Geomorphology 246 (2015) 113–122

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Gravel transport by ice in a subarctic river from accurate laser scanning

Eliisa Lotsari [a,*], Yunsheng Wang [b,d], Harri Kaartinen [d], Anttoni Jaakkola [d], Antero Kukko [d], Matti Vaaja [c], Hannu Hyyppä [c,e], Juha Hyyppä [d], Petteri Alho [b,c]

[a] Department of Geographical and Historical Studies, Geography Section, University of Eastern Finland, P.O. Box 111, FI-80101 Joensuu, Finland
[b] Department of Geography and Geology, Geography Section, University of Turku, FI-20014 Turku, Finland
[c] Department of Real Estate, Planning and Geoinformatics, Aalto University, P.O. Box 11000, FI-00076 Aalto, Espoo, Finland
[d] Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute FGI, Geodeetinrinne 2, FI-02430 Masala, Finland
[e] The School of Civil Engineering and Building Services, Helsinki Metropolia University of Applied Sciences, P.O. Box 4011, FI-00079 Metropolia , Espoo, Finland

ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form 3 June 2015
Accepted 4 June 2015
Available online 9 June 2015

Keywords:
Laser scanning
River ice
Bedload transport
Erosion

ABSTRACT

For decades the importance of ice and the effects of cold-region processes on river channel morphology have been discussed, with a general consensus as to their importance emerging only recently. River ice cover, anchor ice, frazil ice, and ice jams may not only scour the channel bed and banks but also pick up, transport, and deposit fine sediments and gravels during winter, especially during the spring ice breakup period. However, knowledge of the interactions between coarse sediment transport and ice processes remains insufficient, particularly in rockier river reaches, with a lack of accurate and sufficiently extensive data hindering their quantification.

The aim of this study was to quantify and analyse the impact of river ice on gravel transport in a subarctic river during one winter via the acquisition of laser scanning data for the river channel and ice surface. Terrestrial and mobile laser scanning were performed in 2012–2013 on the Tana River in northern Finland. Both of these techniques are considered accurate and applicable for detecting elevation and volumetric changes in river bed, defining gravel clast sizes, and detecting the movement of individual clasts. More importantly, ice surface, thickness, and decay during spring were also captured via laser scanning.

In the winter of 2012–2013, a period characterised by an absence of ice jams and mid-winter ice-decay periods, with spring ice breakup discharges close to average yearly conditions, ice had the most significant role, greater than that of flowing water, in erosion and transport of coarse sediment from the channel bed and gently sloping banks. Changes in river bed elevation and volume were recorded throughout the study site, and erosion predominated. In addition to broader scale erosion, the movement of single clasts up to 2 m in size occurred. However, the observed overall channel change patterns did not coincide with the areas of fastest ice decay. The obtained results could also be applied to the enhancement of riverine planning in subarctic environments.

1. Introduction

In subarctic and arctic areas, river ice erosion is a major factor in river morphodynamics. After decades of discussion, a general consensus has recently emerged as to the importance of ice and the effects of cold-region processes on channel morphology and sediment transport (Turcotte et al., 2011). The presence of ice increases irregularities in channel plan form (Ettema and Daly, 2004), with river ice cover, anchor ice, frazil ice, and ice jams scouring channel bed and banks, as well as transporting fine sediments and gravels during winter. Although a significant amount of sediment transport and channel modification is believed to occur during the spring ice-breakup period, particularly owing to ice-rafting, field data are scarce for a variety of hydrological, climatic, and morphological settings (Kempema and Ettema, 2011; Turcotte et al., 2011).

Recent years have seen an increasing amount of research examining ice jam effects on rivers (Smith and Pearce, 2002; Boucher et al., 2009; Beltaos, 2013), with many laboratory studies investigating ice erosion and sediment transport under ice. Fewer field studies have taken place, with those that have been focusing on the effects of ice and frazil ice jams on the characteristics of sediment transport and riverbed deformation (Sui et al., 2000), the effects of anchor ice on sediment rafting (Kempema and Ettema, 2011), and pre-breakup sediment transportation (Milburn and Prowse, 2002) under natural river channel conditions. However, these aforementioned studies were largely performed in cohesive (Milburn and Prowse, 2002), sandy or pebbly rivers (Sui et al., 2000), with less research examining river reaches consisting of coarser material (Kempema and Ettema, 2011). Earlier, qualitative studies of ice effects on gravel transport have been performed in cold region rivers (Ettema and Kempema, 2012), and Ettema and Kempema (2012) have highlighted that the question of river ice effects on bed material

* Corresponding author.
E-mail addresses: eliisa.lotsari@uef.fi (E. Lotsari), yunsheng.wang@utu.fi (Y. Wang), harri.kaartinen@nls.fi (H. Kaartinen), anttoni.jaakkola@nls.fi (A. Jaakkola), antero.kukko@nls.fi (A. Kukko), matti.t.vaaja@aalto.fi (M. Vaaja), hannu.hyyppa@aalto.fi (H. Hyyppä), juha.hyyppa@nls.fi (J. Hyyppä), mipeal@utu.fi (P. Alho).

http://dx.doi.org/10.1016/j.geomorph.2015.06.009

transport is still largely unaddressed. The need to quantify the effects of ice on gravel-bed rivers by using the newest instrumentation has been acknowledged (Ettema and Kempema, 2012). Researchers have yet to utilise accurate laser scanning data for the detection of coarse sediment transport in subarctic environments, while the detailed measurement of erosion and sedimentation has thus far proven difficult.

This lack of accurate data of sufficient resolution and coverage has hindered the quantification of transport of coarse sediment, including channel forms, and their relationship with prevailing processes at the reach scale (Legleiter, 2014). Terrestrial laser scanning (TLS), a technique able to operate at high resolution and survey frequency, has lately been applied successfully to the examination of vertical river bank dynamics in natural river environments (e.g., Nasermoaddeli and Pasche, 2008; Resop and Hession, 2010; Alho et al., 2011; O'Neal and Pizzuto, 2011; Lotsari et al., 2014b) and to the examination of the gravel movement and channel forms in rivers fed by glaciers (Stickler and Alfredsen, 2009; Kociuba et al., 2014), but not in gravel-bed rivers without headwater glaciers. The entire river channel surface above the water level can be measured via TLS. Nevertheless, despite its accuracy, TLS is more time consuming than mobile laser scanning (MLS). Even though the absolute accuracy of MLS is lower than that of TLS, it is able to provide spatially and temporally accurate multitemporal change data for spatially larger areas and can be used from different platforms, such as backpacks (Vaaja et al., 2011, 2013; Kaartinen et al., 2012; Kukko et al., 2012; Glennie et al., 2013). As a result, rapid and accurate multitemporal measurements and change detection of river bed and sediment transport caused by river ice in gravel-bed rivers is now possible for the first time. In addition, methods with which to model and detect the size of coarse

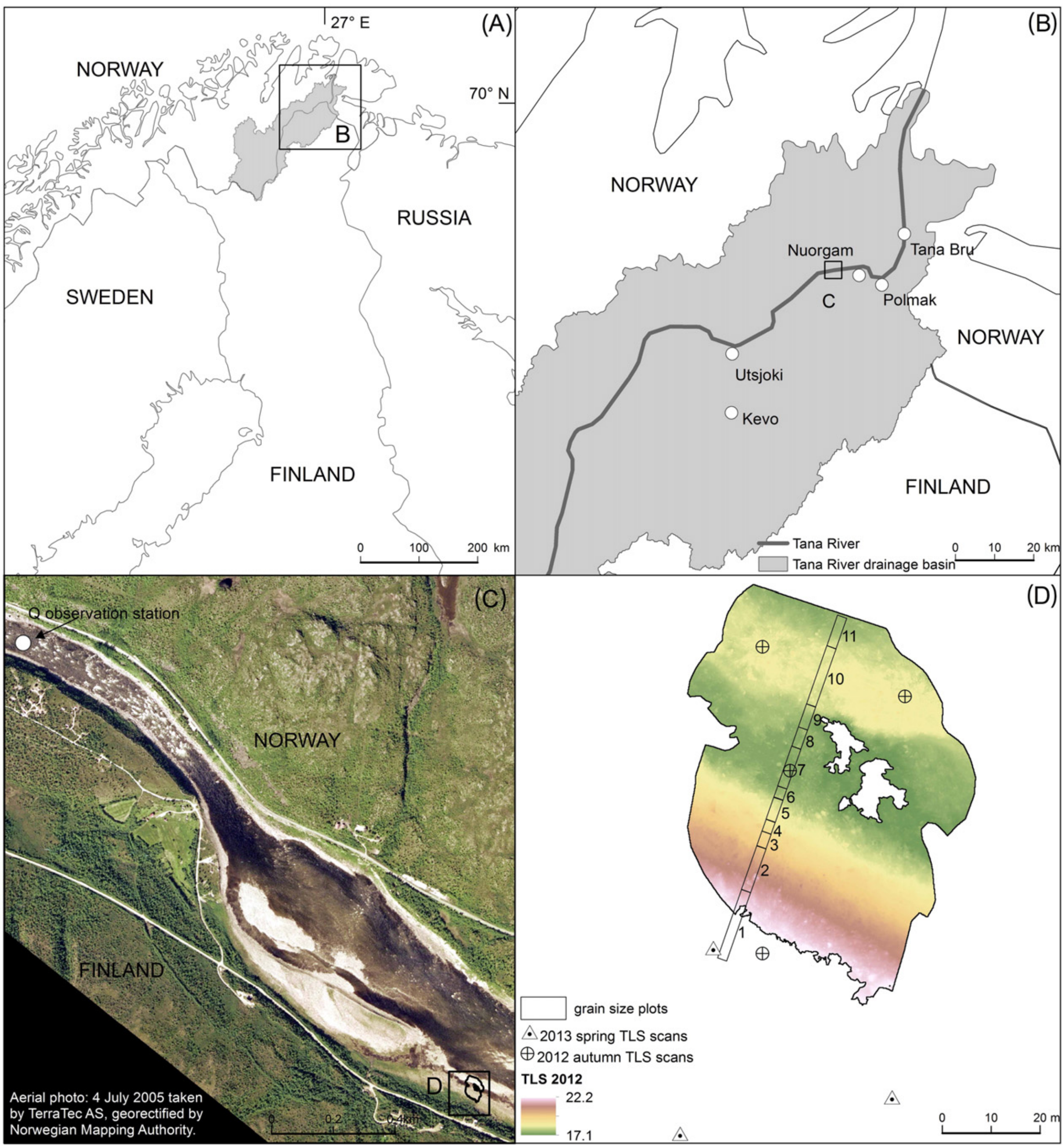

Fig. 1. Study site located on the right bank side of the Tana River (Finland) and downstream of the Alaköngäs rapids. The discharge observation station of the Finnish Environment Institute (light circle) is located upstream of the study site. For the sake of clarity, the MLS lines for autumn 2013 are not shown in (D); instead only the area within which the measured points for autumn 2012 TLS and autumn 2013 MLS data were horizontally within 1 cm of each other is shown. This TLS 2012 data, which is shown on the background (D), was used for grain-size calculations along a 2 × 70 m region of interest (plots 1–11).