SOILS PROPERTIES AND CARBON CONTENT AT RESEARCH OBJECTS IN FIR-BEECH FORESTS ON CALCAREOUS BEDROCKS OF THE DINARIC MOUNTAIN CHAIN: A CASE STUDY FROM SLOVENIA AND BOSNIA

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ABSTRACT

Large areas of European fir-beech forests are characteristic for the Dinaric Mountains and represent one of the most important forest ecosystems in the region. Such forests extend in high karst plateaus from the eastern Alps in SE Slovenia to the N Albanian massifs at the altitudes from 700 to 1200 (1500) m a.s.l. This is the area with a diverse landscape configuration. The bedrock is consisted of limestone, occasionally of dolomite limestone and dolomite. There are various soil conditions, where in a small area, a mosaic of Leptosols, Rendzic Leptosols, Chromic Cambisol, Calcaric and Chromic Luvisols occur. As climate conditions are very favourable for the growth of forests (high precipitation and air humidity), production function of wood is much more emphasized. Very little is known about the long-term effects of forest management and intensity of logging on soil organic matter quality and carbon stocks in these forest soils. Therefore, with an objective to understand better variations in soil properties, both in space and time, aiming to minimize the uncertainties of the SOC (soil organic carbon) and TN (total nitrogen) stocks, we have set up a research objects in silver fir-beech forests, in Slovenia (research plots in Kočevje, Snežnik and Trnovo) and Bosnia and Herzegovina (research plots on MT Bjelašnica). We analysed soil properties of the unmanaged and managed sites studying differences between treatments and also changes for the two years period of observations. Preliminary results from Slovenian sites show that the high intensity of logging (50 and 100% cut of growing stock) causes a decrease in SOC and TN contents, wider C/N ratio and higher

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pH values, with the largest level of alternations in the organic part of the soils. The study in Bosnia gave information on inherent SOC and TN concentrations in the organic and surface mineral soil, and also indicated no differences in soil properties between unmanaged and managed sites characterized by low (14-18%) intensities of logging.

Keywords: *forest management, organic matter, calcareous bedrocks, C stocks*

INTRODUCTION

Fir-beech forests (*Omphalodo-Fagetum*, syn.: *Abieti-Fagetumiliricum,* Horvat 1938, 1957 in Puncer 1979, 1980) in the Dinaric mountain region are recognized as uneven aged, self-regenerative and attributed to diverse soil and climate conditions highly favourable for forest growth, due to the abundant precipitations and high air humidity. This is the area with a diverse landscape configuration. The bedrock is predominantly consisted of limestone, dolomitic limestone and dolomite, on which a mosaic of Rendzic Leptosols, Chromic Cambisol, Calcaric Cambisol and Chromic Luvisols occur. Such forests extend in high karst plateaus from the eastern Alps in SE Slovenia to the northern Albanian massifs at the altitudes from 700 to 1200 (1500) m a.s.l. Herein, the applied management system favourites preservation of genuine forest structure, with least changes in canopy openings and site microclimatic conditions. In Slovenia, fir-beech forests have been recognized by Natura 2000 as one of the most extensively managed forest systems (Kutnar *et al*., 2011). Considering the number of one stand entries per ten year's rotation period, also in Bosnia they match the same category and they have been described by high biodiversity and unstable ratios the mixture of their major species (Ćirić *et al*., 1971; Stefanović *et al*., 1983).

In mountain regions, characterized mainly by shallow soils, organic matter (SOM), in both organic and mineral soil is found in substantially high concentrations (Baritz *et al*., 2010). This characteristic is crucially important for ecosystem functioning and forest productivity, as it is a major reservoir of carbon, nutrients and water. It is known that the forest soils on limestone and dolomites are highly heterogeneous, and thus they may vary considerably in a small area in their depth, bulk soil amounts, gravel content, etc. Also, the concentrations of SOC and TN vary considerably in karst areas (Schrumpf *et al*., 2011). Natural factors, which alter on a site level in relation to complex karst hydro-geological features, along with anthropogenic disturbances, which are comparable to natural disturbances, influence great spatial diversity of soil properties. Such spatial variability of soil properties limits the precision of measurement of changes in soil carbon and hence, the ability to detect changes (Homann *et al*., 2008).

Changes in SOC and TN concentrations for understanding alterations in forest soil productivity are broadly investigated and documented (Johnson and Curtis, 2001, Lal, 2005). The accumulation and quality of SOM is controlled by site factors and anthropogenic activities (Schoenholtz *et al*., 2000). Under the adjacent site conditions logging operations are usually generating differences in the SOM such as fresh litter accumulation at some places, but extracting major fraction of the organic material and associated elements (nutrients) from others, which may affect SOM on a long term (Schulze, 2000). In addition to SOM, authors report negative, positive or no influence of forest management activities (Prescott, 2002; Bauhaus *et al*., 2004), which can be explained by different intensities of selective logging, site differences and sampling strategy. Therefore, detecting variability in soil properties in space and time is of vast importance for quantification of differences between treatments in SOC and TN stocks (Homann *et al*., 2008).

In Slovenia effort was made in detecting and quantifying changes in SOC stocks, which are relevant for the purposes of reporting sources and sinks of C in regard to Kyoto obligations. Examining the impact of forest management system to SOC stock, as an important indicator of sustainable management practice is understudied topic in Bosnia and the data are also needed for filling the gap for South-eastern European regions, especially if considering climate change scenarios and their influence on beech forests on Balkan Peninsula. Investigations of variations in SOC concentrations are still scarce and actual data are needed for the purpose of assessing forest management impacts (Luyssaert *et al*., 2011).

The objective of this study was to understand better variations in soil properties, both in space and time, with an aim of minimizing the uncertainties of the SOC and TN stocks estimations. For that purpose, this study combined two approaches applied in the Dinaric fir and beech forests in Slovenia and Bosnia. We analysed soil properties of the unmanaged and managed sites studying differences in soil properties between sites with different logging intensities.

MATERIAL AND METHODS

Study sites

Three study sites were selected in Slovenia (Kočevski rog, Snežnik, and Trnovo) and one site in Bosnia (Mt Bjelašnica) (Table 1). The criteria for choosing study plots in each of the study sites were similar ecological factors: altitude, slope positions, inclination, soil properties, forest species composition and structure. Prior to sampling, in each study site we made a survey using a spade and 1 m auger (Pürckhauer auger) to address soil type according to WRB classification (IUSS WRB, 2015) for site level (Christophel, 2013).

Table 1. Site characteristics in Slovenia (Kočevski Rog, Snežnik, Trnovo and Bosnia (Bjelašnica)

Study site	Kočevski rog	Snežnik	Trnovo	Bjelašnica
Position	south-eastern Slovenia; 45.668°N, 15.033°E	southern Slovenia; 45.672°N, 14.460°E	western Slovenia; 45.989°N, 13.759°E	central Bosnia 43.4484°N 18.1541°E
Elevation	831-902 m a.s.l.	753-815 m a.s.l.	801-869 m a.s.l.	1350-1500 m a.s.l.
Area	70 ha	70 ha	70 ha	70 ha
Relief	high karst range with diverse terrain with numerous sinkholes, ridges, and slopes	high karst range with diverse terrain with numerous sinkholes, ridges, and slopes	high karst plateau with diverse terrain with numerous sinkholes, ridges, and slopes	high karst range with diverse terrain with numerous sinkholes, ridges, and slopes
Geology and soil	limestone and dolomite; Leptosol, Chromic Cambisol and Luvisol	limestone and dolomite; Leptosol, Chromic Cambisol and Luvisol	limestone and dolomite; Leptosol, Chromic Cambisol and Luvisol	limestone and dolomite; Rendzic Leptosol, Chromic Cambisol, Calcaric Cambisol and Luvisol
Meal annual precipitation	approximately 1700 mm	approximately 1700 mm	approximately 2000 mm	approximately 1200 mm
Mean annual temperature	8°C	8°C	9°C	1,4°C
Average annual increment of the whole management unit	9.4 m^3/ha/yr	8.3 m^3/ha/yr	6.2 $m^{3/}$ ha/yr	6.1 m^3/ha/yr
Forest management history	First forest management plan devised by Hufnagelintroduced close-to-nature management and suspended clear-cutting; some virgin forest remnants were protected in this region.	Systematic and organized forest management planning since the beginning of the 20^{th} century	First forestry plans in the 18th century; individual edicts for regulating forests as early as the 15^{th} century	Systematic and organized forest management planning since the beginning of the 20^{th} century

Note: The data for Slovenian sites are cited from Kutnar *et al*. (2015)

Plot selection, soil sampling, soil analysis

First approach applied in Slovenia involved 27 investigation plots which were selected in karst sinkholes in three study sites: Kočevski rog, Snežnik, Trnovo (Table 1). Circular plots of 0.4 ha were established in the central/bottom part of the selected sinkhole. At each of the site three logging intensities were provided:1) 1/3 of control plots: without any measures-0%, 2) 1/3 plots: 50% of growing stock logged, 3) 1/3 plots: 100% of growing stock logged. Samples were collected on a systematic sampling grid at the top, middle and on the bottom of sinkholes. Second approach applied in Bosnia, involved selection of four plots 0.5 ha which were selected with two intensities of silvicultural measures 1) control plot: without any measures-0% and 2) three plots with 14-18% of growing stock logged in different after-logging chronosequences (two, three and ten years). Samples were collected following restricted random sampling, which considered excluding disturbed sites and positions close to tree trunk. At each sampling point in Slovenian and Bosnian sites the organic layers of soil (Ol-litter layer, Of-fragmented or ferment zed layer and Oh-humified) were sampled with a wooden frame (25 cm x 25 cm). Mineral soil in Slovenia was sampled up to the depth of 80 cm and in Bosnia down to 10 cm of depth which represented mostly Ah (humus enriched mineral) horizon. The minimum sample size was 25, where 4 subsamples represented one composite sample (Cools and De Vos, 2010).

Organic and mineral soil samples were air dried. Rocks and roots were separated from the soil samples. Rocks were measured for mass and volume and dry roots were measured for mass. Dried samples were then grinded and samples with pH values ≥7.0 were analysed for mineral carbon content. Total organic C and total N were analysed using Element Analyser (LECO) and pH values were determined in 0.01M $CaCl_2$ solution. Basic statistical analysis encompassing T-test and ANOVA analysis were applied.

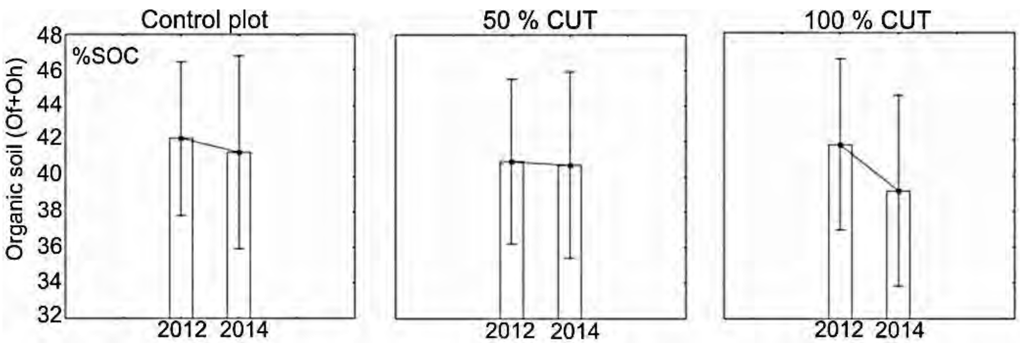
RESULTS

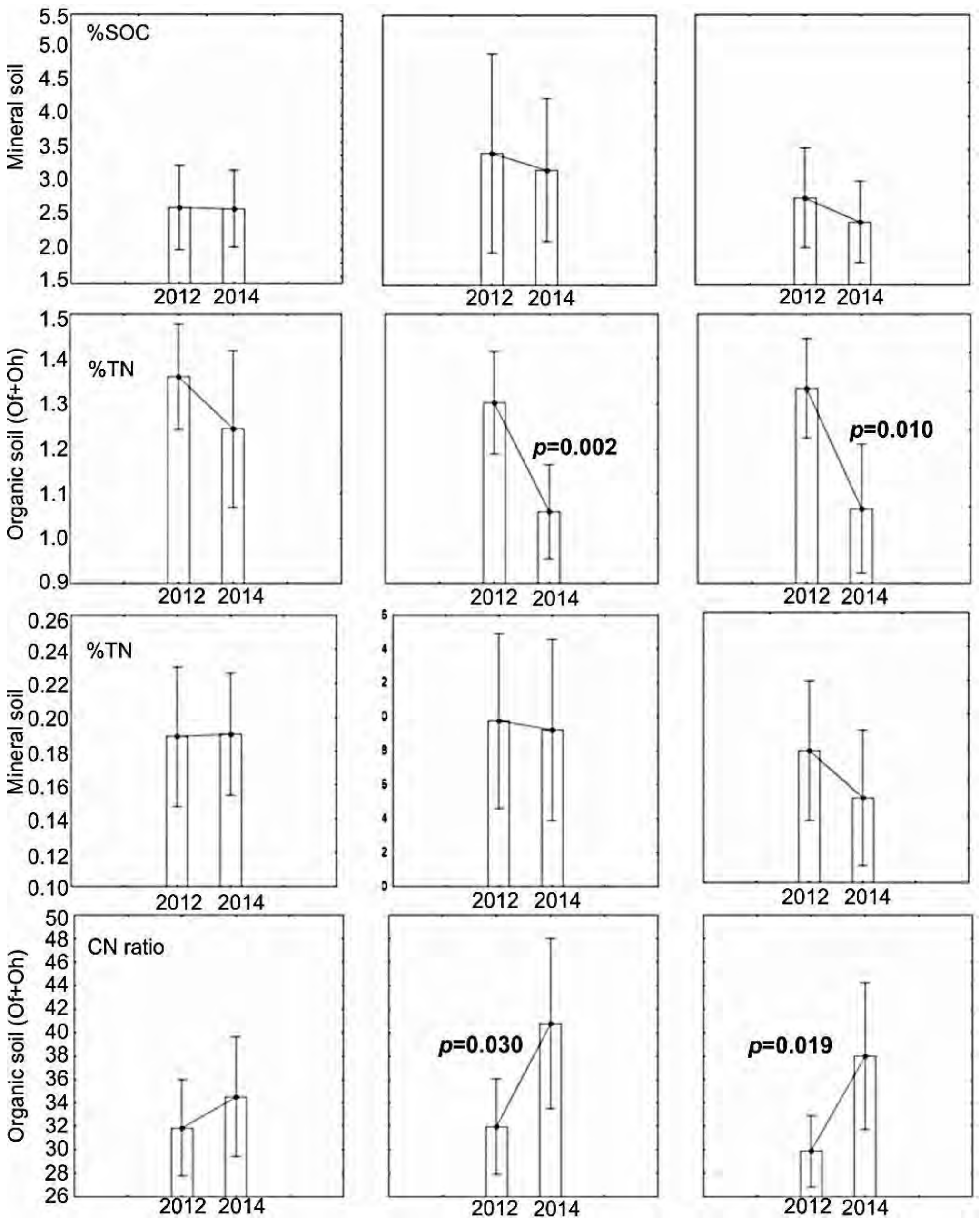
Organic and mineral soil analysis in Slovenian and Bosnian sites

Results of the site surveys, made with a Pürckhauer auger, indicated dominant presence of Chromic Cambisol for the compared sites in Slovenia (Kočevski rog, Snežnik, Trnovo) and Calcaric Cambisol, Chromic Cambisol following with Rendzic Leptosol. This part of the site survey gave only limited results considering estimation of soil horizon depth and humus characteristics, due to high content of gravel, stone and root which interfere the process of augering.

Analysed soil properties in Slovenia show insignificant and inconsistent differences between treatments control plot vs. 50 and 100% of cut (Figure 1). Values of SOC, TN and CN ratio were more variable for mineral soil compared to organic soil layer (Of+Oh). The repeated measurements (in 2012 and 2014) inferred to insignificant changes in SOC concentrations, which was markedly noticed in 100% of cut of total growing stock, in both organic (Of+Oh) and mineral soil. However, statistically significant decline (p<0.002, p<0.010) was detected in TN values only in organic horizons for the repeated measurements, for both intensities of logging (50 and 100% of cut). Also, significantly wider CN ratio (p<0.030, p<0.019) indicating changes in humus quality occurred in the organic soil for both intensities of logging (50 and 100% of cuts), observed in spotted periods. Soil pH values differed insignificantly between treatments for Slovenian plots (Figure 2), although significant (p<0.034) changes occurred again for plots with 100% logged growing stock in the organic horizons (Of+Oh).

Compare to Slovenia, Bosnian site was attributed to larger amounts of SOC, TN and higher pH values in both organic and mineral soil. In Bosnia, analysed soil properties indicated either no, or insignificant differences between treatments representing different chronosequences after last cut (2011, 2012, 2014 and control). Concentrations of the SOC and TN in the litter layer (Ol), fragmented (Of) and humified organic layer (Oh) were more or less the same among the treatments (Figure 3). Lower level of variability with less than 20% of standard deviation was observed in SOC and TN in the organic soil horizons compare to surface mineral soil characterized with higher standard deviations (exceeding 50%). Differences were not found between treatments in pH values.




%SOC
Mineral soil
%TN
Organic soil (Of+Oh)
p=0.002
p=0.010
%TN
Mineral soil
CN ratio
Organic soil (Of+Oh)
p=0.030
p=0.019
2012 2014

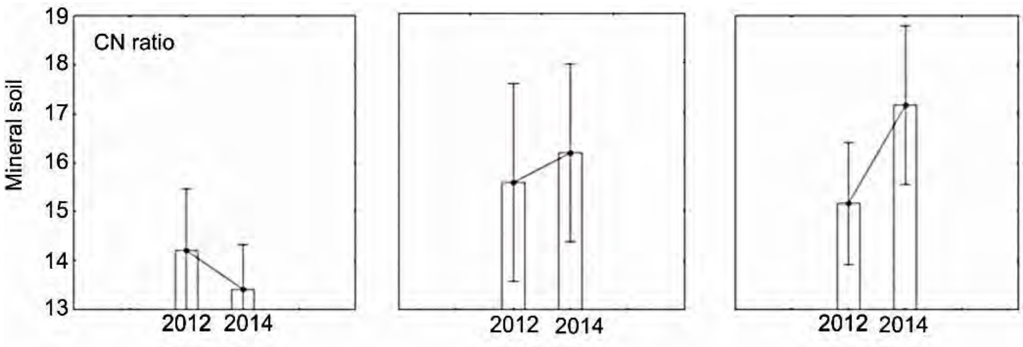


Figure 1. Soil organic carbon, total nitrogen and CN ratio (SOCC, TN, CN ratio) in the organic (Of+Oh) and mineral soil in control, 50% and 100% cut of growing stock plots examined in 2012 and 2014 in Slovenian sites

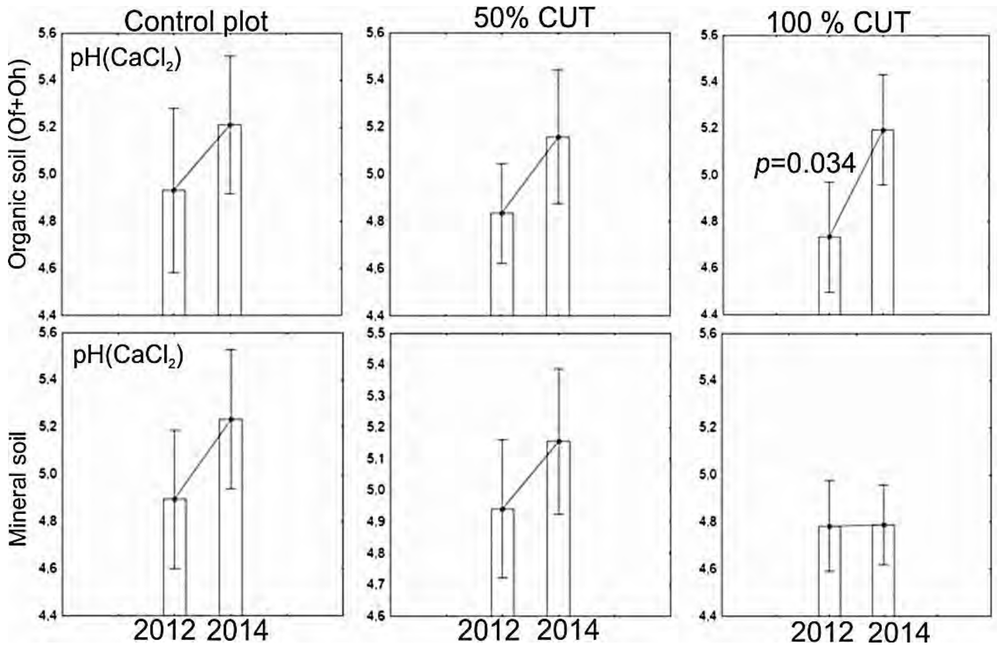


Figure 2. pH ($CaCl_2$) values in the organic (Of+Oh) and mineral soil in control-0%, 50% cut and 100% cut of growing stock plots examined in 2012 and 2014 in Slovenia

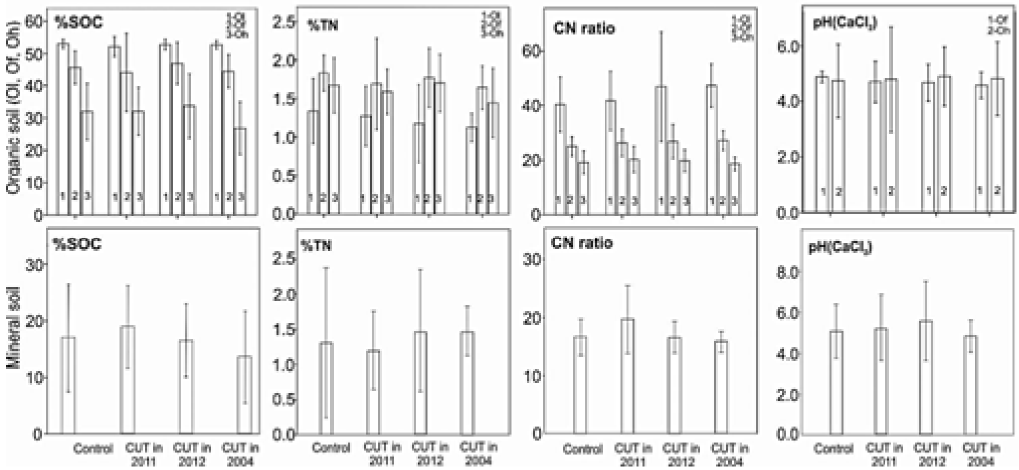


Figure 3. Quantity of soil organic carbon (C), total nitrogen (N), CN ratio (C/N) and pH values (pH ($CaCl_2$))in different organic (Ol, Of, Oh) and mineral soil layers (0-10 cm) in control vs. managed forest (14-18% cut of growing stock) analysed in different chronosequences (three, four and eleven years) after harvest in Bosnia

DISCUSSION

As expected for a mountainous region, soils at the study sites in Slovenia and Bosnia showed large small-scale (<1 m) variability of morphological features under the same soil unit. A Pürckhauer auger survey provided only limited insight into soil morphology because soils found on Jurassic-Cretaceous limestones are attributed to large proportion of gravel, stones and roots, which makes difficult to estimate soil horizon depth, presence of horizons when they are under stones and also discriminate humus horizon. Variability in SOM at site level influences a possibility to detect differences between treatments in quantities of SOC and TN. Such findings indicate the issue of treatments comparability (Yanai *et al*., 2003), which was addressed (in study) by following the criteria, while choosing plots, of identical parent material, soil types, forest association, climate and managing system. Also, selection of appropriate sampling techniques and soil variables (in this study large soil cores and small soil pits of known area and volume were used), allow minimal changes and differences to be detected comparing to other area-based approaches (Johnson *et al*., 1990; Ellert *et al*., 2002). Differences in relief are restricting comparison between Slovenian and Bosnian plots. As an example, the hydrology of karst sinkholes, specific for Slovenian sites, influence more intense processes of leaching and lower pH values compare to Bosnian sites. Also, higher altitudes in Bosnia may have affected higher SOC concentrations.

Comparison between treatments (unmanaged vs. managed forest) in Slovenia and Bosnia pointed to different results. Regarding the differences in treatments, both studies showed insignificant differences. However, the decrease in concentrations of SOC and TN found in Slovenian sites corresponds to changes obtained by repeated measurements (2012 and 2014), indicating the influence of logging intensity on these parameters. Large opening of the forest canopy after logging may lead to increased solar radiation, which may have influenced to intermittent periods of temporarily increased decomposition and mineralization of forest floor organic matter of managed stands (Prietzel, 2010). In Bosnia, SOC and TN concentrations cannot be connected to logging operations, since no differences in treatments were detected. Low intensity of logging applied in selectively managed forests, also applied in this region, is usually connected with insignificant changes in quantities of SOC and TN (Bauhus *et al*., 2004; Jurgensen *et al*., 2012). Some recent studies made in forest soils on calcareous bedrock of Bavarian Alps show on one hand insignificant differences in concentrations in both organic and mineral horizons, but on the other significant differences in stock values between treatments (Christophel *et al*., 2013).

Higher level of changes that occurred in TN, C/N ratio and pH values in Slovenian sites, found in the organic layer, is considered to be influenced by higher concentration of light fraction in humus and higher sensitivity to changes in site factors (Currie, 1999). While abundance of Ca ion and bioturbation processes inherent to soils formed on calcareous bedrock could explain greater resistance of SOC in surface mineral soil (von Lützow *et al*., 2006).

CONCLUSIONS

Exploring the heterogeneity of soil properties is one of the initial steps for estimating SOC stocks. Approaches applied to detect soil properties and differences between unmanaged and managed mountainous fir-beech forests in Slovenia and Bosnia indicate to negative influence of high (clear cutting)-, and no influence of low-intensity selective logging. Significant changes which were detected include: a) in Slovenia, a significant reduction in the proportion of nitrogen, and a significant increase of CN ratio and pH values, and b) in Bosnia, no differences in soil features between unmanaged and managed forest. Alternations in the stand microclimate which may affect humification and mineralization processes can consequently increase the amount of CO_2 emissions from the soil, and therefore these consequences are important to be addressed in regard to organic matter functional roles stored in mountain forests.

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