Impacts of Coppice Harvesting Operations on Soil

Rodolfo Picchio, Marco Senfett, Irene Luchenti and Rachele Venanzi

INTRODUCTION

Coppice is a traditional method of stand regeneration to produce woody biomass, a management system that is still widespread in many regions worldwide. Until the middle of the 20th century, coppice forests were common in most parts of Europe; although this has since changed, several issues relating to coppicing are still relevant. In Italy, coppice has much economic and social relevance for hilly and mountainous areas. Coppice produces timber for firewood and charcoal production (Picchio et al. 2011b) and has been an important source for litter collection and pasture (Gimmi et al. 2008; Glatzel 1999). At the same time, coppice harvesting could have a significant degrading influence on woody regeneration, fauna and the soil, causing compaction, horizon mixing and topsoil removal (Korb et al. 2007). In particular, compaction reduces both soil porosity and pore connectivity, thus increasing soil density and shear strength (Klvac et al. 2010; Picchio et al. 2012b; Williamson and Neilsen 2000). Such soil degradation can decrease tree growth (Grigal 2000), while carbon dioxide efflux from the soil may change significantly (Olajuyigbe et al. 2012). In this paper, two different coppices were analyzed, characterized by different stand types of Turkey oak (*Quercus cerris* L.) and chestnut (*Castanea sativa* Mill.).

In Italy, the traditional management of Turkey oak is coppice with standards, which involves felling about 80–85% of the total woody biomass and releasing about 70–120 standards/ha. For chestnut, the forests are mainly managed as coppices with standards, for productive and phytosanitary purposes (to cater for bleeding canker or chestnut blight), felling about 85-90% of the total woody biomass and releasing about 30–100 standards/ha. Logging systems may differ, depending on silvicultural management and the final product. The technical and economic utilization of coppice forests depends on various factors, including the type of terrain, transportation networks and harvesting technologies, as well as the silvicultural treatment and logging system (Cavalli and Grigolato 2010; Vusic et al. 2013). Although in recent years significant innovations in the technology and methodology of forest operations have occurred (Picchio et al. 2012a, 2011b), the majority of private and public coppice forests are still harvested using traditional methods, i.e. motor manual felling with chainsaws or using mules and/or agricultural tractors for extraction (Picchio et al. 2011a, 2011b; Laschi et al. 2016). The effects of harvesting can affect changes to the vegetation, nutrient availability, soil microclimate, soil structure and litter quantity and quality (Borchert et al. 2015; Edlund et al. 2013). In particular, operations such as forwarding and skidding have a high potential for causing soil compaction (Jamshidi et al. 2008; Cambi et al. 2015, 2016). However, properly managed forest ecosystems are claimed to be highly resilient in the long term (Sánchez-Moreno et al. 2006). Some studies also suggest that compaction can be avoided by minimizing areas of soil disturbance and soil compaction by designing thinner networks of strip roads (Mederski 2006).

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In coppice management, the time between harvests is called "rotation", or sometimes also "cutting cycle" (Espelta et al. 1995; Retana et al. 1992). During this time the stands are mostly restocked by natural regeneration through seedlings (gamic) and sprouts (agamic), a process that is strictly dependent on physico-chemical soil quality. This aspect of soil quality should also include some assessment of different biodiversity patterns. Biodiversity conservation has long been a goal of European conservation policy (CBD 2010; CEC 1998) and the monitoring of this aspect is essential to support management decisions that maintain multiple forest ecosystem functions (CBD 2001). A better understanding of the importance of biological diversity is needed to support the provision of multiple forest ecosystem services (Corona et al. 2011; Mattioli et al. 2015).

Within the COST Action FP1301 EuroCoppice, studies specifically designed to analyze the impact of the silvicultural treatment and logging operations on forest soils in coppices were performed using both standard and "innovative" wood extraction systems. In addition to the usual physical and chemical analyses (pH, organic matter, bulk density, penetrometric and shear resistance) (Cambi et al. 2015), an innovative methodology using an arthropod-based Biological Soil Quality index "QBS-ar" was applied (Parisi et al. 2005; Venanzi et al. 2016). The use of this index has valuable potential as a tool in ecosystem restoration programs in monitoring soil function and biodiversity, and in preventing the negative effect of soil compaction due to logging activities (Blasi et al. 2013).

METHODOLOGIES

Similar study methods were applied to the two different coppice types in order to determine the impacts on soil, while some differences between each type were determined by the site conditions. The silvicultural treatment applied was coppice with standards, aiming to guarantee a profit for the forest owner and to maintain an even-aged forest. For each area (described in Venanzi et al. (2016)), transects were examined in order to estimate that proportion impacted by machinery. Each transect was rectangular in shape (2 m x 50 m), laid crosswise to the maximum slope, making it possible to assess the percentage of the surface impacted by forest operations. In each forest, one random sampling plot (SP) per hectare was selected (18 for Turkey oak forest and 40 for chestnut forest) to determine: bulk density (BD), pH, organic matter content, penetration resistance (PR), and shear resistance (SR). Each SP was a circular area of 12 m in diameter, in which two different points (PO) were visually selected (e.g. based on the presence or absence of damaged understory, crushed litter, soil ruts or soil mixing) to represent disturbed or undisturbed soil conditions. To estimate the impact solely caused by the above ground removal of woody biomass (the silvicultural treatment, excluding the winching and skidding), it was compared with a control in a neighboring forest parcel which had remained undisturbed for over 10 years.

A QBS-ar analysis was carried out in each treatment by taking three soil core samples, each measuring 100 cm^2 and 10 cm deep. Microarthropods were extracted using a Berlese-Tüllgren funnel and the specimens were collected and identified to different taxonomic levels (class: Myriapoda; order: Insecta, Chelicerata and Crustacea). Soil quality was estimated with the QBS-ar index (Parisi et al. 2005; Gardi et al. 2008; Tabaglio et al. 2009;

Menta et al. 2010), based on the premise that the higher soil quality, the higher would be the expected number of microarthropod groups well adapted to soil habitats. Soil organisms were separated according to their morphological adaptation to soil environments; each of these forms is associated with an EMI score (eco-morphological index), which ranges from 1 to 20, according to the degree of adaptation. The QBS-ar index value is obtained from the EMI sum of all collected groups. The organisms belonging to each biological taxon were counted in order to estimate their density at the sampled depth and the ratio of the number of individuals and the sample area to 1 dm^2 of the surface.

RESULTS AND DISCUSSION

The proportion of forest surface impacted by logging operations is strictly related to the adequacy of the road network. In the coppices studied, the tractors skidded the trees on the forest floor only occasionally, and in these cases the impact was not only due to the amount of winching, but also the frequency of vehicle movements. The forest surface strongly impacted by forest operations ranged from 3.4% to 26.9% of the total area, showing a statistical difference between situations with good or inadequate forest trail networks. These results were notably lower than those obtained in other studies which had much higher densities of trees released after harvesting.

There were significant differences in bulk density, heavily influenced by both the silvicultural treatment and the impact by vehicles on the soil (Table 1 and Figure 1). Soil bulk density values were higher in the disturbed areas compared with undisturbed ones (average increase from 0.073 g/cm^3 to 0.209 g/cm^3, ranging from 10% to 27%). This was considered to be mainly the result of compaction caused by load transportation and in some cases vehicle traffic, but it affected only a low percentage of forest area. In comparison with the control (where there was no harvesting in the past decade), the BD in the undisturbed areas increased from 0.123 g/cm^3 to 0.210 g/cm^3, ranging from 19% to 39%. This was probably due to precipitation directly affecting the soil in all forest areas where above-ground biomass was removed.

Compared with the observations for bulk density, penetration resistances did not always show significantly greater values between the control and undisturbed areas, ranging from 0 to 0.06 MPa; 0-88%. However, the PR increased

Table 1. Results of the ANOVA and Tukey test for soil characteristics (average ± SD; letters show groups with statistically significant difference); differences tested between disturbed, undisturbed and control soil (Marchi et al. 2016; Venanzi et al. 2016)

Area	Soil typology	Bulk density [g/cm^3]	Penetration resistance [MPa]	Shear resistance [t/m^2]	Organic matter [%]	QBS-ar index
Quercus	Undisturbed	0.773±0.098a	0.128±0.05a	3.622±0.88a	13.5±1.85a	172a
	Disturbed	0.982±0.080b	0.294±0.09b	8.773±2.48b	11.1±2.20a	93b
	Control	0.650±0.101c	0.068±0.03c	2.544±0.74c	19.0±2.09b	251c
Castanea	Undisturbed	0.747±0.150a	0.066±0.011a	1.550±0.272a	18.1±1.3a	213a
	Disturbed	0.820±0.210b	0.276±0.090b	4.113±0.591b	13.1±1.6b	102b
	Control	0.537±0.110c	0.069±0.012a	1.569±0.310a	19.2±1.3a	198c

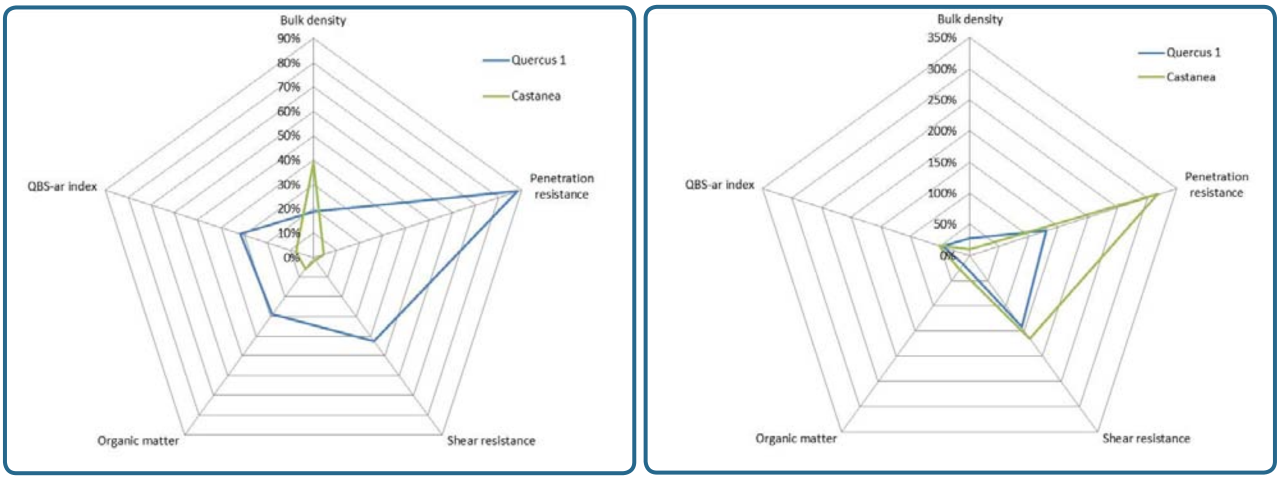

Figure 1. Percentage of impact for soil characteristics, on the left differences tested between undisturbed and control (silvicultural treatment) and on the right differences tested between undisturbed and disturbed soil (Marchi et al. 2016; Venanzi et al. 2016)

from 0.166 MPa to 0.210 MPa (ranging from +130% to +318%) when comparing disturbed and undisturbed areas. Similarly, while the soil shear resistance was not always greater in the control compared with the undisturbed areas (range from 0 to 1.08 t/m^2; 0-42%), in comparing disturbed and undisturbed areas, the SR increased from 2.56 to 5.15 t/m^2 (ranging from 142% to 165%). These relative differences among the three variables of bulk density and penetrometric and shear resistance showed similar significant trends, the greatest being for the latter two.

Soil organic matter content was also analyzed within the control site that had no utilization, and then within the forest areas harvested in this study. The organic matter content was lower in all areas affected by vehicle movements and from extracted loads. In chestnut coppice there was no significant statistical difference between areas undergoing harvesting (but not impacted by vehicles) compared with the control site. The areas disturbed by mechanical vehicle movement show a notable decrease in organic matter content, from 18 to 28%. This decrease can be linked to reduced mineralization as a result of less microbial activity in the disturbed area (Astolfi et al. 2011). Organic matter content was lower in all areas impacted by vehicles, while the removal of the above-ground woody biomass seems to only have caused significant change in Turkey oak coppice, at least during the first two years after the harvesting. Similarly, pH changes, which can influence many soil parameters and processes (Astolfi et al. 2011), did not seem to be affected by either the silvicultural treatment or the logging operations.

The QBS-ar index showed significant differences between the silvicultural treatment and the control, as well as between undisturbed and disturbed soils, indicating that the microarthropod community was affected in part by the silvicultural treatment and always by forest operations. Further analysis still in progress, two years after the treatment, shows that the QBS-ar index was lower than in the control within all of the areas directly involved with logging activities (temporary tracks), but that the recovery of the impacted soil was significant, but slow. From the same research in progress, the QBS-ar index was also affected by the silvicultural treatment, but in the soil surfaces not impacted by logging activities, recovery of the microarthropods was rapid. These results show that vehicle movement had a major impact on the soil condition, while the silvicultural treatment alone also had a clearly defined impact, but one that was recovered from quickly.

The QBS-ar index showed a high range of variation from disturbed to control areas (93–251 in Turkey oak, corresponding to a range of 8% to 52%), as was also observed by Blasi et al. (2013) and Rüdisser et al. (2015). In summary, the microarthropod communities were probably affected by the bunching and extraction operations of vehicle traffic and log dragging, causing soil compaction, while their density was similarly lower in all areas affected by vehicles and logging. Moreover, there was a statistically significant difference between the area subject to silvicultural treatment (but not impacted by vehicles) compared with the control site. In this case, however, it seems that the silvicultural treatment had a positive effect, perhaps related to an increase in soil nutrients immediately after the harvesting.

The QBS-ar can be considered a very useful qualitative indicator for coppice forests, as it is extremely sensitive to environmental variations caused by anthropic disturbance. This study has also shown that forest soil is extremely fragile in physical, as well as chemical and biological terms, and their highly complex interaction. Forest soils are extremely vulnerable to natural or anthropic disturbances, for example in logging operations (Vossbrink and Horn 2004). It is therefore extremely important that the impacts caused by forest management are quantified and the results used to design lower impact logging methods. These observations show that tractor tracks consistently cause compaction that can extend to a depth of at least 10 cm, creating a high risk of water runoff and wash out, which over time can cause a loss of fertile soil. Compacted soil can also impede seed germination, hinder regeneration and decrease forest productivity and continuity. Moreover, increased compaction causes a loss of soil micro- and macroporosity, reducing oxygen and moisture in the soil and drastically reducing micro-biological activity and fine root growth (Lynch et al. 2012). From a phytopathological viewpoint, increases in water runoff facilitate the expansion and transmission of pathogens as spores and rhizoids (Vannini et al. 2010). The overall consequence of soil compaction is a decrease of soil permeability, growth and nutrient supply to root systems. These negative consequences have also been shown by others (Heinonen et al. 2002; Alakukku 2000).

The coppice management system and the silvicultural treatment applied did not show any particular problems (i.e. in terms of seedling regeneration, fluctuations in seed production, prolonged periods of uncovered soil), but reduced impact logging (RIL) methodologies could be beneficial (Enters et al. 2002; Maesano et al. 2013). The logging operations in this case were carried out with appropriate mechanization, with tractors only skidding the trees on the forest floor occasionally, although physical-mechanical impacts caused by vehicle movement on forest soils (off the track) are evident even here. Carefully designed skid roads are therefore recommended, as well as setting out strip roads, skid trails and forwarder use so as to reduce soil disturbance. In future research, it would be interesting to evaluate the capacity for recovery from soil damage over longer periods of 2–16 years. For this specific study and other similar forest situations, if silvicultural treatments and logging activities are well planned and sustainable forest management guidelines were followed, no particular post-harvesting operations would be necessary. A forest road network that is viable and functional will further ensure a limited impact on forest soil, with impacted soil surfaces of <5–10%. It is important to consider the results of studies such as this one when compiling guidelines, criteria and indicators of sustainable forest management.

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