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Human and natural factors influence on bryophyte distribution and diversity in a southern Alpine valley

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Contents

ABSTRACT

The thesis is part of a multi-taxonomic study set in a southern Alpine valley: Val di Sole, in the north-west of Trento Province. It is characterized by high levels of biodiversity, but in the meanwhile, forests are highly managed.

The study aimed at understanding whether forest management and blockfields have an impact on bryophytes.

We identified 20 sample areas divided in four classes, five areas for each class: managed with blocks (BM), managed without blocks (NBM), unmanaged with blocks (BNM) and unmanaged without blocks (NBNM).

After collecting field data, bryophyte cover and species richness were related to a set of forest structural characteristics and then to the presence or absence of forest management and blockfields.

We found out that the driver of bryophyte cover and species richness is the presence of blocks. However, it came out that forest management does not affect bryophytes. While high trees DBH values negatively affect bryophyte richness, because we did not consider wood-dwelling species, that are strictly related to big and old trees.

RIASSUNTO

Questa tesi fa parte di uno studio multi-tassonomico che è stato svolto in Val di Sole, nella zona nord ovest della Provincia Autonoma di Trento. Quest'area si contraddistingue per elevati livelli di biodiversità. Allo stesso tempo, nei boschi è da sempre praticata la selvicoltura.

Lo studio ha lo scopo di approfondire la relazione tra la biodiversità delle briofite, la gestione forestale e la presenza di una particolare copertura quaternaria: i versanti e le frane a grossi blocchi, anche *blockfields*.

Sono state identificate 20 aree di studio divise in quattro categorie: gestite con blocchi (BM), gestite senza blocchi (NBM), non gestite con blocchi (BNM) e non gestite senza blocchi (NBNM). Per ciascuna tipologia sono state individuate cinque aree.

A seguito della raccolta dei dati in campo, la ricchezza di specie e la copertura delle briofite sono state correlate con i dati strutturali del bosco e successivamente con la presenza o assenza di gestione e blocchi.

I risultati ottenuti mostrano che la copertura e la ricchezza di specie delle briofite è guidata dalla presenza dei blocchi. Tuttavia, la gestione non ha alcun impatto sulle briofite. Mentre abbiamo riscontrato che valori elevati dei diametri degli alberi influenzano negativamente la ricchezza delle briofite, in quanto non sono state considerate le specie epixiliche, le quali sono strettamente legate alla presenza di alberi vecchi e di grandi dimensioni.

1. INTRODUCTION

1.1 Bryophytes and forest management

The increasing awareness of the importance of biodiversity and structural heterogeneity for ecosystem functions and services (Lewkowicz and Way 2019) made biodiversity conservation an important part of forest management programmes across Europe (Harrison et al. 2014; Kraus & Krumm, 2013).

Despite many research investigations have been carried out to compare biodiversity between managed and unmanaged forests, most of these studies have been focused only on a single taxon, while multi-taxa investigations are still scarce (Paillet et al. 2010; Sitzia et al. 2017).

According to the current bibliography stand biodiversity benefits from forest management. Canopy openness was found to be the most important structural feature that drives above-ground α-diversity in forests (Penone et al. 2019) indicating that beside resource availability also favourable microclimatic conditions are of general importance for local biodiversity (Schall et al. 2020).

According to a study conducted by Müller et al. (2019) in Central European beech forests, selection forests present the highest species richness, whereas unmanaged beech forests revealed a lower species number. Moreover, increasing conifer proportion increased bryophyte species. Another study of Schall et al. (2020) found the maximum multidiveristy in a landscape composed of 100% even-aged and it declined with increasing shares of uneven-aged and unmanaged, independently of the weighting of species frequency.

On the other hand, many studies conducted in Europe about the evaluation of the impact of forestry on biodiversity in European forests are related to boreal forests (Paillet et al. 2010) and they compare intensively managed forests (subjected to clearcutting, that is not allowed in Italy) and non-managed forests. All these studies agree on the beneficial effect of abandonment on biodiversity. Specie richness tend to be higher in unmanaged than in managed forests (+ 6.8%) (Paillet et al. 2010). Indeed, intensive forest management practices are frequently a major driver of biodiversity loss worldwide (Sala et al., 2000).

However, as Sitzia et al. (2017) say, the positive effects of forest abandonment may not be consistent across taxa, because each of them has different factors driving its presence. According to the intermediate disturbance hypothesis (Grime 1973, Connell 1978), higher species diversity may be expected under non-intensive forest management systems where disturbances occur at intermediate frequencies. That is why assessing forest harvest impacts on biodiversity is one of the core elements of contemporary forest management practices which remain a significant challenge for managers (Aubin et al. 2013).

Some studies dealt with forest management effects on bryophytes and demonstrated their sensitivity to management practices. Forest harvest represents a potential threat to forest floor bryophyte communities primarily through alteration of the microclimate and disturbance of substrates on the forest floor (Fenton et al. 2003). Studies worldwide provide evidence that bryophyte species diversity, and populations of certain species, decline in association with a range of forest management scenarios (Ericsson, Berglund, and Östlund 2005; Fenton and Frego 2005; Jalonen and Vanha-Majamaa 2000; Uotila and Kouki 2005; Vanderpoorten, Engels, and Sotiaux 2004; Vellak and Paal 1999). Depending on the scale considered, bryophytes can have a significant correlation with different factors. For example, as shown by Frego (2007), at the landscape scale, bryophyte diversity may be significantly correlated with forest cover and soil type (Vanderpoorten and Engels 2003). Over a range of scales from 2500 to 314 m^2, there are correlations between bryophyte richness and a variety of biotic and environmental variables, the strongest of which appear to be bird richness (Sauberer et al. 2004), vascular plant richness (Gunnar Jonsson and Jonsell 1999; Sætersdal et al. 2004), especially fern richness (Pharo, Beattie, and Binns 1999), and lichen richness (Gunnar Jonsson and Jonsell 1999; Sætersdal et al. 2004). At a finer scale (< 1 m^2), bryophyte diversity is correlated with lichen richness (Humphrey et al. 2002) and substrate diversity (Vellak and Paal 1999; Zechmeister and Moser 2001), especially decay state of wood (Turner and Pharo, 2005; Ross-Davis and Frego, 2002; Crites and Dale, 1998).

Another study conducted by Paillet et al. (2010) demonstrates that "selective felling" and "selective felling close-to-nature" significantly decrease the species richness of bryophytes. Fenton and Frego (2005) confirm that many terricolous and epiphytic bryophytes may benefit from abandonment, preferring closed, canopied forests, thanks to the most favourable microclimatic conditions. However, in the same study they say that an intermediate level of shading may be more hospitable than either heavy shade or high light intensity of tall vs open (Peterson, 1999; Olsson and Staaf 1995). Together, these interactions are likely to influence bryophyte hydration time, a key factor in growth and establishment (Päivänen, 1966; Økland, Rydgren, and Økland 1999; Tamm 1950).

A report of Horvat et al. (2017) in temperate silver fir-beech forests in the western Pyrenees shows a negative effect of forest management on bryophyte diversity. Indeed, according to Vellak and Paal (1999) the bryoflora of old unmanaged forests is considerably richer in species than that of managed forests. It appears also that the cover percentage of bryophytes in unmanaged stands is usually higher than in managed forests also thanks to the higher availability of substrates characteristic for an old-growth stand. Higher bryophyte species diversity in old (natural) forests in comparison with younger and/or managed ones has been described by several authors (Bazzaz 1983; Söderström 1987, 1988a, b, 1993; Gustafsson and Hallingbäck 1988; Jonsson and Esseen 1990; Andersson and Hytteborn 1991). They have all pointed out that in unmanaged old-growth stands, due to the presence of big trees, soil disturbances caused by windfalls, and the abundance of coarse woody debris included decaying logs, there is a large heterogeneity of microsites, which provides additional habitats for species with different ecological requirements (Keddy and Drummond 1996).

On the other hand, a study conducted in the boreal forest by Uotila and Kouki (2005) showed that bryophytes richness is higher at the early successional stages than in older stands regardless of management. Moreover, liverworts are markedly more diverse in seminatural forests than in managed ones. Later in the succession, liverworts are reduced and replaced by more competitive acrocarpous mosses and then pleurocarpous mosses (Krusenstjerna, 1945; Schimmel, 1993). Cuttings and management can decrease the number of liverwort species due to the absence of coarse woody debris (Uotila and Kouki 2005).

Moreover, a study of Müller et al. (2019) conducted in Germany, in some areas bryophyte specie richness was higher in managed than in unmanaged forests. Managed age-class forests and selection forests may even exceed unmanaged forests in bryophyte species richness due to higher substrate (rock or deadwood) supply and therefore represent important habitats for bryophytes. Moreover, maintaining and increasing a variability of substrates and habitats, such as coarse woody debris, increasing structural heterogeneity by retaining patches with groups of old, mature to over-mature trees in managed forests, maintaining forest climate conditions by silvicultural methods that assure stand continuity, e.g. by selection cutting rather than clear cutting and shelterwood logging might promote bryophyte diversity. The richness of terricolous bryophyte species in conifer forests likely profits from higher light availability on the ground due to a less closed canopy (Tinya et al. 2009) and reduced litterfall compared with deciduous forests. These conditions facilitate the occurrence of thick mats of terricolous bryophyte species composed of feather mosses in conifer forests, which are rather typical for montane or boreal forests. However, Müller et al. (2019) affirm that the species richness of bryophyte in forests mainly depend on the availability of soil instead of the type of forest management. Bryophyte cover and richness are related to canopy cover, microclimate and other site conditions in stands (e.g., forest structure, air humidity, light intensity, substrate types, soil moisture, pH, understory composition) (Bartels et al. 2018; Márialigeti et al. 2016; Mills SE, Macdonald, 2004, 2005).

Spitale (2017) The same author, in another study (Spitale 2016), says that the bryophyte assemblages inhabiting the forest floor is less subject to climatic variability than deadwood and tree trunks.

According to Márialigeti et al. (2009) and Startsev et al. (2008) low light intensity below coniferous canopies appears to favour development of bryophytes by decreasing the risk of desiccation. In the same study they reported that the most important factors affecting the diversity and composition of forest-floor bryophyte assemblages are the amount and heterogeneity of potential substrates and microsites (Mills and Macdonald 2004, 2005). The availability of these microsites (dead wood, open patches, pits and mounds), and microclimatic conditions are considerably influenced by forest management such as slash harvesting, different felling treatments, dead wood management and management history (see also Åström et al. 2005; Jalonen and Vanha-Majamaa 2001; Fenton and Frego 2005; Jonsson et al. 2005; Ódor and Standovár 2001; Rose 1992).

1.2 Bryophytes in multi-taxa forest biodiversity studies

Multi-taxa analyses are useful to obtain a more robust comprehension of how forest disturbances may affect forest biodiversity over a wide group of biological taxa (Fattorini, Dennis, and Cook 2011; Lawton J. H. et al. 1997; Vessby et al. 2002).

Due to the sensitivity of the bryophyte layer to environmental conditions, bryophyte species and community metrics have often been used in environmental monitoring (Berdugo and Dovciak 2019). Moreover, thanks to their specific structure bryophytes react rapidly to environmental changes (Gustafsson and Hallingbäck 1988; Vellak and Paal 1999), while vascular plants are more tolerant (Masing 1953; Kollist 1957). To date, functional metrics have been used only rarely in bryophyte community studies (Wang et al. 2017) because uniqueness of bryophyte traits hindered the development of a trait framework comparable to that developed for vascular plants (Deane-Coe and Stanton 2017).

As diversity and quality of substrates is affected by forest management, bryophytes are suitable indicators for the effect of management on forest conditions (Rose, 1992), but after researching the actual bibliography we noticed that bryophytes are not included in many multi-taxa studies.

Bryophytes, as saproxylic beetles, lichens, and fungi are substrate-dependent taxa, so they suffer from reduction of microhabitat availability and diversity in managed forests (Paillet et al. 2010).

A recent multi-taxa study in European beech forests revealed higher regional γ-diversity for many taxonomic groups, including forest specialist and deadwood-dependent species (as bryophytes), in even-aged compared to uneven-aged forests (Schall et al. 2018). This was explained by a high between-stand variation in environmental conditions compared to uneven-aged stands. The latter are characterized by a high within heterogeneity but relatively homogenous stand structures at the landscape scale (Decocq et al. 2004; Werner and Raffa 2000).

A multi-taxonomic study of Nascimbene et al. (2014) aiming to find the effect of forest management intensity on biodiversity in the Alps, found that bryophytes were the least species rich group. In the intensively managed and abandoned stands, light was a limiting factor due to increased respectively tall grasses and trees density which hindered bryophyte biomass growth. Under the extensive management regimes, large pleurocarpous mosses were allowed to establish, indicating that light was not a limiting factor.

Furthermore, Tinya et al. (2021) conducted a study to find the environmental drivers of forest biodiversity in temperate mixed forests. It came out that stand structure, tree species diversity and composition, and microclimate conditions (influenced by forest stand) proved to be the most important determinants of forest organisms (included bryophytes). Litter and soil conditions, landscape characteristics, and land-use history had much weaker effects.

1.3 Bryophytes and blockfileds

According to a definition of Whittow and John (1984) blockfield is a surface covered by boulder-sized angular rocks usually associated with alpine and subpolar climates and periglaciation (Fig. 1). Blockfields differ from screes and talus slope (< 25°) because they do not originate from mass wasting, but they are formed by frost weathering below the surface (Thomas et al., 2000) (Fig. 2). Another term used to say blockfields is *felsenmeer*, that comes from the German and means "sea of rock" (Whittow and John, 1984). In a felsenmeer or blockfield, freeze-thaw weathering has broken up the top layer of the rock, covering the underlying rock formation with jagged, angular boulders (Author and Dahl 1966). Freeze-thaw (FT) weathering is one of the most important factors in deterioration of rocks and other porous geomaterials in areas where the temperature periodically fluctuates around the freezing point (Matsuoka and Murton 2008). When the temperature drops below the freezing point, moisture bearing materials will be subjected to internal stresses caused by the phase transition from water to ice (Winkler, 1968). These stresses are consequently released during thawing. In natural circumstances, most materials will not disintegrate due to one FT cycle, but sequential FT loading will cause deterioration of the porous subjects. Generally, by subsequent freezing and thawing, the materials gain in porosity through the introduction of micro-cracks (Martínez-Martínez et al. 2013). This is expressed in overall weakening of material.

Figure 1. An example of blockfield in the Luisenburg forest, Germany (https://www.alamy.it/fotos-immagini/blockfield.html?sortBy=relevant).

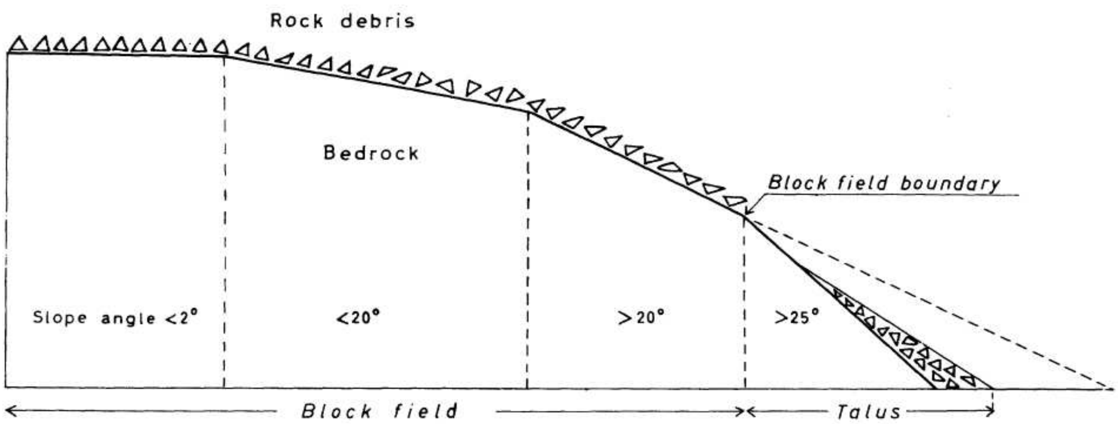


Figure 2. Outline sketch, illustrating the method recommended for classifying blockfields. The lower block-field boundary is often found with slope angle < 25°. At slope angle > 25° there would be accumulations of talus type instead of block fields (Author and Dahl 1966).

Blockfields are most often found in high mountain periglacial regions near the Arctic Circle, especially in Iceland, the Canadian arctic and Norway and are still active in parts of Central Europe that were not covered by ice sheets. Some studies associate blockfields to landslides, and they have not been well examined in depth, for example in the article of Alexandrowicz and Margielewski (2010). However, Walker and Shiels (2013) say that the relation between biodiversity and landslides is still poorly explored.

In relation to the influence of blockfields on the presence of bryophytes just few studies have been conducted. Kubešová (2010) found that in a treeless blockfield bryophyte cover is lower in the open part of the block field than in the ecotone. Moreover, variability of species data is associated with position on slopes and potential direct irradiation. Moreover, the bryophyte species composition in block fields may be influenced by several environmental factors, such as presence of tree canopy (Kubešová 2000, Nìmcová 2001), insolation, soil factors (Cox and Larson 1993a, b, Nìmcová 2001) and rock-fall disturbances (Larson et al. 1989). The bryophyte assemblage also depends on relative position within the blockfield: lower parts are usually more humid and are subject to more cold air movement. Altitude also plays a critical part (Lüth 1999).

2. OBJECTIVES

This study is part of a wider multi-taxonomic analysis (eight taxonomic groups), whose aim is to find how human and natural disturbances may influence biodiversity and structural diversity of forest stands in Val di Sole.

In particular, the aim of the present study focuses on bryophytes. The aim is to assess the effect of forest management (as a human disturbance) and blockfields (as a natural disturbance) on forest bryophytes communities.

A focus is done on the relation between bryophytes cover and specie richness, and the presence of blockfields, an aspect that is still not much explored.

3. MATERIALS AND METHODS

3.1 Study area

The study area chosen to develop this study is the north-western part of the Province of Trento: the Val di Sole (Fig. 3). The Valley is surrounded by Ortles-Cevedale, Adamello-Presanella and Dolomiti di Brenta mountain ranges. The highest picks are Ortles (3905 m), Gran Zebrù (3859 m) and Cevedale (3764 m).

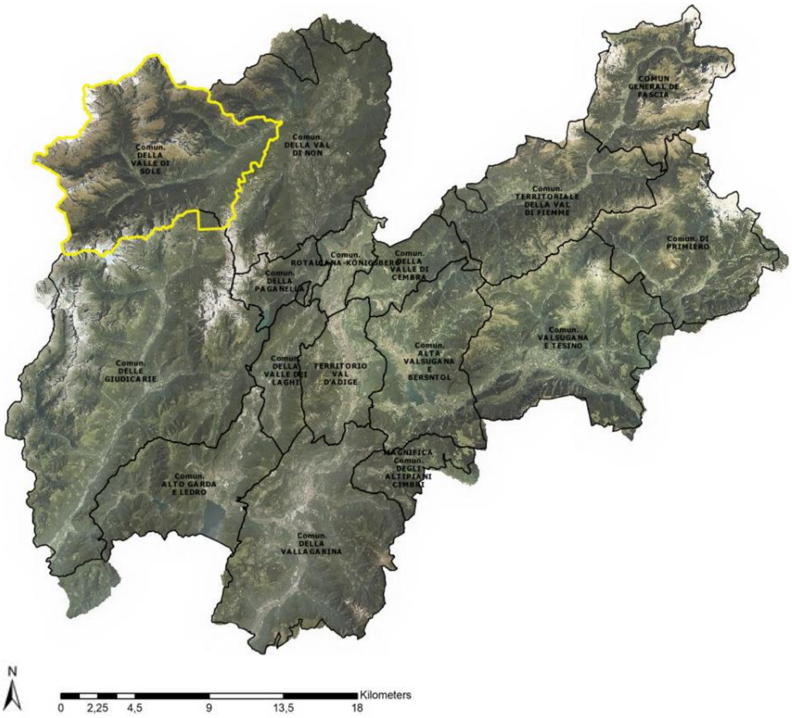


Figure 3. Map of the Province of Trento highlighting Val di Sole.

3.1.1 Hydrography

Thanks to the glaciers around the Valley, Val di Sole is characterised by the presence of many waterways and small lakes (more than a hundred). The main river is the Noce River, that rises in Val di Pejo from Corno dei Tre Signori. It forms the artificial lake of Pian Palù and then crosses the Valley from west to east. It is fed by other streams coming from the secondary Valleys of Peio and Rabbi: Noce Bianco, Rabies and Vermigliana (Fig. 4)

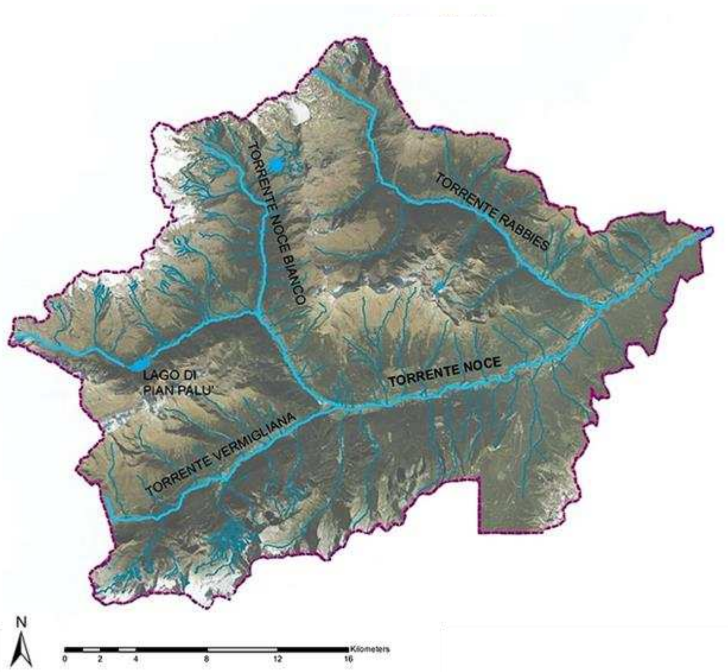


Figure 4. Map of the main streams in Val di Sole.

3.1.2 Climate

Thanks to its location in the middle of the Alps, Val di Sole is a geographical area characterized by high altitude gradients and strong seasonal differences in the climate (Fig. 5). The climate is cold and temperate, with quite high rainfall all year round. Val di Sole is characterized by an alpine climate, or rather short summers and long and cold winters, with high snowfall.

According to Köppen climate classification in Val di Sole there are two climatic classes: warm-summer humid continental climate (*Dfb*) and cold-summer humid continental climate (*Dfc*) (Fig. 6). At the lowest altitude (700-1600 m a.s.l.), that represent most of the area, we can find the first class, where July is the rainiest month (mean precipitation: 216 mm) and January is the driest one (mean precipitation: 50 mm). The warmest month is July with maximum temperatures of 20°C, while January is the coldest one (mean temperatures lower than -9°C).

Where altitude is higher than 1600 m a.s.l., unlike the previous area summers are cold (*Dfc*). Indeed, the maximum temperature is 15°C and it is rainy, with mean annual rainfall that is higher at lower altitude.

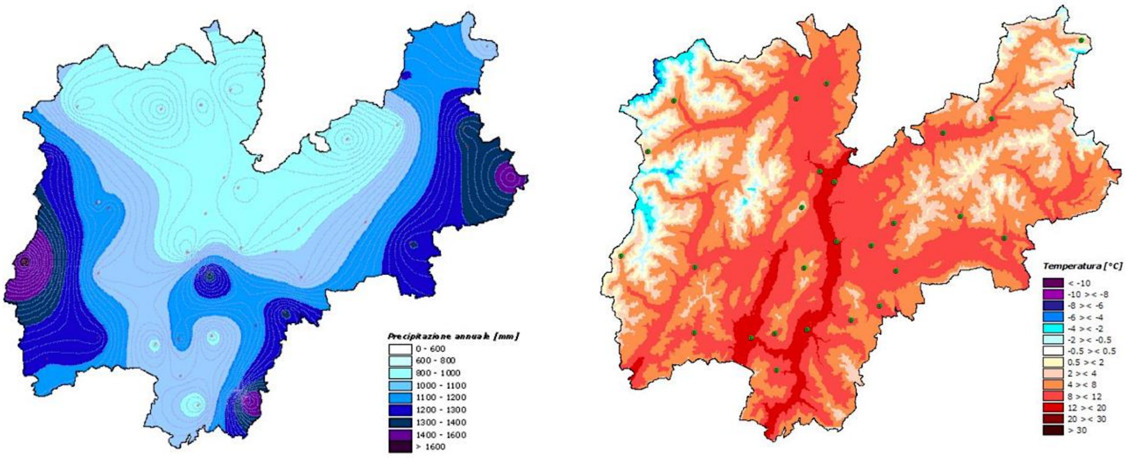


Figure 5. Map of mean annual precipitation, on the left; map of mean annual temperatures, on the right. They both concern the period between 1981-2010 in the Trento Province.

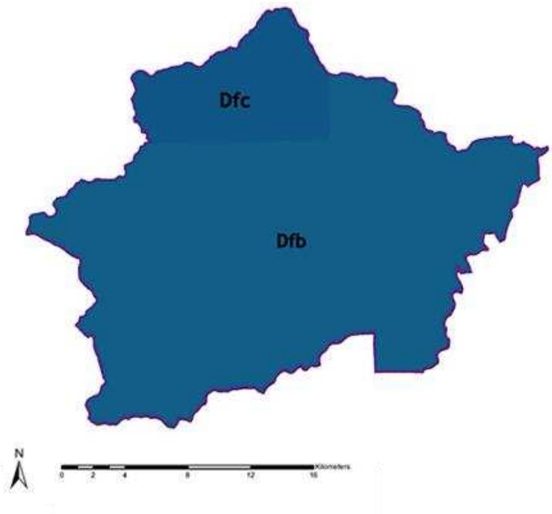


Figure 6. Map of Köppen climate classification in Val di Sole.

3.1.3 Pedology and land use

According to the substratum an analysis of the main categories has been done (Fig. 7). The main type is metamorphic rocks, on the north side of the valley, where Ortles-Cevedale mountainous group is set; corresponding to Adamello, on the south, we find intrusive magmatic rocks; finally, the east side is composed of calcareous sedimentary rocks, particularly dolomite rock, where Dolomiti di Brenta are.

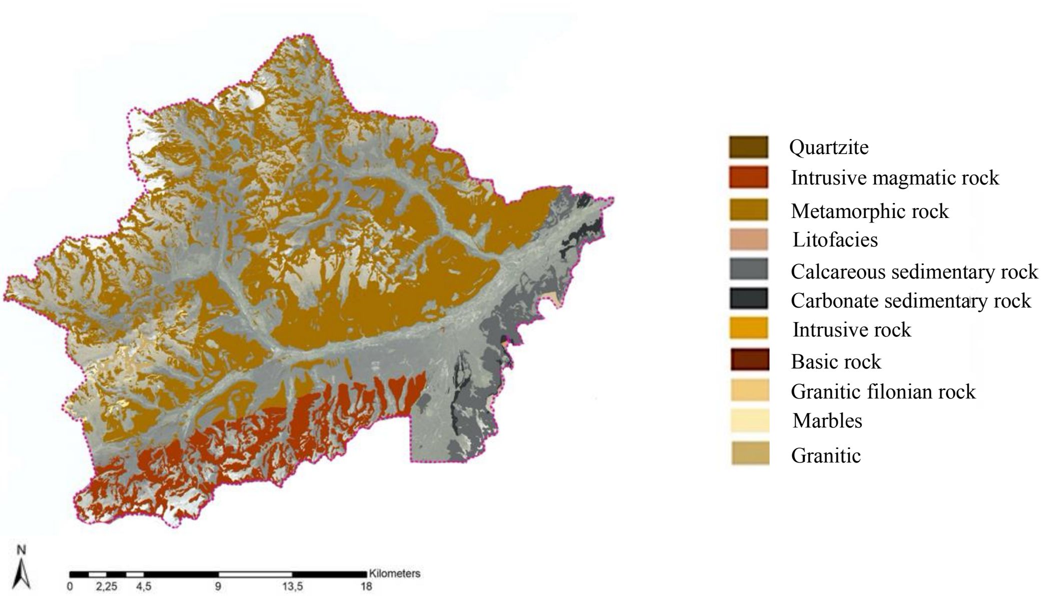


Figure 7. Map of substratum of Val di Sole.

Val di Sole landscape is characterised by post-glacial landslides. Studying natural disturbances we considered landslide and quaternary deposits (Fig. 8). We just focused on the biggest grain sizes: blocks (B), but we also included secondary grain sizes where blocks were predominant (G: gravel, S: sand, A: clay, L: loam).

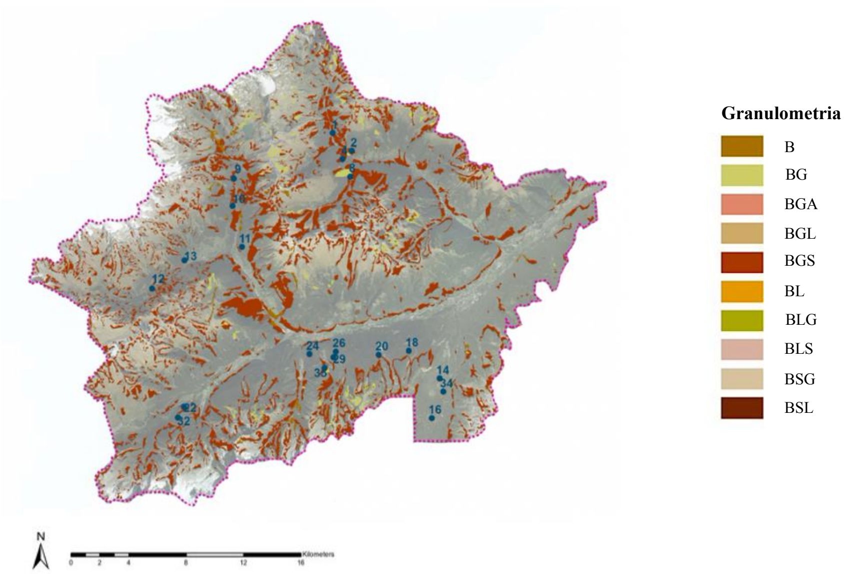


Figure 8. Deposits map of the classes where blocks dominate in Val di Sole.

Reading the Corinne Land Cover helped us to study the land use of the Valley (Fig. 9). It came out that 40,3% of the surface consists in forests, whose 93,3% is conifer; 20,1% is sparse vegetation; 18,5% is rocks, due to the quite high quantity of land above the treeline.

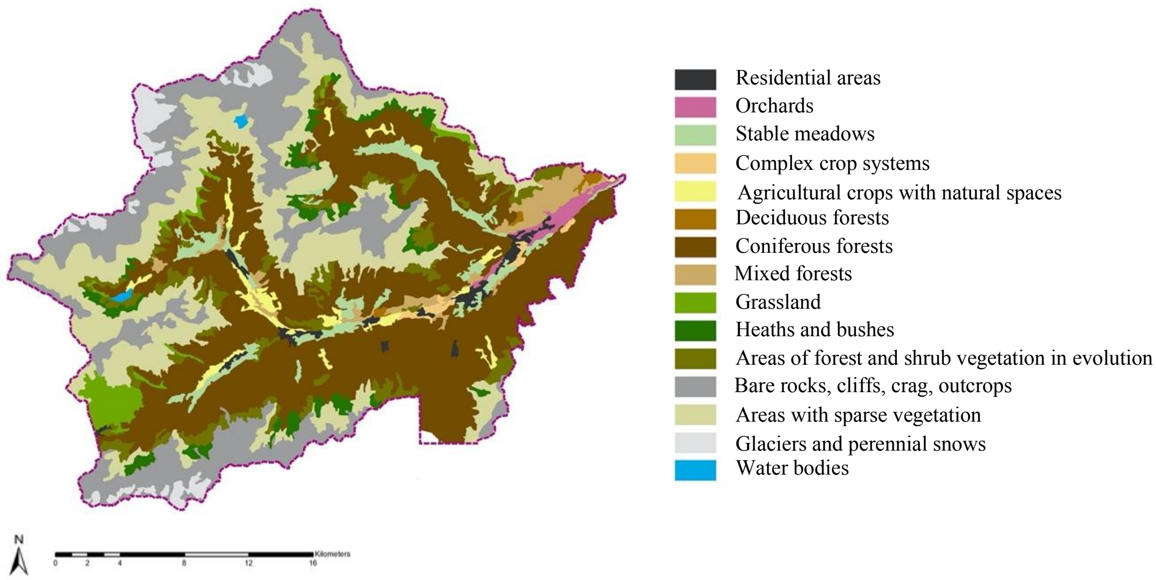


Figure 9. Corinne Land Cover 2018 map of Val di Sole.

3.1.4 Vegetation

As we can see from Figure 10, in Val di Sole the main forest type is spruce forest, followed by larix forest. That is why our plots are in spruce forest. The main spruce forest types are:

- Heather spruce forest with Scotch pine
- Spruce forest with tall herbs and green alder
- Typical high mountainous spruce forest
- Xeric high mountainous spruce forest
- Secondary or replacement spruce forest
- Subalpine spruce forest

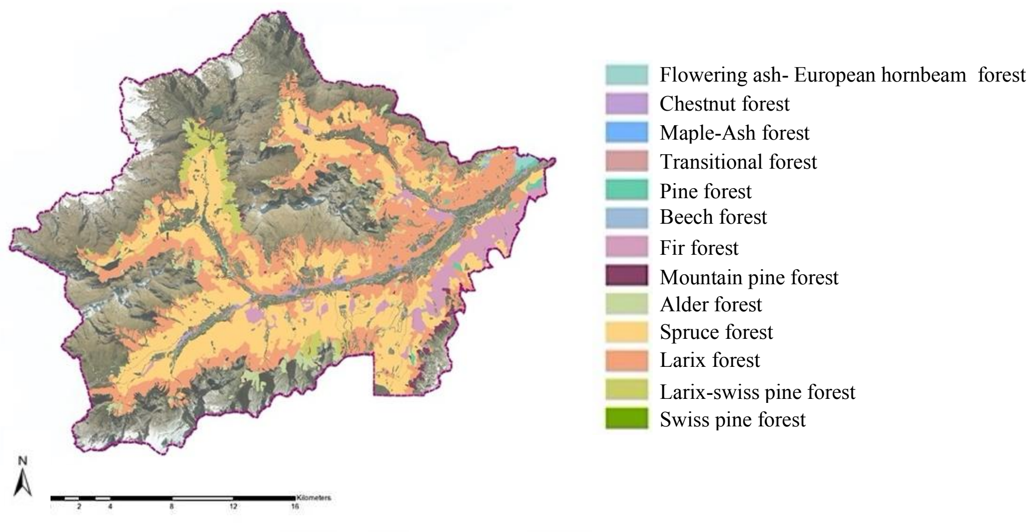


Figure 10. Map of forest categories of Val di Sole

3.1.5 Protected areas

All these characteristics lead to small-scale local differences that have promoted the development and preservation of a high level of biodiversity. That is why the Valley includes part of two protected areas: the Stelvio National Park: one of the oldest Italian National Parks and one of the widest European reserves) and the Adamello Brenta Natural Park (the widest protected area of the Province) (Fig. 11).

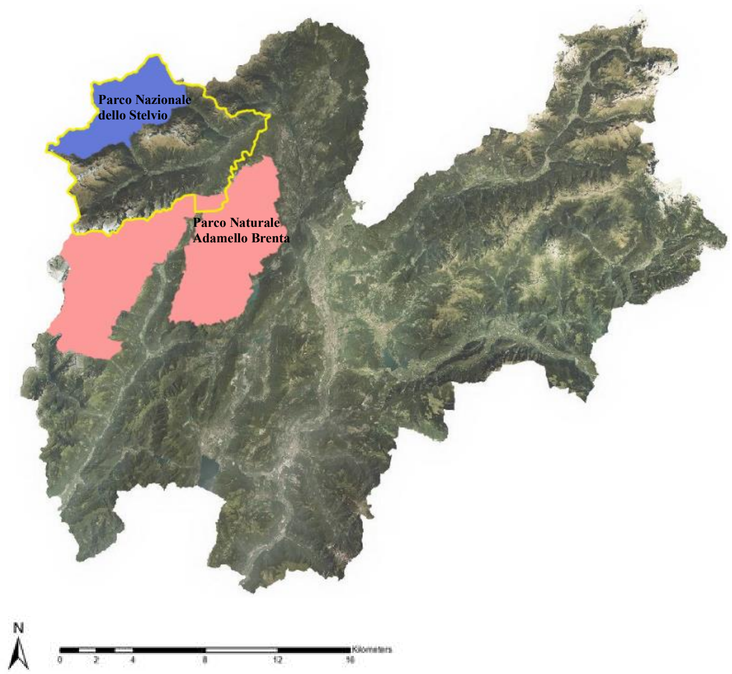


Figure 11. Highlight of the Stelvio National Park (blue), and of the Adamello Brenta Natural Park (pink) in the Province of Trento

Val di Sole also includes areas of Natura 2000 network: there are 3 Special Protection Areas (SPA) extended for 184 km^2 and 11 Special Areas of Conservation (SAC), that in total are 160 km^2 wide (Fig. 12).
Thanks to the high sensitivity of the Province, within the Valley's territory there are also 16 reserves which perform the function of ecological corridors, that help species spread, genetic diversity and conservation.

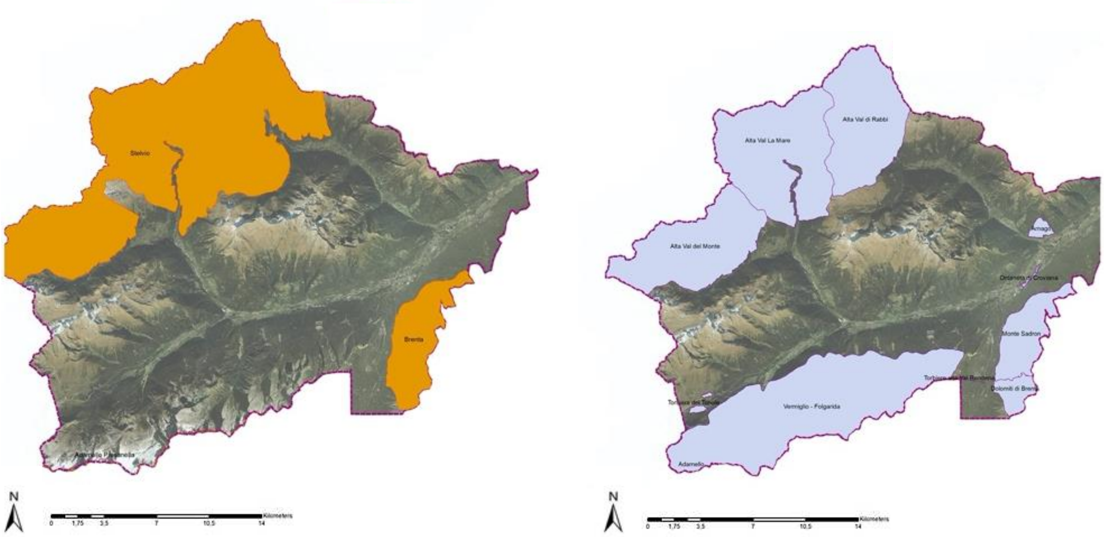


Figure 12. A highlight of SPA on the left and of SAC on the right, of Val di Sole.

3.2 Sampling scheme

In order to select the forest patches, we used a GIS overlay procedure using the following layers: a forest types map, a slope raster map calculated from a digital elevation model, a map of landslides from which we selected the patches corresponding to rock fields and big rocks landslides, a map of forest compartments, retrieved from the Trentino forestry agency, and a map of roads. The map of forest compartments was useful to select unmanaged patches (no or lower management intensity) and managed patches (regular management intensity). From the intersection of these two treatments with the map of landslides we obtained four final treatments: unmanaged forest with no blocks (NBNM), unmanaged forest on blocks (BNM), managed forest with no blocks (NBM), managed forest on blocks (BM). For each treatment we randomly selected 5 forest patches. The forest patches were selected belonging, as much as possible, to the same altitudinal range (1500-1800 m asl), the same slope range (< 30°), the same forest categories (spruce forests or spruce with larch forests), and the same stand age (mature forest stands). The sampling patches have been firstly mapped on software and maps and subsequently they have been visited and verified. One sampling plot was located in each patch for a total of 20 sampling plots (Fig. 13).

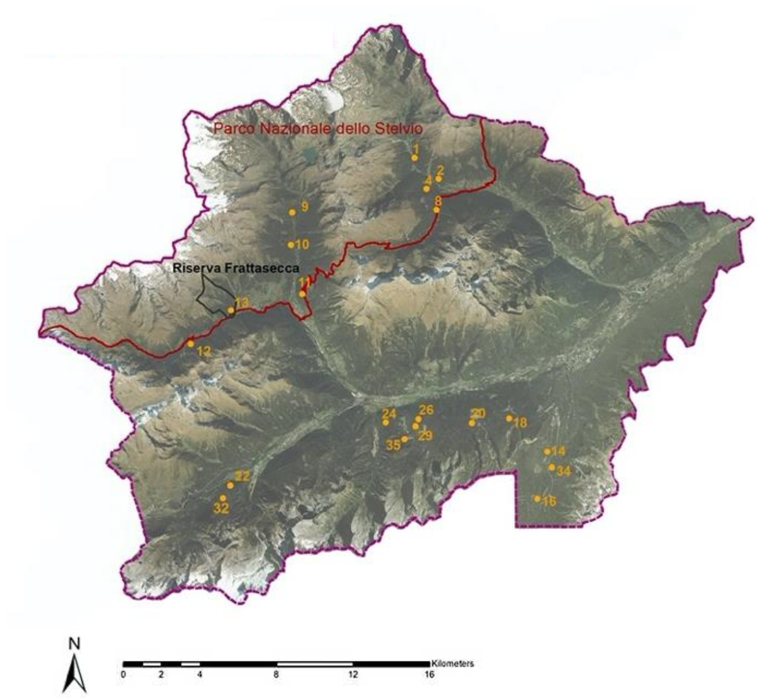


Figure 13. Sampling plots position (yellow dots) in Val di Sole and a highlight on Stelvio National Park (red) and Frattasecca reserve (black).

3.3 Method of analysis of the forest structure

Stand structure is a key element for assessing the ecological functions and services in forest ecosystems. The plots had a 20 m radius (surface: 1256 m^2) and for each of them we measured many variables: geographical or relative position, species, diameter at breast height (DBH), stem and crown height, crown surface area, age and decay stage (following Kraft's classification).

According to their vitality, trees have been classified (Maser C. et al., 1979) as in Figure 14:

- LT (Living Tree);
- DT (Dead Tree): dead tree standing, without crown, not rotting, but species still identifiable;

- SN (Snag): standing, dead or dying tree, often missing a top or most of the smaller branches, higher than 1.30 m;
- ST (Stump): the basal part of a tree that remains standing after the tree has been felled or cut off. Hight is lower than 1.30 m;
- Log: lying, dead and decomposed tree

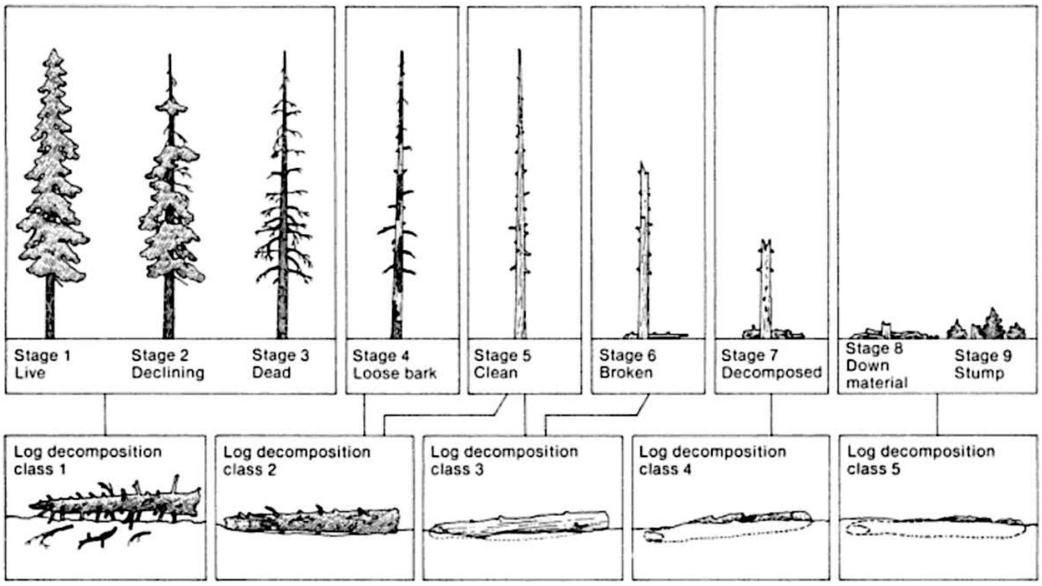


Figure 14. Classification of standing and lying tree according to Maser (1979)

To sampled snags, stumps, and logs a Maser (1979) degradation class was attributed. The field work provided different measurements for standing trees (live and dead trees, snags, and stumps) and lying trees (log) and all data were wrote down on a field table (Fig. 15). In the first case, in each sample area all trees with DBH ≥ 7.5 cm have been measured. First, for each tree we identified the specie, we measured the azimuth with a compass, the distance from the centre of the area and then its hight, these last two data thanks to the Vertex. Secondly, we defined the stand social class using Kraft (1884) and Maser (1979) table. After that, we measured the DBH (with tree calliper) and estimate the crown radius. To identify the mean age of the stand, using a Pressler borer we took woody cores from three live spruce trees: the closest to the centre of the plot and with the largest diameter.

According to stump we measured its hight, the basal diameter and the top one. For dead trees and snag crown radius, height and specie were not considered.

Information about stand age and trees relative positions, according to the sampling of azimuth-distance coordinates and tree cores, respectively, are not part of the present work.

Date ____________ Sample area n. ______________ Data collector __________________________

ID	CATHEGORY	AZIMUTH (°)	DISTANCE (m)	DBH (cm)	SPECIE	HIGHT (m)	CROWN r (m)	KRAFT	SNAG	CORED

Figure 15. Example of forest structure table.

To study logs we used the LIS (Line Intersect Sample) method. It consists in tracing a 50 m long transect, starting from the centre of the sample area, following a given azimuth direction. For each log with a diameter higher than 10 cm crossed by the line we identified the specie, the length and decomposition stage Maser (1979) (Fig. 16).

Date __________ Sample area n. ____________ Data collector ______________

ID	DBH INTERSECT	LEGTH (cm)	SPECIE	DECOMPOSITION STAGE

Figure 16. Example of log survey table.

3.4 Dendrometric analysis

The data collected with the field surveys allowed us to define Val di Sole forest stand characteristics.

3.4.1 Number of trees

The number of trees comes from trees calibration, and it is expressed as the number of individuals present on hectare (N_{trees}/ha).

$$\frac{Calibrated\ plants}{S_{SA}} = \frac{N_{trees}}{ha}$$

Where:

- S_{SA}: sampling area surface (20 m radius)

3.4.2 Basal area

Basal area (G) indicates the surface of the cross-section of a tree, measured at 1.30 m above the ground (La Marca, 2017). This is directly proportional to the square of the DBH and is determined according to the equation:

$$G = \frac{\pi}{4} d^2$$

The parameter of interest is the basal area per hectare (G/ha), that with the number of plants per hectare is used to evaluate the density of a forest stand and to consider the productivity of the stand itself.

$$\frac{G}{ha} = \frac{G_{SA} \cdot 10.000}{S_{SA}}$$

Where:

- d: diameter at breath height;
- G: basal area;
- G_{SA}: sampling area basal area;
- S_{SA}: sampling area surface.

3.4.3 Average diameter

From the basal area value we can extract an additional reference parameter: the average diameter (d_g), which corresponds to the tree with average basal area, calculated through the equation:

$$d_g = \sqrt{\frac{4 \cdot G_{average}}{\pi}}$$

$G_{average}$ comes from the following formula:

$$G_{average} = \frac{G}{N_{trees}}$$

3.4.4 Standing trees volume

To calculate the wood volume we used the formulas found in the document resulted from a long study conducted by Tabacchi G. et al. (2011). They allow to estimate the volume (m^3) of each of the most common Italian tree species. The following formulas are those we used:

- *Picea abies*

  $v = b_1 + b_2 d^2 h + b_3 d$ $\boldsymbol{b'} = [-9.1298 \quad 3.4866 \cdot 10^{-2} \quad 1.4633]$
- *Larix decidua*

  $v = b_1 + b_2 d^2 h + b_3 d$ $\boldsymbol{b'} = [-1.6519 \cdot 10 \quad 2.9979 \cdot 10^{-2} \quad 3.1506]$
- *Abies alba*

  $v = b_1 + b_2 d^2 h + b_3 d$ $\boldsymbol{b'} = [-1.8381 \quad 3.7836 \cdot 10^{-2} \quad 3.9934 \cdot 10^{-1}]$
- *Salix caprea*

  $v = b_1 + b_2 d^2 h$ $\boldsymbol{b'} = [-2.3140 \quad 3.8926 \cdot 10^{-2}]$
- *Pinus cembra*

  $v = b_1 + b_2 d^2 h$ $\boldsymbol{b'} = [2.8521 \quad 3.9504 \cdot 10^{-2}]$
- *Fagus sylvatica*

  $v = b_1 + b_2 d^2 h$ $\boldsymbol{b'} = [8.1151 \cdot 10^{-1} \quad 3.8965 \cdot 10^{-2}]$
- Other broadleaves (*Alnus incana*, *Betula pendula*, *Populus tremula*, *Sorbus aucuparia*):

  $v = b_1 + b_2 d^2 h + b_3 d$ $\boldsymbol{b'} = [2.3118 \quad 3.1278 \cdot 10^{-2} \quad 3.7159 \cdot 10^{-1}]$

Where:

- v: volume (dm^3);
- d: diameter (cm);
- h: height (m).

To calculate the volume of snag and stump a distinction between species was not needed, so we used the following formulas:

- for snag the cylinder volume formula, but using a reduction coefficient to better simulate a conoidal shape (trunk without top and in decomposition)

$$v = G \cdot H_{snag} \cdot 0{,}5$$

Where:

- G: basal area
- H_{snag}: total snag hight
- 0.5: reduction coefficient.

- for stump the truncated cone volume formula:

$$v = \frac{(S_B + S_b + \sqrt{S_B \cdot S_b}) \cdot h}{3}$$

Where:

- S_B: area calculated in relation of the collar diameter (m^2);
- S_b: area calculated in relation of the top of the trunk (m^2);
- h: total stump height.

3.4.5 Diameter classes

Diameters have been divided in classes with a range of 5 cm. Thanks to the graph of each plot we can understand if the stand is even-aged, if it has a Gaussian distribution, or uneven-aged, if it follows a negative exponential trend.

3.4.6 Social classes

To define the social classes of the trees we used the Kraft classification (Fig. 17). This classification is based on a tree's position in the stand's social structure and its crown development and extent. Kraft divided the stand in two layers: the dominant stand and the suppressed one. To the dominant stand the classes 1-3 make part:

1. predominant trees with exceptionally well-developed crowns;
2. dominant trees, forming the main stand as a rule with relatively well-developed crowns;
3. low co-dominant trees; crown shape is still normal, yet they are relatively weakly developed and restricted often already with the onset of degeneration.

To the suppressed stand the classes 4-5 make part:

4. dominated trees, with crowns more or less dying back, restricted on all sides or on two sides, or with one-sided development;
   a. intermediate trees, essentially free of canopy cover with restricted lateral crown growth;
   b. partially overtopped crowns, the upper crown free, the lower crown under canopy cover;
5. entirely overtopped trees
   a. with crowns capable of growth;
   b. with dead crowns.

Kraft Classification		
1		Individuo predominante
2		Individuo dominante
3		Individuo co-dominante
4	IV a	Individuo intermedio, con crescita della chioma laterale e ristretta
5	IV b	Individuo intermedio, con chioma sotto il livello della canopy cover
6	V a	Individuo soppresso, con chioma ancora viva
7	V b	Individuo soppresso, con chioma morta

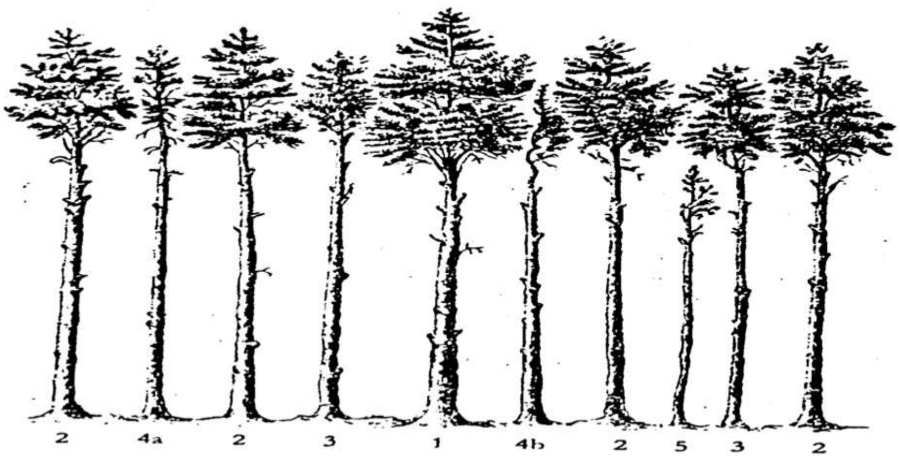


Figure 17. Kraft classes and their graphical representation on a model stand.
Source: Grala-Michalak and Kaźmierczak 2011Grala-Michalak and Kaźmierczak 2011Grala-Michalak and Kaźmierczak 2011Grala-Michalak and Kaźmierczak 2011

3.4.7 Deadwood

To calculate deadwood volume we referred to the study of Van Wagner, C.E. (1982), using the following equation:

$$v = \frac{k}{L} \cdot \sum d^2$$

Where:

- k: constant as a function of the desired unit of measurement to describe the volume;
- L: transect length (50 m);
- d: diameter at the intersection point with the transect.

3.4.8 Canopy cover

Canopy cover level was estimated using the crown radius of the sampled tree. Once the average radius of each plant has been calculated we could obtain the canopy surface took up by the crowns of the stand. After that, we related this data to the sample area surface to know the percentage of canopy cover.

3.5 Method of analysis of bryophytes

In each plot 10 areas were chosen to take a sample picking up all the bryophyte species found. Bryophytes were systematically sampled in 0.5 x 0.5 m square, and we repeated it 5 times for each of the substrates chosen: ground and blocks. Altogether 200 samples were done. On blocks we surveyed the leaning side because it is the part with less litter sediment, which could divert the sampling result. Then, we estimated a percentage of vascular plants and bryophyte cover on the sampling. After that, we did a floristic survey, spending 15 minutes searching along the plot for other species we may not found in the samplings.

LIS was applied to estimate the bryophyte cover, using three 20-m parallel transects in each stand: one passing through the centre of the area (10 m on the right and 10 m on the left of the centre), one upstream the centre and another one downstream the centre. For each meter of the transect the amount of centimetre of bryophytes intercepting the rope, used to do a line, was wrote down. Then, the data of each transect were added up and then divided by sixty (20 m per three transects). The result was expressed in percentage.

3.6 Statistical analysis

The effect of forest management (human disturbance), blockfields (natural disturbance) and their interaction on bryophytes cover and species richness was tested through a generalised linear model using the *glm* function from the package stats (version 3.6.2) in the R software. We used the Poisson error distributions for species richness, while cover data were modelled with Gamma error distributions. The F test ($\alpha = 0.05$) on the two models was performed trough the *anova* function from the package stats (version 3.6.2) in the R software.

The relationship between a set of stand structural variables, and bryophytes cover and species richness values was explored through the Excel linear regression estimation function based on the evaluation of the R^2 parameter.

4. RESULTS AND DISCUSSION

4.1 Bryophytes

Overall 120 species of bryophytes were found. The following species are the most common in the sampling areas:

- *Dicranum scoparium* (Fig. 18): is a very common specie which occurs in a wide range of habitats. It is frequent on the ground in woodland, but also occurs on trees and logs, on heathland, in mires, on sand dunes, acidic rocks and in short turf on the mountains (British Bryological Society).

Figure 18. *D scoparium*. Ph Daniel Spitale.

- *Hylocomium splendens* (Fig. 19): is common and may be abundant amongst grass and heather on heaths and moorlands and in acidic woodlands. Whilst usually occurring in acidic habitats, it may sometimes be found in well-leached chalk grassland (British Bryological Society).

Figure 19. *H. splendens*. Ph: Daniel Spitale.

- *Hypnum cupressiforme* (Fig. 20): is thriving in shaded areas where the soil is consistently damp. It can often be found covering fallen branches on dead trees, stones/rocks, and will even grow vertically up living trees and concrete walls. It grows on acidic substrates (British Bryological Society).

Figure 20. *Hypnum cupressiforme*. Ph: Daniel Spitale.

- *Pterigynandrum filiforme* (Fig. 21): is common on exposed sandstone, limestone or igneous rocks. Although it grows on hillsides and in river gorges, *P. filiforme* tends to reach its maximum abundance on boulders on loch margins. It is also uncommon on mature trees with base-rich bark, especially ash (*Fraxinus excelsior*) (British Bryological Society).

Figure 21. *Pterigynandrum filiforme*. Ph: Michael Lüth.

- *Brachythecium velutinum* (Fig. 22): it occurs on wood, including the branches, base and roots of trees, and on dead wood, as well as stones and compacted soil (British Bryological Society).

Figure 22. *Brachythecium velutinum*. Ph: Michael Lüth.

- *Isothecium alopecuroides* (Fig. 23)*:* occurs in woodland, on stream banks and other sheltered places, most commonly on the lower part of tree trunks and on the roots. It also occurs on rocks and stones, especially where base-rich (British Bryological Society).

Figure 23. *Isothecium alopecuroides*. Ph: Michael Lüth.

- *Paraleucobryum longifolium* (Fig. 24): is a plant of sheltered sites on the sides of large rocks in, or associated with, areas of scree in the mountains (British Bryological Society).

Figure 24. *Paraleucobryum longifolium*. Ph: Michael Lüth.

- *Rhytidiadelphus triquetrus* (Fig. 25): grows on calcareous ground in woodland, and also on acidic ground in woods of native pine (*Pinus*). It can also be found in open grassland on chalk, on sand dunes and in churchyards (British Bryological Society).

Figure 25. *Rhytidiadelphus triquetrus*. Ph: Daniel Spitale.

- *Barbilophozia hatcheri* (Fig. 26): are locally abundant on mossy boulders and in turf on north-facing slopes. They usually like some shelter but may also be found on exposed boulders or drystone walls (British Bryological Society).

Figure 26. *Barbilophozia hatcheri*. Ph: Sharon Pilkington.

- *Pleurozium schreberi* (Fig. 27): avoids calcareous or base-rich habitats and is most found amongst grass and heather on heathland and in open, heathy woods. In such places, it can be truly abundant. *P. schreberi* also commonly occurs in bogs (British Bryological Society).

Figure 27. *Pleurozium schreberi*. Ph: Claire Halpin.

The rest of the species found in the sampling areas are showed in the following Tab. 1.

Anastrophyllum minutum	*Grimmia elatior*	*Plagiothecium denticulatum*
Andreaea rupestris	*Grimmia hartmanii*	*Plagiothecium laetum*
Apometzgeria pubescens	*Grimmia montana*	*Pogonatum urnigerum*
Atrichum undulatum	*Grimmia muehlenbeckii*	*Pohlia cruda*
Barbilophozia lycopodioides	*Grimmia ovalis*	*Pohlia nutans*
Bartramia halleriana	*Hedwigia ciliata*	*Polytrichum alpinum*
Bartramia ithyphylla	*Heterocladium dimorphum*	*Polytrichum formosum*
Blepharostoma trichophyllum	*Heterocladium flaccidum*	*Polytrichum juniperum*
Brachythecium rivulare	*Homalothecium sericeum*	*Polytrichum piliferum*
Brachythecium salebrosum	*Hylocomiastrum pyrenaicum*	*Pseudoleskeella nervosa*
Bryoerythrophyllum recurvirostrum	*Lejeunea cavifolia*	*Ptilidium pulcherrimum*
Bryum subelegans	*Lepidozia reptans*	*Ptilium crista-castrensis*
Buxbaumia viridis	*Lescuraea saxicola*	*Racomitrium canescens*
Calypogeia azurea	*Leucodon sciuroides*	*Racomitrium elongatum*
Calypogeia integristipula	*Lophocolea heterophylla*	*Racomitrium microcarpon*
Campylium protensum	*Lophozia longidens*	*Radula complanata*
Cephalozia bicuspidata	*Lophozia sylvicola*	*Rhizomnium punctatum*
Ceratodon purpureus	*Metzgeria furcata*	*Rhodobryum roseum*
Cirriphyllum piliferum	*Mnium spinosum*	*Rhytidiadelphus squarrosus*
Climacium dendroides	*Neckera complanata*	*Rhytidium rugosum*
Cynodontium gracilescens	*Neckera crispa*	*Sanionia uncinata*
Cynodontium strumiferum	*Orthotrichum rupestre*	*Schistidium apocarpum*
Dicranodontium denudatum	*Orthotrichum striatum*	*Schistidium papillosum*
Dicranoweisia crispula	*Oxystegus tenuirostris*	*Sciuro-hypnum plumosum*
Dicranum muehlenbeckii	*Pellia epiphylla*	*Sciuro-hypnum populeum*
Eurhynchium angustirete	*Plagiochila asplenoides*	*Sciuro-hypnum starkei*
Eurhynchium striatum	*Plagiochila porelloides*	*Syntrichia ruralis var. ruralis*
Frullania dilatata	*Plagiomnium affine*	*Tetraphis pellucida*
Grimmia alpestris	*Plagiomnium cuspidatum*	*Thuidium recognitum*
Grimmia decipiens	*Plagiomnium ellipticum*	*Tritomaria exsecta*
Grimmia donniana	*Plagiomnium undulatum*	

Table 1. List of the less common bryophyte species found in the sampling areas.

Among the species one is included in the Habitats Directive (*Buxbaumia viridis*). 11 mosses (*Cynodontium gracilescens, Cynodontium strumiferum, Dicranodontium denudatum, Eurhynchium angustirete, Grimmia montana, Hylocomiastrum pyrenaicum, Oxystegus tenuirostris, Paraleucobryum longifolium, Plagiomnium ellipticum, Plagiothecium denticulatum, Racomitrium microcarponare*) and 4 hepatics (*Anastrophyllum minutum, Blepharostoma trichophyllum, Calypogeia azurea, Lepidozia reptans*) are of conservation concern, according to the International Union for Conservation of Nature, due to their habitat width decline. We also found 2 hepatic (*Calypogeia azurea, Lepidozia reptans*) and 5 moss (*Cynodontium strumiferum, Eurhynchium angustirete, Grimmia montana, Plagiomnium ellipticum, Plagiothecium denticulatum*) species that are considered rare in Italy (Tab. 2).

Specie	Rarity in Italy	IUCN classes	Habitats Directive	Red list
Anastrophyllum minutum	Frequent	NT		x
Buxbaumia viridis	Rare		Annex II	
Blepharostoma trichophyllum	Frequent	NT		x
Calypogeia azurea	Rare	EN		x
Cynodontium gracilescens	Frequent	VU		x
Cynodontium strumiferum	Rare	VU		x
Dicranodontium denudatum	Frequent	NT		x
Eurhynchium angustirete	Rare	EN		x
Grimmia montana	Rare	VU		x
Hylocomiastrum pyrenaicum	Frequent	VU		x
Lepidozia reptans	Rare	VU		x
Oxystegus tenuirostris	Frequent	VU		x
Paraleucobryum longifolium	Frequent	VU		x
Plagiomnium ellipticum	Rare	VU		x
Plagiothecium denticulatum	Rare	VU		x
Racomitrium microcarpon	Frequent	NT		x

Table 2. List of all the rare or threaten bryophyte species recorded in this study.
EN: Endangered; VU: Vulnerable; NT: Near Threatened.

4.2 Forest structure

For each plot we examined the dendrometric parameters, as shown in Tab. 3. The number of plants in the plots has been obtained by summing the number of living trees and dead trees. Then, we calculated the number of plants per hectare. This last data gives us an idea of the stand density and we can notice that due to regular cuttings, on average in managed plots we find less plants (332 plants/ha) and a higher number of stumps (186 per hectare) compared to the unmanaged ones (650 plants/ha and 87 stumps/ha). The lower density results in a higher value of mean DBH. On the other hand, in unmanaged stands we find a higher number of dead trees (541 per hectare versus 54 in managed plots) and snags (45 per hectare versus 5 in managed plots), due to the lack of forest management. Another interesting data is that in plots without blocks the G/ha is higher, probably thanks to the lack of obstacles for trees growth.

Plot	Type	LT	DT	SN	ST	N_{trees}/SA	N_{trees}/ha	G/SA	G/ha	Mean DBH
4	BM	69	0	0	69	69	549	6.78	54.00	35.39
8	BM	64	0	2	3	64	510	3.71	29.55	27.18
20	BM	42	0	0	14	42	334	8.15	64.89	49.72
32	BM	39	0	0	8	39	311	6.55	52.14	46.72
35	BM	5	27	2	11	32	255	6.56	52.21	51.09
1	BNM	17	78	7	0	95	756	6.77	53.90	30.13
2	BNM	77	0	0	22	77	613	6.07	48.32	31.69
12	BNM	2	57	2	13	59	470	4.20	33.46	30.12
13	BNM	5	74	7	17	79	629	8.45	67.27	36.91
26	BNM	6	47	3	5	53	422	9.31	74.11	47.30
14	NBM	34	0	0	18	34	271	8.55	68.07	56.60
18	NBM	36	0	0	24	36	287	8.41	66.97	54.56
22	NBM	7	41	1	62	48	382	6.42	50.09	41.27
24	NBM	25	0	1	13	25	199	6.16	49.03	56.02
34	NBM	28	0	0	12	28	223	8.78	69.93	63.22
9	NBNM	4	68	4	8	72	573	4.80	38.23	29.15
10	NBNM	9	105	17	14	114	908	7.04	56.07	28.05
11	NBNM	6	72	3	10	78	621	9.75	77.65	39.91
16	NBNM	9	144	11	11	153	1218	7.25	57.70	24.56
29	NBNM	2	34	3	9	36	287	9.34	74.40	57.50

Table 3. Number of plants, basal area and mean diameter at breath height of the forest stand.
LT: living trees; DT: dead trees; SN: snag; ST: stump

The analysis of logs confirms the expectation that its amount is higher in unmanaged stands (Tab. 4).

Plot	Type	N log/SA	N log/ha
4	BM	2	16
8	BM	1	8
20	BM	2	16
32	BM	2	16
35	BM	5	40
1	BNM	7	56
2	BNM	1	8
12	BNM	7	56
13	BNM	3	24
26	BNM	3	24
14	NBM	1	8
18	NBM	1	8
22	NBM	1	8
24	NBM	1	8
34	NBM	1	8
9	NBNM	1	8
10	NBNM	6	48
11	NBNM	4	32
16	NBNM	21	167
29	NBNM	3	24

Table 4. Number of logs in each plot and per hectare.

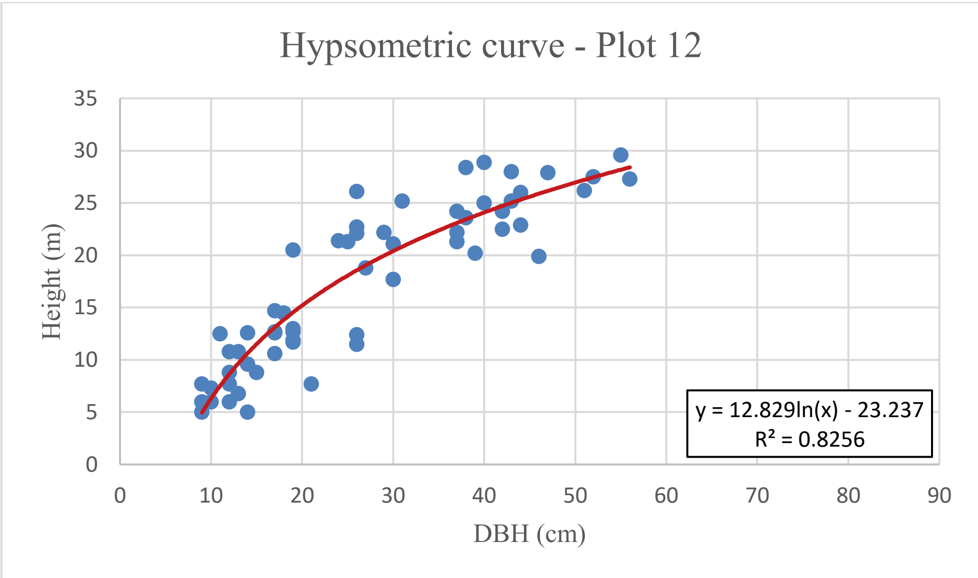
In Tab. 5 values about heights, average crown radius and an estimation of the canopy cover are reported. Using standard deviation we could see that NBM plots have more homogeneous trees height. Regarding canopy cover we noticed that in unmanaged areas the percentage is higher, as we could expect.

Plot	Type	h average	h max	R average	Canopy cover
4	BM	31.1	49.3	1.9	65%
8	BM	17.5	37.2	2.0	64%
20	BM	34.6	44.2	2.2	49%
32	BM	27.1	43.7	2.1	44%
35	BM	26.2	44.8	2.2	38%
1	BNM	24.4	39.9	1.7	72%
2	BNM	23.0	42.2	2.0	75%
12	BNM	17.6	29.6	1.8	48%
13	BNM	26.4	37.2	1.9	69%
26	BNM	32.4	40.0	2.6	93%
14	NBM	37.1	45.0	2.4	49%
18	NBM	35.3	43.2	2.0	37%
22	NBM	28.7	40.8	2.4	72%
24	NBM	35.4	41.2	2.5	40%
34	NBM	42.8	50.5	2.2	34%
9	NBNM	16.4	31.8	1.9	65%
10	NBNM	19.2	43.7	1.8	95%
11	NBNM	23.8	38.9	2.5	124%
16	NBNM	18.4	31.3	1.7	110%
29	NBNM	32.0	41.7	2.7	67%

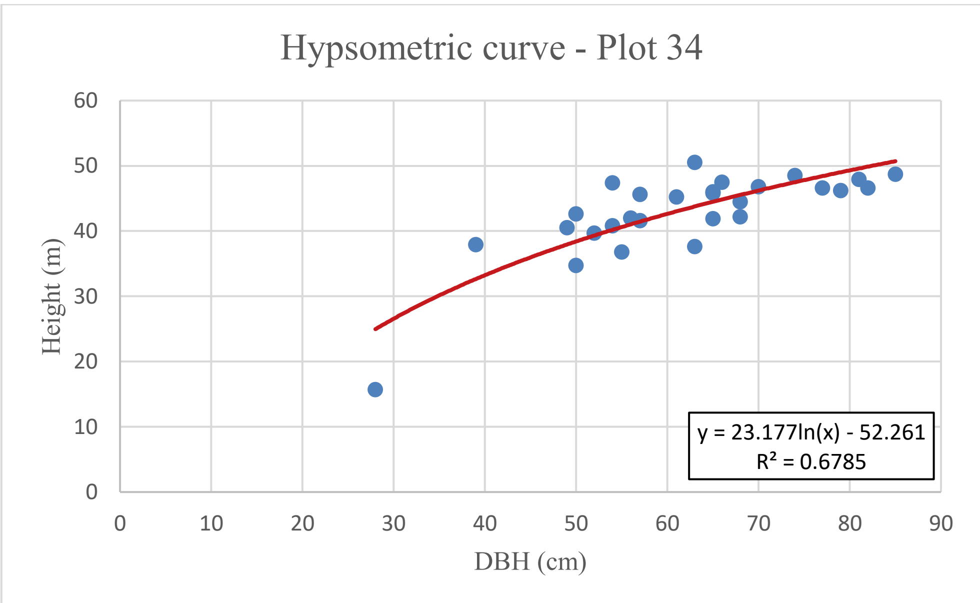
Table 5. Shows heights, average crown radius and an estimation of the canopy cover.

Then, to better understand the plots' structure we did the hypsometric curve of each stand. Below there are the most significative graphs of the sampling areas, where the high values of R^2 point out a good correlation between the two variables. Graph. 1 shows the uneven-aged forest structure of most of the analysed plots (55%), where all the diameter classes are represented.

35% of the plots are mature and even-aged, as we can see from Graph. 2

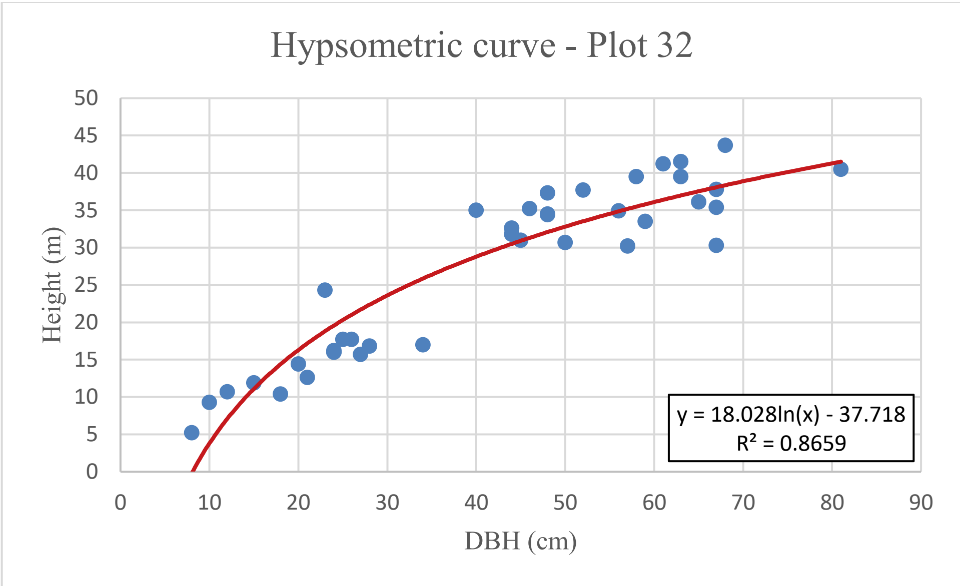


Graphic 1. The most represented forest structure of the sampling areas.



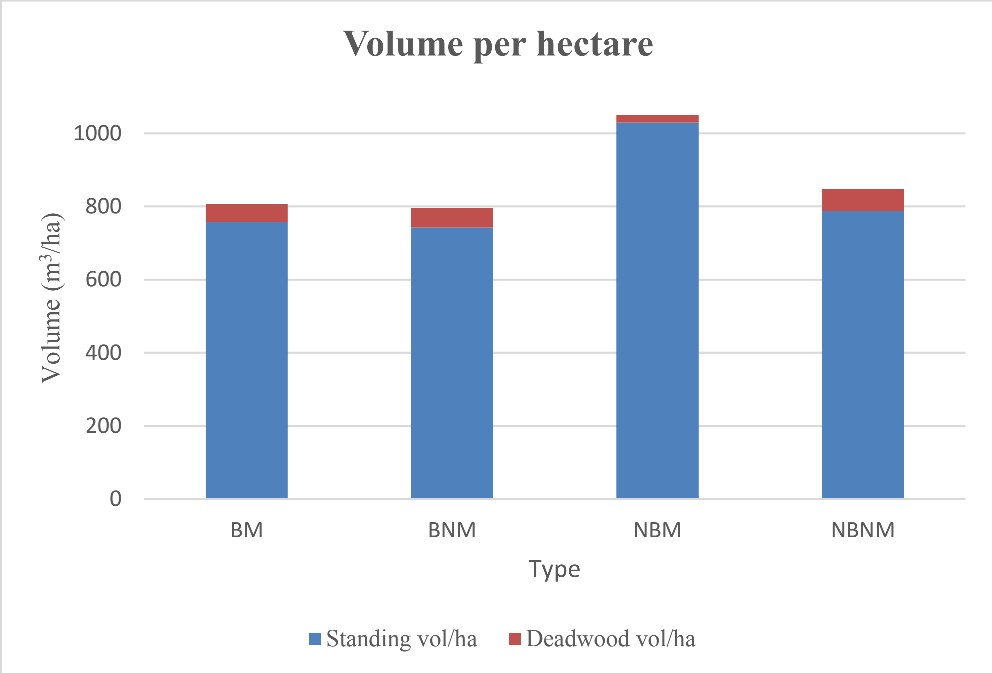
Graphic 2. Representation of a mature even-aged stand.

Then, just in 10% of the plots we can notice the presence of two stands: a young one under an old one (Graph. 3).



Graphic 3. Representation of a plot made by a young stand and a mature one.

For the structural analysis, the volume per hectare (m^3/ha) of the living trees (LT and DT) and deadwood (log, SN and ST) was calculated (Graph. 4). From Tab. 4 we can easily notice that the managed areas without blocks have the highest amount of standing volume (1029.6 m^3/ha) and the lowest of dead wood (21.18 m^3/ha), while the other three type of plots are quite similar according to the total volume per hectare and the partition between standing trees and deadwood volume.



Graphic 4. Shows the standing and dead volume per hectare for each type of management.

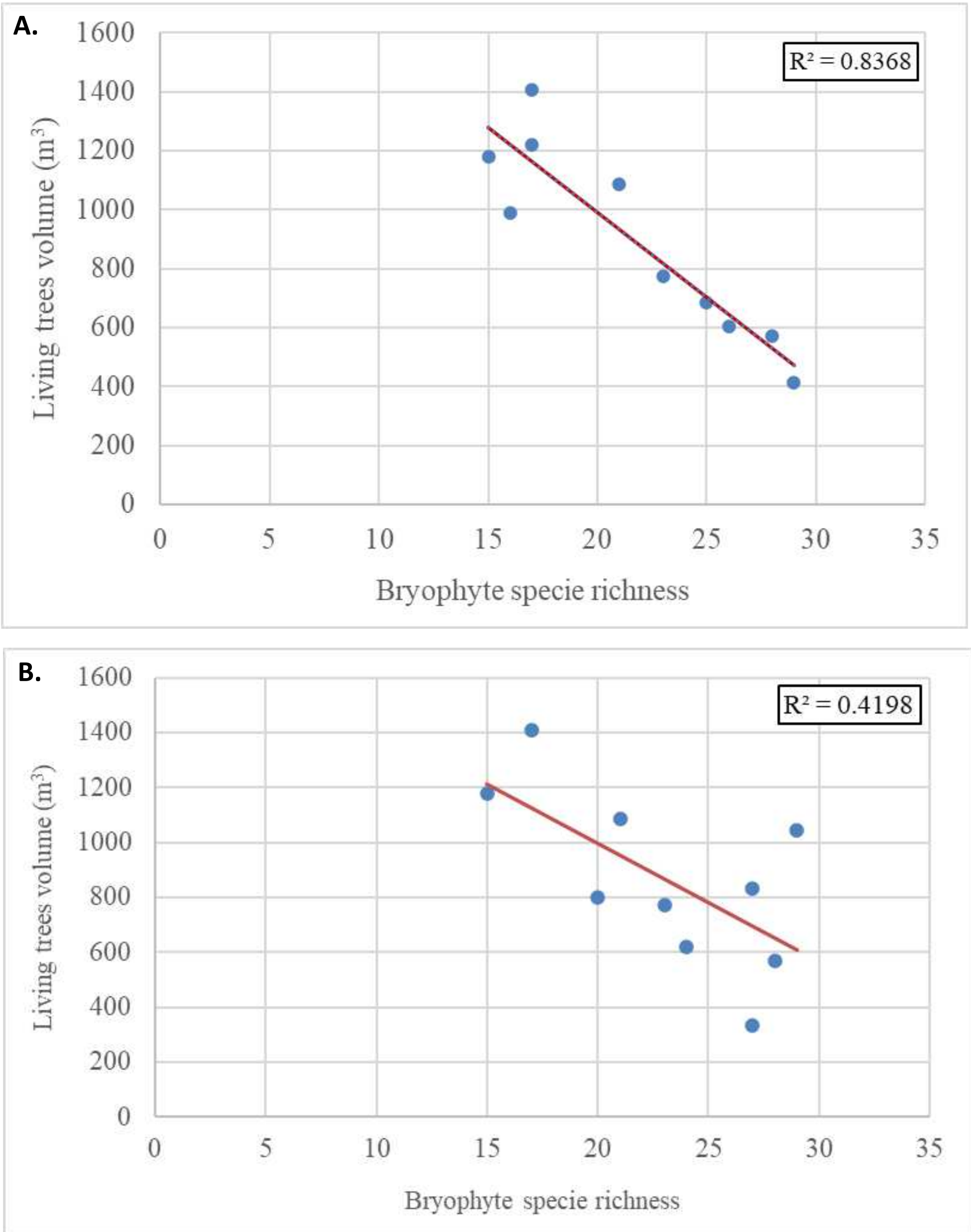
Type	Standing vol/ha	Deadwood vol/ha	Tot vol/ha
BM	757.71	49.23	806.93
BNM	742.95	53.04	795.98
NBM	1029.60	21.18	1050.79
NBNM	786.83	61.41	848.24

Table 4. Mean volume per hectare values of living trees and deadwood for the four management types.

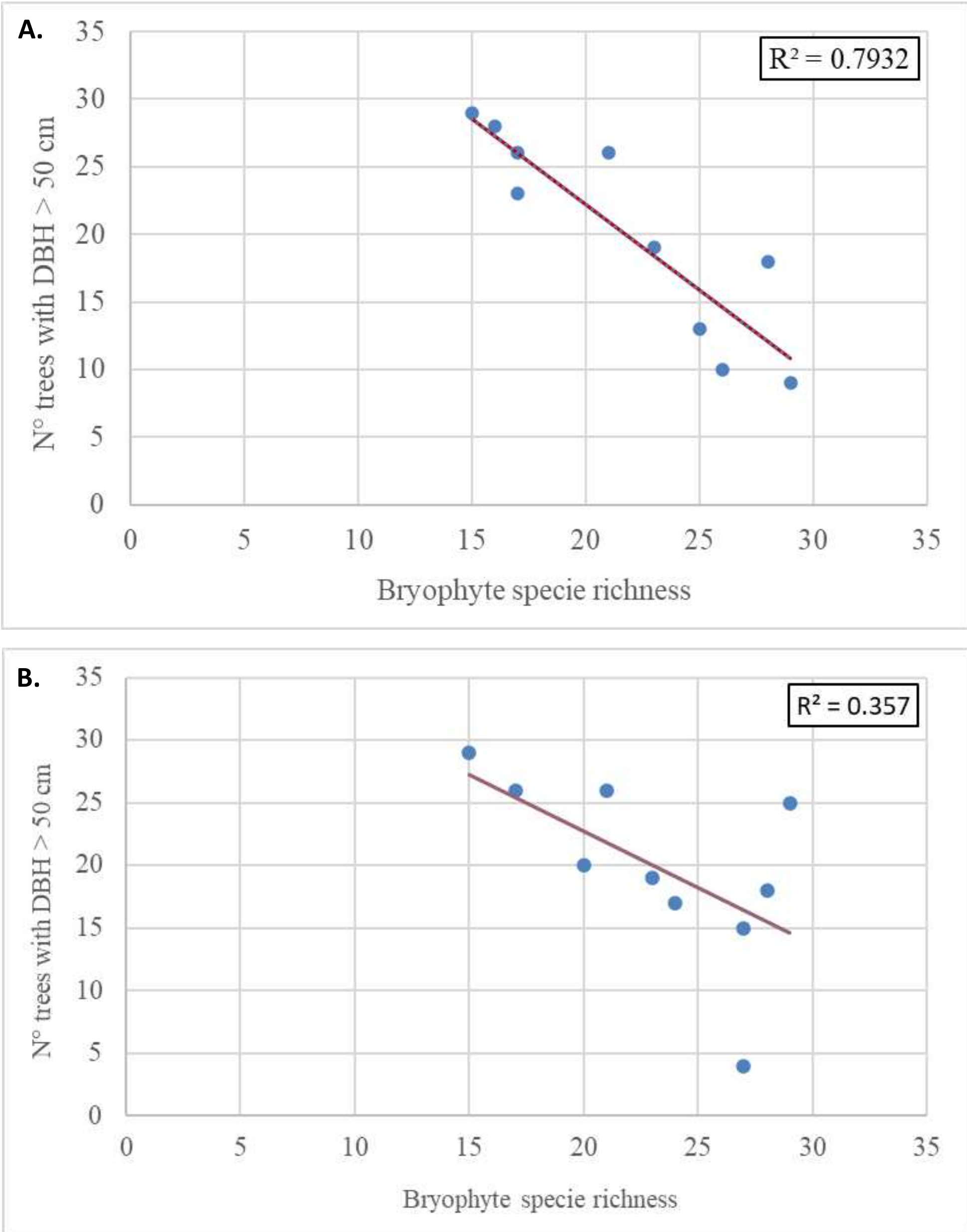
4.3 Relation between the forest structure and bryophytes

To evaluate whether differences in bryophyte species number and cover between disturbed and undisturbed forests could be attributed to differences in variables of stand structure, we estimated the effect of stand structure variables on the species groups. As we can see from the following Graphics 5, 6, 7 there is a negative relation between living trees volume, number of trees with DBH > 50 cm and mean DBH, and bryophyte richness. High values of R^2 indicate a strong relation between the variables.

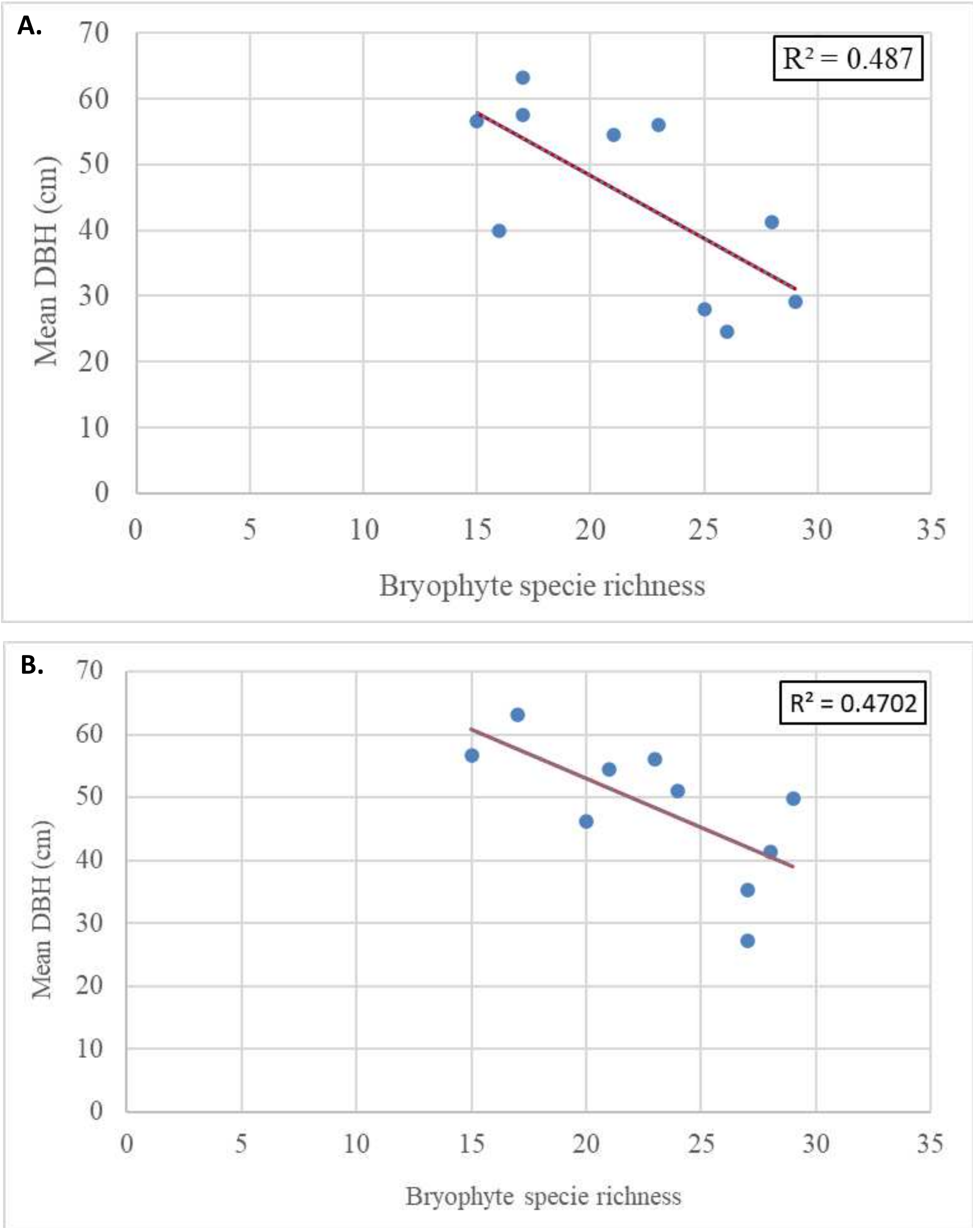
In our stands, as in those analysed by Márialigeti et al. (2009), the size of dominant trees, which is often correlated with the overall age of the stand and timber volume especially in managed forests, has a negative effect on bryophytes. In many studies large trees act positively on the bryophyte richness and cover, but these studies consider mostly epiphytic species, that we did not consider. For epiphytic species the presence of large trees is favourable, because of the increase in the number of microhabitats, the changes in bark structure and elongation in colonisation time (see also Aude and Poulsen 2000; Bardat and Aubert 2007; McGee and Kimmerer 2002; Gustafsson and Eriksson 1995; Löbel et al. 2006; Snäll et al. 2003).



Graphic 5. Shows the negative relation between bryophytes richness and the volume of living trees. A. on plots without blocks; B. in managed plots.

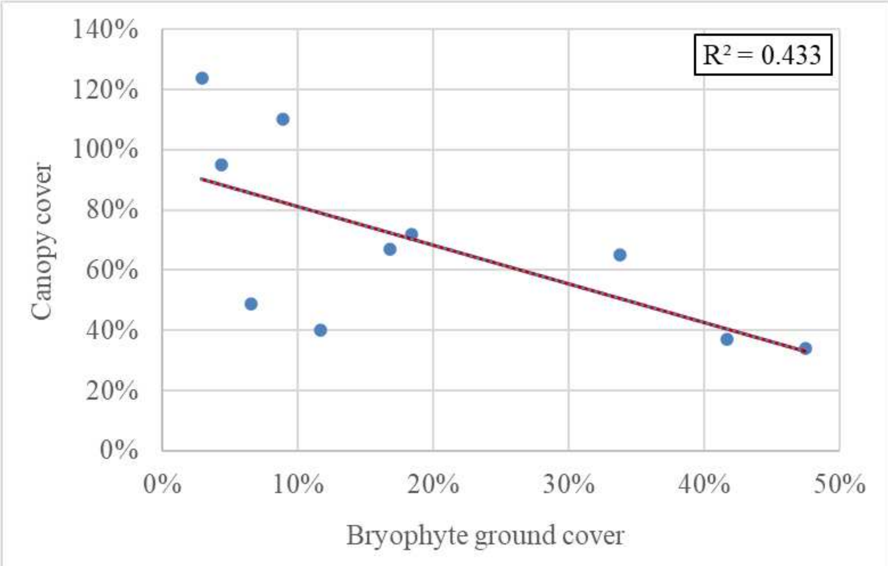


Graphic 6. Shows the negative relation between bryophytes richness and the number of trees with DBH > 50 cm. A. on plots without blocks; B. in managed plots.



Graphic 7. Shows the negative relation between bryophytes richness and the mean trees DBH. A. on plots without blocks; B. in managed plots.

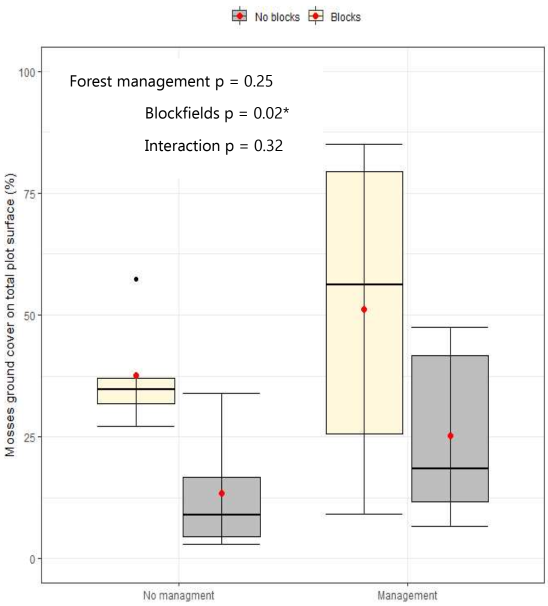
Unlike as we could expect from a bibliography study, increasing canopy cover causes a decrease in bryophyte cover (Graph. 8). Just few studies confirm that bryophyte cover benefit from canopy openness (Berdugo and Dovciak 2019; Márialigeti et al. 2009; Startsev et al. 2008; Nascimbene et al. 2014).

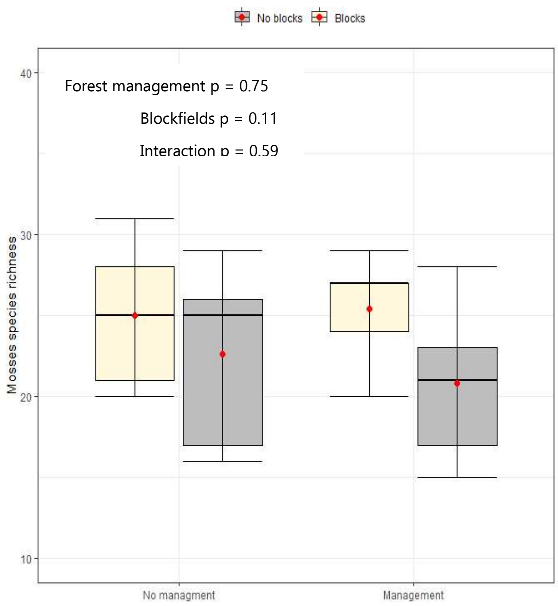


Graphic 8. Shows the negative relation between bryophyte cover and canopy cover in plots without blocks.

4.4 Relation between human and natural disturbances and bryophytes

From Graph. 9 is possible to notice that the highest percentage of cover is found in managed plots with blocks. The presence of block has a significance level ($F = 6.96$, $p = 0.02$). Also bryophyte specie richness is related to the presence of blocks, but in this case the relation is not significant (Graph. 10).





Graphic 9. Shows the positive effect of the presence of blocks and management on bryophyte cover.
Graphic 10. Shows the absence of a relation between human and natural disturbances and bryophyte richness.

5. CONCLUSION

Our results show that blockfields have a higher bryophyte specie richness and cover. This last variable is statistically significative. This can be explained by the fact that blockfields help to increase heterogeneity in the stands (Startsev et al. 2008) and are able to modify microclimate condition (Mills and Macdonald 2004, 2005), helping to increase forest biodiversity.

However, contrary to expectations, the results show that forest management does not affect bryophyte cover and richness.

In accordance with the study of Márialigeti et al. (2009) , high trees DBH values reduced bryophyte richness, probably because we did not consider wood-dwelling species, that are strictly related to big and old trees.

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