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An object-based approach to delineate wetlands across landscapes of varied disturbance with high spatial resolution satellite imagery ☆

Amy Mui [a,*], Yuhong He [a], Qihao Weng [b]

[a] Department of Geography, University of Toronto Mississauga, 3359 Mississauga Road, Mississauga, Ontario L5L 1C6, Canada
[b] Center for Urban and Environmental Change, Department of Earth & Environmental Systems, Indiana State University, Terre Haute, IN 47809, USA

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ABSTRACT

Mapping wetlands across both natural and human-altered landscapes is important for the management of these ecosystems. Though they are considered important landscape elements providing both ecological and socioeconomic benefits, accurate wetland inventories do not exist in many areas. In this study, a multi-scale geographic object-based image analysis (GEOBIA) approach was employed to segment three high spatial resolution images acquired over landscapes of varying heterogeneity due to human-disturbance to determine the robustness of this method to changing scene variability. Multispectral layers, a digital elevation layer, normalized-difference vegetation index (NDVI) layer, and a first-order texture layer were used to segment images across three segmentation scales with a focus on accurate delineation of wetland boundaries and wetland components. Each ancillary input layer contributed to improving segmentation at different scales. Wetlands were classified using a nearest neighbor approach across a relatively undisturbed park site and an agricultural site using GeoEye1 imagery, and an urban site using WorldView2 data. Successful wetland classification was achieved across all study sites with an accuracy above 80%, though results suggest that overall a higher degree of landscape heterogeneity may negatively affect both segmentation and classification. The agricultural site suffered from the greatest amount of over and under segmentation, and lowest map accuracy (kappa: 0.78) which was partially attributed to confusion among a greater proportion of mixed vegetated classes from both wetlands and uplands. Accuracy of individual wetland classes based on the Canadian Wetland Classification system varied between each site, with kappa values ranging from 0.64 for the swamp class and 0.89 for the marsh class. This research developed a unique approach to mapping wetlands of various degrees of disturbance using GEOBIA, which can be applied to study other wetlands of similar settings.

1. Introduction

Mapping wetlands across natural and human-altered landscapes is important for understanding their responses to natural and anthropogenic activities, for developing strategies to conserve wetland biodiversity, and to prioritise areas for restoration or protection. While public perception of the conservation value of wetlands has increased over the past century (Brock et al., 1999), wetland loss appears to continue with little abatement and this change requires ongoing monitoring.

The ability to delineate wetlands and monitor changes in a semi-automated, and ongoing manner is important to the management of these ecosystems. A viable approach is the use of satellite remote sensing data, which provides advantages of large area coverage, ongoing data collection, and improved spatial resolution for wetland detection. While a variety of methods to delineate wetlands have been used with varying success (Davranche et al., 2010; Hirano et al., 2003; Schmidt and Skidmore, 2003; Shanmugam et al., 2006), less attention has been given to the applicability of such methods across different landscapes. Urban and rural landscapes represent uplands subjected to disturbance related to increased surface heterogeneity, changes to hydrologic regime, and land cover composition which may affect wetland detection accuracy.

Previous research has demonstrated that wetlands can be detected within upland surroundings, yet a unified approach to mapping wetlands across landscapes of varying complexity has not been identified. Further, fewer studies have included the detection of small and ephemeral wetlands even though pools as small as 0.2 ha represent important, often critical habitat

☆ Research was conducted in the Department of Geography, University of Toronto Mississauga
* Corresponding author.

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(Semlitsch and Bodie, 1998). In some areas such as the glaciated prairie pothole region of central Canada, almost 88% of wetlands are less than 0.4 ha in area (Halabisky, 2011). Coarser 30 m data such as those from the Landsat constellation require a minimum of 9 pure pixels (0.9 ha) to consistently identify a feature (Ozesmi and Bauer, 2002), resulting in many mixed pixels and small wetlands below this threshold being missed (Klemas, 2011; Powers et al., 2011). At the local scale, protection of small wetlands is vital, particularly for the maintenance of biodiversity (Gibbs, 1993; Semlitsch and Bodie, 1998), and many wetlands in altered landscapes are significantly reduced in size from their former coverage. While the current cost associated with obtaining high spatial resolution satellite data can be high, the cost is still significantly lower than field surveying or aerial photographs (see Wei and Chow-Fraser, 2007 for a cost breakdown) and provides the advantage of repeat coverage for monitoring over time and the addition of data outside of the optical range (e.g., in the near infrared region). Current work with high spatial resolution sensors has been used to successfully monitor the change in aquatic vegetation in coastal marshes (Wei and Chow-Fraser, 2007), to discriminate between submerged and emergent wetland vegetation (Davranche et al., 2010), and to estimate marshland composition and biomass in riparian marshes (Dillabaugh and King, 2008).

High resolution data provides the needed spatial resolution to capture smaller wetlands, but it also results in greater within-class spectral variance, making separation of mixed and similar land cover classes more difficult than with coarser-resolution imagery (Klemas, 2011; Hu and Weng, 2011). To address this increased variance an appropriate classification method must be employed. In recent decades object based image analysis (OBIA), or geographic object based image analysis (GEOBIA), has gained much attention as an alternative to traditional pixel-based methods. The packaging of pixels into discrete objects minimizes the variance (noise) experienced by high spatial resolution images, allowing the objects, rather than individual pixels to be classified. Past work has found that the object-based approach is preferred over the pixel-based approach for classifying urban areas (Myint et al., 2011; Hu and Weng, 2011), mapping land cover (Whiteside and Ahmad, 2005; Yan et al., 2006), and land cover change (Dingle Robertson and King, 2011). The object-based approach has also been successfully used in wetland research for classifying macrophyte communities in coastal marsh habitat (Midwood and Chow-Fraser, 2010; Rokitnicki-Wojcik et al., 2011), evaluating the structure of patterned peatlands (Dissanska et al., 2009), and mapping multiple classes of wetlands according to the Canadian Wetland Inventory (Grenier et al., 2007). Fournier et al. (2007) reviewed wetland mapping methods to be applied to the Canadian Wetlands Inventory program and identified the object-based approach as most appropriate due to its flexibility and ability to address the spatial heterogeneity of wetlands. Despite past successes in mapping wetland classes and vegetative communities, the majority of previous research has focussed on wetlands by masking out the surrounding upland matrix in order to concentrate on methods of within wetland classification. Yet the ability to delineate wetlands from regions where a previous wetland inventory does not exist, is important for monitoring trends and mitigating further wetland losses.

Approaches to classification have ranged from traditional unsupervised (Sawaya et al., 2003; Jensen et al., 1995) and supervised algorithms (Wang et al., 2004; Yu et al., 2006) including fuzzy methods (Benz et al., 2004; Townsend and Walsh, 2001) and object-based approaches (Blaschke, 2010; Blaschke et al., 2014) to more complex machine learning algorithms such as classification tree methods (Midwood and Chow-Fraser, 2010; Wright and Gallant, 2007) including random forest classification (Corcoran et al., 2013) with some complex models drawing from numerous data layers to discriminate among wetland types (Wright and Gallant, 2007). As a result, it is not surprising that many studies have been devoted entirely to comparing the utility of these different methods (Dingle Robertson and King, 2011; Duro et al., 2012; Harken and Sugumaran, 2005; Shanmugam et al., 2006) with no general consensus reached on a universal methodology. Similarly, the use of ancillary data in improving wetland mapping accuracy has been demonstrated by the inclusion of LIDAR (Hopkinson et al., 2005) and RADAR data (Grenier et al., 2007) to characterize vegetation height, time series image data for wetland boundary and change detection (Davranche et al., 2010; Johnston and Barson, 1993), and passive microwave data to map flooded areas (Prigent et al., 2001). Understandably, the process of mapping complex and variable ecosystems such as wetlands have led to equally complex approaches.

This paper focusses instead on the variability in landscapes where wetlands are found and applies a parsimonious approach to mapping these features across each variable scene using high spatial resolution 4-band multispectral imagery from WorldView2 and GeoEye1. Here, we employ a constant GEOBIA supervised-classification approach to wetland landcover mapping across three landscapes varying in disturbance from human activity representing a semi-natural park, agricultural, and urban landscape, to determine the robustness of this method across scenes of varying heterogeneity and composition.

2. Study area

Three study sites were selected and categorized as natural, agricultural, and urban. As most natural areas have undergone some level of alteration or disturbance, we define the natural landscape and cover types based on criteria adapted from Fahrig et al. (2011) as areas where (1) most primary production is not consumed by humans, either directly or indirectly, (2) the main species of the cover type has an evolutionary or long-term association with that area, and (3) the frequency and intensity of anthropogenic disturbances are low relative to those in agricultural and urban regions. Study sites were further categorized based on population density with an urban area defined as an area of over 400 people/km^2, a rural-agricultural area of less than 400 people/km^2, and a natural site with no permanent human population which was represented by a relatively undisturbed landscape (http://www.statcan.gc.ca/subjects-sujets/standard-norme/sgc-cgt/notice-avis/sgc-cgt-06-eng.htm).

The natural study site is located in the northeast corner of Algonquin Provincial Park (Ontario, Canada), hereafter referred to as the park site, which represents a protected and relatively undisturbed landscape (Fig. 1a). The park was established in 1893 and encompasses 7630 km^2 which includes approximately 340 ha of wetlands of all classes as defined by the Canadian Wetlands Classification System (NWWG, 1997). Logging activity occurs in the study area as well as recreational use by park visitors, though the study site is located in a less heavily visited section. The agricultural site is in the County of Brant (Ontario, Canada) which sits within the Grand River watershed and is located approximately 130 km west of Toronto, supporting a population of 35,000 people (Fig. 1b). Provincial and private roads bisect the agriculturally dominated landscape and surround the Oakland Swamp, an 890 ha wetland of provincial significance. Several smaller wetlands of variable size and shape are also distributed throughout the study area. The urban study site encompasses the eastern portion of Toronto and the adjacent city of Pickering (Fig. 1c). Toronto is the largest city in Canada and supports a population of 2.79 million people, and a greater Toronto area (GTA) population of 5.5 million. The study site includes the Rouge Urban National Park, a