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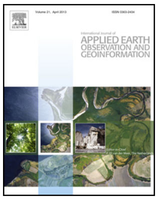

Retrieving aboveground biomass of wetland *Phragmites australis* (common reed) using a combination of airborne discrete-return LiDAR and hyperspectral data

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ABSTRACT

Wetland biomass is essential for monitoring the stability and productivity of wetland ecosystems. Conventional field methods to measure or estimate wetland biomass are accurate and reliable, but expensive, time consuming and labor intensive. This research explored the potential for estimating wetland reed biomass using a combination of airborne discrete-return Light Detection and Ranging (LiDAR) and hyperspectral data. To derive the optimal predictor variables of reed biomass, a range of LiDAR and hyperspectral metrics at different spatial scales were regressed against the field-observed biomasses. The results showed that the LiDAR-derived H_p99 (99th percentile of the LiDAR height) and hyperspectral-calculated modified soil-adjusted vegetation index (MSAVI) were the best metrics for estimating reed biomass using the single regression model. Although the LiDAR data yielded a higher estimation accuracy compared to the hyperspectral data, the combination of LiDAR and hyperspectral data produced a more accurate prediction model for reed biomass ($R^2 = 0.648$, RMSE = 167.546 g/m^2, $\text{RMSE}_r = 20.71\%$) than LiDAR data alone. Thus, combining LiDAR data with hyperspectral data has a great potential for improving the accuracy of aboveground biomass estimation.

1. Introduction

Wetlands are one of the most important and productive ecosystems on the earth (Desta et al., 2012; Mitsch et al., 2009), which provide multiple ecosystem services, such as water quality improvements, wildlife and flood protection (Klemas, 2013b). Moreover, wetlands are vital habitats for a wide variety of animals and plants (Klemas, 2013b), and they also have high economic, cultural and recreational values (Desta et al., 2012).

Wetland vegetation plays an important role in wetland ecological functions and is a critical component of wetland ecosystems (Adam et al., 2010; Mutanga et al., 2012). *Phragmites australis* (common reed), a globally widespread species, is one of the most common species in wetland environments and is considered highly productive (Soetaert et al., 2004).

Vegetation biomass is defined as the total dry weight of living organic matter (Drake et al., 2003), and vegetation aboveground biomass (AGB) is the total dry weight of flowers, fruits, branches, stems, foliage and bark per unit area above the ground surface (Zhu and Liu, 2015). Vegetation biomass is an important biophysical parameter for modeling global changes and carbon cycles, and has been widely used to estimate vegetation gross primary productivity and terrestrial carbon stocks (Ji et al., 2012; Lucas et al., 2008). Wetland biomass offers valuable information for monitoring the stability and productivity of wetland ecosystems (Klemas, 2013a; Mutanga et al., 2012), and accurate estimations of the AGB of wetland vegetation are required for such applications (Chen et al., 2012; Yang et al., 2009). Conventional field methods for estimating biomass are the most accurate and reliable (Englhart et al., 2011), and they are based on destructive sampling (harvesting

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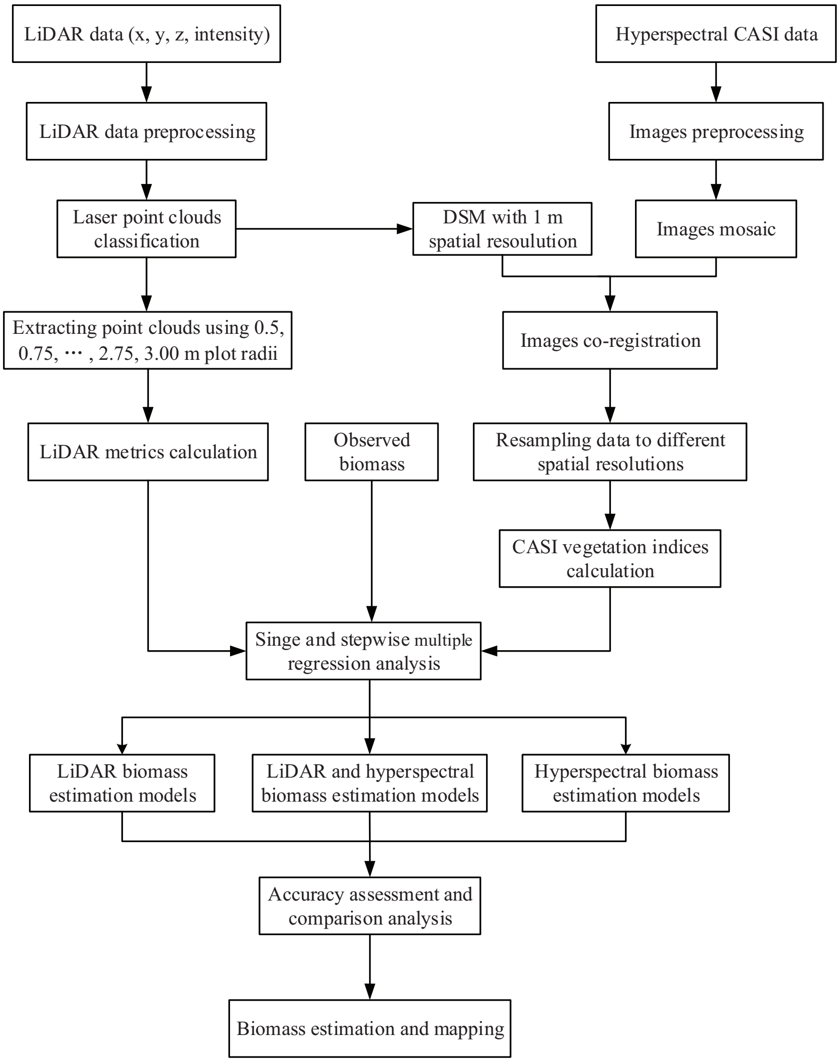

Fig. 1. Flowchart of data processing and biomass estimation using field-observed biomass, LiDAR data and CASI data.

method) and non-destructive field measurements (using allometric equations) (García et al., 2010; Ji et al., 2012). However, field measurements are often expensive, time consuming and laborious (Asner et al., 2010), and only feasible over limited temporal and spatial scales (Barrachina et al., 2015; Yang et al., 2009). Therefore, field methods for estimating biomass over large areas are not feasible, especially for remote, inaccessible and dangerous locations where in situ observations are impractical (Englhart et al., 2011).

Remote sensing technologies can rapidly and repetitively collect land surface information at regional and global scales, and remotely sensed data can be used to retrieve vegetation parameters efficiently and economically (Adam et al., 2010; Lu, 2006). Because of these advantages, remotely sensed data have been extensively applied for estimating vegetation biomass at different spatial scales (Englhart et al., 2011). In the published literature, a number of studies have performed AGB estimations using passive optical remote sensing (e.g., Barrachina et al., 2015; Dillabaugh and King, 2008; Mutanga et al., 2012; Psomas et al., 2011; Ramoelo et al., 2015) and radio detection and ranging (radar) (e.g., Gao et al., 2013; Solberg et al., 2015). Optical remote sensing data are used to estimate biomass through empirical relationships established between the vegetation indices (VIs) and the field-measured biomass data (Englhart et al., 2011; García et al., 2010). Commonly used VIs include the normalized difference vegetation index (NDVI), simple ratio vegetation index (SRVI) and soil-adjusted vegetation index (SAVI). However, the main problem associated with using optical VIs to estimate biomass is that they asymptotically reach a saturation level in densely vegetated areas as the biomass density or leaf area index (LAI) reaches a certain threshold (Chen et al., 2009; Tsui et al., 2012). This problem can seriously influence estimation accuracy of vegetation biomass (Chen et al., 2009). Moreover, conventional remote sensing technologies cannot offer sufficient vertical information on the vegetation structure, which is highly correlated with vegetation biomass (Tsui et al., 2012). Therefore, accurately estimating biomass using passive optical or radar data is still a difficult task.

Table 1
Hyperspectral CASI data acquisition parameters in this study.

Flying altitude	2000 m
Swath width	1500 m
Number of spectral bands	48
Spatial resolution	1.0 m
Spectral resolution	7.2 nm
Field of view	40°
Spectral range	380–1050

LiDAR, an active remote sensing technique (Qin et al., 2015), can rapidly acquire three-dimensional point clouds of objects with high vertical and horizontal accuracies (Popescu, 2007). Optical sensors can only detect the surface features of the vegetation canopy,