Object-based assessment of tree attributes of *Acacia tortilis* in Bou-Hedma, Tunisia

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ABSTRACT:

Acacia tortilis subsp. *raddiana* represents the most important woody species in the pre-Saharan zone. It is the only forest tree persisting on the edge of the desert. Due to tree/environment interactions, canopy sub-habitats arise, enabling an increased storage of soil water, soil nutrients and soil oxygen. Depending on their density, they can also reduce erosion and reverse desertification. Soil erosion and desertification are the main problems faced by the UNESCO Biosphere Reserve in South-Tunisia (Bou-Hedma National Park). The restoration of the original woodland cover to combat desertification (particularly) by afforestation and reforestation of *Acacia tortilis* goes hand in hand with a climate change in the Biosphere Reserve, also influencing rural population outside the Biosphere Reserve. In order to study the different effects of woodland restoration in Bou-Hedma, the number of *Acacia* trees and their attributes have to be known. High resolution satellite imagery (GeoEye-1), was used with a GEOBIA approach. Field measurement of bole diameter, crown diameter and tree height were collected at > 400 locations. After segmentation, correlations with > 200 object features and tree attributes were calculated. For crown diameter and tree height, high correlations were observed with the features *area* and *GLCM Entropy Layer 4* (*90°*). Relations between these features and measured tree attributes were modeled, resulting in RMSE values of resp. 1.47 m and 1.62 m for crown diameter estimation and 0.92 m for tree height. The results show that a GEOBIA working strategy is suitable for estimating tree attributes in open forests in semi-arid regions.

RÉSUMÉ:

Acacia tortilis subsp *raddiana* est l’espèce ligneuse le plus importante dans la zone présaharienne. C’est le seul arbre qui peut vivre au bord du desert. Grace aux des interactions arbre/environnement, des sub-habitats se forment, permettant une augmentation de stockage d’eau, de nutriments et d’oxygène dans le sol. Dépendant de la densité des arbres, ils peuvent en plus diminuer l’érosion et la désertification. L’érosion et la désertification sont les problèmes majeurs de la Reserve Biosphère d’UNESCO au Sud Tunisie (Bou-Hedma National Park). La rétablissement des bois originaires, pour combattre la désertification, par (re)boisement a un impact sur le climat local, influençant aussi la population rural. Le nombre d’*Acacia* et leur attributs doivent être connus pour étudier les différents impacts du (re)boisement. Une image haute résolution (GeoEye-1) a été analysé, avec une approche GEOBIA. Des mesures de diamètre de tronc, diamètre de cime et hauteur des arbres ont été recueilli à > 400 locations. Ces mesures sont utilisé pour modeler les relations entre traits d’objets et les attributs. Après segmentation, > 200 traits d’objets ont été calculé. Pour estimer la diamètre de la cime et l’hauteur de l’arbre, corrélations élevées ont été observé avec les trait *area* et *GLCM Entropy Layer 4 (90°)*. Les modèles ont résulté en RMSE de 1.47 m et 1.62 m pour l’estimation de la diamètre de cime et RMSE de 0.92 m pour l’hauteur. Ces résultats montrent que GEOBIA est convenable pour l’estimation d’attributs des arbres dans des bois ouvert en des zones semi-arides.

1. INTRODUCTION

Acacia tortilis subsp. raddiana is an important woody species in the pre-Saharan Tunisia zone. The species is able to tolerate extreme drought (in the range of 20 to 200 mm), through special adaptations such as a deep lateral root and partial repelling of leafs in the dry season. It is the only forest tree persisting on the edge of the desert and is therefore considered a keystone species (Abdallah et al., 2008; Grouzis & Le Floc'h, 2003). The restoration of the original woodland combating desertification, particularly by afforestation and reforestation, is therefore an important research activity in the Bou-Hedma region. The restoration goes hand in hand with a climate change in the Biosphere Reserve. The impact of this local climate change is also felt outside the Biosphere Reserve, where the local rural population depends on rain fed agriculture and the water resources originating from water infiltrated on the mountains of the Bou-Hedma mountain chain. This change in climate conditions has been directly observable on the mountain chain, where *Stipa tenacissima* (*Poaceae*) now grows without human intervention. However, scientific documentation remains scarce. In order to study the different effects of woodland restoration in Bou-Hedma, the number of *Acacia* trees (individuals and tree groups) and their crown cover need to be accurately estimated, and that is exactly the focus our study. Very high spatial resolution (VHR) remotely sensed data and a Geographic Object-Based Image Analysis (GEOBIA) working strategy make it possible to directly estimate individual tree attributes (Falkowski et al., 2009).

2. DATA

2.1 *Study area*

The region of Bou-Hedma is situated at the northern edge of the Sahara. The altitude varies between 90 m and 814 m above sea level. The Bou-Hedma National Park is situated in arid Tunisia (34°24'N to 34°32'N and from 09°23'E tot 09°41'E) and is characterized by an extremely irregular spatiotemporal rainfall pattern (Figure 1). The main climatic characteristics are an average annual rainfall of 180 mm, an average annual temperature of 17.2 °C, a mean maximum temperature of 38.0 °C and a mean minimum temperature of 3.9 °C. Bou-Hedma is famous for its relicts from pre-Saharan savanna. However the Biosphere Reserve faces mainly problems of desertification caused by excessive livestock grazing, partial land clearance, ploughing and resulting effects such as soil erosion. In 1955 only a few old trees were present at the *Bordj* (caravanserail), while in 1853 this *Acacia* forest steppe covered 38.000 hectare.(Karem, 2001; Tarhouni, 2003) Therefore in 1957-1958, protective measures were taken by fencing 700 hectares. In the sixties, actions were taken to combat erosion because the *FAO* reported that the *Mountain Bou-Hedma* was being degraded (Caron, 2001). One of these actions was the construction of a tree nursery and the creation of *Integral Protection Zones*. Since the year 1970, these protective actions and measures resulted in a gradual restoration of the vegetation (Tarhouni, 2003). In 1977, 2400 ha was protected and in the same year, the park became part of the network of Biosphere Reserves of UNESCO. In 1985, regeneration actions were undertaken and these paid off as the number of *A. tortilis* was multiplied with a factor of about 30 (Caron, 2001).

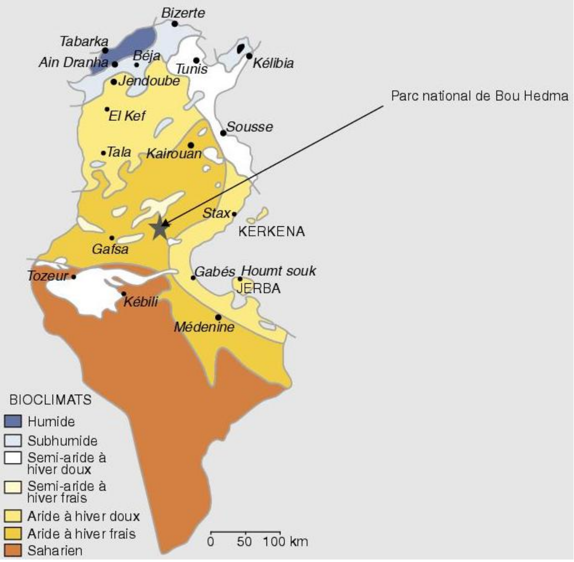

Figure 1: Geographical location of Bou-Hedma national park on the bioclimatic map of Tunisia (Tarhouni et al., 2007)

2.2 *Imagery*

The Geo-Eye-1 (formerly known as OrbView-5) satellite was launched on September 6, 2008 and is the next-generation high-resolution imaging mission of GeoEye, Dulles, VA, USA. The Geo-Eye pushbroom imaging system records the reflected radiation from the Earth's surface in the blue (0.450-0.510 µm), green (0.510-0.580 µm), red (0.655-0.690) and near-infrared (0.780-0.920 µm) portions of the electromagnetic spectrum with a spatial resolution of 2 m. A panchromatic band (0.450-0.800 µm) is also recorded with 0.41 m spatial resolution, which is resampled to 0.50 m for commercial customers. The radiometric resolution is 11 bits per pixel (GeoEye, 2009; GIM, 2009; Kramer 2009).

The image used for the analysis was acquired on the 1st of August 2009 at 10:18 GMT. Cloud cover was 0 %, which was highly expected, considering the time of the year (hot and dry season). The image was geometrically corrected by GeoEye Inc. and provided in the UTM (WGS 84) coordinate system.

2.3 *Field data collection*

With the aid of the GeoEye-1 and Google Earth imagery (and confirmed by the field work), it could be noticed that, at Bou-Hedma, *Acacia's* appear in two spatial configurations. First, there are plantations wherein trees are found in linear formations, scattered over the entire National Park. Secondly, there are also *Acacia* trees located in depressions and dried (temporal) riverbeds (*wadi* or *oued*). The latter trees have a more natural aspect and co-occur with larger shrubs (*Periploca* sp. and *Retama* sp.). Moreover, *Acacia*'s are found as individuals or as tree groups with adjacent crowns. Next to *Acacia's* also *Eucalyptus* sp. trees are present, situated beside the road (North-South orientation) and in some dense plantations close to the *Bordj*. In order to sample both *Acacia* tree forms including different tree diameter classes, > 400 *Acacia tortilis* trees were randomly sampled. Using a Garmin GPSMap 60Cx, tree coordinates were determined and stored in UTM units (WGS 84). Tree bole diameter was measured at two reference heights (1.30 m and 0.10-0.15 m above the ground). A second measured tree attribute was total tree height, through the use of a clinometer. Errors associated with height measuring were lower than 2 % on straight terrain objects. However field conditions will probably increase the error, but it is to be expected that error will remain in the range of 2 % - 5 %, which is the average error reported in Needham & Peasly (2003). Crown diameter was also measured in two perpendicular directions (North-South and East-West direction). For tree groups, only total crown diameter was measured, as it was not possible to discriminate individual crowns. As no statistical differences between these two directions were found, the arithmetical mean was calculated and used in further analysis. To increase efficiency in data analysis, all measurements were normalized (Groh et al, 2007) and entered in a relational database using *Microsoft Office Access 2007.*

3. METHODOLOGICAL FRAMEWORK

In order to estimate total tree height and crown diameter, a Geographic Object-Based Image Analysis (GEOBIA) approach is adopted consisting of 1) a sensor-specific analysis followed by 2) a scene-specific analysis (Benz et al., 2004). As the basic units of object-based image analysis are image objects (and not single pixels), these objects have to be created in the sensor-specific analysis step. This can be accomplished by applying segmentation algorithms, of which multiple variants exist (Schiewe, 2002). For each resulting object, several object features relating to object shape, texture and spectral reflectance are computed, which are employed for subsequent modeling and classification. The classified objects (trees) are then used for a scene-specific analysis, i.e. the estimation of tree attributes through the modeled relationships. In our study the image analysis is performed within Definiens eCognition Developer 8 (Definiens, 2009a). The subsequent analysis steps are segmentation, computation of object features and classification. For accuracy assessment, the sampled trees were also manually delineated.

3.1.1 Segmentation: Segmentation or the subdivision of an image into separate regions, is the first step of the image analysis. The goal is to find regions of minimum heterogeneity (or maximum homogeneity) (Benz et al., 2004). Definiens provides multiple segmentation algorithms, each with different strengths for different applications (Definiens, 2009a). Distinction is made between top-down and bottom-up strategies. The former cuts bigger regions into smaller sub-regions, while the latter merges smaller pieces to get a larger area. For the analysis of the GeoEye-1 image, two different algorithms are sequentially used. First a *multiresolution segmentation* (bottom-up) is executed followed by a *contrast split segmentation* (top-down). For a description of the algorithms and their parameters we refer to Definiens (2009b) and Benz et al. (2004).

3.1.2 Computation of object features: Based on field measurements relationships are established between measured tree attributes and computed object features. The established relationships are then used to model the tree attributes for all objects classified as *Acacia* in the subsequent classification stage.

3.1.3 Classification: Through *Feature Space Optimization* (FSO), the combination of object features which are most suitable to separate different categories is assessed. FSO is a algorithm that compares the features of selected classes to find the combination of features that produces the largest average minimum distance between the samples of the different classes. For the samples, object statistics of the optimized feature space are calculated, which are then used for classifying all image objects based on their nearest sample neighbours (Nearest Neighbour (NN) classification). The same set of features is applied to all classes (Standard NN). For a full description see Definiens (2009a).

The objective of our study is to define object features that can be used as reliable estimators for tree attributes like bole diameter, total tree height and crown diameter. This paper presents some preliminary results related to crown diameter and total tree height estimation.

4. PRELIMINARY RESULTS AND DISCUSSION

4.1 *Segmentation*

For both the *multiresolution* and *contrast split segmentations* the algorithms' parameters are determined by trial and error on a subset of the image. Best segmentation results are acquired by solely using the panchromatic band (mainly driven by its more suitable spatial resolution in the context of individual tree delineation). After several applications of the *multiresolution segmentation* algorithm with different scale parameters, a scale parameter of 40 was considered optimal. The homogeneity criterion is determined by two parameters: shape and compactness. These are respectively set to 0.2 and 0.5. This results in an initial segmentation, correctly delineating larger trees. However smaller trees are not segmented, but are included in larger segments with multiple smaller trees and soil/vegetation in between. Therefore a sequential segmentation is performed on the initial segments. For the greater part *contrast split segmentation* is able to isolate smaller trees (Figure 2). The split is based on the contrast present in the panchromatic band using the parameters mentioned in Table 1 (for a full description of parameters we refer to Definiens (2009b)). Comparison of manually delineated tree polygons and segmentation results, reveals that the manually delineated polygons overestimate crown diameter or segmentation gave a more reliable crown isolation. Furthermore, trees with a crown diameter < 3.5 m are often not correctly isolated, although manual delineation is possible.

Parameter	Value
Contrast mode	Edge difference
Minimum relative area dark	0.1
Minimum relative area bright	0.1
Minimum contrast	0
Minimum object size	10

Table 1: Parameters used for *contrast split segmentation*

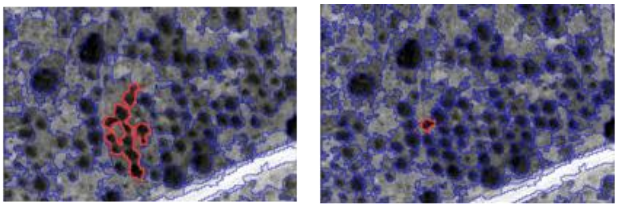

Figure 2: Results of the initial *multiresolution segmentation* (left) and subsequent *contrast split segmentation* (right) (for used parameters see text)

4.2 *Crown diameter estimation*

If tree attributes are to be estimated from features derived from the GeoEye-1 image at the object level, models have to be empirically built based on field measurements. As segmentation errors occur, especially for trees smaller than 3.5 m, those segments are eliminated from the dataset before modeling. After elimination, 344 trees (scattered over the entire study area) remained in the dataset. This dataset is randomly divided in a training and test set, respectively 226 and 118 data points. More than 200 features are thereafter extracted from the *Acacia* objects for both the training and test set (e.g. elliptic fit, number of pixels, texture measures (Haralick, 1973), …). For each of these features, correlations are calculated with measured tree attributes.

Based on the computed object features, we first tried to discriminate between tree groups and tree individuals. As only 39 tree groups are present in the dataset, no test set is used for this part of the analysis. Low correlations are found between the Boolean variable *group* and the calculated object features. Decision tree analysis is used to distinguish between tree groups and tree individuals. However, no satisfying results are found as only 19 of 39 tree groups are successfully identified. Hence, none of the extracted features could be considered meaningful for the discrimination between tree groups and individuals.

On the contrary, a high correlation is found between the crown diameter (CD) and the feature *area* of the *Acacia* segments, which is calculated as the number of pixels. Based on the theoretic relation between crown area and crown diameter, a power function is fitted through the training data points (Figure 3). The regression results in equation (1), with a R^2 of 0.64 and RMSE of 1.67 m (MAPE of 21.6 %).

$$CD\ (m) = 0.9095 \times area^{0.4183} \tag{1}$$

Additionally, the correlation dataset also revealed a strong relationship between the feature *area* and *GLCM entropy layer 4 (90°)* (with layer 4 being the NIR band and 90° the horizontal direction for calculation based on GLCM). The observed relationship is exponential (Figure 4). Regression results in equation (2), with a R^2 equal to 0.96 and a RMSE of 14.7 pixels (MAPE of 13.0 %).

$$area\ (pixels) = 1.8367 \times e^{1.2718 \times GLCM\ entropy\ layer\ 4\ (90^\circ)} \tag{2}$$

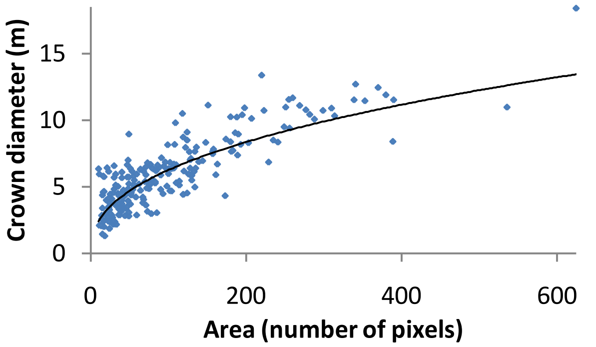

Figure 3: Estimation of Crown diameter using the *area* feature

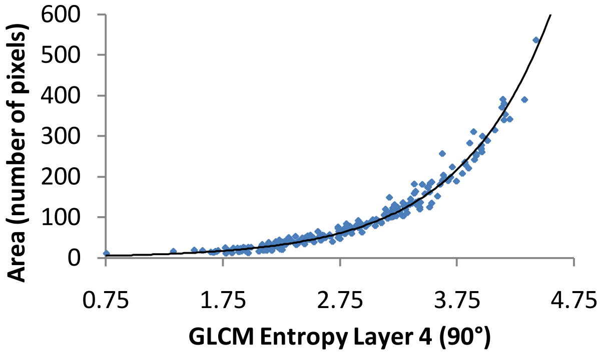

Figure 4: Relation between *GLCM Entropy Layer 4 (90°)* and *area*

As both equation (1) and equation (2) feature acceptable RMSE values, both equations are combined to build a model, directly predicting crown diameter based on *GLCM Entropy Layer 4 (90°)* (equation (3), Figure 5). The RMSE between predicted and measured crown diameter is 1.61 m (MAPE of 22.0 %).

$$CD\ (m) = 1.1758 \times e^{0.5320 \times GLCM\ entropy\ layer\ 4\ (90^\circ)} \tag{3}$$

When crown diameter classes for the test set are visualised in a histogram (Figure 6), derived diameter classes through our models show acceptable results. An overestimation of crown diameter class]4,6] is however observed for both models.

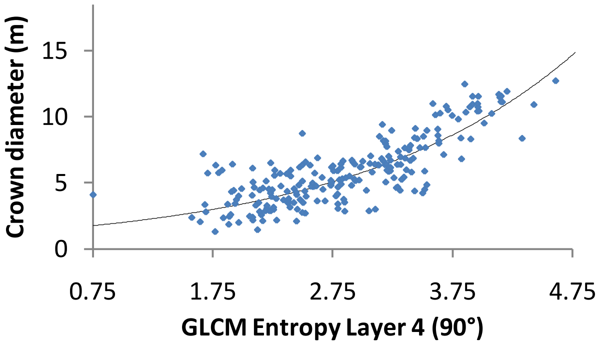

Figure 5: Estimation of Crown Diameter using the GLCM Entropy Layer 4 (90°) feature

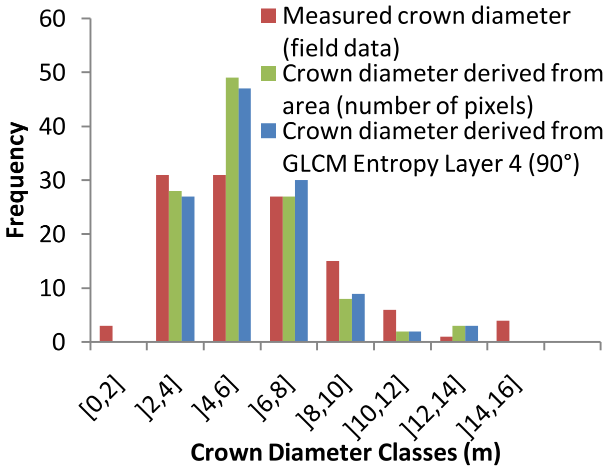

Figure 6: Measured versus derived crown diameter classes

4.3 *Tree height estimation*

When focusing on tree height, the correlation dataset shows a high correlation between tree height and the features *area* and *GLCM Entropy Layer 4 (90°)*. Considering the high correlation between both features, analogous reasoning leads to a model for the estimation of tree height through the entropy feature (equation (4), Figure 7). A RMSE value of 0.92 m was found, with a MAPE of 20 %. Comparison of derived versus measured three heights show good resemblance. Smaller tree heights were however not detected with our model (Figure 8).

$$tree\ height\ (m) = 1.3822 \times e^{0.3689 \times GLCM\ entropy\ layer\ 4\ (90^\circ)} \tag{4}$$

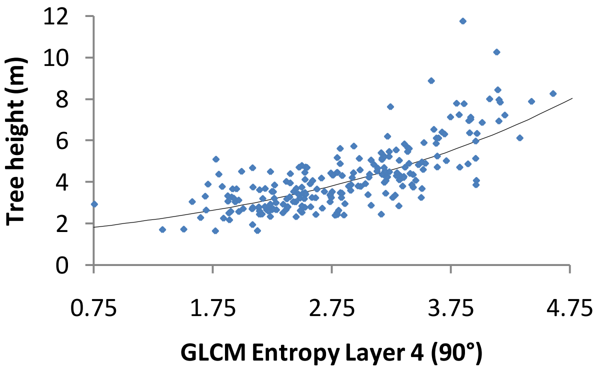

Figure 7: Estimation of tree height using the GLCM Entropy Layer 4 (90°) feature

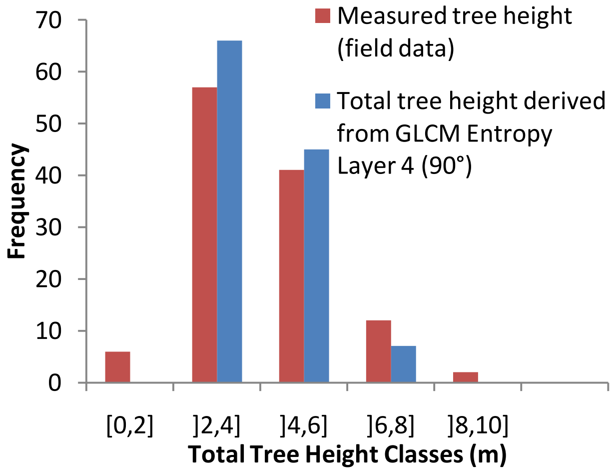

Figure 8: Measured versus derived tree height classes

4.4 *Classification*

Finally the models can be used to estimate crown diameter classes of all Acacia trees at BHNP. Therefore *Acacia* trees have to be identified on the image, through classification. At this stage, a presentation of a full image classification was not yet possible as the classification process is still running (estimated computational time of one week). However, classification of the small image subset already shows the NN algorithm is performing very well (Figure 10). As the *Acacia*'s have to be separated from the soil polygons and other vegetation such as *Eucalyptus* sp., three classes of interest are considered. All 38 Acacias present in the image subset were used as training samples, while resp. 16 Eucalyptus and 31 soil samples were manually selected. Through FSO an optimal feature set of 34 object features (out of 20 categories) was determined (Figure 9). In Table 2, feature categories used for classification are listed. The Forest Discrimination Index (FDI) (Bunting & Lucas, 2006) was adjusted for the GeoEye-1 image (FDI=NIR-(R-B)).

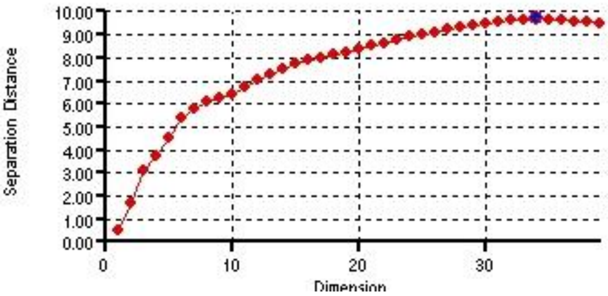

Figure 9: Result chart of *Feature Space Optimization*

Table 2: Feature categories used for classification

Type	Feature
Customized	FDI, SAVI, NDVI
Layer Values	Mean, Min, Max, Mean of outer border, Border contrast, Contrast to neighbor pixels, Edge contrast of neighbor pixels, StdDev to neighbor pixels, Circular mean
Geometry	Assymetry, Density, Compactness
Texture after Haralick	Homogeneity, Mean, Correlation, Ang 2nd moment, Entropy

The three classes of interest are rendered in colours with *Eucalyptus* sp. in red, *A. tortilis* subsp. *raddiana* in green and soil in brown. The remaining non classified image objects are buildings and roads (Figure 10). Because of the limited number of *A. tortilis* samples, no test samples were selected (all of them were used for training). However only statistics of the samples are used in the classification process (samples are not automatically assigned to their class). Therefore a (biased) accuracy assessment is performed yielding a KIA of 1 indicating that all samples were correctly classified

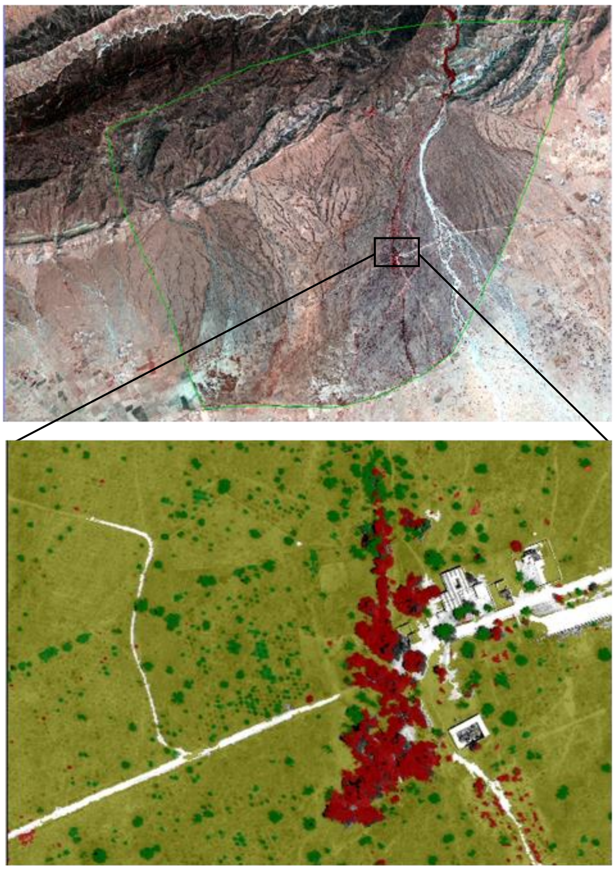

Figure 10: Study area (above) and classification of image subset (red = *Eucalyptus sp.*, green= *Acacia tortilis subsp. raddiana*, brown=soil).

5. CONCLUSIONS

As local climate change is potentially caused by the reforestation and afforestation programs in Bou-Hedma, it is important to understand the impact. However in order to do so, number of trees and tree attributes have to be known. Preliminary results showed that the presented GEOBIA approach is suitable for the estimation of crown diameters and total tree height of *Acacia* trees. Two consecutive segmentation algorithms (*multiresolution segmentation* followed by *contrast split segmentation*) resulted in satisfying crown delineations for both large and small crowns. However errors occurred, especially for crown diameters smaller than 3.5 m. Differentiation between tree groups and tree individuals, through the use of decision tree analyses, was however not successful (error of about 50 % for tree groups). Both *area* (number of pixels) and the *GLCM Entropy Layer 4 (90°)* features were found suitable to estimate the different crown diameter classes, with RMSE values of 1.67 m and 1.61 m respectively. A model to estimate tree height based on the *GLCM Entropy Layer 4 (90°)* resulted in a RMSE value of 0.92 m. Classification of the segmented objects through a *Nearest Neighbor Classification* on a subset of the image, showed promising results. Classification of the full image is to be completed in the near future. In order to be able to claim that the GEOBIA method is a robust technique in estimating tree attributes in the open deciduous forest of Southern Tunisia, more extensive and in-depth research is planned, including the estimation of additional tree attributes, such as bole diameter.

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