Forest Ecology and Management 405 (2017) 391–403

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Impacts of modern mechanised skidding on the natural and cultural heritage of the Polish Carpathian Mountains

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ARTICLE INFO

Keywords:
Logging roads
Skid trails
Road density
Selective logging
LiDAR
South-eastern Poland

ABSTRACT

The aim of the research was to determine the scale and forms of logging road impacts on the natural environment and residual cultural heritage of Ruthenian Highlanders that characterise the Polish part of the north-eastern Carpathians. To this end, we used LiDAR-derived DEM to detect and map forest roads and skid trails, and to estimate road density, in 60 forest divisions sampled at random from among the 2639 km^2 of forest managed in the above region by the State Forests National Forest Holding. The determined road network was then validated by GPS ground control. Supplementary, detailed LiDAR data were used to detect features of the past cultural landscape, and to determine the interference in that due to contemporary logging roads. Overall skidder traffic was estimated on the basis of a thorough analysis of State Forests documents, including legal acts, guidelines, management plans, detailed databases and maps of planned cuts.

LiDAR data proved to be an adequate tool in the mapping of the network of logging roads present under the tree canopy, although it slightly underestimates road density in a densely vegetated, post-landslide topography. Our LiDAR-assessed density of Carpathian logging roads (at 108.5–140.7 m ha^{-1}, including skid trails) is nevertheless among the highest reported in the literature, and one that far exceeds recommended values. Spatial pattern analysis further revealed the unfavourable phenomenon of multiple parallel roads forming contiguous areas of disturbed soil and constituting dispersal paths for invasive plants. Many examples of cultural remains being run over and destroyed by skidders could also be reported.

The observed process of log extraction is one of the least sustainable aspects to forest management in the Carpathians, and our results emphasise very clearly the need for rules to support the preservation of cultural heritage in forested areas, as well as improved tools by which skidding practices can be monitored.

1. Introduction

The Carpathians form an ecologically, socio-culturally and historically unique European mountain region, covered by the multi-level governance mechanism provided for in the Framework Convention on the Protection and Sustainable Development of the Carpathians, which came into force in 2006 (Anfodillo et al., 2008; UNEP, 2007). These mountains provide a refuge for populations of large mammals, and harbour some of the largest contiguous and ecologically valuable forests in Europe. Although a part of this area of high biological diversity is protected within National Parks or Nature Reserves, and remains relatively intact, forests outside these protected areas remain objects of intensive exploitation.

The technological advances in forestry occurring over the last decades have contributed significantly to increased productivity. The power of men and strength of draught horses have gradually been replaced by heavy logging equipment, mainly skidders. Although mechanised skidding is far more efficient, and can be carried out in almost all topographic and weather conditions, it has greater negative impacts on the environment (Dudek and Sosnowski, 2011; Shrestha et al., 2008).

The 'selective cutting' method of timber harvesting introduced by Leibundgut (1981) has several advantages (i.e. creating a diverse age structure and spatial patterns of forest stands) when set against the 'clear cut' harvest method. However, it requires much more frequent skidder access to forest. Logging operations are scattered throughout a Forest District and stands rarely remain cut-free for any longer period. A semi-natural, uneven-aged forest is thus achieved at the expense of a

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http://dx.doi.org/10.1016/j.foreco.2017.09.047
Received 18 July 2017; Received in revised form 17 September 2017; Accepted 18 September 2017
Available online 02 October 2017
0378-1127/

large area being subject to harvesting each year.

Commonly-given recommendations that the density of logging roads should be minimised and sections of forest large enough to conserve disturbance-sensitive areas retained (Avon et al., 2013) are of only limited use in mountain locations. After just a few skidder rides, Carpathian slopes composed of soft sedimentary flysch rocks, and covered with muddy brown soils, develop trails that are deep and marshy, and hence unsuitable for further use. In this way, forest haul-roads and skid trails became integral components of the Carpathian landscape.

The ecological impacts of logging roads are well documented in the literature and tend to be regarded as mainly adverse (e.g. Avon et al., 2013; Cambi et al., 2015; Solgi et al., 2015). However, less attention has thus far tended to be paid to the possible impacts of logging roads on remnants of past cultural landscapes, which are often afforested but still detectable in the microrelief of an area (Affek, 2016; Roman et al., 2017). In the Polish part of the north-eastern Carpathians, remnants of deserted villages, old rural roads and traces of former field mosaics now hidden under the tree canopy, constitute exceptional cultural heritage of former inhabitants known as Ruthenian Highlanders who were in fact displaced by force from this region in the 1940s (Eberhardt, 2011).

One of the most accurate technologies by which to detect and map micro-topographic features under forests over larger areas is airborne LiDAR (Light Detection and Ranging) (Ferraz et al., 2016; Sittler et al., 2007). While this has already been used to map logging infrastructure, this occurred most frequently in tropical regions, and with the aim of new methodologies being developed, tested or validated (d'Oliveira et al., 2012; Ellis et al., 2016; Ferraz et al., 2016; White et al., 2010). There remains a dearth of studies aiming to apply LiDAR data to assess possible logging impacts on the natural environment and cultural heritage of the Carpathians. As we investigated LiDAR-detectable variations of the Earth's surface, we use the term *cultural heritage* in the narrow sense, to denote tangible, immovable traces of human existence, left before the displacement action of the 1940s, and resulting from anthropogenic changes in land level (agricultural terraces, ridge-and-furrow patterns, hollow ways, stone foundations, etc.).

In the current study, the main objective was to explore the implications of mechanised skidding for the natural environment and cultural heritage in forests in the Polish part of the north-eastern Carpathians, managed by the State Forest National Forest Holding. In achieving this goal, specific research questions addressed as regards the forms and scale of the impact were:

- What are the characteristics of logging roads (width and depth, network density, location in the topography)?
- What is the reliability of LiDAR-derived road mapping?
- How do measured parameters of roads relate to forestry standards?
- What is the estimated skidder traffic (frequency of access, types of vehicles)?
- What are the direct effects of mechanised skidding on soils, water, fauna and flora?
- Is the Ruthenian cultural heritage concealed within the Carpathian forests endangered by logging operations?

2. Materials and methods

2.1. Study area

The Carpathians are the largest mountain range in Europe and the largest continuous temperate forest ecosystem, of outstanding importance for nature conservation and of great value for tourism (UNEP, 2007). The area selected for study has been the Polish part of the north-eastern Carpathians, comprising the Low Beskids, the Bieszczady Mountains and adjacent foothills (Fig. 1). It is built of sedimentary rocks (the so called Carpathian Flysch Belt) and covered mostly by brown soils. Those soils have been developed from loamy and clay weathered covers, characterised by a significant content of the < 0.002 mm fractions, which affects their compactness and plasticity (Zawadzki, 1999). Elevations here range from 150 to 1350 m a.s.l. The climate conditions are temperate, with average annual temperatures of 4–7 °C and mean annual rainfall of 80–130 cm/year. The potential natural vegetation is temperate mixed forest, with common beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) dominating in the upper elevations, and oak (*Quercus robur* L.) and hornbeam (*Carpinus betulus* L.) in the lower parts (Matuszkiewicz, 2008).

The natural vegetation of the study area is much-transformed by human activity. Ever-more intensive colonisation of the valleys in the 13th and 14th centuries induced extensive deforestation (Kozak, 2010). Although old-growth forest still occupied 80–90% of the Bieszczady Mountains in the second half of the 16th century (Schramm, 1958), further development of settlement, agriculture and pasturage resulted in considerable ongoing shrinkage of forest cover, which was thus down to 35% by the mid-19th century (Kozak and Kaim, 2016). However, it was not only the extent of forests, but also their composition, that changed. A natural process by which silver fir is displaced by common beech was observed throughout the study area at that time (Marszałek, 2011). In turn, at the beginning of the 20th century, beech was exploited intensively, with a monoculture of spruce (*Picea abies* L.) frequently being planted in its place.

Up to World War II, the north-eastern Carpathians constituted a highly populated Polish-Ukrainian ethnic borderland (Maryański, 1963; Soja, 2012). However, due to border shifts and the displacement of the Ukrainian-speaking population in the 1940s (Eberhardt, 2011), population density on the Polish side of a newly-delineated border more than halved (Maryański, 1963; Soja, 2012). In consequence, forest cover expanded substantially over subsequent decades, to reach 72% in 2013 (Kozak and Kaim, 2016). Approximately 36% of this forested area in the Bieszczady Mountains is occupied by post-agricultural forests, both planted and naturally regenerated. Extensive areas of former arable land were afforested with conifer monocultures (mainly of Scots pine – *Pinus sylvestris* L.) or they were subject to spontaneous secondary succession (particularly by Scots pine and grey alder – *Alnus incana* (L.) Moench) (Marszałek, 2011).

Most of the forests in the Polish Carpathians (78%) are state-owned, with 12% falling under National Park management, while the remainder are administered by the State Forests National Forest Holding (State Forests – SF) (Koziol, 2007). Our study area in the Polish part of the NE Carpathians thus comprises 15 SF Forest Districts of total area 2639 km^2 under forest stands. Nearly all (92%) of those stands have been classified as protective forests (e.g. valuable in soil and/or water protection). They are managed by way of complex cutting systems (the shelterwood system and stepwise cutting) (Koziol, 2007; Leibundgut, 1981; State Forests, 2016). The dominant age class is 81–120 years for common beech, 101–120 years for silver fir, and 61–80 years for pine (State Forests, 2016).

2.2. LiDAR based delineation of logging roads

For the purpose of this study, a logging road was defined as any section of a route suitable for wheeled transport located in forest and used to take logs out of that forest, and detectable on the LiDAR-derived DEM. This denotes that account is taken of all forest roads, be these paved or unpaved, as well as skid trails and haul roads (Figs. 2 and 3). To assess the density of logging roads in the north-eastern Carpathians in Poland, 60 forest divisions were sampled randomly using a random-number generator, with 4 such divisions located in each of the 15 Forest Districts. The forest divisions were used as the units of replication, since they constitute the smallest (on average 40 ha), independently managed units, with their own network of logging infrastructure. The interval estimation was applied (with a 95% confidence interval around the mean) to determine the values between which the estimated logging-road density in the entire region falls. We assumed that such a