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Short communication

Satellite retrieval of woody biomass for energetic reuse of riparian vegetation

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ABSTRACT

Streamside vegetation plays a multifunctional role in many interconnected hydraulic, ecological and sedimentological processes of great interest for flood risk assessment and river restoration practices, which need frequent riparian vegetation maintenance interventions. The reuse of riparian vegetation as a potential energy source represents a sustainable way to support the costs of buffer management. As a consequence, reliable and cost-efficient modelling of woody biomass is crucial to quantify the theoretical energy budget of riparian corridors and to drive decision-making processes. Potential capabilities of multi-spectral satellite data in retrieving riparian woody biomass (*B*) are explored in this paper. The method is organized in five sequential steps: 1) riparian vegetation mapping; 2) Principal Component Analysis of the vegetation spectral signatures; 3) estimation of the correlation structure between arboreal spectral signatures and ground-observed biomechanical properties – tree high (*h*) and stem diameter (*D*); 4) identification/calibration/validation of spectral-based predictive models of *h* and *D* and 5) use of a standard allometric relationship to calculate the riparian woody biomass. The methodology is tested over a 3 km reach of the forested floodplain of the Avisio river (Trentino Alto Adige, Italy) by using an extended field surveys and a synchronous SPOT-5 multi-spectral image acquired on 28/08/2004. Results showed strong correlation coefficients between spectral signatures and vegetation parameters ($r_k(h) = 0.783$ and $r_k(D) = 0.695$) and valuable satellite capabilities in retrieving biomechanical parameters through tri-parametric power lows ($R^2(h) = 0.732$ and $R^2(D) = 0.619$). The remotely-derived woody biomass map shows comparable estimates than those obtainable thought ground measurements (RMSE(B) = 0.019 m^3) and represents a repeatable and accurate device to assess the potential energy budget within riparian corridors. A simple simulated scenario of the riparian management is also provided to assess the biomass-derived net calorific value and the corresponding cost-benefit analysis.
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1. Introduction

Riparian vegetation plays a crucial role in many interconnected hydraulic-sedimentological-ecological processes by: (1) providing flow resistance during flooding event and reducing erosion; (2) delivering nutrients to streams from litter fall and large woody debris; (3) stabilizing stream banks through the root mass; (4) controlling water temperature

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through shade; and (5) adding to the recreational, habitat and aesthetic value of streams [1,2].

Flood risk reduction and river restoration practices need frequent riparian corridor maintenance interventions that can considerably burden with the financial budget of the institutions responsible for land management. The reuse of streamside vegetation as woody biomass represents a sustainable way to support the costs of buffer management (cutting/plantation operations) and to create new economic opportunities in the floodplain areas for energy production [3,4]. Approximated theoretical energy budget derivable from Poplars, Willows and Acacia can reach 160–450 GJ/ha, 178–276 GJ/ha, 178–231 GJ/ha, respectively [5]. Therefore, an accurate assessment of riparian biomass represents an essential tool to drive decision-making processes for a multi-functional riparian vegetation management.

Techniques for biomass estimation focus on allometric relationships which use vegetation structural parameters, such as stem diameter and tree height [6], estimated through conventional ground surveys [7,8] or more recent in situ measurement techniques based on terrestrial laser scanning and digital parallel photography [9,10]. However, a systematic monitoring of the vegetation parameters using such field sampling is often infeasible, as these methods are time consuming, expensive and allow characterizing only small portions of riparian buffers. As in many other environmental monitoring problems, remote sensing may provide unprecedented mapping capabilities.

In the last years Light Detection and Ranging (LiDAR) data are becoming a widely used tool in river applications thanks to their capacity to capture the 3D structure of monitored vegetated surfaces. Several studies applied airborne laser scanning data for the estimation of stand volume and forest characterization by showing encouraging performances on conifer areas and lower reliability estimates on broad-leaved patters with overlapped crowns and complex plant morphology [11,12]. Furthermore, LiDAR-derived parameterizations of riparian ecosystem are strongly dependent on flight acquisition opportunities and they can only provide limited information about the vegetation dynamics that would require acquisition and processing of long time series of remote sensing data [13]. Satellite images are expected to play a key role in the next years to explain riparian ecosystem dynamics, due to their relative low revisiting time and increasing spatial resolution [14]. Several research studies have been developed to estimate the aboveground biomass using satellite sensors, prevalently focusing on landscape-scale applications [15,16], whereas only few river-scale analyses have been conducted. Dillabaugh and King [17] by using Ikonos imagery demonstrated significant correlations between spectral information and biomass of shrubs in riparian marshlands. Despite the valuable results achieved in multispectral-based methodologies of riverine ecosystems focusing on vegetation spectral indices and image spectral enhancements of forested floodplains [18–20], there is a greater need to progress in satellite remote sensing to develop reliable and time-efficient tools for woody biomass retrieval in forested floodplains.

In this paper the spectral-based method described in [21], originally developed for floodplain hydraulic roughness parameterization, is applied to assess the potential of satellite retrieval of riparian woody biomass. The proposed technique is based on the optimization of the vegetation spectral signatures derivable from remote sensing platforms and on the exploration of spectral properties as biomass predictors.

2. Methods

2.1. Study area

The mouth of the Avisio river (Trentino Alto Adige, Italy) is used as study area (Fig. 1). It consists in a 3 km reach, which includes the floodplain from the clearway bridge (SS12 – Brennero), in the municipality of Lavis, to the confluence of the Avisio in the Adige River. The total area is ∼1,041,000 m^2, its 54% is made up of vegetated lands, including herbaceous, shrub and arboreal patterns. Riparian forest is mainly made up of high-trunk plant species at the evolutionary stage with homogeneous density and is prevalently located in the confluence zone where the river presents a multi-channel path.

2.2. Remote sensing and field data

To characterize the spectral properties of riparian vegetation a SPOT-5 image acquired on 28 August, 2004 was used in this study. The image is composed of a 10 × 10 m resolution short-wave band (wavelength range from 1.58 to 1.75 μm) and three 5 × 5 m resolution visible/near-infrared bands (wavelength ranges: blue 0.43–0.47 μm, red 0.61–0.68 μm and near infrared 0.78–0.89 μm). The short-wave band was resampled at the same spatial resolution of the finer visible/near-infrared channels. The SPOT-5 image was orthorectified in UTM/WGS-84 projection using a 1 m orthophoto image and a rational function model and then corrected from the atmospheric effects through the ENVI module FLAASH Model [22].

The vegetation properties of the investigated riverine ecosystem were measured through an extensive field campaign in August 2004 (synchrony between field and remote sensing acquisition). Field surveys indicate three main vegetation classes: 1) mixed arboreal (*willows*, *false acacia*, *black poplar*; 2) shrub (*elder*, *cornel tree*, *alder*) and 3) herbaceous (*nettle*), see inset pictures in Fig. 1. Over mixed arboreal patterns a set of 17 sample plots with homogeneous vegetation characteristics was selected, over which planimetric extentions, tree height (h) and stem diameter (D) were carried out using GPS and forestry instrumentation (hypsometer with lens, dendrometric tripod). Sample plots are showed in red polygons in Fig. 1.

2.3. Methodology

In this paper, the main goal is to assess the riparian woody biomass through satellite multi-spectral data. For this purpose vegetation parameters – tree high (h) and stem diameter (D) – that represent input variables in standard allometric relationships for woody biomass calculation, are initially quantified. The investigated relationship that links vegetation parameters and spectral information assumes the following general mathematical formulation:

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