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# Spatial and thematic assessment of object-based forest stand delineation using an *OFA-matrix*

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The delineation and classification of forest stands is a crucial aspect of forest management. Object-based image analysis (OBIA) can be used to produce detailed maps of forest stands from either orthophotos or very high resolution satellite imagery. However, measures are then required for evaluating and quantifying both the spatial and thematic accuracy of the OBIA output. In this paper we present an approach for delineating forest stands and a new *Object Fate Analysis (OFA) matrix* for accuracy assessment. A two-level object-based orthophoto analysis was first carried out to delineate stands on the Dehesa Boyal public land in central Spain (Avila Province). Two structural features were first created for use in class modelling, enabling good differentiation between stands: a relational *tree cover cluster* feature, and an arithmetic *ratio shadow/tree* feature. We then extended the OFA comparison approach with an *OFA-matrix* to enable concurrent validation of thematic and spatial accuracies. Its diagonal shows the proportion of spatial and thematic coincidence between a reference data and the corresponding classification. New parameters for Spatial Thematic Loyalty (*STL*), Spatial Thematic Loyalty Overall ($STL_{OVERALL}$) and Maximal Interfering Object (*MIO*) are introduced to summarise the *OFA-matrix* accuracy assessment. A stands map generated by OBIA (classification data) was compared with a map of the same area produced from photo interpretation and field data (reference data). In our example the *OFA-matrix* results indicate good spatial and thematic accuracies (>65%) for all stand classes except for the *shrub stands* (31.8%), and a good $STL_{OVERALL}$ (69.8%). The *OFA-matrix* has therefore been shown to be a valid tool for OBIA accuracy assessment.



## 1. Introduction

Appropriate management of a forest area is dependent on knowledge of its composition. The basic unit used for forest planning is the stand, which comprises any homogenous patch of vegetation that is distinct from adjacent stands in species composition, structure, and future management possibilities (Hernando et al., 2010). Stands have traditionally been delineated visually from aerial photographs by human pattern recognition, and then interpreted with the support of local field data and inventories (tree diameters, heights, crown sizes, etc.) and additional observations. This method is time consuming, subjective, and expensive. New cost-effective techniques are therefore required to supplement, and eventually replace, the traditional methods (Tiede et al., 2004; Petr et al., 2010; Pascual et al., 2008). Many recent studies have used object-based image analysis (OBIA) to characterise forest stands (Tiede et al., 2004; Petr et al., 2010; Radoux and Defourny, 2007; Hay et al., 2005; Flanders et al., 2003; Laliberte et al., 2007; Laliberte et al., 2004). They achieved satisfactory results compared to pixel-based methods and have enhanced the utility and versatility of *eCognition* software (Definiens Imaging GmbH, 2002). Latterly, most attempts at stand mapping have used Light Detection and Ranging (*LiDAR*) data, achieving good results in most cases (Tiede et al., 2004; Petr et al., 2010; Pascual et al., 2008; Wulder et al., 2008; Arroyo et al., 2010; Suarez et al., 2005). Airborne *LiDAR* data are, however, expensive and not always available. Fortunately, other alternatives are available for stand discrimination. Digital colour-infrared orthophotos (50 cm resolution) have recently become available in Spain through the National Plan for Aerial Orthophotography (PNOA) (Gallego Priego et al., 2010). New specialised techniques are therefore required for stand mapping from orthophotos.

OBIA offers a relatively new approach for producing land cover maps, providing automated methods for the analysis of very high resolution images. In contrast to the traditional pixel-based approach, OBIA describes the imaged reality using spectral, textural, spatial, topological, and hierarchical object characteristics (Blaschke, 2010; Lang, 2008). Use of this new method, however, raises concerns about subsequent validation strategies, since the

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classic point-based sampling strategies do not rely on the same concept of objects (Radoux et al., 2010). Accuracy assessment of object-based maps should include both thematic (difference in assigned labels) and spatial (difference in delineated object boundaries) components. New methods are therefore required for OBIA accuracy assessment, based specifically on the concept of objects (Lang et al., 2010; Albrecht, 2010).

### 1.1. Thematic and spatial accuracy

With regard to thematic accuracy, a review of 20 recent papers on OBIA revealed that error matrix was still used in most cases (60%) (Radoux et al., 2010). This matrix and its derived statistics, such as user's and producer's accuracy or Kappa coefficient, provide information on the quality of thematic maps (Congalton and Green, 1999). Compared to these established measures for pixel-based accuracy assessment, a state-of-the-art approach for object-based accuracy assessment is not available up to now. Nevertheless, some progress has been made towards this goal. Van Coillie et al. (2008) developed a "Potential Mapping Accuracy" measure for assessing (with a binary variable) the number of correctly classified pixels within each segment (Van Coillie et al., 2008). Radoux et al. (2010) proposed an object-based sampling strategy for thematic accuracy assessment using an error matrix. One of the advantages of this predictor over other approaches lies in the minimised sampling effort involved.

With regard to spatial accuracy, objects boundaries are more critical in OBIA than in a traditional pixel-based approach (Albrecht, 2010). Radoux and Defourny (2007) showed that the two main sources of spatial error were residual parallax and automatic segmentation. Both were assessed using simple statistics, bias, and standard deviation (Radoux and Defourny, 2007). Object Fate Analysis (OFA) is a method presented by Schöpfer et al. (2008) for investigating the spatial relationships between corresponding objects in two different representations. In OFA the topological relationships between overlapping objects are categorised by an error band and by evaluating whether or not the centroid of the classification object falls inside the reference object (Tiede et al., 2010). Two stability measures, offspring loyalty and interference (Schöpfer et al., 2008), combine the relationships between objects to describe their spatial correspondence, both having ranges from 0 to 1. The first of these measures describes how correctly the objects are delineated and the second indicates those objects that have no overlap with the reference object. Van Coillie et al. (2008) proposed a Purity Index, a simple measure based on the shared area between segmentation objects and reference objects. Clinton et al. (2010) reviewed vector-based measures (area-based, location-based, and a combination of both), calculating the similarities between segments and training objects. Johnson and Zhixiao (2011) proposed two goodness measures for optimal segmentation: global intra-segment homogeneity (the variance of each object), and inter-segment heterogeneity (how similar a region is to its neighbours). Both were calculated for each of the three spectral bands (Johnson and Zhixiao, 2011).

All previous methods summarised spatial quality and have therefore been able to complement other thematic accuracy assessments, and vice versa. While this has been proposed by some authors (Radoux and Defourny, 2007; Van Coillie et al., 2008; Radoux et al., 2011), none of the above studies undertook both thematic and spatial accuracy assessment simultaneously, but rather as complementary measures. Further developments based explicitly on the concept of objects are therefore clearly necessary. In this paper we describe an approach for identifying forest stands from digital orthophotos using OBIA and propose extending the OFA approach by using an *OFA-matrix* for simultaneous validation of thematic and spatial accuracy.

## 2. Study area and data sets

### 2.1. Study area

The study area is the public Dehesa Boyal forested area (815 ha) in the Ávila Province of the Castilla y León Region, central Spain (Fig. 1). It occupies flat or gently sloping land (slopes 5–12%) between 1220 and 1395 m. The area has a temperate Mediterranean climate with hot dry summers, cool, damp winters. This site has been designated as Special Area of Conservation "Pinares del bajo Alberche" within the European Commission's Natura 2000 Mediterranean biogeographical region because of habitats listed in the first annex of the Habitat Directive (92/43/EEC).

Most of the area is covered by *Quercus pyrenaica* (Habitat code: 9230) and pasture. *Q. pyrenaica* Willd. is a marcescent white oak tree species widely distributed throughout the Iberian Peninsula. It has traditionally been pruned and felled to provide firewood and cattle forage. Consequently today it forms a coppice forest with various different types of stands. Stands are forest management units (usually 10–30 ha) with similar attributes such as species composition, density, closure, height, and age (Van Coillie et al., 2008). From field work we can distinguish the following stands (Fig. 2): (i) *shrubs* (<1 m high) which are very palatable to cattle and are continuously browsed, (ii) *low polewood* (>1 m high), with a diameter breast height (DBH) < 10 cm, (iii) *high polewood* (10 cm < DBH < 20 cm), (iv) *high forest* (20 cm < DBH < 35 cm), characterised by the largest trees in the forest, and (v) *coppice tall shrubs*, with groves of stump shoots forming scattered circular groups within grassland (Hernando et al., 2010).

### 2.2. Data sets

For our research a digital orthophoto (1372 ha) covering the study area was downloaded from the National Geographic Institute of Spain (Fig. 1). The PNOA produces (for free download) digital colour-infrared orthophotos (1:5000) with 50 cm pixel size and 16 bits radiometric resolution. The photogrammetric flight with digital camera navigation (Digital Mapping Camera S/N: 0037) using GPS provides 4 bands in red, green, blue, and near-infrared (R, G, B, NIR) in the European Terrestrial Reference System 1989 (ETRS89).

## 3. Methods

### 3.1. Stands mapping

Our approach to mapping stands, and its validation through an *OFA-matrix*, was based on the OBIA concept. OBIA offers a methodological framework for automated interpretation of complex classes defined by spectral, textural, spatial, and hierarchical object properties (Lang, 2008; Benz et al., 2004). OBIA interlinks two main phases, often in a cyclic process: (i) segmentation, which creates objects using a scale parameter and one or more criteria of homogeneity, and (ii) classification, encoding and relating the relevant intrinsic spectral and spatial properties in the image (Tiede et al., 2010). For our investigations we used the *Definiens Developer 8* software (Definiens, 2010), which has recently been acquired by Trimble and renamed *eCognition*. For segmentation we used the *multiresolution segmentation algorithm*, which consecutively merges pixels or existing objects (Baatz and Schäpe, 2000). The main algorithms that we used for classification were the *assign class algorithm*, which uses threshold conditions to determine whether or not an image object belongs to a particular class, and the