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The role of trees in the geomorphic system of forested hillslopes — A review

Łukasz Pawlik *

Department of Geomorphology, Institute of Geography and Regional Development, University of Wrocław, Poland

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A B S T R A C T

Forested hillslopes form a special geoecosystem, an environment of geomorphic processes that depend strongly on forest ecology, including the growth and decay of trees, changes in structure, disturbances and other fluctuations. Hence, the following various functions of trees are reviewed here: their role in both biomechanical and biochemical weathering, as well as their importance for the hillslope geomorphic subsystem and for transport of soil material via tree uprooting and root growth. Special attention is paid to tree uprooting, a process considered the most efficient and most frequent biogeomorphological indicator of bio-physical activity within forest in complex terrain. Trees have varied implications for soil formation in different environments (boreal to tropical forests) and altitudes. In this paper an attempt has been made to emphasize how trees not only modulate geomorphic processes, but also how they act as a direct or indirect agent of microrelief formation, the most striking example of which being widespread and long-lasting pit-and-mound microtopography. Based on the analyzed literature it seems that some problems attributed to forest ecology can have a fundamental effect on forested hillslope dynamics, a relationship which points to the need for its integration and interpretation within the field of geomorphology. The biology of individual trees has a key influence on the development of e.g. rock faces, weathering front migration and changes in the soil biomantle within upper and lower forest belts. Additionally, forms and sediments depend largely on the horizontal and vertical extent, volume and structure of root systems, as well as on active processes taking place in the root zone and rhizosphere. Furthermore, although trees to a large extent stabilize slope surfaces, their presence can also have a dual effect on slope stability due to tree uprooting, a process which in some circumstances can trigger mass movements (e.g. debris avalanches). So far, several attempts at quantifying the influence of trees on slopes have been made via the use of mathematical equations, enabling researchers to calculate: 1) the root plate volume of uprooted trees, 2) the amount of soil displacement due to tree root growth, and 3) rates of erosion, sedimentation and soil creep. In light of the reviewed literature, the most urgent issue appears to be the need for a thorough study of the interactions and feedbacks occurring between trees and geomorphic systems (e.g. soil mixing and biotransport by trees) in different climate zones, altitudes and time frames, especially in terms of the development of forest ecosystems during the Holocene.

Contents

* Tel.: +48 782859870; fax: +48 713435184.

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1. Introduction

Since their first expansion, trees have remodelled landscapes and have been an important element of the Earth's natural history from at least the Devonian (Meyer-Berthaud et al., 1999). Were early terrestrial plants including trees able to create new niches and habitats? And, in turn, did they help in the evolution of new plant and animal species? This question remains to be answered satisfactorily (Kelly et al., 1998; Gabet and Mudd, 2010). Others, while considering the evolution of trees, seed plants and the colonization of land by forests during the Devonian, have hypothesized that the development of terrestrial vegetation induced a brief late Devonian glaciation by causing a drawdown in atmospheric pCO_2 (the partial pressure of CO_2) (Algeo and Scheckler, 1998; Berner, 1998, as cited by Goudie and Viles, 2012). Forests currently cover at least 30% of the global land surface (FAO, 2005). As a component of vegetation cover, they form a biological membrane (also known as the Earth's biospheral envelope) that absorbs solar energy (a concept first proposed by Vernadsky, 1926, 1944; see also reviews by Ghilarov, 1995 and Lapo, 2001) and which also acts as a large reservoir of rainwater (Osuch, 1998; Phillips, 2009). Through their growth and decay, trees have a critical and continuous effect on the land surface of the Earth, and, as components of forest ecosystems, their structural development and exchange of species and stands must also be stressed. These natural phenomena occasionally happen in a catastrophic manner, when slow changes are intensified and quickened (e.g. via windstorms).

Since at least the end of the 19th century, trees have been considered agents of soil disturbance and mixing (Shaler, 1891; Hack and Goodlett, 1960; see reviews by Johnson, 1993; Wilkinson et al., 2009). However, for a long time the forest environments of the upper and lower montane belts were assumed to be static, or at least with infrequent changes (Jahn, 1989; but see for example Dietrich and Dunne, 1978), and were thus neglected in geomorphic studies (e.g. Klimek and Latocha, 2007). Nevertheless, some exceptions exist. For instance, the above-mentioned remark does not apply to humid tropical denudation systems where "*the study of the geomorphology of the humid tropics cannot be divorced from a consideration of the vegetation*" (Douglas, 1969, p. 13; also Thomas, 1994). Similarly, interactions between vegetation and hillslope geomorphology have recently been emphasized as crucial to our understanding of linkages between different ecoregions (Marston, 2010). In retrospect, biological influences on geomorphological processes have gained much more attention (see, for example, Table 1 in Phillips, 2009). At present, the need for such an interdisciplinary approach to geomorphology is undeniable, with this approach's character and methods formalized in the subject of biogeomorphology (Viles (Ed.), 1988a, 1988b, 1990; Corenblit et al., 2008; Corenblit and Steiger, 2009). This sub-discipline aims at full integration of the biotic and abiotic aspects of geomorphic systems at all levels of complexity. *Forest geomorphology* defines the functions of forests and of individual trees, and has already been appreciated as an important discipline within the frame of geomorphology, dealing with many problems typical of mountainous areas (*protective forests*: FAO, 2005; Sakals et al., 2006). The most important issue currently facing forest geomorphology appears to be the integration of the efforts of different disciplines towards producing an explanation of forested hillslope dynamics. This theory will be based on tendencies in forest ecosystem changes and will thus involve integrating knowledge of forest ecology (White, 1979). Similar efforts attempt to bridge the gap between pedology and forest ecology (Šamonil et al., 2010a), as well as between climate change and sediment transport (Constantine et al., 2012).

The main aim of this review is to explore, based on existing literature, the role of trees within the forested hillslope domains of mountain geoecosystems, with the most important question arising being: How do trees contribute to the activity and modification of geomorphic processes, and thus also to landscape evolution at different spatial and temporal scales?

2. Trees and rock weathering

Vegetation contributes to weathering via various mechanisms over a full range of scales, from the microscale (e.g. the interaction of fine roots with minerals) to the macroscale, where the physical fragmentation of large rocks may take place in the root zone. Trees contribute to weathering processes in many ways and their action can be considered *biotic weathering* which, as proposed by Selby (1993), is a combination of chemical and physical weathering effects (Fig. 2). Biological weathering is, as proposed by Yatsu (1988), the

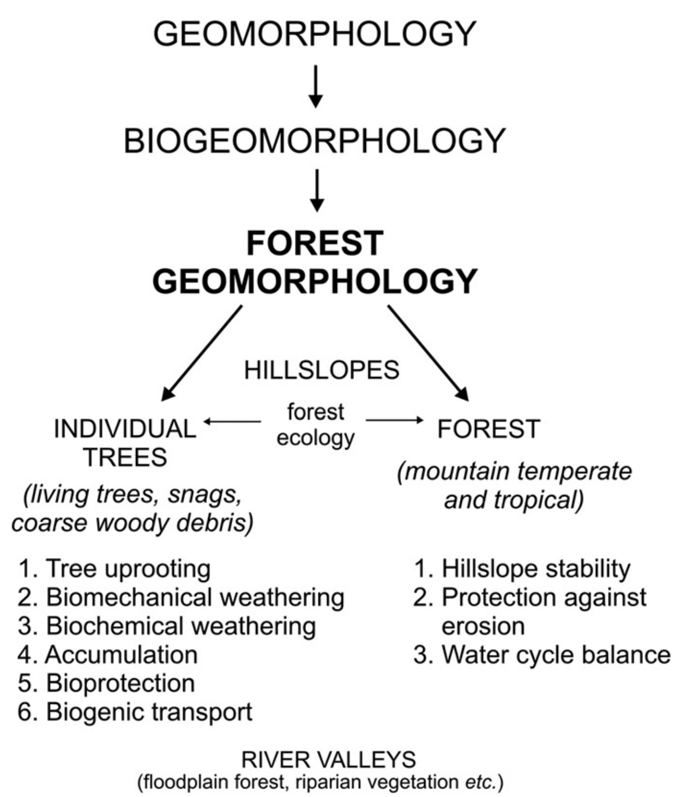

Fig. 1. Forest geomorphology as a subdiscipline within biogeomorphology. Only natural processes are included, although Rosenfeld (2004) also considered the effects of forest management activities within the frame of forest geomorphology. See text for explanation (figure not yet published).