arid ecosystems is difficult to tackle by managers and policy makers since biodiversity spots or patches are frequently immersed into a huge matrix of bare land. Therefore, its identification and assessment is costly and hard to implement. Furthermore, these dots are always closely related to the few water sources that are also demanded by industry and human consumption (Ezcurra 2006). This dependency makes arid ecosystems susceptible to water stress, although their plant and animal species are well adapted to survive water scarcity. But species resistance has limits and thresholds have to be determined in order to preserve biodiversity in deserts. The new generation of high spatial resolution satellites, starting with IKONOS in 1999 and followed by Quickbird2 in 2001 and WorldView2 in 2009, has become a real option to tackle the scale problem of biodiversity conservation in deserts. These datasets enable identification of small features in desert landscapes such as individual trees, shrubs and small patches of grasslands or little ponds. However, spectral analysis of these features using high spatial resolution imagery had been limited to just a few broad bands, generally blue (450-520 nm), green (520-600 nm), red (630-690 nm) and NIR (760-900 nm). Recently, in 2009, the sensor carried by the WorldView2 satellite incorporated 4 extra bands: coastal (401-453 nm), yellow (589-627 nm), red-edge (704-744 nm) and NIR2 (862-954) and slightly modified the bands blue (448-508 nm), green (511-581 nm) and NIR (772-890 nm) combined with an increased spatial resolution to 0.5 meters for the panchromatic channel and to 2 meters for the multispectral channels. This enables a spectral analysis of spatial features at a very high spatial resolution.

Nevertheless, the huge amount of spatial detail as well as the increment of spectral information of the WorldView2 satellite poses a challenge for image analysis and computational processing. In this sense traditional pixel-based classification utilizes mainly the spectral information and neglects important spatial characteristics of the image features such as shape and context (Blaschke 2010). A different approach has been used in recent years for high spatial resolution image classification, the so-called object-based analysis. In this approach, image regions of homogeneous pixels are grouped into meaningful objects, which can be described and classified in terms of internal spectral composition as well as in terms of spatial attributes such as position, size, shape and relation with neighboring objects (Blaschke et al. 2005).

Object-based analysis and classification seems to be a very suitable approach to take advantage of the spatial-spectral characteristics of the WorldView2 data for detection of vegetation spots in arid ecosystems and for health condition assessment of small vegetation features. In this study we explore the usefulness of WorldView2 images to first identify single trees as objects with position, size and shape within an arid landscape, secondly to assess tree condition testing the new red-edge band as part of two different vegetation indices (NIR/Re and ReNDVI), and third to extract and combine spectral and spatial information using an object-based analysis for image classification.

4 Material and methods

4.1 Study area

A complete absence of vegetation coverage is the most common condition in the Atacama desert (Houston and Hartley 2003). Vegetation spots are scarce, limitedly distributed and closely related to water sources. An exceptional example of adaptation to these extreme environmental conditions is the Tamarugo forest. Tamarugo (*Prosopis tamarugo* Phil.) is an endemic tree species, highly adapted to hyper-arid conditions and limitedly distributed (Mooney et al. 1980) (Riedemann et al. 2006) (Altamirano 2006). Its original natural distribution corresponds to desert plains between 19°33'S and 21°50'S at 1,100 m.a.s.l., which is locally known as Pampa del Tamarugal (Altamirano 2006).

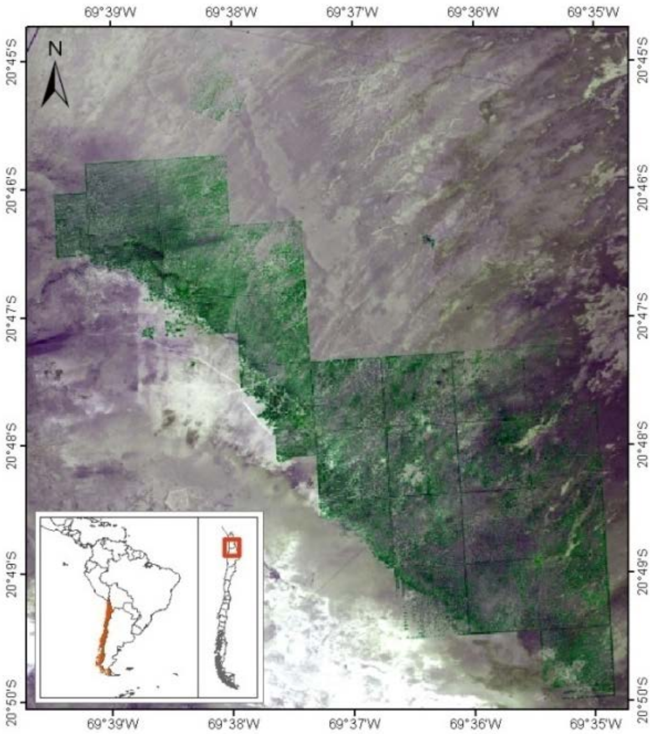


Figure 1. False color multispectral WorldView2 scene of the Bellavista plantation, southern Pampa del Tamarugal National Reserve, Chile.

The Tamarugo natural population was almost extinct during the 19th century because it was used as a main combustible source for the saltpeter industry and the railway (Briones 1985). Between 1965 and 1970 a big effort for Tamarugo's conservation was promoted by the Chilean government and 13,800 hectares were planted (Aguirre and Wrann 1985); (CONAF 1997). Currently, Pampa del Tamarugal plantations constitute around 68% of the remaining Tamarugo´s population (Aguirre and Wrann

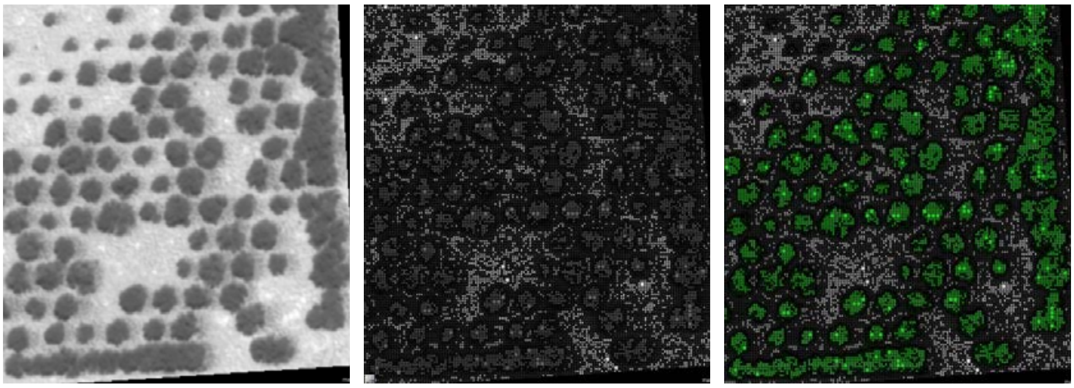
1985). They are under official protection and currently belong to the Pampa del Tamarugal National Reserve, which is administrated by the Chilean National Forest Service (CONAF). Tamarugo is a phreatophytic tree and therefore it is completely dependent on groundwater supply (Aravena and Acevedo 1985). At present, there is an enormous pressure for extracting water from the Pampa del Tamarugal aquifer (Rojas and Dassargues 2007) and studies regarding the water status of the Tamarugo forest are required by local water management and for environmental monitoring. The relationship between the plantation water status and groundwater depletion has not been established yet. However, it is possible to observe areas where trees are evidently dry. This study aims to contribute to the understanding of this problem using modern remote sensing tools to assess tree condition in deserts.

The study area corresponds to a WorldView2 scene of 100 km^2 of the Bellavista Saltflat acquired on October 15th, 2010 (Figure 1). It covers the Bellavista plantation located in the southern Pampa del Tamarugal National Reserve. The scene was specially taken and delivered by Digital Globe as part of the "8-band Research Challenge" initiative.

4.2 Identification of single trees using object-oriented image classification

An algorithm was developed to identify single trees using the 0.5 meters pixel resolution of the panchromatic WorldView2 image. The algorithm was built up using the object-based analysis software eCognition. The algorithm considered spectral values and spatial characteristics of the image features and it is constituted by the following 5 steps or sub-routines (see Figure 2):

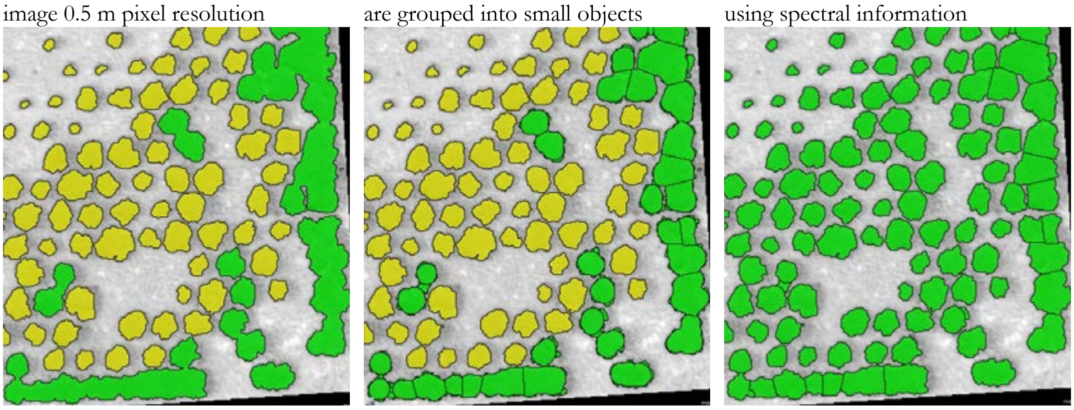
- Segmentation: using a Quadtree segmentation, the complete scene was split into homogeneous squared objects until a predefined maximum difference of internal digital values was reached.
- Object classification using spectral values: using spectral information the resulting objects were classified into two categories: trees and potential shadows.
- Shadow extraction and object merge: using shape criteria, actual shadows and dark bare areas were removed and tree objects were merged. Considering shape and size criteria the resulting objects were classified into 2 categories: single trees and multiple overlapped trees.
- Round and split of overlapped trees: adjusting circles of different size inside overlapped tree objects and using internal size relationships, multiple-trees were split and re-merged until getting single trees.
- Residual cleaning and final tree identification. Using size, shape and spatial relationship criteria, undesirable objects were extracted and remaining tree objects were merged.



a) Panchromatic WorldView2 image 0.5 m pixel resolution

b) Quadtree segmentation. Pixels are grouped into small objects

c) Object classification into trees using spectral information



d) Shadow extraction and object merge into single trees (yellow) and multiple overlapped trees (green)

e) Round and split of multiple-overlapped trees

f) Residual cleaning and final merge into single trees

Figure 2. Object-based analysis procedure for single tree identification.

4.3 Vegetation indices based on red-edge band

Under water stress plants react by adjusting several biochemical cellular and molecular processes and closing stomata to regulate their water content (water inputs from soil to plants, which become less, and water outputs from plants to the atmosphere, which is constantly demanding water). This regulatory mechanism minimizes desiccation temporally, but also produces a decrease in the photosynthesis rate and biomass production. If the water depletion is severe, foliage will gradually lose its water (shrinking process) and photosynthetic pigments until leaves die (Suárez et al. 2008). In this process, changes occur in the light reflection and light absorption properties of plants (Chaerle and Straeten 2000; Gillon et al. 2004; Seelig et al. 2009). Spaceborne multispectral sensors are able to measure these changes accurately (Berni et al. 2009; Leinonen and Jones 2004) and many spectral vegetation indices have been developed to assess water condition in plants. Studies have shown that changes in plant pigments are evident in the visible and near-infrared region of the spectrum, while changes in water content are recognizable in the short-wave infrared region (Govender et al. 2009). Furthermore, the transition between red and NIR, the red-edge region, has been used for many vegetation studies. Changes in position and slope of this transition region have been related to plant stress, resulting in a shift of the slope towards shorter wavelengths (Horler et al. 1983).

The WorldView2 sensor measures the spectral reflection in the visible and NIR region ranging from 401nm to 954nm and delivers multispectral 8-band images (Table 1). In this study we used the bands NIR and Red-Edge to calculate two vegetation indices: a simple NIR/Red-edge ratio which is a modification of the chlorophyll index (CIred edge = R780/R710 – 1) proposed by Gitelson (Gitelson et al. 2006) and Red-edge NDVI ([NIR-Red-edge]/[NIR+Red-edge]). Additionally, the standard NDVI was calculated using the bands NIR1 and Red in order to compare the results with the red-edge based vegetation indices. Finally, all vegetation indices were assigned to the single tree objects. For this purpose, the average value of the pixels whose centres were inside the tree canopy object were assigned to each tree. Top of atmosphere (TOA) radiance values were used for the indices calculation. To transform pixel digital values to TOA values the absolute calibration factors of the WorldView2 scene were used (Table 1).

Table 1. WorldView2 band passes.

Spectral band	Center wavelength (nm)	50% Band Pass	Abs. Cal. Factor
Panchromatic	632	464-801	
Coastal	427	401-453	9.30E-03
Blue	478	448-508	1.78E-02
Green	546	511-581	1.36E-02
Yellow	608	589-627	6.81E-03
Red	659	629-689	1.85E-02
Red-Edge	724	704-744	6.06E-03
NIR1	831	772-890	2.05E-02
NIR2	908	862-954	9.04E-03

4.4 Field evaluation of tree health condition

The three vegetation indices (NIR/Re, ReNDVI and NDVI) assigned to single trees were compared with 48 field observations of green canopy percentage (GC%) carried out at the Bellavista plantation in December 2006 (PRAMAR-SQM 2008a). Just trees matching 1 to 1 to object tree positions were included in this sample. GC% was measured as qualitative observation using the ranges 1 (0-5%), 2 (5-25%), 3(25-50%), 4(50-75%), 5(75-100%) as shown in Figure 3. Different tree conditions were sampled during the field campaign, from very dry up to absolutely green trees. In order to measure the correlation between the quantitative vegetation indices and categorical GC% values, the Spearman rank correlation coefficient (rho) was calculated.

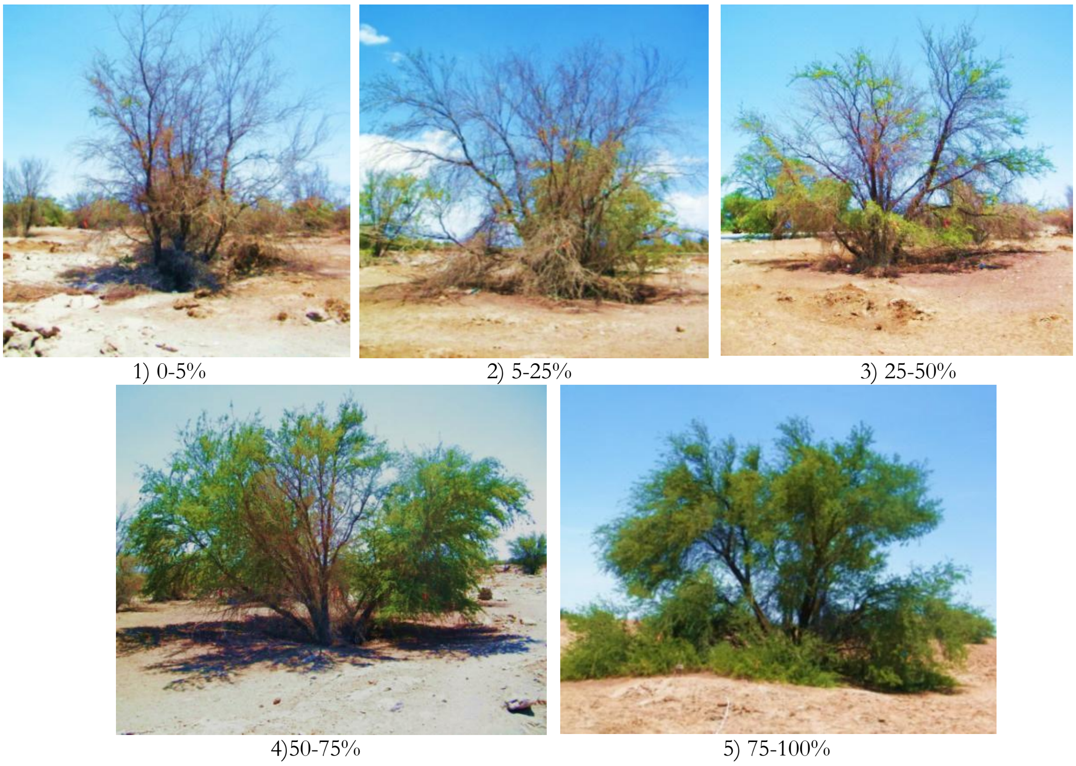


Figure 3. Examples of green canopy percentage (GC%) measurements of Tamarugo trees.

5 RESULTS AND DISCUSSION

5.1 Forest inventory

A total of 90,350 trees were automatically identified in the study area. This result is very similar to an inventory carried out in 2006, where 93.879 trees were counted visually on a Quickbird2 image (PRAMAR-SQM 2008b). However, the area covered by the 2006 inventory was slightly bigger than the area of this study and part of the differences can be attributed to this fact. Also, there was a very good correspondence of the locations of trees. Main differences are caused by overlapping crowns of trees. Automatic approaches, such as the one used in this study, have the advantage of being repeatable since an algorithm is used to quantify the forest population. Thus, operator effects in systematic monitoring can be avoided.

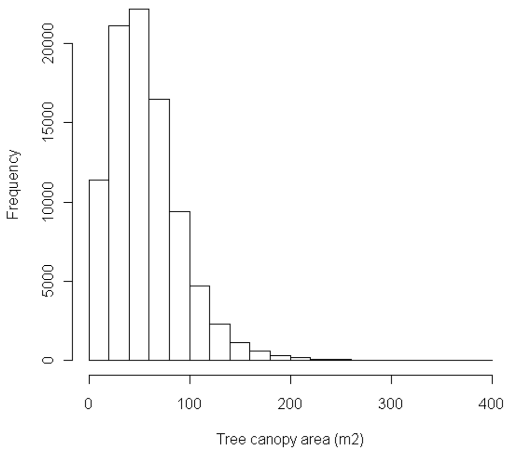


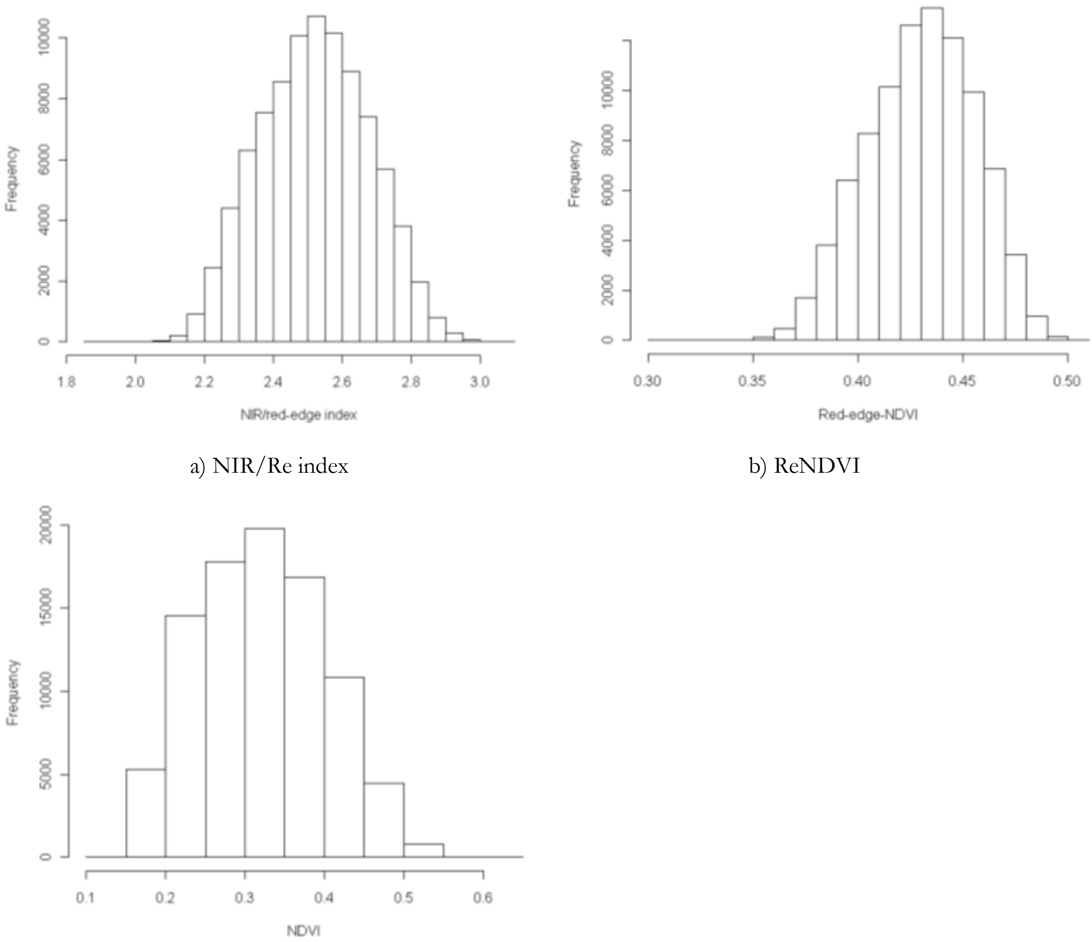
Figure 4. Histogram of single tree canopy area

For forest inventory purposes or population ecology studies, the main advantage of the object-based approach is the possibility of calculating total and single tree canopy area in addition to tree identification. These dasometric variables are also important for assessing vegetation health conditions in arid ecosystems, because some arid species react by shrinking the crown size when suffering from water stress while keeping the remaining canopy healthy (Alpert and Oliver 2002). Consequently, reduction of canopy size can be used for monitoring purposes. Field observations by the authors suggest that Tamarugo is able to dry out some branches when suffering from water stress, while keeping the remaining branches healthy. Nevertheless, this hypothesis needs to be proven.

Figure 4 shows the histogram of single tree canopy size of the Bellavista plantation. Total canopy area was estimated at 5.2 km^2, and single tree average canopy at 57.6 m^2. Minimum canopy size was found by the algorithm as 5.25 m^2. Maximum value was 967 m^2, corresponding to overlapped trees which could not be split by the algorithm. In general, trees above 400 m^2 corresponded to overlapped trees, although a few cases were apparently huge single trees. Just 43 trees belonged to this canopy size category.

5.2 Vegetation indices for single trees

Histograms of the single tree values for the three indices show a normal distribution (Figure 5). Mean values for NIR/Re index, ReNDVI and NDVI were 2.52, 0.43 and 0.32 with standard deviations of 0.16, 0.03 and 0.08, respectively. Resulting coefficients of variation (CV-%) are 6.4%, 7.0% and 25.0%. Although some studies promote the use of a red-edge band over the red band, this shows that use of the red-edge band reduces the relative dynamic range (CV) of the index. The results show that the Bellavista plantation has an 'average' tree condition with around 25-50% of green canopy area (Figure 5 and 7).



a) NIR/Re index

b) ReNDVI

c) NDVI

Figure 5. Histograms of different vegetation index values assigned to single trees.

Figure 6 shows the spatial distribution of the three indices assigned to individual trees for the study area (left) and also a detailed view of a transitional area of high and low vegetation index values (right). Health condition of the plantation is variable in space, irregular, but not randomly distributed. In fact, distinguishable groups of trees with good condition (blue tones) are visible in the stand edges, in the upper middle area of the plantation (a big area) and in some lines or stripes in the lower part. Despite the general trend, locally it is possible to see trees with very different vegetation index values (Figure 6, right). The results obtained from the object-based classification of WorldView2 imagery can be used for further studying spatial patterns using geo-statistical methods. For instance, the relationship between the tree health spatial distribution and environmental variables, such as groundwater depth, groundwater depletion rates or management practices can be analyzed.

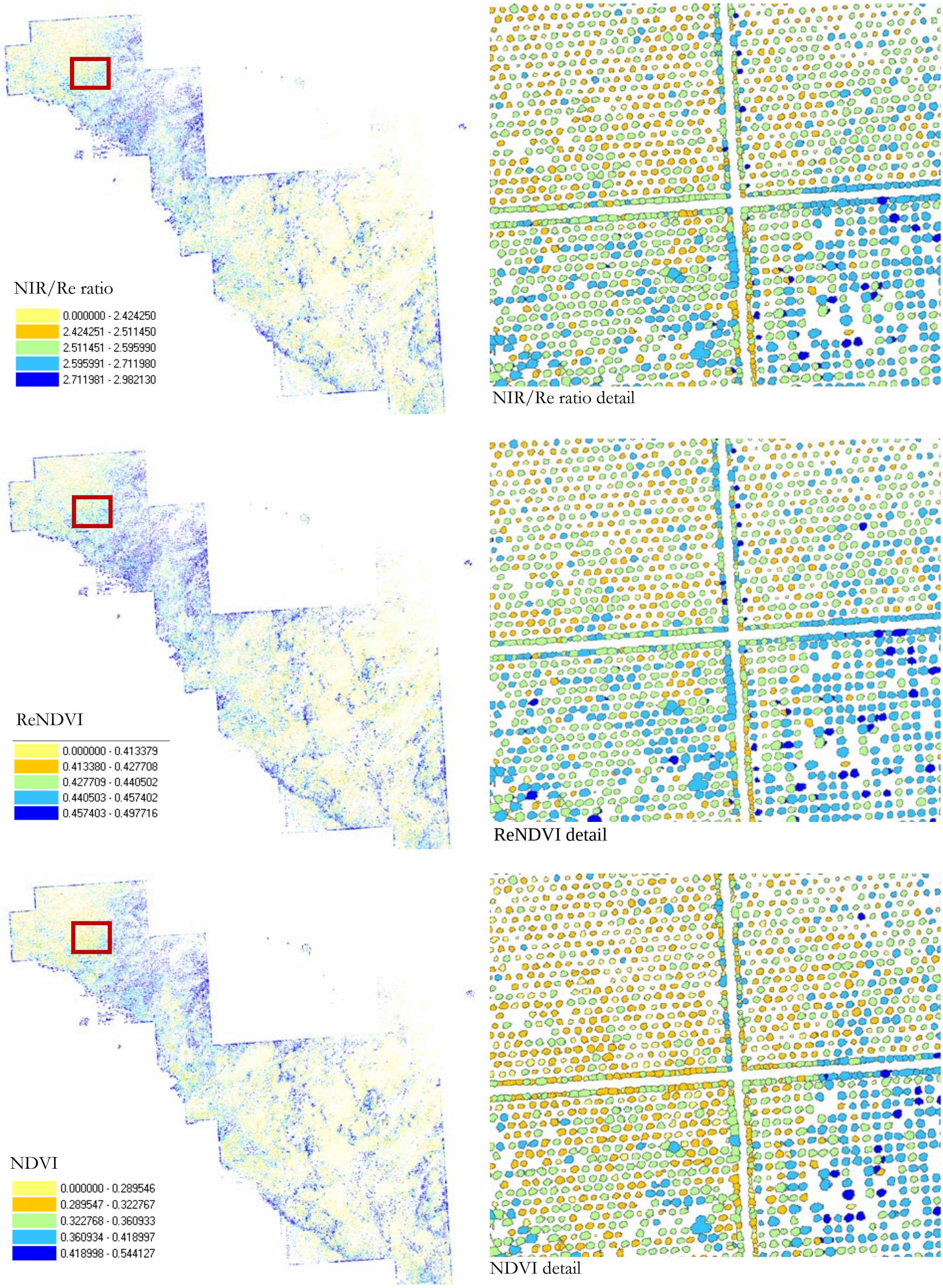


Figure 6. Spatial distribution of vegetation index values assigned to single trees

5.3 Field evaluation of tree health condition

The percentage of green canopy cover has been assessed in the field for 48 trees. This assessment was then related to the index values derived from the WorldView2 image. All three indices, NIR/Re ratio, ReNDVI and NDVI, showed a significant correlation with GC% according to the Spearman Rho coefficient (0.83, 0.83, 0.91, respectively). The highest correlation was observed between the traditional NDVI and GC%. This coincides with the larger dynamic range for this traditional NDVI observed in section 3.2. The central wavelength of the red-edge band of WorldView2 is at 724 nm. Better results might be expected using a band centered around 705 nm (Wu et al. 2008).

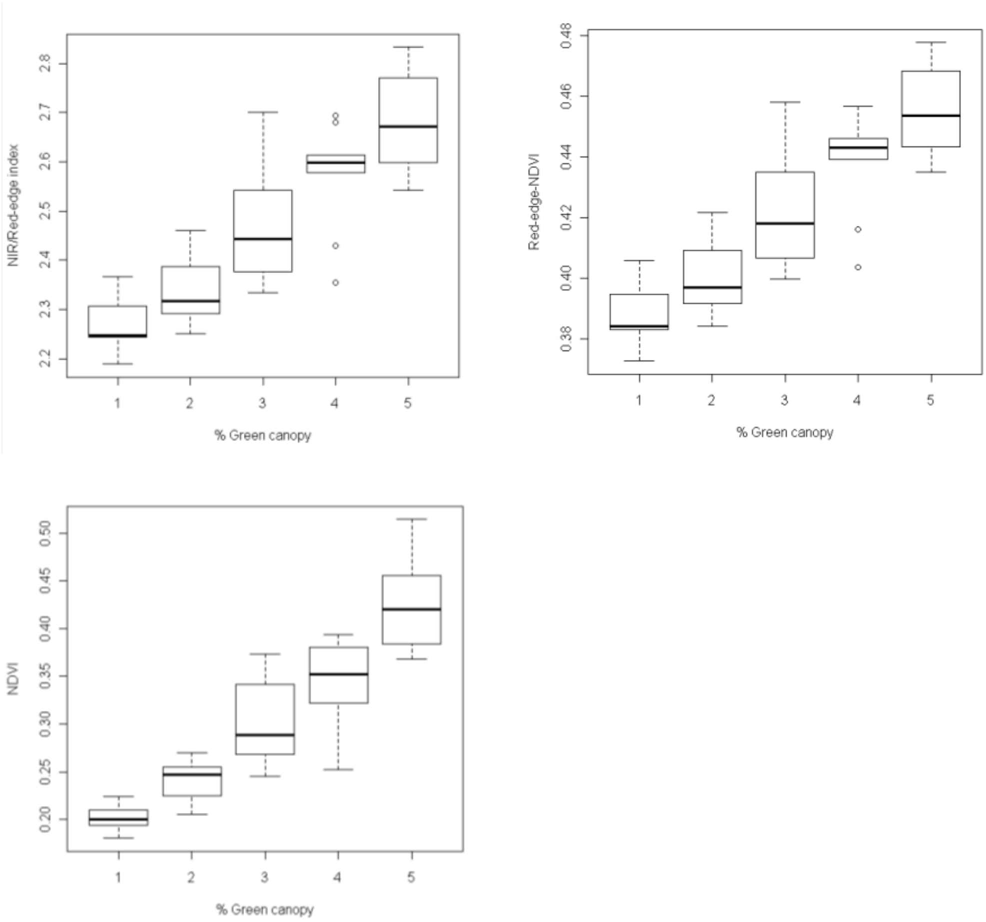


Figure 7. Boxplots showing vegetation indices and percentage of green canopy measured during the field campaign. Percentage of green canopy values are: 1 (0-5%), 2 (5-25%), 3 (25-50%), 4 (50-75%), 5 (75-100%).

6 CONCLUSIONS

In this study the possibilities of using WorldView2 data for automatic identification of desert trees and assessment of health condition were explored. An object-based analysis was performed to combine the detailed spatial information of the panchromatic image with the spectral features of the multispectral 8-bands image. As a result single tree assessment was achieved. The spectral and spatial information of the panchromatic dataset was successfully used to first identify tree canopies, second to extract shadows, and third to split overlapped trees. Results are comparable with human-based recognition and have the advantage of calculating canopy total area and single tree canopy area in addition to tree identification. Furthermore, object trees can be used to accurately extract spectral features from multispectral images and subsequently from all possible calculated vegetation indices. This way, vegetation health assessments can be performed at tree level which is very important for conservation of endangered and limitedly distributed plant species, such as Tamarugo trees. In this study we tested two vegetation indices which use the new red-edge band of WorldView2 (NIR/Red-edge ratio and Red-edge NDVI) and we compared the results with the traditional NDVI. All indices showed similar results and high correlation with green canopy percentage (GC%) measured over 48 trees in the field. The results obtained in this study are very promising for further research on the relationship between the increased spectral features of the WorldView2 sensor and ground attributes of vegetation as well as the study of the spatial patterns using geo-statistical methods.

7 Acknowledgement

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