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Title: Silvicultural and logging impact on soil characteristics in Chestnut Mediterranean coppice

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Abstract: Commonly, in Italy coppice utilization consists in a felling of about 80-85% in mass of the total woody biomass, with release of standard (about 70-120 standard/ha). This is a crucial operation in forest management, which also has important effects on understory, fauna, and soil. The aim of this study is to investigate the impact generated by the silvicultural treatment observed and by the logging methodology on the soil characteristics, within the chestnut coppice located in central Italy on the Cimini Mountain area. In particular, this study has paid close attention to the silvicultural treatment of the coppice with standards for chestnut forest, its utilizations and problems. The applicative use of equipment and methods were also included in this study to evaluate the entity of impact on forest soil characteristics. For the study of the silvicultural treatment and logging impacts on the forest soils in addition to the usual physical and chemical analysis (pH, organic matter, bulk density, penetrometric and shear resistance), soil quality was estimated with the QBS-ar index. Our findings demonstrate that physical, chemical and biological soil features can be strongly impacted by harvesting operations and, consequently, certain soil processes may be influenced at the imposed compaction levels. On other hand, physical, chemical and biological soil features are not impacted by silvicultural treatment applied. The results confirm that chestnut coppice soils are characterized by the highest biodiversity level among edaphic fauna and from a well-structured and mature microarthropod community, which is typical of stable ecosystems (QBS-ar value >200).

Viterbo, 26 September 2015

Dear Ecological Engineering Journal,

on behalf of my co-authors, I am submitting the enclosed material for possible publication in the Ecological Engineering Journal. It has not been submitted for publication nor has it been published in whole or in part elsewhere. I attest to the fact that all authors listed on the title page have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission to the Ecological Engineering Journal.

We are submitting the work titled: "Silvicultural and logging impact on soil characteristics in Chestnut Mediterranean coppice".

This scientific paper focus on topics treated in recent years in this and other important Journal and currently of great scientific interest in the global social and environmental sustainability context. Silvicultural and logging activity influences the forests conservation and their management, for these reasons must be supported by an adequate impact analysis, and must be compatible with a sustainable forest management. For a specific sylvicultural management systems "coppice with standards" were investigated the impacts generated by the silvicultural treatment observed and by the logging methodology on the main soil characteristics, chemical, physical and biological.

Touching both environmental aspects and engineering aspects, the research is well within the scope of ecological engineering. So I hope that the editor considers this paper appropriate to be published.

We are a research group formed by Rachele Venanzi, Gianluca Piovesan and Rodolfo Picchio like corresponding author. These Authors are two professors and one researcher from Tuscia University (Viterbo, Italy), with expertise in forestry mechanization, forestry, silviculture, reduced impact logging practices, logging impacts and pedology and ecology.

Best regards

Rodolfo Picchio

Research Highlights

Research highlights

- Silvicultural and logging impacts of semi-mechanized logging method in coppice.
- Impacts of silvicultural treatment and logging method on soil chemical characteristics.
- Impacts of silvicultural treatment and logging method on soil physical characteristics.
- Impacts of silvicultural treatment and logging method on soil biological characteristics.
- The impacts caused by silvicultural treatment and logging method were determined and discussed.

Silvicultural and logging impact on soil characteristics in Chestnut Mediterranean coppice

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Keywords

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Abstract

Commonly, in Italy coppice utilization consists in a felling of about 80-85% in mass of the total woody biomass, with release of standard (about 70-120 standard/ha). This is a crucial operation in forest management, which also has important effects on understory, fauna, and soil. The aim of this study is to investigate the impact generated by the silvicultural treatment observed and by the logging methodology on the soil characteristics, within the chestnut coppice located in central Italy on the Cimini Mountain area. In particular, this study has paid close attention to the silvicultural treatment of the coppice with standards for chestnut forest, its utilizations and problems. The applicative use of equipment and methods were also included in this study to evaluate the entity of impact on forest soil characteristics. For the study of the silvicultural treatment and logging impacts on the forest soils in addition to the usual physical and chemical analysis (pH, organic matter, bulk density, penetrometric and shear resistance), soil quality was estimated with the QBS-ar index. Our findings demonstrate that physical, chemical and biological soil features can be strongly impacted by harvesting operations and, consequently, certain soil processes may be influenced at the imposed compaction levels. On other hand, physical, chemical and biological soil features are not impacted by silvicultural treatment applied. The results confirm that chestnut coppice soils are characterized by the highest biodiversity level among edaphic fauna and from a well-structured and mature microarthropod community, which is typical of stable ecosystems (QBS-ar value >200).

Introduction

Coppice is a traditional method of regeneration to produce woody biomass rapidly. Coppice historically represents an important source of firewood, litter collection and pasture (Glatzel, 1999; Gimmi et al., 2008). In fact, low-input coppice may be an efficient and sustainable biomass production system. After 1950 the management of coppice was affected by a progressive abandonment as a consequence of environmental policies and socio-economic changes (Bürgi, 1999; Bičik et al., 2001; Lo Monaco et al., 2011, 2014). The cessation of cuts produced the so-called stored coppice or “aged coppices” and started to alternative systems of coppice management such as the conversion of coppice into high forest (Picchio et al., 2009). This phenomenon for phytosanitary and productivistic purposes has only marginally affected chestnut coppices, which, especially in Italy, have remained with the traditional form of management of the coppice with standards. Generally, coppice has supplied timber for consumption both as firewood and charcoal production for centuries (Picchio et al., 2011b), in particular chestnut coppices have provided structural timber of great value.

Chestnut coppices are the fruit and result of a silviculture of this species that has lasted for centuries, and although it is not the only type of forestry among the most naturally stable, it does guarantee continuity and stability to the forest cover. They also have significant economical and traditional factors, so much so that the expansion of cultivation regarding composition and formation are presently government issues (Maetzke et al, 1991). The chestnut tree has taken on a preeminent role in Italian forest formation, not only for the range in quality and variety of wood, but mostly due to the consistent presence on Italian territory. It is infact found from the Alps to Sicily, usually in extended territories as a result of intense diffusion and cultivation done up to the recent past. Today the chestnut grows in hilly and mountainous territories where there is a high level of naturalistic value or within protected areas, where the economy also depends on tourism activities connected to the quality of the product and the agro-forest landscape. Moreover, chestnut forests are habitats of Community interest (9260 Castanea sativa Forests). Data from ISTAT 1950 report 447,000 hectares of surface for fruit producing chestnuts and 275,186 hectares for coppices. Following radical economical, social, ecological and phytopathological changes when cultivation methods of this species were remarkably modified, a majority of the chestnut producing forests were coppiced. Presently, the total surface amount of chestnut forests is 788,408 hectares of which 147, 586 hectares are fruit producing and 605,888 hectares are for wood (IFNC 2007). The chestnut tree is a species that has numerous positive aspects such as the rapidity of growth, good quality of wood, a vast variety, and high pollination capacity. Even where the environmental needs of the chestnut are not fully present, production is still well sustained. Growing rates are kept high allowing for a good flexibility in the choice of rotation. On the other hand, this species has some negative aspects, such as susceptibility to pathogens and the tendency to ring shake. Generally, these limiting factors are linked to the type of management applied. The INFC states that the overall health of Italian chestnut forests is not among the best; only 29% is free of any type of damage. This species is mainly affected by two serious fungal diseases: bark cancer caused by Cryphonectria parasitica and 'ink disease' caused by Phytophthora cambivora. There is damage caused by insects which is not less important, such as the Dryocosmus kuriphilus Yasumatsu, commonly known as the 'chestnut gall wasp'.

The coppice harvesting is a crucial operation in forest management, which has important effects on the understory, the fauna and, last but not least, the soil (Frey et al., 2011: Picchio et al., 2012a,b). Also the carbon dioxide efflux from the soil may change significantly after harvesting (Olajuyigbe et al., 2012) due to modified inputs of light, heat and water to the ground and root density, but also due to machinery-induced compaction of soil, which reduces porosity and connectivity of pores, and increases soil density and shear strength (Picchio et al., 2012b). These impacts could produce a tree growth reduction (Grigal, 2000), soil horizon mixing and topsoil removal (Korb et al., 2007).

For these reasons, one of the most important problem of the forest sector is to minimize the ground damage caused by forest operations (Edlund et al. 2013). Generally, harvesting effects include changes in vegetation, nutrient availability, soil microclimate and structure and litter quantity and quality. In particular, forest operations, such as forwarding and skidding, have a high potential for soil compaction (Jamshidi et al. 2008, Cambi et al., 2015a,b). However adequately managed forest ecosystems are suggested to be highly resilient in the long-term perspective (Sánchez-Moreno et al. 2006).

At any rate, all extraction systems have a potential for logging damage. Research on logging damage started at the beginning of the twentieth century and its importance has been rising with the spread of mechanized wood harvesting (Vasiliauskas, 2001). Mechanical injury to residual standing trees, soil and forest regeneration are caused by machine vehicle traffic and log dragging (Klvac et al., 2010; Picchio et al., 2011a, 2012a,b). The impact on residual trees and soil depends on several factors, such as: harvesting system (Spinelli et al., 2010); site characteristics removal intensity design of the skid trails skill of operators (Bragg et al., 1994; Picchio et al., 2011a, 2012a,b) and degree of mechanization. Machinery-induced soil compaction strongly reduces porosity and pore connectivity and increase soil density and shear strength (Klvac et al., 2010; Williamson and Neilsen, 2000).

Logging systems may be different depending on the silvicultural management and the final products. Technical and economic utilization of coppices is dependent on various factors concerning terrain conditions, transportation networks and harvesting technologies, as well as systems, silvicultural and forest operation management (Cavalli and Grigolato, 2010; Vusic et al., 2013). Although in recent times significant innovations have become available in forestry utilization (Picchio et al., 2011a,b), both in terms of technology and methodology, the majority of private and public coppice forests in Italy are still harvested by applying traditional methods, i.e., motor-manual felling (chainsaw) and low mechanized extraction methods (mules and/or agricultural tractors) (Picchio et al., 2011). These machines are often not adequately prepared for forestry works.

In order to improve silvicultural management and logging methods, a better knowledge about the long-term impact of forest operations is needed (Maesano et al., 2013; Picchio et al., 2011b). The reduction of the negative effects of felling and extraction is one of the main goals when achieving sustainable forest management (Sist and Nguyen-Thé, 2002; Sist at al., 2003).

Before starting logging operations, attention is paid to soil consistency and adhesiveness in order to infer if machinery can work easily, but little care is sometimes devoted to the effects of such operations on soil quality. Forests growing on slopes, in particular, require detailed preventive and posterior analyses aimed at assessing the real impact of operations (Picchio et al., 2011a).

A better knowledge about the impact of forest operations in coppice harvesting is needed for improving logging systems (Cambi et al., 2015a). The reduction of the negative effects of felling and extraction is one of the main goals when achieving sustainable forest management. Forests growing on slopes, in particular, being the most liable ones to the negative impact on soil of vehicles in harvesting (Jourgholami et al., 2014), require detailed preventive and posterior analyses aimed at assessing the real impact of management operations (Picchio et al., 2011a).

Unfortunately, the studies focused on the effects of the utilizations on the forest soil physical properties are uncommon, and companies are rarely required to take into account the impact of their operation on the territory and the sustainability of the forest, or better, the real application of a sustainable forest management.

For the study of the silvicultural treatment and logging impacts on the forest soils in addition to the usual physical and chemical analysis (pH, organic matter, bulk density, penetrometric and shear resistance), soil quality was estimated with the QBS-ar index (Blasi et al., 2013). This index can be also a valuable tool in ecosystem restoration programs to monitor the development of soil functions and biodiversity and to prevent the negative effects of soil compaction due to logging activities. More in general, QBS-ar is a candidate index for continuous biomonitoring of soil fauna communities to describe patterns and processes in the microarthropod biodiversity across the landscape. A deeper knowledge of soil biodiversity in response to landscape use will provide guidance in effective management planning for sustainable renewable resource use and nature conservation (Blasi et al. 2013).

Biodiversity monitoring is essential to support management decisions in maintaining multiple forest ecosystem functions at long term (CBD 2001). A better understanding of the roles of the components of biological diversity for supporting the provision of multiple forest ecosystem services it is necessary (Corona et al. 2011; Mattioli et al. 2015). Touching both environmental aspects and engineering aspects, the research is well within the scope of ecological engineering (Mitsch and Jørgensen, 2003).

The aim of this study is to investigate the impact generated by the silvicultural treatment observed and by the logging methodology on the soil characteristics, within the chestnut coppice located in central Italy on the Cimini Mountain area. In particular, this study has paid close attention to the silvicultural treatment of the coppice with standards for chestnut forest, its utilizations and problems. The applicative use of equipment and methods were also included in this study to evaluate the entity of impact on forest soil characteristics.

Matherial and methods

Study sites

The study was conducted in a chestnut (*Castanea sativa* Mill.) coppice on the Cimini Mountain (42°36’92.16’’N, 12°20’28.00’’E) near Viterbo, Lazio region, Central Italy. The forest stand was a 10 ha of coppice with standards. It was located at an elevation of 590 m a.s.l., on a slope with an average gradient of 45% (ranging between 15% and 55%). Ground surface was uneven, with about 10% of the surface showing obstacles to machine traffic, such as rock outcrops and hollows. The climate was Mediterranean, characterized by hot, summers, and mild, rainy autumns and early springs. Mean annual precipitation was about 900 mm and mean annual temperature was 14.8 °C. Highest daily temperatures were recorded in July or August (31 °C) and the lowest ones in January (1 °C). The coppice was felled at the growth age of 16 years, releasing 60 standards per hectare.

The area has two forest-rural roads, artificially surfaced, that divide the forest into two parcels. The road slope is medium-low at 5% and the average width of the roadway is 3.20 meters. The forest has no tracks. The landing area was made along a wider part of the main road.

The soil formation of the territories described is mostly connected to the type of materials resulting from volcanic eruptions, which are exposed to weather conditions. The smooth or stony types of materials have conditioned their alterability and therefore the thickness and type of land. Moreover, the entire soil of the area is characterized by a remarkable permeability, that favours percolation and the internal circulation of waters, and a rapid decomposition of litter that creates a mull type humus (Maetzke et al, 1991). The soil area is non-hydromorph brown soil, acidic reaction or sub-acidic. This soil belongs to the brown andro-soil type, class 2 potential, and therefore has good agronomical potential. It is adapt for every type of cultivation, but particularly tree cultures (Maetzke et al, 1991).

In this study area, post operations analyses were conducted, using research methods based on internationally shared protocols, elaborated and adapted to this context of study as proposed in Picchio et al. (2009).

Treatment and logging methods

The chestnut forest under study is characterized by a silvicultural treatment defined as coppice with standard. The coppice with standard is the most used silvicultural treatment method in coppice forests of Italy, typically within the Italian situational context, aimed mainly towards guaranteeing a profit for the forest owner and towards maintaining coetaneous forest. The yield of chestnut coppice in the mountains of the Cimini and Vicani (central Italy) is very high, thanks to growth on volcanic terrains and to thinning that have brought to variety with a good average volume.

The treatment consisted in the almost complete removal of the trees, releasing 60 standards per hectare. The harvesting operation was done mainly during the winter season which was completed in about 100 days. Tree Length System was adopted, trees were taken uphill to a landing site, crossed by a single permanent road. Before this final cutting, the stand was thinned once. Pre-harvest stand data were obtained with standard mensuration techniques on eight circular sample plots of 20 m diameter, hence covering an area of 314 m^2 each one. Stand data are shown in Table 1.

Three soil samples were taken randomly from the top 30 cm of mineral soil to determine the particle size distribution, which are considered crucial indicators of vulnerability to soil compaction (Marchi et al., 2014; Cambi et al., 2015b). For particle size distribution, rock fragments (particles with >2 mm diameter) were removed from the air-dried samples by sieving. Afterwards, three sand fractions – 2.00-0.50 mm (coarse), 0.50-0.25 mm (medium), and 0.25-0.05 mm (fine) – were separated by wet sieving. Finally, silt and clay were determined by a hydrometer (Picchio et al., 2012b; Cambi et al., 2015a).

Logging was performed by six operators according to the “tree length system” (TLS), with the intent of producing mainly structural timber. All trees were cut motor-manually with a Stihl MS 260 chainsaw. Bunching and extraction was performed winching uphill with a farm tractor using a skidding arch. The wheeled tractor was a 79 kW Lamborghini, weighing 4300 kg and carrying a bolt-on hydraulic winch with a maximum pull of 40 kN. This tractor travelled on the forest soil and rarely a winching operation was conducted for viability, this is due mainly to the complete absence of tracks.

Analytical methods

For each area under examination, 3 transects were assigned to indicate represented areas so as to estimate the surface area impacted. Each transect was rectangular in shape (2 m x 50 m), individualized parallel to the level curve, using a tape measure, recording clearly and in detail the surface portions which were and were not affected. The results from this procedure made it possible to record the percentage of the affected area.

The impact on soil was assessed on 20 randomly selected sampling plots (SP). In each plot, we measured for the soil: bulk density, pH, organic matter content, penetration resistance, and shear strength. Each SP consisted of a circular area 12 m in diameter, where two different points (PO) were selected based on visual assessment (e.g. presence or absence of bent understory, crushed litter, ruts or soil mixing) to represent disturbed and undisturbed soil conditions, respectively. As a control, for the effect due to the silvicultural treatment, a neighboring forest area was considered, managed, but not impacted for more than 10 years; in this area 20 randomly selected SP were identified. One measurement for each PO for bulk density, pH, organic matter, and three measurements for penetration resistance and shear strength were performed.

For bulk density determination, we inserted a steel cylinder of known volume, 8.5 cm high and with a 5.0 cm inner diameter, into the top of the mineral soil. The soil was removed from the cylinder and, once in the lab, weighed after oven drying at 105 °C to constant weight (dry weight). The dry weight divided by the volume of the cylinder is the bulk density (Db) expressed as Mg m^{-3}.

Penetration resistance of soil was measured by a penetrometer Pen-P100 and shear strength by a scissometer Sciss-S100. These parameters were measured in the top 5 cm of soil. The measured values were standardized to water-holding capacity of soil, which was determined to be 21% inferred from the particle-size distribution as in Saxton et al. (1986).

The pH value was measured by potentiometric analysis, using soil/saline solution suspensions (soil-KCl 1 mol) in a 1:2.5 proportion. Organic matter measurement was done by incineration in a mitten at 400°C for 4 hours, after the thorough elimination of water and pretreatment at 160°C for 6 hours.

For the microarthropods extraction and QBS-ar index application, three soil cores 100 cm^2 and 10 cm deep were sampled in each soil typology. Microarthropods were extracted using a Berlese-Tüllgren funnel; the specimens were collected in a preserving solution (75% ethyl alcohol and 25 % glycerol by volume) and identified to different taxonomic levels (class for Myriapoda and order for Insecta, Chelicerata and Crustacea) using a stereo microscope. 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). The QBS-ar index is based on the following concept: the higher the soil quality, the higher the number of microarthropod groups will be which are well adapted to soil habitats. Soil organisms are separated into biological forms according to their morphological adaptation to soil environments; each of these forms is associated with a score named EMI (eco-morphological index), which ranges from 1 to 20 in proportion to the degree of adaptation. The QBS-ar index value is obtained from the sum of the EMI of all collected groups. The organisms belonging to each biological taxon were counted in order to estimate their density at the sampled depth (0–10 cm) and relating the number of individuals and the sample area to 1 m^2 of the surface (ind/m^2).

Statistics

Statistical analyses were carried out with the Statistica 7.1 (2007) Software. As a first step, data distribution was plotted and checked for normality (Lilliefors) and homogeneity of variance (Levene test). All the data points then underwent to t-test, ANOVA or MANOVA test, to test the effect of different treatments. In order to determine the relation among QBS-ar, bulk density, penetration and shear resistance, a nonparametric correlation analysis (Spearman correlation matrix) was applied. Data were not normally distributed and with insufficient homogeneity of variance, as suggested in Picchio et al. (2009), were statistically processed using the non parametric ANOVA the Kruskal-Wallis test. Principal Components Analysis (PCA) was applied for the descriptive analysis of the soil biodiversity.

Results and discussion

Analysis of the impacted surface

The silvicultural treatment studied and applied results to be simplified and without any particular applicative problem. However, the limited level of planning and applied technology in the forest utilizations did not allow for a proper low impact operation. The logging operations were done by a type of simplified mechanization but not light, the lack of tracks made it frequently necessary for tractors to enter through forest ground, the impact was not only characterized by the passage of logs but also vehicles. The forest surface impacted by the activity was 26.9%, a result notably lower to that obtained in other studies, characterized however by a much higher density of the trees. (Picchio et al., 2012; Marchi et al., 2014; Tavakar et al., 2013).

Soil Physical Chemical Analyses

The granulometry is characterized by a high content of sand 60.9%. The presence of silt is at 36% while the clay contents is quite low at 3.1%, but does however come into the FS soil material class (franco-sandy). Along with the granulometric values and through the Soil Water method (K.Saxton), the soil field capacity was calculated (CC) at 21%.

As far as regards the forest soil, the analyses conducted by a corer for soil sample gathering and the successive laboratory tests, gave the results shown below.

Regarding soil moisture during the sampling period, no significant statistical differences were observed in the samples as well as the comparative treatments (moisture range 51-59%).

There were significant differences in bulk density in comparative treatment. This parameter is heavily influenced by both the silvicultural treatment and the soil impact by vehicles. When comparing the soil control area (with no silvicultural treatment whatsoever in the last decade), and the non disturbed soil portions but subject to silvicultural treatments, the bulk density difference measured is increased on the average of 0.210 g/cm^3 which is equal to 39%. This is considered to be mainly caused by the action of atmospheric events, in particular precipitation followed by the undercovering due to silvicultural operations.

When comparing the non disturbed soil (but subjected to silvicultural treatment) and the portions of soil disturbed by vehicles, the difference measured in terms of bulk density is an average increase of 0.073 g/cm^3 equal to about 10%. This is considered to be mainly caused by the compacting action of load transportation and vehicles. Similar values have been observed in another study where not only loads but vehicles moved on the forest soil (Picchio et al., 2012b). Where no vehicle entered on the forest soil, but winching operations allowed vehicles to impact the soil, bulk density value increase vary from 1 to 3% (Marchi et al., 2014; Picchio et al., 2012b). In Cambi et al. (2015a), an increase over 30% was measured where vehicles moved repeatedly. This data gives more evidence that the need to limit the passage of vehicles over the same tracks.

Once field tests were conducted, the penetrometric and scissometric data gathered were subjected to relative statistical investigation in order to find any significant statistical difference between the non disturbed forest soil and the one where utilization operations had been conducted.

The MANOVA test gave positive results showing a remarkable difference between the groups. Contrary to what was observed for bulk density, the scissometric and penetrometric analyses do not show significant differences between the control particle (without any silvicultural treatment in the last decade) and the non disturbed soil portions but subjected to silvicultural treatment.

In particular, the difference obtained from the penetrometric data is about 0.210 MPa which is equal to 320.6%. This is considered to be a result of the utilization activities carried out in the area.

The results obtained show a significant concordance with the same for bulk density; the percentage of variation is outstandingly superior to the variation recorded for bulk density.

The same can be said for the scissometric analyses. The difference observed is 2.563 t/m^2 which shows an increase of 165%. This is considered to be a result of the utilization activities carried out in the area.

The results obtained show a significant concordance with the same for bulk density and the penetrometric investigation; the variation percentage-wise is remarkably superior to the variation recorded for bulk density and in line with the variations observed for the penetrometric data.

In the utilization soil impact analysis, the percentage of organic matter content was also analyzed initially in a control site that had no utilization, and then within the areas of interest. Similar impact values were obtained as from Cambi et al. (2015a) on soils with characteristics similar to those in of this study.

As seen from the data obtained, the organic matter content is inferior in all the areas affected by the impact of vehicle movement and from loads, whereas there is no significant statistical difference between the area undergoing silvicultural treatment (but not impacted by vehicles) in comparison to the control site. Particularly, the areas disturbed by mechanical vehicle movement notably influence the organic matter content. This decrease in OM in the portions of disturbed soil can be linked to the decrease in mineralization and moisturing activity by the micro-organisms present in the disturbed area.

Following the utilization activities performed within the area of study, the organic matter content is inferior in all the areas impacted by vehicles, while the silvicultural treatment does not seem to have caused any significant modification of this parameter, at least during the first two years after the intervention.

The pH value is another value that was obtained during the study of the soil impact of forest utilization. In this case, no influence on pH was observed as a result of the silvicultural treatment or the terrain compaction. As stated before, pH is a very important parameter for the correct functioning of the soil system, due to the fact that pH variations influence various parameters and processes. However, within the context of this study, this parameters does not seem to have been influenced by the vehicle movement or silvicultural operations. Perhaps, this is due to the fair level of acidity that generally is found on soils that are studied.

Soil biodiversity analysis

The QBS-ar is an index for soil impact. It is very useful as it is extremely sensitive to environmental variations caused by anthropic disturbance. This index is exclusively qualitative, and evaluates the presence and the complexity of the soil conditions of the sites under study. Specifically, a high value index corresponds to a situation where there are ample and well structured soil conditions with a high level of biodiversity in terms of biological forms. The soil conditions are closely connected to the presence of empty spaces on the soil that give vital space to the same community, and therefore on soil where anthropic activity generates a high level of compaction is missing from this particular habitat and the community is thus disturbed. Through analysis of samples gathered within the area under study, it was possible to evaluate the utilization impact on the soil micro-arthropod community.

The data gathered (tab. 6 and fig. 1), shows the QBS-ar index to be inferior in all the areas involved in load and vehicle movement impact, while there is a significant statistical difference between the area subject to silvicultural treatment (but not impacted by vehicles) compared to the control site. However, in this case it seems that the silvicultural operation had a positive influence, even if a minimum one. This increase of the index in the area subjected to treatment as compared to the control site is considered to be due to an increase of possible micro-habitats after the onset of tree and grass renovation phenomena.

The results show that the movement of vehicles have a major impact on the soil condition community, while the silvicultural intervention does not seem to have any distinct impact. In some cases, it seems to favour improvement of the biological quality of the soil.

The movement of mechanical vehicles and loads, however, have a negative influence on the index as observed for many other parameters.

The QBS-ar index showed a very large variation range (92-248), consistently with what was observed by Blasi et al. (2013) and Rüdisser et al (2015). As the QBS values showed an excellent (Spearman's test, QBS-ar vs bulk density: Rs= -0.59; $p<0.05$; QBS-ar vs penetration resistance: Rs= -0.68; $p<0.01$; QBS-ar vs shear resistance: Rs= -0.72; $p<0.01$;) correlation with soil compaction (and since there was a significant difference between disturbed and undisturbed soil), most of the observed variation in our sample is explained by the different degree of soil compaction rather than by physical habitat heterogeneity. Namely, microarthropod communities are probably affected by bunching and extraction operations because of the negative effect of soil compaction, in turn due to vehicle traffic: as already shown by Blasi et al. (2013) for forest ecosystems, soil compaction leads to the disappearance of specialized groups such as Symphyla, Diplopoda and Chilopoda.

In addition to the QBS-ar index, the population density was evaluated during sampling in terms of individuals per dm^2, intending that this soil unit is specifically sampled at a pre-established depth of 10 cm.

As can be observed from the data gathered, the micro-arthropod density is inferior in all the areas involved in the impact caused by the movement of vehicles and loads, while there is a significant statistical difference between the area subject to silvicultural treatment (but not impacted by vehicles) compared to the control site. In this case, however, it seems that the silvicultural intervention had a negative effect, even if a minimum one. The movement of mechanical vehicles and loads has a negative influence on the index as observed for many other parameters.

The PCA of the EMI-by-sites matrix (Fig. 2) showed a negative relationship between the degree of faunistic complexity and soil compaction: the most impacted (and thus most compacted) sites featured an over-simplification of the faunistic assemblages, that lost the taxonomic and functional groups specifically adapted to soil habitats.

The forest soil is extremely fragile in physical terms as well as chemical and biological terms, with a low density bulk, low resistance to compression and cut with high values of permeability. These parameters make forests extremely vulnerable to anthropic disturbances of various nature, the first among all is forest utilization (Vossbrink and Horn,2004).

As observed from soil conditions (fig. 3), it appears evident that the tracks used for vehicle movement above all determine an increase of compaction that is recorded at a depth of 10 cm. All this can transform into the risky phenomenon of water run off and wash outs that over time can cause a loss of fertile soil. It must not be neglected that these soil conditions could impede seed germination, therefore hinder regeneration and continuity of the forest, and lead to the possible loss of green areas.

Moreover, increased compaction determines the loss of micro-macroporosity, diminishing the presence of oxygen and moisture in the soil, causing the lack of the vital conditions for microbiological activity. From a phytopathological viewpoint, the increase in water run off facilitates the expansion and the transmission of pathogens in the form of spores and rhizoids.

The overall consequences of compaction, of the decrease of soil conduction and the increase of growth and supply of root systems are clear and definitely not positive as also shown by various authors (Heinonen et al., 2002; Alakukku, 2000; Gaerting, 2001).

Conclusions

This study allowed for an assessment of the impact on soil generated by the silvicultural treatment and the harvesting operations. Physical, chemical and biological soil properties are often significantly impacted by the active forest management, in particular by silvicultural treatments and by harvesting operations, and it may imply compaction and consequent restrictions to tree growth and natural regeneration.

Our findings demonstrate that physical, chemical and biological soil features can be strongly impacted by harvesting operations (fig. 3) and, consequently, certain soil processes may be influenced at the imposed compaction levels. On other hand, physical, chemical and biological soil features are not impacted by silvicultural treatment applied. Designated skid trails should be used to confine such an impact, hence preserving the rest of the area. A careful technical surveillance during each phase of the work by trained and remunerated people is required to keep low the impact on soil and the whole ecosystem. For similar conditions, the motor-manual felling and extraction with whole tree system or tree length system by yarder could be more environment-friendly than using winching and skidding methodologies, because it did not modify soil penetrability and shear strength. In those cases where winching is unavoidable or convenient, careful supervision and appropriate training are required to minimize logging impacts where also directional felling is required.

In general, the conspicuous impact caused by the vehicle movement on forest soils is made evident by elaborating the data of the physical-mechanical soil components. This reveals the absolute necessity that it should be limited to a minimum required. It would be interesting to evaluate the capacity of recovery from these types of stress of the soil that were object of this study.

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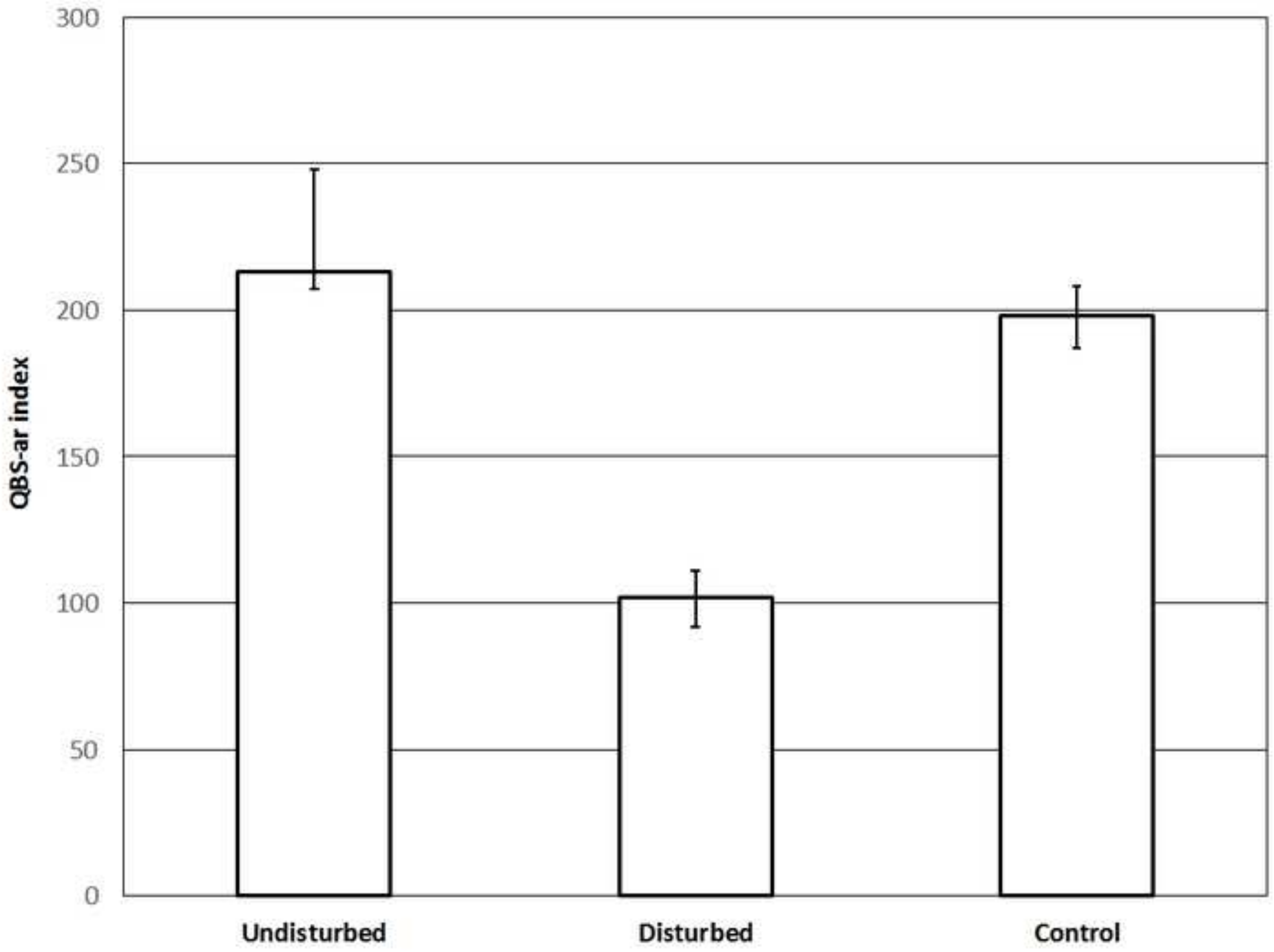
Figure 1: QBS-ar index variation for the three soil typologies.

Figure 2: PCA analysis of the EMI-by-sites matrix, difference tested among soil disturbed, undisturbed and control (red ellipse: disturbed; dark green: control; light green: undisturbed).

Figure 3: Silvicultural and logging-induced average % impact. The data shown are statistically confirmed (Pr: soil penetration resistance; Sr: soil shear resistance; Density: microarthropods density; QBS-ar: Soil biological quality; saplings elimination; Db: soil bulk density; OM: organic matter content).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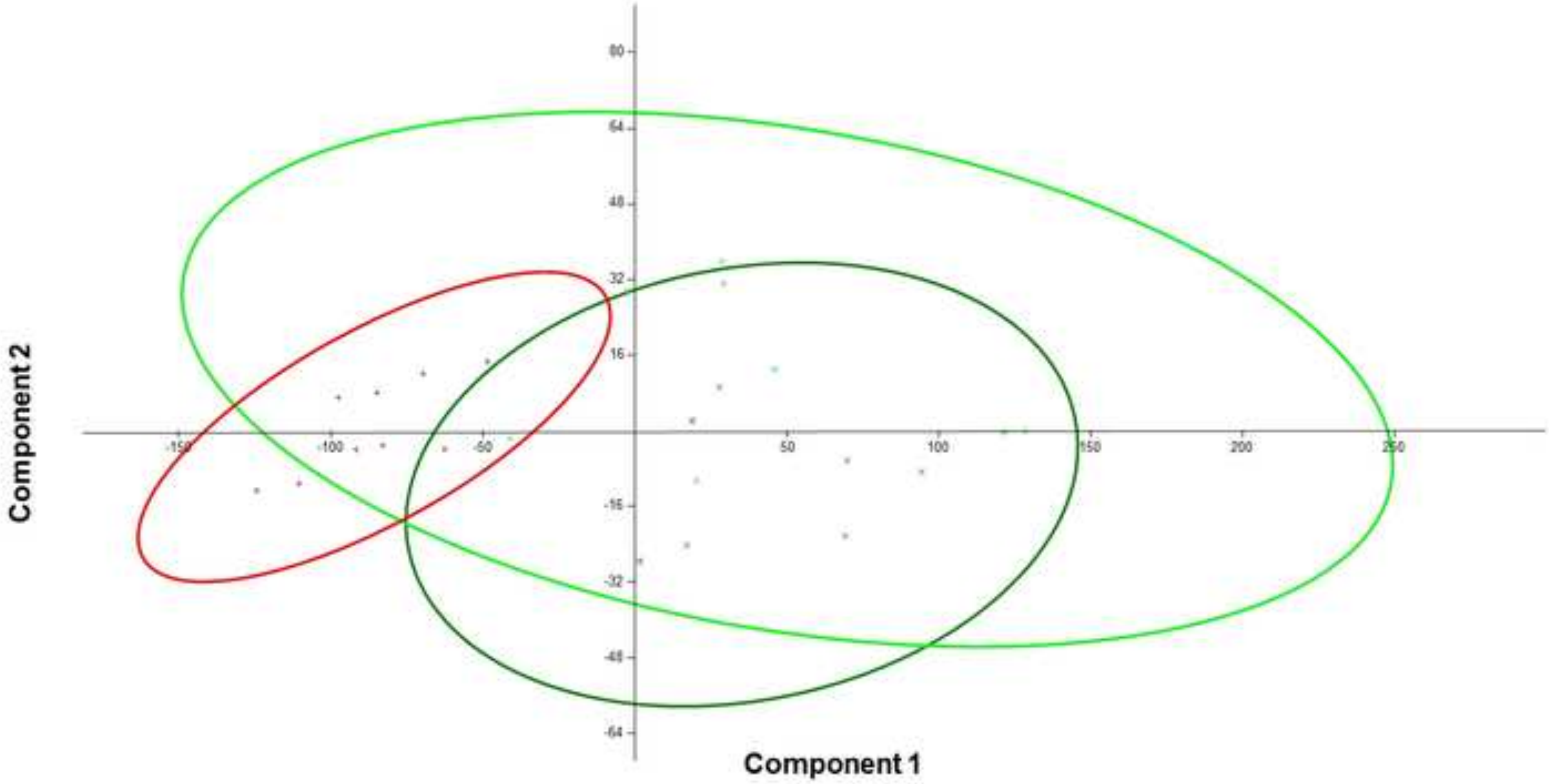
QBS-ar index
Undisturbed
Disturbed
Control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Component 2
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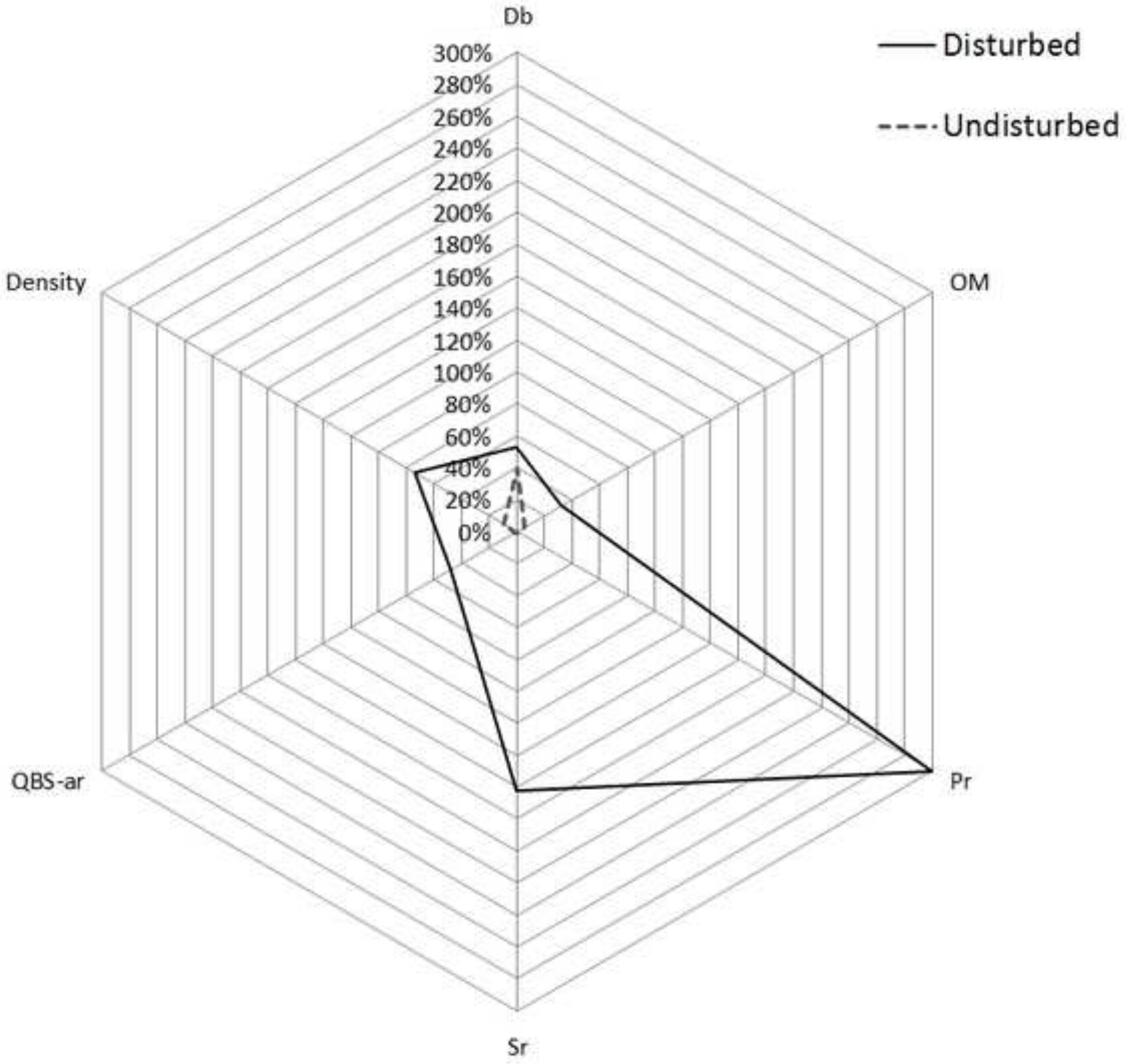
Figure_3


Db
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240%
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180%
160%
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120%
100%
80%
60%
40%
20%
0%
OM
Pr
Sr
QBS-ar
Density
Disturbed
Undisturbed

Table

Table 1: main dendrometrical and technological characteristics of the coppice (average ± SD).

DBH [m]	Height [m]	Density [trees/ ha]	Fresh wood density [kg/m^3]	Biomass stock		Biomass harvested	
				[m^3/ha]	[t/ha]	[m^3/ha]	[t/ha]
0.16±0.03	12.40±1.41	1250±57	921±10.5	187,3	172,5	175,3	161,5

Table 2: soil area impacted by bunching and extraction activities (t-test analysis).

Plot	P-value	Disturbed soil	Undisturbed soil
1	>0.05	27%	73%
2		25%	75%
3		29%	71%
4		24%	76%
5		30%	70%
6		27%	73%
7		26%	74%
8		27%	73%

Table 3: results of the ANOVA and Tukey test for the soil moisture and bulk density (average ± SD), difference tested among soil disturbed, undisturbed and control.

Soil typology	Moisture %	p-value	Bulk density [g/cm^3]	p-value	Tukey test	n
Undisturbed	52.1±2.3	>0.05	0.747±0.15	<0.01	a	20
Disturbed	50.8±3.5		0.820±0.21		b	20
Control	58.9±1.1		0.537±0.11		c	20

Table 4: results of the MANOVA (Wilks Lambda 0.323; Rao R 28.963; p-level <0.01) and Tukey test for penetrometric and shear resistance data (average ± SD), difference tested among soil disturbed, undisturbed and control.

Soil typology	Penetration resistance [MPa]	p-value	Tukey test	Shear resistance [t/m^2]	p-value	Tukey test	n
Undisturbed	0.066±0.01	<0.01	a	1.550±0.27	<0.01	a	60

Disturbed	0.276±0.09		b	4.113±0.59		b	60
Control	0.069±0.01		a	1.569±0.31		a	60

Table 5: results of the ANOVA and Tukey test for organic matter content and soil pH data (average ± SD), difference tested among soil disturbed, undisturbed and control.

Soil typology	Organic matter [%]	p-value	Tukey test	pH	p-value	n
Undisturbed	18.1±1.31	<0.01	a	5.3±0.97	>0.05	20
Disturbed	13.1±1.59		b	5.2±0.89		20
Control	19.2±1.27		a	5.2±0.95		20

Table 6: results of the Kruskall Wallis and Tukey test for QBS-ar index and soil microarthropods density data (median), difference tested among soil disturbed, undisturbed and control.

Soil typology	QBS-ar index	p-value	Tukey test	microarthropods density [ind/dm^2]	p-value	Tukey test	n
Undisturbed	213	<0.01	a	178	<0.05	a	9
Disturbed	102		b	50		b	9
Control	198		c	196		c	9