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Field-based estimates of floodplain roughness along the Tisza River (Hungary): The role of invasive *Amorpha fruticosa*

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ABSTRACT

River flooding has become a major issue in the last decades, placing at risk wide portions of the planet. Modeled scenarios are the most helpful tools to reduce flood hazard; nevertheless they can lead to significant over- or underestimation of flood discharge and peak flood level if field attributes, especially floodplain roughness, are not carefully surveyed and reasonably included in their design. Besides, floodplains provide optimal habitats for invasive species, which can form dense stands, influencing roughness and flow velocity considerably. The floodplains of the Tisza River and its tributaries (Hungary) are highly invaded by invasive plants, however their existence is not considered during flood modeling. Among these plants *Amorpha fruticosa* has the greatest impact and creates impenetrable shrubbery on the floodplain, having 5–10 branches sprouting from its stump. The aim of this study is to give a precise and field-based estimation of vegetation density and floodplain roughness of different vegetation categories along the floodplain of the Tisza River, to overcome inaccuracies caused by the use of reference values. Through the Parallel Photographic Method, digital images are used to create photo mosaics and derive accurate estimates of vegetation density and floodplain roughness. Further, the role of invasive *A. fruticosa* in increasing vegetation density of the floodplain is also investigated. Results confirm a considerable underestimation of vegetation density and floodplain roughness (average difference: 0.04–0.06) by using simple reference values, as invasive *Amorpha* contributes for 55% of vegetation density on average, and on abandoned fields it constitutes 100% of the woody vegetation. These values suggest that modeled flood water levels can be remarkably underestimated if density of invasive species is not considered. The results of this study stress the importance of including field-based assessments of vegetation characteristics and the influence of invasive species in river modeling, to generate realistic predictions and address effective flood hazard strategies.

1. Introduction

Over the last decades, frequency and magnitude of extreme meteorological events have continuously increased, placing at risk wide areas worldwide. Flood hazard represents a major issue particularly in urban areas (Krellenberg, Müller, Schwarz, Höfer, & Welz, 2013; Morelli, Battistini, & Catani, 2014, 2012), therefore the realization of realistic flood scenarios has become a major objective in river modeling as they allow to define and address effective protection and mitigation strategies (deKok & Grossmann, 2010). In this context, reliable roughness coefficients remain the most complex parameters to achieve as their misuse can lead to significant and unpredictable inaccuracies in hydraulic modeling (Sudhaus et al., 2008), in particular under- or overestimation of flood levels. After surface topography, hydrodynamic roughness of floodplains is largely determined by vegetation, being a function of its physical characteristics, in particular structure and density (Dawson & Charlton, 1988; Straatsma & Baptist, 2008). Riparian vegetation plays a crucial role in influencing the flood conveyance of floodplains, as its hydraulic friction may substantially change flood patterns, reducing velocity and causing raising flood levels with an attenuation of flood wave celerity during peak discharges (Straatsma, Warmink, & Middelkoop, 2008).

One of the key characteristics to determine floodplain roughness is hydrodynamic vegetation density (Baptist et al., 2007), which is a very difficult and sensitive parameter to measure accurately in the field due to the high number of irregularities featured by complex vegetation structures as curved stems, side branches and leaves (Straatsma et al., 2008). Many studies have attempted to develop resistance laws able to quantify the hydrodynamic impact of rigid and flexible vegetation during floods (e.g. Järvelä, 2004; Kouwen & Fathi-Moghadam, 2000; Petryk & Bosmajian, 1975); nevertheless they have often revealed difficult to apply due to the infeasibility of collecting reliable, cost-effective and timesaving field data. For this reason, in a large number of modeling operations vegetation roughness has been frequently assigned

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by roughly comparing cross-sectional areas and river profiles with images of standardized river cases (Arcement & Schneider, 1989) or by simply extracting reference values derived from empirical equations (Chow, 1959; Yen, 2002). Various remote sensing techniques, as LiDAR (Abu-Aly et al., 2014; Forzieri, Moser, Vivoni, & Castelli, 2010) and Satellite Imagery (Forzieri, Degetto, Righetti, Castelli, & Preti, 2011) have allowed in the recent years to acquire floodplain vegetation characteristics over broader extents for roughness purposes, but they are often unable to characterize complex vertical vegetation structures (Antonarakis, Richards, Brasington, & Bithell, 2009) as well as they need extensive field reference data to be collected (Straatsma et al., 2008). At local scale, a very promising, even if rather expensive, technology to surveying with an extremely high accuracy complex and 3-dimensional vegetation structures and derive essential parameters for hydrodynamic roughness is Terrestrial Laser Scanning (TLS) (Antonarakis et al., 2009; Straatsma et al., 2008). Among the different methods to acquire vegetation characteristics, photography has recently gained much consideration because of its cost-efficiency and time-saving virtues (Straatsma et al., 2008; Zehm, Nobis, & Schwabe, 2003). The accuracy of photographic-derived estimates proved to be consistent and well comparable with most of remote sensing technologies, particularly at local scale (Straatsma et al., 2008; Warmink, 2007). To overcome several limitations and uncertainties caused by the central projection of images, as the gradual distortion of object dimensions going from the center to the sides of the photograph and the high occlusion rate, the new approach called Parallel Photographic Method was developed in the last years (Warmink, 2007; Straatsma et al., 2008). This methodology consists in the creation of digital photo mosaics from parallel images, from which the fractional coverage of vegetation against a contrasting background can be extracted and used to derive vegetation density (Warmink, 2007; Straatsma et al., 2008). The Parallel Photographic Method was considered particularly appropriate for the investigation of floodplain density at plot scale along the Tisza River, which features complex land-use and vegetation structures, and is highly invaded by invasive plants (Fig. 1).

Floodplains provide optimal habitats for invasive species, because they tolerate frequent and high inundations, burial by deposits, dry conditions during low stages and human disturbance (i.e. irregular forest clearance, abandonment after agricultural usage). Invasive species cause considerable problems on floodplains, as they endanger the reproduction and regeneration of indigenous species, and cause economic, environmental and health problems (Tamás, 2001; Radovanivić et al., 2017). The most significant invasive plant species along the Tisza River, Hungary, are green ash *(Fraxinus pennsylvanica)*, box elder *(Acer negundo)*, false indigo *(Amorpha fruticosa)*, wild cucumber *(Echinocystis lobata)*, common cocklebur *(Xanthium italicum)* and thicket creeper *(Parthenocissus inserta)* (Botta-Dukát & Mihály, 2006). In the floodplain of the Tisza River *Amorpha fruticosa* causes the greatest problems, as it spreads out very aggressively in riparian forests (Mihály & Botta-Dukát, 2004), increasing significantly vegetation density, thereby it deteriorates flood conveyance of the floodplain (Sándor & Kiss, 2007). *Amorpha fruticosa* originates from the south-eastern part of North America. It was brought to the region at the end of the 19th century to stabilize riverbanks against intensive erosion (Simonkai, 1893). The species favors areas with loose soil, periodical inundation and partial shadow (Dumitraşcu, Grigorescu, Kucsicsa, Dragota, Năstase, 2014). It appears massively on abandoned arable land and pastures (Szigetvári, 2002; Mihály & Botta-Dukát, 2004). As the land-use of the Tisza floodplain changed from arable lands to planted forests during the last 30–40 years (Sándor & Kiss, 2008) and the forests are not managed properly, the growth of *Amorpha* stands is exceptionally rapid. The species forms fast-growing (up to 3–4 m), impenetrable shrubbery on the floodplain, having 5–10 branches sprouting from its stump (Mihály & Botta-Dukát, 2004). Due to the dense woody stems, in plots invaded by *Amorpha* flood flow velocity can be reduced from 0.5 m/s to 0 m/s (Sándor & Kiss, 2007). Therefore, it becomes very important to measure and evaluate the role of *Amorpha fruticosa* on floodplain vegetation roughness and flood conveyance.

Considering the rapid spreading of the invasive *Amorpha fruticosa* in the last decades on the floodplain of the Tisza River (Mihály & Botta-Dukát, 2004) and the issues related to its impact on vegetation density and roughness, the main objectives of this study are:

(1) to reach local-scale and accurate estimates of vegetation density of different vegetation structures along the Lower Tisza River, using and testing the Parallel Photographic Method;
(2) to achieve reliable estimates of floodplain roughness in different vegetation categories and compare them to widely accepted reference values (Chow, 1959);
(3) to evaluate the temporal evolution and impact on vegetation density of invasive *Amorpha fruticosa* in different vegetation categories.

2. Study area

The Tisza River is the second largest river of Hungary (L: 962 km, A: 157,200 km^2; Lászlóffy, 1982). The analysis was carried out on its lower reach at Mindszent (Fig. 2).

Floods usually develop due to early spring snowmelt and early summer rainfall (Lászlóffy, 1982), though late autumn and winter floods are becoming more frequent. A special characteristic of the Lower Tisza is that, during the last decades, the maximum stage measured during the record flood of 1970 (9.82 m) was exceeded twice (2000: 10 m and 2006: 10.62 m, measured at Mindszent gauge station), resulting in 0.8 m of water level increase without the raising of discharge (1970: 3820 m^3/s; 2000: 3530 m^3/s; 2006: 3781 m^3/s). In the whole system of the Tisza both the duration and the level of floods have increased, which is explained by extreme precipitation (Szlávik, 2000), land-use and vegetation changes on the catchment (Illés & Konecsny, 2000), and decreasing flood conductivity of the channel and the floodplain (Kiss, Fiala, & Sipos, 2008). The maximum water depth on

Fig. 1. The floodplain of the Tisza River is densely invaded by various invasive plants. a) Wild cucumber *(Echinocystis lobata)* common cocklebur *(Xanthium italicum)* and thicket creeper *(Parthenocissus inserta)* cover the native vegetation. b) False indigo *(Amorpha fruticosa)* stand on an abandoned field.