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Spectral analysis of wetlands using multi-source optical satellite imagery

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ABSTRACT

The separability of wetland types using different spectral bands is an important subject, which has not yet been well studied in most countries. This is particularly of interest in Canada because it contains approximately one-fourth of the total global wetlands. In this study, the spectral separability of five wetland classes, namely Bog, Fen, Marsh, Swamp, and Shallow Water, was investigated in Newfoundland and Labrador (NL), Canada, using field data and multi-source optical Remote Sensing (RS) images. The objective was to select the most useful spectral bands for wetland studies from four commonly used optical satellites: RapidEye, Sentinel 2A, ASTER, and Landsat 8. However, because the ultimate objective was the classification of wetlands in the province, the separability of wetland classes was also evaluated using several other features, including various spectral indices, as well as textural and ratio features to obtain a high level of classification accuracy. For this purpose, two separability measures were used: The T-statistics, calculated from the parametric *t*-test method, and the U-statistics, derived from the non-parametric Mann-Whitney U-test. The results indicated that the Near Infrared (NIR) band was the best followed by the Red Edge (RE) band for the discrimination of wetland class pairs. The red band was also the third most useful band for separation of wetland classes, especially for the delineation of the Bog class from the other types. Although the Shortwave Infrared (SWIR) and green bands demonstrated poor separability, they were comparatively more informative than the Thermal Infrared (TIR) and blue bands. This study also demonstrated that ratio features and some spectral indices had high potential to differentiate the wetland species. Finally, wetlands in five study areas in NL were classified by inserting the best spectral bands and features into an object-based Random Forest (RF) classifier. By doing so, the mean Overall Accuracy (OA) and Kappa coefficient in the study areas were 86% and 0.82, respectively.

1. Introduction

Wetlands are valuable natural resources that provide many ecological services to both flora and fauna. Their benefits are a result of the natural hydrological and biogeochemical processes carried out in these ecosystems. These processes, which are sometimes called wetland functions, include hydraulic storage and recharge, bio-geochemical transformation, biomass production, and habitat (Marton et al., 2015). In addition, these habitats are important forms of economic resources in many countries in the form of recreation, fishing, waterfowl hunting, and animal grazing (Marton et al., 2015; Guo et al., 2017). In recent times, wetlands have also become a popular topic in discussions of climate change because they contain 12% of the global carbon pool (Erwin, 2009; Guo et al., 2017).

Because of the valuable services that wetlands provide, the Ramsar Convention carried out a review of wetland inventories across the globe in an effort to analyze the extent, status, and effectiveness of inventories around the world, and to provide several specific recommendations as to how different countries can establish or improve on these important wetland tools (Finlayson et al., 1999). Consequently, attempts have been made to develop a wetland classification system based on the specific types of wetlands in each country (Ozesmi and Bauer, 2002; Tiner et al., 2015; Guo et al., 2017; Mahdavi et al., 2017b). For instance, there are two well-known wetland classification systems in Canada (National Wetlands Working Group, 1987; Smith et al., 2007): the Canadian Wetland Classification System (CWCS, refer to Table 1 for the list of acronyms) and the Enhanced Wetland Classification System (EWCS). The CWCS is the only Canada-wide classification system, which incorporates ecological characteristics of wetlands and their functions into the classification (National Wetlands Working Group, 1987). The CWCS categorizes wetlands into five classes based on their soil, water, and vegetation characteristics: Bog, Fen, Marsh, Swamp,

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Table 1
Acronyms and corresponding description.

Acronyms	Description
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
B	Band
CWCS	Canadian Wetland Classification System
DEM	Digital Elevation Model
DVI	Difference Vegetation Index
EWCS	Enhanced Wetland Classification System
F-test	Fisher-test
ML	Maximum Likelihood
NIR	Near Infrared
NL	Newfoundland and Labrador
NDSI	Normalized Difference Soil Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
OBIA	Object-Based Image Analysis
OA	Overall Accuracy
PA	Producer Accuracy
RF	Random Forest
RE	Red Edge
RE-NDVI	Red Edge Normalized Difference Vegetation Index
RS	Remote Sensing
SWIR	Shortwave Infrared
SAVI	Soil Adjusted Vegetation index
SAM	Spectral Angle Mapper
SAR	Synthetic Aperture RADAR
TIR	Thermal Infrared
UA	User Accuracy

and Shallow water. Table 2 summarizes the ecological characteristics of these five wetland classes (National Wetlands Working Group, 1987; Mitsch and Gosselink, 2000; Smith et al., 2007), which provides the framework for analyzing the spectral characteristics of wetlands.

The characteristics and properties of wetlands can be effectively studied by measuring the spectral response of wetland types in different parts of the electromagnetic spectrum (Ozesmi and Bauer, 2002; Mahdavi et al., 2017b). In this regard, collecting the spectral information of wetlands can be performed using field spectrometry. However, besides the common limitations of field work (e.g. labor intensiveness, high expenses, and time limitation), inaccessibility has proven to be a major disadvantage when collecting wetland ground-truth data (Adam and Mutanga, 2009; Gallant, 2015; Mahdavi et al., 2017b). Because of these limitations, there is a need to develop a more effective and practical approach for analyzing the spectral characteristics of wetlands. In this regard, using the data collected by various optical RS satellites, characterized by different spatial, temporal, and spectral resolutions, is an optimum way to study the spectral characteristics of wetlands (Ozesmi and Bauer, 2002; Gallant, 2015; Tiner et al., 2015; Guo et al., 2017; Mahdavi et al., 2017b).

Optical RS supplies images in various parts of the electromagnetic spectrum, including the visible and infrared (near, shortwave, and thermal). It should be noted that RS-based spectral analysis of wetlands requires knowledge of the spectral characteristics of vegetation and soils, as well as their correspondence with the vegetation cover and soil conditions in wetland areas (see National Wetlands Working Group (1987) for the characteristics of wetland species). Hyperspectral sensors may be the best choice for spectral analysis of wetlands. However, the corresponding data are generally expensive and difficult to obtain and process (Guo et al., 2017). Moreover, since there are not current hyperspectral orbital assets, it is necessary to figure out how to perform this using multispectral data. In addition, most current wetland inventories are based on the data acquired by multi-spectral satellites such as Landsat (Ozesmi and Bauer, 2002; Guo et al., 2017; Mahdavi et al., 2017b). Moreover, there are currently many satellites, which provide valuable multi-spectral imagery for users free of charge, including Landsat, Sentinel 2A, and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Thus, it is often more

Table 2
The characteristics of the five wetland classes specified by the CWCS.

Wetland class	Characteristics						
	Water source	Water table	Hydrology	Soil	pH	Nutrient conditions	Vegetation physiognomy
Bog	Ombrogenous	At or slightly below the surface	May have standing water	Organic	Acidic	Oligrotrophic	Byrophytes (sphagnum moss), graminoids (sedges), ericaceous shrubs
Fen	Minerogenous	Fluctuating (at, slightly above, or slightly below the ground surface)	Standing or gently flowing water	Organic	Acidic to alkaline	Eutrophic, mesotrophic, oligotrophic	Bryophytes (brown and sphagnum mosses), graminoids (sedges), shrubs
Marsh	Minerogenous	At or below the ground surface	Standing or flowing water with fluctuating water levels	Mineral	Neutral to alkaline	Usually eutrophic	Aquatic emergent graminoids and shrubs
Swamp	Minerogenous	At or below the ground surface	Seasonal standing or flowing water	Organic or mineral	Alkaline to slightly acidic	Eutrophic, mesotrophic, oligotrophic	Trees and shrubs greater than 1 m, forbs
Shallow Water	Minerogenous	At the surface	Seasonally stable standing or flowing water < 2 m	Mineral	Neutral to alkaline	Usually eutrophic	Submerged and floating aquatic macrophytes

Note: Water Source: The source of water that feeds a wetland. Ombrogenous wetlands receive water only from precipitation (rain, snow, and atmosphere), while Minerogenous wetlands receive water from multiple sources (e.g. precipitation and surface water flow).
Water Table: The upper portion of the zone of saturation, which is the area underground where the ground is totally saturated by water.
Soil: Wetland soils can be broadly defined as being Organic or Mineral. Organic soil is a result of a buildup of poorly decomposed organic (carbon) matter, while Mineral soil contains little or no organic matter, and can be described as mucky.
Nutrient conditions: General nutrient quality of the wetland. Oligotrophic wetlands are poor in nutrients, mesotrophic wetlands have moderate levels of nutrients, and eutrophic wetlands have high levels of nutrients.
Vegetation physiognomy: Describes the functional and morphological attributes of vegetation (e.g. shrubs have woody stems, and macrophytes are aquatic plants).