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A review of supervised object-based land-cover image classification

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ABSTRACT

Object-based image classification for land-cover mapping purposes using remote-sensing imagery has attracted significant attention in recent years. Numerous studies conducted over the past decade have investigated a broad array of sensors, feature selection, classifiers, and other factors of interest. However, these research results have not yet been synthesized to provide coherent guidance on the effect of different supervised object-based land-cover classification processes. In this study, we first construct a database with 28 fields using qualitative and quantitative information extracted from 254 experimental cases described in 173 scientific papers. Second, the results of the meta-analysis are reported, including general characteristics of the studies (e.g., the geographic range of relevant institutes, preferred journals) and the relationships between factors of interest (e.g., spatial resolution and study area or optimal segmentation scale, accuracy and number of targeted classes), especially with respect to the classification accuracy of different sensors, segmentation scale, training set size, supervised classifiers, and land-cover types. Third, useful data on supervised object-based image classification are determined from the meta-analysis. For example, we find that supervised object-based classification is currently experiencing rapid advances, while development of the fuzzy technique is limited in the object-based framework. Furthermore, spatial resolution correlates with the optimal segmentation scale and study area, and Random Forest (RF) shows the best performance in object-based classification. The area-based accuracy assessment method can obtain stable classification performance, and indicates a strong correlation between accuracy and training set size, while the accuracy of the point-based method is likely to be unstable due to mixed objects. In addition, the overall accuracy benefits from higher spatial resolution images (e.g., unmanned aerial vehicle) or agricultural sites where it also correlates with the number of targeted classes. More than 95.6% of studies involve an area less than 300 ha, and the spatial resolution of images is predominantly between 0 and 2 m. Furthermore, we identify some methods that may advance supervised object-based image classification. For example, deep learning and type-2 fuzzy techniques may further improve classification accuracy. Lastly, scientists are strongly encouraged to report results of uncertainty studies to further explore the effects of varied factors on supervised object-based image classification.

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1. Introduction

In recent years, with advances in remote sensing data acquisition technologies and the increased demand for remote sensing applications, high spatial resolution remote sensing data is steadily becoming more widespread (Belward and Skøien, 2015). This includes satellite (e.g., WorldView, Gaofen, SuperView) and aerial (e.g., unmanned aerial vehicle (UAV)) remote sensing data. The availability and accessibility of vast amounts of high-resolution remote sensing data have created a challenge for remote sensing image classification. As a result, object-based image analysis (OBIA) techniques have emerged to address these issues. The OBIA technique has now replaced the traditional pixel-based method as the new standard method (Blaschke et al., 2014) that will facilitate land-cover classification from high spatial resolution remote sensing imagery. However, it has not yet been quantitatively verified, although consensus appears to have been achieved amongst numerous researchers (Cleve et al., 2008; Myint et al., 2011; Duro et al., 2012a; Tehrany et al., 2014).

Over almost the last twenty years, the remote sensing community has undertaken considerable efforts to promote the use of object-based technology for land-cover mapping (Blaschke and Strobl, 2001; Blaschke et al., 2004; Walker and Blaschke, 2008). The first biennial international conference on OBIA was held in Salzburg, Austria in 2006. It is the most influential international event to date in the OBIA community, and the six conferences have, undoubtedly, considerably promoted the development of OBIA techniques and applications (Hay and Castilla, 2008; Powers et al., 2012; Arvor et al., 2013; Costa et al., 2014; Blaschke et al., 2014). Thanks to the publication of special issues on OBIA in various journals, e.g., the special issue "Geographic Object-Based Image Analysis (GEOBIA)" for journal "Photogrammetric Engineering & Remote Sensing" (Hay and Blaschke, 2010), and the special issue "Advances in Geographic Object-Based Image Analysis (GEOBIA)" for journal "Remote Sensing" (http://www.mdpi.com/journal/remotesensing/special_issues/geobia#editors, 2014), supervised object-based classification techniques have been an integral part of remote sensing research related to land-cover mapping since 2010 (Myint et al., 2011; Dronova et al., 2011; Duro et al., 2012a; Puissant et al., 2014; Ma et al., 2015; Li et al., 2016).

Generally, land-cover mapping is a complicated process with numerous factors influencing the quality of the final product (Khatami et al., 2016). For supervised object-based classification processes, many options must be selected, including image type, segmentation method, accuracy assessment, classification algorithm, training sample sets, input features, and target classes. To deal with these uncertainties, many researchers have devised supervised object-based classification methods that are specifically adapted to individual study areas, which are further compared with existing methods and processes, thereby validating their applicability. However, due to variations between study areas, it is difficult to derive generalized research results. Namely, a certain method may exhibit good classification accuracy and be applicable to a certain study area, yet derive inconsistent results in other study areas. For example, it was already proved that the K-Nearest-Neighbors (K-NN) method generally performed better for land-cover mapping than Decision Tree (DT) and Support Vector Machines (SVM) methods using SPOT 5 images (Tehrany et al., 2014), whereas a superior capability for producing higher classification accuracies using SPOT 5 images in agriculture areas with SVM or Random Forest (RF) methods was demonstrated by Duro et al. (2012a). Therefore, it is important to determine which classification process is the most promising and how various uncertainties affect classification performance. To do this, it is necessary to synthesize the collective knowledge on this topic, as opposed to using individual experience and expertise.

Past review articles have provided useful descriptive summaries and guidelines for the general object-based image analysis technique (Blaschke, 2010; Blaschke et al., 2014), which have focused on the review of more extensive OBIA techniques, including change detection. However, in recent years, supervised classification has shown rapid advances, and thus more and more issues have arisen. Hence, this review presents a summary of the advances in current supervised object-based classification techniques and examines future development prospects. Although the literature on object-based image analysis classification was already reviewed by Dronova (2015), the classification objects of concern only included wetlands. Furthermore, they also reviewed literature on object-based fuzzy rule-based classification, which generated considerable limitations in their research because substantial discrepancies remain between fuzzy rule-based classification and supervised classification.

Meta-analysis techniques provide a unique chance to integrate results from peer-reviewed studies rather than simply describing the results, and therefore allow us to quantitatively or qualitatively assess the patterns and relationships of an effect (e.g., classification performance) due to uncertain factors (e.g., sensor type, classification algorithm, and other variables of interest) (Chirici et al., 2016). In recent years, meta-analysis of remote sensing applications from various perspectives has provided reliable scientific guidance for