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Assessing the potential of multi-seasonal high resolution Pléiades satellite imagery for mapping urban tree species

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ABSTRACT

This study evaluated the potential of five seasonal high resolution Pléiades satellite images for improving urban tree species classification in the City of Tampa, FL, USA. We assessed and compared the capabilities of individual and combined Pléiades images acquired during different seasons for classifying the urban tree species to understand the seasonal effect on tree species mapping accuracy. The seven species and groups included sand live oak (*Quercus geminata*), laurel oak (*Q. laurifolia*), live oak (*Q. virginiana*), pine (species group), palm (species group), camphor (*Cinnamomum camphora*), and magnolia (*Magnolia grandiflora*). A multi-level classification system was adopted to classify image objects of the tree species and groups. Species classification performance was compared between the five individual seasonal Pléiades images, between two combined dry-wet season images, and between the optimal single season and combined dry-wet season image data. Shade image objects were spectrally normalized to similar sunlit image objects. The tree species fraction features were extracted from the seasonal images using the Mixture Tuned Matching Filtering approach and used as additional features to a set of spectral and spatial/textural features. Random Forest, Support Vector Machine and Linear Discriminant Analysis classifiers were used to classify the seven tree species and groups with image objects features. The experimental results indicate significantly improved tree species mapping accuracies using late spring season (April) image compared to all other seasonal images ($p < 0.01$), and combined dry-wet season images performed even better. Results suggest a significant seasonal effect on tree species classification. The results also demonstrate that the Random Forest outperformed the Support Vector Machine and Linear Discriminant Analysis classifiers for tree species classification. Therefore, in practice, it is important to choose appropriate seasonal remote sensing data for mapping tree species.

1. Introduction

During the last two decades, very high resolution (VHR) satellite remote sensing has demonstrated its potential for comprehensive and detailed mapping and classification of forest traits such as tree canopy cover and species composition (*e.g.*, Ustin and Gamon, 2010; Pu and Landry, 2012; Karlson et al., 2016). However, classification of urban forest cover types and species using VHR satellite imagery remains challenging in urban areas due to some of the inherent characteristics of urban environments. These characteristics may include the high heterogeneity of urban surface cover types (Du et al., 2012; Gu et al., 2015), the high frequency of shaded and shadow areas (hereafter referred to as shade) caused by trees and buildings (Chen et al., 2007; Pu and Landry, 2012; Adeline et al., 2013), and the abundant biodiversity and high complexity of urban forests compared to natural and planted forests.

One of the major problems using VHR satellite imagery for fine-scale land cover classification is due to the increasing number of detectable class elements (pixels) and thus a within-class (*e.g.*, within a tree crown) spectral variance. This can increase classification error, leading to a so-called "salt-and-pepper" effect when a pixel-based classification method is used (Du et al., 2012). For example, when the spectral response of tree crowns is affected by complex background and various illumination conditions in an urban area, the use of VHR imagery for mapping detailed urban tree species needs to consider spectral variation within tree crowns. In practice, many studies have indicated that using VHR imagery with pixel-based tree species classification approaches might result in a relative low mapping accuracy (*e.g.*, Wang et al., 2004; Goodwin et al., 2005; Chubey et al., 2006; Johansen and Phinn, 2006; Ke and Quackenbush, 2007). To overcome this problem, many researchers (*e.g.*, Carleer and Wolff, 2006; Blaschke, 2010) have investigated and developed an Object-Based Image Analysis (OBIA) classification method. The OBIA method first segments a pixel-based image into image objects (IOs) within which spectral and spatial/

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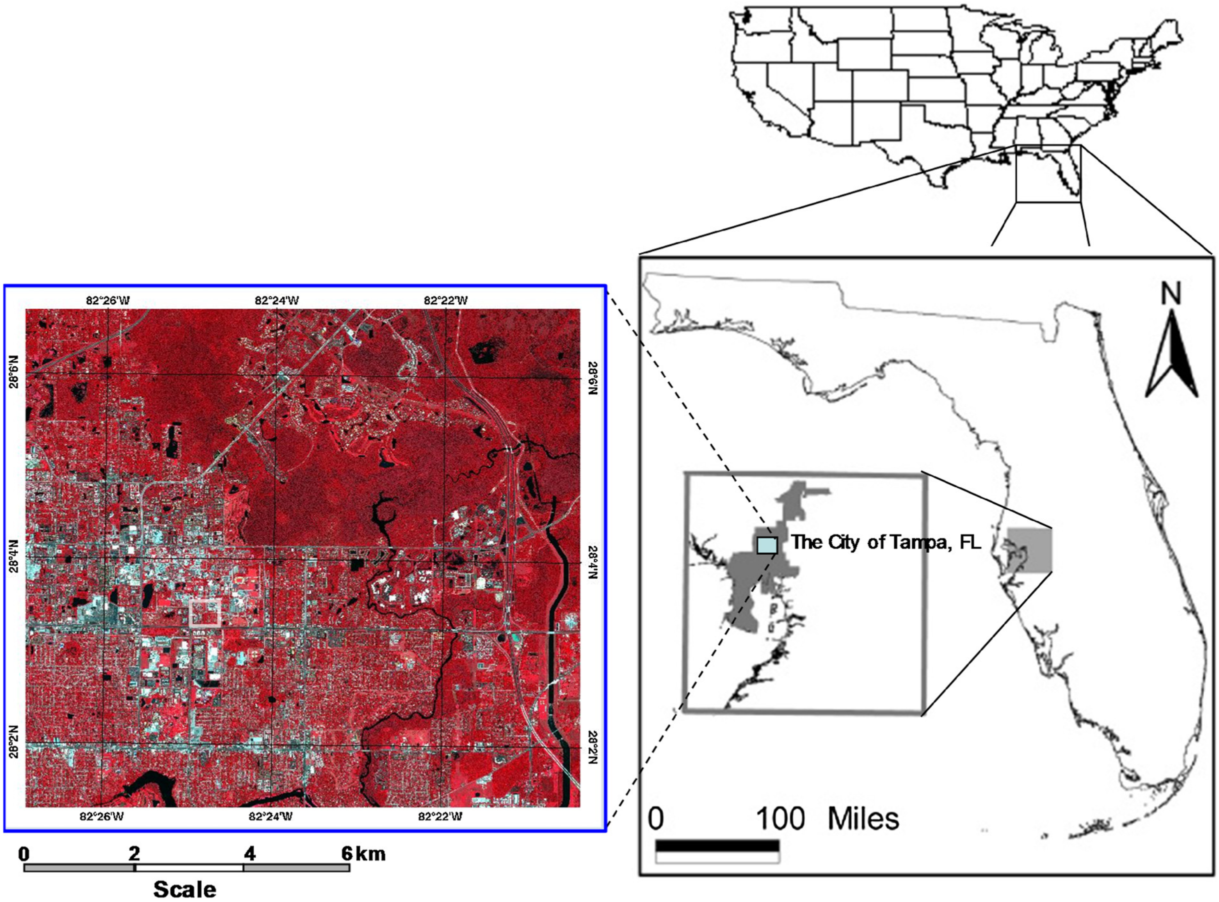

Fig. 1. A study area map. The pseudo-color composite image that covers the study area was made with Pleiades bands 4, 3, 2 *vs*. R/G/B. The gray box in the composite image presents the location of a composite image and tree species maps in Fig. 5.

textural characteristics are relatively homogeneous, and then an image classification process is based on the IOs as a mapping unit. Using an OBIA method can potentially increase classification accuracy compared with a pixel-based method when using VHR imagery. Many studies have demonstrated the effectiveness of the OBIA approach in mapping vegetation structure and classifying tree species. For example, compared to the pixel-based approaches, the use of the OBIA methods with different VHR satellite images (including QuickBird, IKONOS, and WorldView-2, *etc*.) has been demonstrated to improve tree species classification and mapping results (*e.g.*, Ke and Quackenbush, 2007; Kim et al., 2011; Pu, 2011). Other studies that support this point also include Yu et al. (2006); Mallinis et al. (2008); Stow et al. (2008); Voss and Sugumaran (2008), and Kaszta et al. (2016).

Given the abundant biodiversity and heterogeneity of forests and vegetation in an urban environment, the use of multi-season VHR image data to map urban forest type and species composition may be expected to outperform the use of a single date image. Many researchers have demonstrated this point (*e.g.*, Pu and Landry, 2012; Li et al., 2015; Karlson et al., 2016; Kaszta et al., 2016; Madonsela et al., 2017). For examples, Li et al. (2015) explored the potential of two-season WorldView-2 (WV2) (Sept. 14, 2012) and WorldView-3 (Oct. 18, 2014) for identifying five dominant urban tree species in the City of Beijing, China, with Support Vector Machines (SVM) and Random Forest (RF) algorithms. They reported that the two-season VHR image data were much better than the corresponding single-date image data in mapping the tree species. Karlson et al. (2016) used a RF algorithm and OBIA method to investigate the capability of two-season WV2 imagery for mapping five dominant tree species at a single tree level in West Africa. Their results indicated that the two-season dataset produced a better result than single date images for mapping tree species, with an overall accuracy (OA) of 83.4%. They also found that dry season imagery (OA = 78.4%) produced a better result than the wet season imagery (OA = 68.1%). In addition, Madonsela et al. (2017) examined whether two-season WV2 images could improve discriminating between four dominant tree species in the southern African savannah environment. They concluded that (1) the use of multi-season images acquired at key points of phenological development of savannah tree species improved tree species classification beyond what could achieved using individual date images; and (2) the transition period from green canopy to senescence provided a better opportunity for tree species than the peak productivity period.

Our literature review indicates the need for continued investigation on tree species classification and mapping using VHR satellite images with the OBIA method. More work is particularly needed to further test the usefulness of these methods for mapping tree species in the urban environment. Moreover, the use of appropriate seasonal data may be an advisable option to overcome the effects of the phenology, variations of tree canopy structure and shadow, and others on mapping forest type and species composition in the urban environment. However, based on our knowledge, previous studies that explored the potential of multi-season VHR satellite sensors for mapping forest types and tree species were limited to using only two-season data (*e.g.*, wet and dry seasons). Therefore, it is necessary to assess the potential of using more than two seasons VHR data for classifying and mapping forest types and species composition in order to fully understand seasonal effects on tree species mapping accuracy. In addition, given the problem of shade effects on

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