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A new methodology for monitoring wood fluxes in rivers using a ground camera: Potential and limits

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ABSTRACT

Ground imagery, which produces large amounts of valuable data at high frequencies, is increasingly used by fluvial geomorphologists to survey and understand processes. While such technology provides immense quantities of information, it can be challenging to analyze and requires automatization and associated development of new methodologies. This paper presents a new approach to automate the processing of image analysis to monitor wood delivery from the upstream Rhône River (France). The Génissiat dam is used as an observation window; all pieces of wood coming from the catchment are trapped here, hence a wood raft accumulates over time. In 2011, we installed an Axis 211W camera to acquire oblique images of the reservoir every 10 min with the goal of automatically detecting a wood raft area, in order to transform it to wood weight (t) and flux (t/d). The methodology we developed is based on random forest classification to detect the wood raft surface over time, which provided a good classification rate of 97.2%. Based on 14 mechanical wood extractions that included weight of wood removed each time, conducted during the survey period, we established a relationship between wood weight and wood raft surface area observed just before the extraction ($R^2 = 0.93$). We found that using such techniques to continuously monitor wood flux is difficult because the raft undergoes very significant changes through time in terms of density, with a very high interday and intraday variability. Misclassifications caused by changes in weather conditions can be mitigated as well as errors from variation in pixel resolution (owing to camera position or window size), but a set of effects on raft density and mobility must still be explored (e.g., dam operation effects, wind on the reservoir surface). At this stage, only peak flow contribution to wood delivery can be well calculated, but determining an accurate, continuous series of wood flux is not possible. Several recommendations are made in terms of maximizing the potential benefit of such monitoring.

1. Introduction

Understanding the impacts of large wood (LW) on channel forms and processes is important to river ecology and for improving risk assessment. In this field, wood budgeting represents one of the main challenges (Wohl et al., 2010). Martin and Benda (2001) highlighted the importance of LW budgets at the watershed scale because of ecological implications such as the understanding of the spatial distribution of aquatic organisms. Similar research motivations were presented by Ruiz-Villanueva et al. (2014) to develop LW budgets, with an emphasis on the flood hazard aspects of jam formation in specific stream reaches.

Wood budgeting encompasses several key elements, wood mobility and wood flux being crucial ones that are still weakly understood. Once recruited by the river, LW can remain in place (sometimes a very long time: up to 1000 years but most of the time < 100 years, according to Bilby, 2003) or be transported downstream with complex accumulation-re-entrainment patterns that depend on the flow conditions, the roughness of channel forms, and the characteristics of wood pieces (Braudrick and Grant, 2001; Boivin et al., 2016). Gurnell et al. (2002) stated that transport of wood pieces is mainly related to the ratio between log length and channel width.

Methods to ascertain wood mobility generally rely on field campaigns to measure logs and log jam characteristics along a reach or an entire stream length (Comiti et al., 2006, 2008; Lassettre and Kondolf, 2012; Ravazzolo et al., 2015; Boivin et al., 2015). All pieces larger than a defined size are counted, measured, and described in order to understand where they were recruited and how long they have been stored in the channel. Such field observations are time-consuming when long reaches are surveyed but also because they must be repeated to examine LW mobility. Aerial (Lassettre et al., 2008; Moulin et al., 2011; Atha, 2013) and satellite (Boivin et al., 2015) imagery analysis appears to complement these field measurements; but riparian tree cover often prohibits the use of remotely sensed images because it partially or

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completely overhangs the channel width. To overcome this, Atha (2013) used aerial LiDAR to acquire workable imagery even with dense forest cover.

Wood fluxes have not been well studied because of inherent measurement difficulties. Only a few studies have investigated this aspect of wood budgeting. Wood recruitment, accumulation, and reentrainment patterns have been explored at the reach scale, shedding some light on large wood kinetics and fluxes. However, these measurements are not sufficient to provide information on the real wood flux (Thévenet et al., 1998) because, most of the time, the field data result from one or several past events and data at the single-event scale is not available. To obtain measurements of wood flux, Moulin and Piégay (2004) and Seo et al. (2008) characterized the output of wood using archived reservoir wood extraction series. Dam reservoirs offer good observation sites because wood flux often fully stops there. In both studies, the data for wood volumes deposited through time were collected by the managing companies of the dams. Historical data were used to document wood fluxes over long periods, but no continuous data were available and the temporal resolution of such monitoring is variable through time.

Wood fluxes can also be estimated from a direct count of the wood floating in a channel. MacVicar and Piégay (2012) achieved this, using video cameras; while Kramer and Wohl (2014) used high frequency photography sequences. Kramer and Wohl (2014) studied the efficiency of wood detection using image analysis and showed that it is quite accurate compared to visual observations carried out in the field when the flow is very slow. In 2004, Moulin and Piégay monitored wood raft evolution over a few weeks using ground photos. It was evident that this kind of data could be complementary to historical imagery, especially with a regular frequency of acquisition and higher temporal scale. But this experiment was conducted only for a few weeks with a manual analysis approach. Lyn et al. (2003) also used a manual approach to analyze videos acquired from a bridge. The accumulation of wood against a bridge pier and two deflectors was followed through time and compared to the discharge. Here some uncertainties remained with no associated field validation, but in all cases, ground imagery emerged as a promising avenue to quantify real wood fluxes and to observe stream processes at high frequencies.

Acquiring large image data sets with a high temporal resolution is particularly relevant to river science because significant processes often occur during short events like floods. MacVicar et al. (2009) detected wood fluxes using a video camera. But contrary to the work of Lyn et al. (2003), the processing was manual only in part: only flood period image sequences were analyzed but the detection of logs was automated. With increasing data set sizes, the automation of image analysis

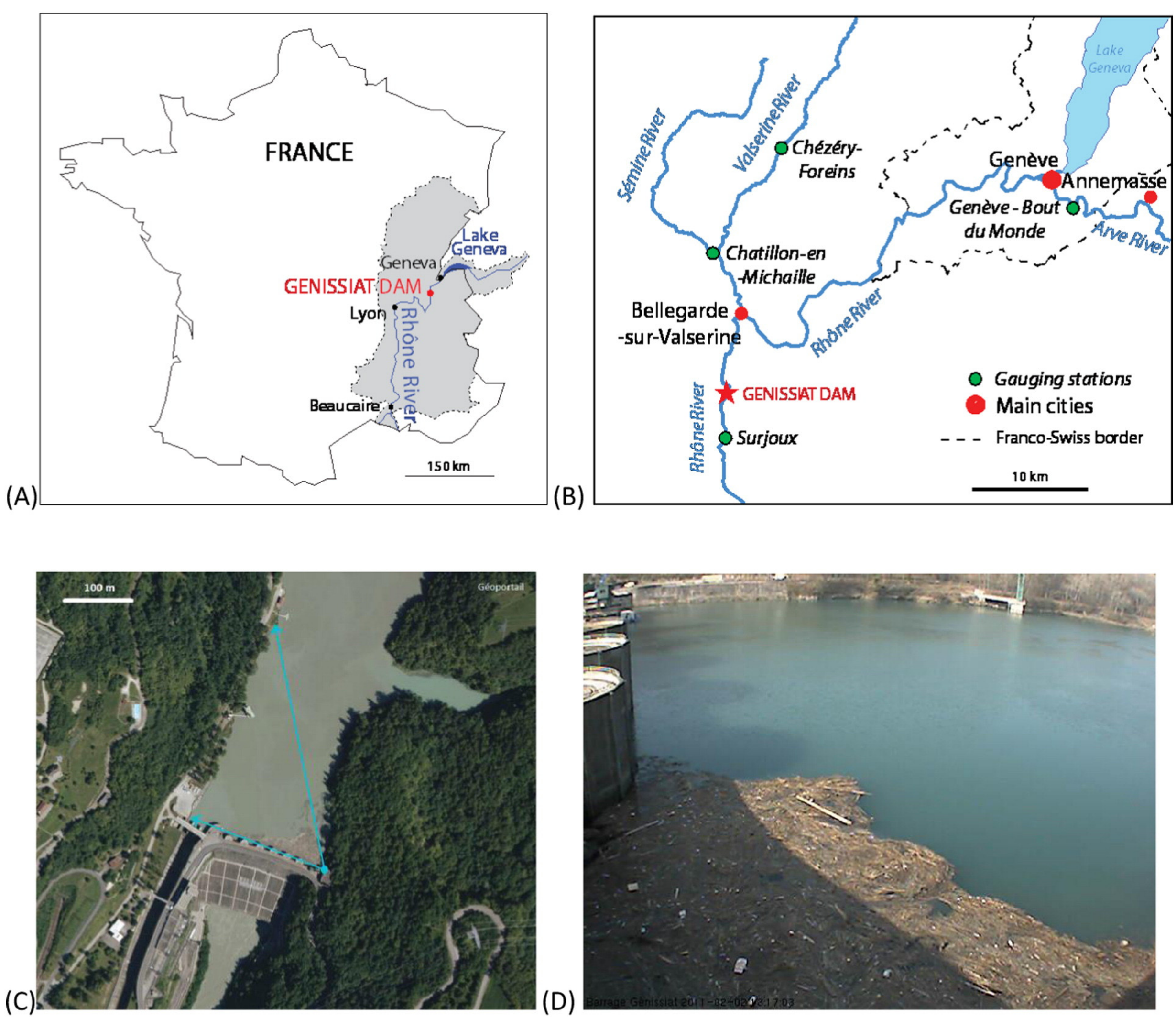

Fig. 1. Characterization of the study site: (A) location of the Rhône River catchment in France; (B) location of the Rhône River and its two main tributaries upstream from Génissiat; gauging stations used to acquire hydrological series; (C) overview of the Génissiat dam reservoir with the camera vantage point (in blue); (D) example of an image acquired 2 February 2011 at 01:20 p.m. with the camera. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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