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Challenges in post-disturbance forest recovery: a case study in Peio valley

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ABSTRACT

KEY WORDS: Natural disturbances, forest recovery, deadwood, Ungulate browsing, adaptive management

Storms are the most frequent and damaging natural disturbance within European forests.
After these events forest recovery occurs mainly through recruitment, i.e. regeneration establishment, that depends on biological legacies left after salvage logging; however, in disturbed areas, tree regeneration is often threatened by Ungulate browsing.

This research aims at investigating the major disturbance regime within the chosen study area, for then analysing forest recovery in the disturbed areas, assessing Ungulate impacts on the proceeding of this process.

The chosen study area is Peio valley, an alpine valley in the north-west of Trento province, that is partially included in Stelvio national park, where red deer *(Cervus elaphus)* density is the highest of the entire Alps.

Firstly, by examining old forest management plans, major disturbance regime since the '50s has been reconstructed; the amount of salvaged wood and effects on forest yield have been analysed, comparing the results with data on Vaia *storm*.
Afterwards, within the most recent disturbed areas, it has been analysed regeneration status, considering species composition, height, location and browsing evidences.

Five major windthrows have occurred in 1960, 1976, 1990, 2003 and 2015, for which the total amount of salvaged wood accounted for the 11.3% of the total planned yield between 1952 and 2017; the amount of salvaged wood due to *Vaia* storm in November 2019 accounted for roughly the 40% of the total salvaged wood volume for the period 1952-2017, but it has not compromised forest planned yield.
The analysis of forest recovery in disturbed areas during 1990, 2003 and 2015 events, evidences that the 30.6% of regeneration is browsed, with highest of 44.5% within Stelvio National park; moreover, it has been observed the important role of deadwood in recovery process, since the 36.1% of regeneration is located on this biological legacy.
Deadwood is very likely to offer protection from browsing damages, but this may come less during winter because of the lifting of forest floor due to the snowpack.

Therefore, forest recovery seems to be a challenging process; the impact due to red deer will have significant consequences on protective and productive functions of forests (e.g. yield); moreover, climate change is expected to further negatively affect this process.
Therefore, it is necessary to address these issues, by adopting a forest management able to improve resistance and resilience of forest ecosystem.

RIASSUNTO

KEY WORDS: Disturbi naturali, ricrescita del bosco, necromassa, brucamento da parte di Ungulati, gestione adattiva

Le tempeste si configurano come eventi naturali altamente impattanti le foreste europee. Dopo questi eventi, la ricrescita del bosco è legata allo sviluppo della rinnovazione naturale, il cui successo dipende dalle *biological legacies* rimaste in bosco successivamente alle operazioni di recupero del materiale schiantato; tuttavia, in queste aree lo sviluppo della rinnovazione è spesso minacciato dal brucamento da parte degli Ungulati.

Questa ricerca ha come obiettivo quello di ricostruire il regime dei disturbi naturali che hanno avuto un impatto significativo all'interno dell'area di studio, analizzando il successivo processo di ricrescita del bosco, verificando anche l'impatto degli Ungulati in questo processo.

L'area di studio è rappresentata dalla Val di Peio, una valle alpina situata nel nord-ovest del Trentino e parzialmente inserita all'interno del Parco Nazionale dello Stelvio, dove si registra la più alta densità di cervi *(Cervus elaphus)* di tutte le Alpi.

Per prima cosa, è stato ricostruito il regime dei disturbi naturali in Val di Peio attraverso l'analisi della serie storica dei piani di assestamento disponibili; sono stati poi analizzati la quantità di materiale recuperato dagli schianti e gli effetti sulla ripresa forestale, confrontando questi dati con quelli della tempesta Vaia.
Successivamente, nelle aree soggette a disturbo negli ultimi trent'anni, è stato analizzato lo stato della rinnovazione, considerando la composizione specifica, l'altezza, il sito di crescita e la presenza di segni di brucamento.

Da questa analisi è emerso che in Val di Peio si sono verificati cinque schianti da vento di una certa importanza rispettivamente negli anni 1960, 1976, 1990, 2003 e 2015; la quantità di legname recuperato è stato pari all'11.3% della ripresa complessiva prevista tra il 1952 e il 2017.
In seguito alla tempesta Vaia è stato recuperato un volume pari al 40% del totale recuperato fino al 2017 (dati aggiornati a Novembre 2019); tuttavia, la ripresa forestale futura non è stata compromessa.
Dall'analisi relativa allo sviluppo della rinnovazione nelle aree danneggiate negli ultimi 30 anni, è emerso che il 30.6% della rinnovazione mostra danni da brucamento, che all'interno del Parco Nazionale dello Stelvio raggiunge il 44.5%.
Inoltre, la necromassa rappresenta un sito favorevole allo sviluppo della rinnovazione, con un 36.1% di piantine cresciute su questo substrato; inoltre, essa sembra offrire protezione contro il brucamento, anche se durante l'inverno questa viene meno a causa della copertura nevosa che innalzando il livello del terreno, espone maggiormente la rinnovazione al rischio di brucamento.
Perciò, si ritiene che la ricrescita del bosco nelle aree schiantate sia un processo difficile.
L'alta densità di cervi della zona nel lungo periodo porterà a una diminuzione progressiva della funzione protettiva e produttiva del bosco, che saranno ulteriormente aggravati anche dall'effetto dei cambiamenti climatici, che porteranno a un aumento delle superfici forestali danneggiate.
Pertanto, si rende necessario affrontare queste problematiche, adottando una gestione forestale capace di migliorare la resistenza e la resilienza degli ecosistemi forestali.

1. INTRODUCTION

A natural disturbance is any event that is relatively discrete in time and space, that disrupts the structure of an ecosystem, community, or population and changes resource availability or the physical environment (White & Pickett 1985).

Avalanches, rockfalls, landslides, windthrows, wildfires, insects' outbreaks, diseases and herbivory grazing are the typical natural disturbances that occur within the Alps, whose frequency and magnitude depend on the site-specific environmental characteristics.

Each ecosystem is characterized by a certain disturbance regime (Keane 2013), that is defined as the pattern of disturbance occurrence over a long period of time; this consist of a complex set of disturbance events characterized by different frequency and magnitude.

It has been observed that there is a correlation between frequency and magnitude of these events (Iwasaki & Noda 2018) , that allows to distinguish between two main types of natural disturbance: *minor disturbances* when characterized by high frequency, but low magnitude and *major disturbances* when characterized by low frequency, but high magnitude.

Among the latter are included also *large infrequent disturbances* (LID), that are unique low frequency and very high magnitude disturbance events, whose effects on the ecosystem are large in extent and may persists for a long time (Turner & Dale 1998); examples of these events are volcanic eruptions, big wildfires and extreme floods or storms.

Storms are the most damaging natural disturbance within European mountain forests of central eastern and western Europe, as well as of the Alps (Schelhaas et al. 2003).

Because of the trail of destruction that they leave behind, these natural events are perceived by humans as disasters or catastrophes (Lindenmayer & Noss 2006); however, ecologists have demonstrated that natural disturbances are an important element of ecosystem dynamics.

They can be considered as "editors" that selectively remove or modify elements of an ecosystem, while leaving others intact (Franklin et al. 2000); in this way they contribute to environmental heterogeneity, increasing structural diversity that is then fundamental for ecosystem recovery (Turner 1987,Franklin et al. 2000, Lindenmayer & Noss. 2006).

In fact, natural disturbances reallocate and change the total growing space (Carlton & Bazzaz 1998), that is the set of ecological factors fundamental for tree growth: sunlight, water, nutrients and physical space.

The presence of this empty space give rise to something of a race to fill the gap created (Ulanova 2000), that according to the size and intensity of the disturbance will occur though different paths of recovery; Liang et al. (2002) observed that in general forest ecosystems respond with either the reorganization of survived vegetation (i.e. regrowth or release) or the establishment of vegetation through regeneration (Everham & Brokaw 1996).

In the Alps, where forests are dominated by conifers, regrowth process is limited as, indeed, few are broadleaves; release may occur, but since in large-scale disturbances the amount of survived vegetation is low, secondary succession is more oriented to the re-establishment of vegetation through regeneration.

Seedling distribution and survival rate of regeneration (Kuuluvainen 1994, Ulanova 2000) is affected by types, numbers and spatial arrangements of biological legacies remaining after the disturbance event (Franklin et al. 2000).

However, natural recovery dynamic of forests after a disturbance is very often altered by salvage logging, i.e. the removal of commercially valuable timber from the "disturbed area", since this practice causes the removal and alteration of significant amounts of biological legacies (Franklin et al. 2000, Van Nieuwstadt et al 2001, Lang et al. 2009, Morimoto et al. 2011); therefore, those left after salvage logging, are very important features for forest recovery.

In particular, their role is fundamental not only for providing propagules (Turner et al. 1998), but also for creating those microsites where regeneration can find the optimal environmental conditions (e.g. temperature, drought, nutrients), which are essential for regeneration establishment and its subsequent development, i.e. for forest recovery.

Nevertheless, this process is affected by additional biotic factors, such as diseases and herbivore attacks (Ulanova 2000); among them, browsing by ungulates is often reported as one of the major hazards for tree regeneration after a disturbance event (Kupferschmid & Bugmann 2005).

In fact, high densities of ungulates can have a profound impact on plant populations, forest structure and ecosystem processes (Kupferschmid et al. 2015), by preventing successful seedling establishment and canopy recruitment of certain tree species (Frelich 2002).

Within the Alps, Ungulates browsing and in particular that due to red deer *(Cervus elaphus)* has become a problem in the second half of the '70s; in fact, many researches (Motta 1996, Motta & Quaglino 1989, Motta & Franzoi 1997, Armani & Franzoi 1998, Provincia Autonoma di Bolzano 1997, Kupferschmid et al. 2015) have highlighted how the high population density reached by this species in some alpine areas is threatening the development of forest regeneration.

As a consequence, this represent an important issue for the recovery of alpine forests affected by large disturbances, that will take more time, with long-term effects on forest yield, thus on forest harvesting, as well as on the economy of some mountain areas.

Therefore, the aim of this research is to firstly investigate the occurrence of large-disturbance events such as windthrows over the last 70 years within a small alpine valley of the eastern Alps and its effects on forest harvesting and yield, comparing the results with the recent *Vaia* storm.

Secondly, it has been analysed forest recovery process in these areas, considering a post-disturbance forest management that consists in salvage logging; a particular stress has been put on the role of structural biological legacies such as deadwood (i.e. stumps and logs) and mounds (i.e. uprooted stumps).

Finally, it has been investigated the level of ungulates impacts over the recovering forests, focusing on red deer population density and its browsing intensity on them, in order to predict which will be the future of those forests that, there, have been impacted by *Vaia* storm.

2. BACKGROUND

2.1 WINDTHROWS REGIME OVER THE LAST CENTURY

Over the period 1950–2000 in Europe, an annual average of 35 million m^3 wood was damaged by natural disturbances (Schelhaas et al. 2003); according to figure 2.1 storms are the most recurrent natural disturbance within European forests.

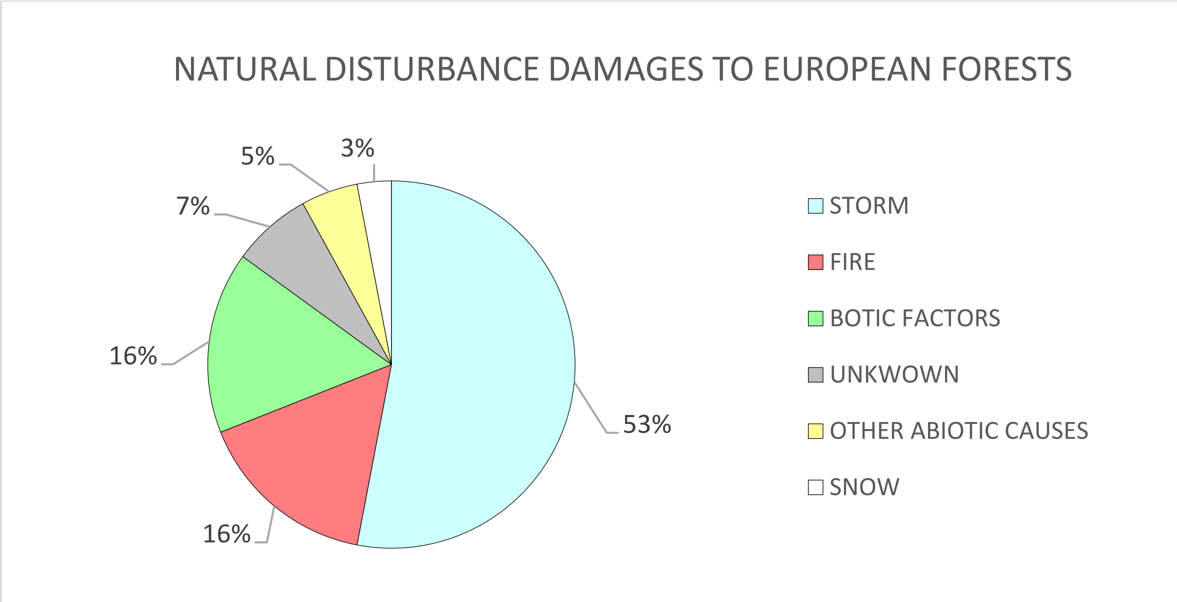


Figure 2.1: Repartition of damages (m^3 of wood) caused by natural disturbances to European forests between 1950 and 2000. (Schelhaas et al. 2003)

Most of the damage from storms was reported in central eastern and western Europe, as well as within the Alps and especially in the more mountainous areas (Schelhaas et al. 2003); the extreme meteorological conditions of storms (e.g. high rainfall intensity and wind speed) are responsible for windthrows over large surfaces, i.e. for the destruction of hectares of forest surface.

Vaia storm is the most destructive large-disturbance event of the entire Alp in living memory; it occurred between the 29th and the 30th of October 2018 over the north-east area of this mountain range system.

The phenomenon started on the 27th of October with very heavy rains, that, between the 29th and the 30th of October, were followed by rushing gusts of Scirocco and heavy storms; according to the meteorological data collected in those three days, in some of these areas it has rained half of the mean annual precipitation and wind velocities in the north reaches 150-200 km/h.

These intense precipitation followed by wind gusts has caused many damages to human infrastructures, as well as to forests; in fact, thousands of hectares of forests have been seriously damaged, with the downing of about 6-8 millions of m^3 of wood between Lombardia, Trentino-Alto Adige, Veneto and Friuli-Venezia Giulia regions.

Despite *Vaia* storm can be classified as a large infrequent disturbance event, this is not the first time that in Italy such kind of events happen; according to figure 2.2, from the '60s to nowadays there has been other three events similar to *Vaia* storm, although their effects on forests have been much lower.

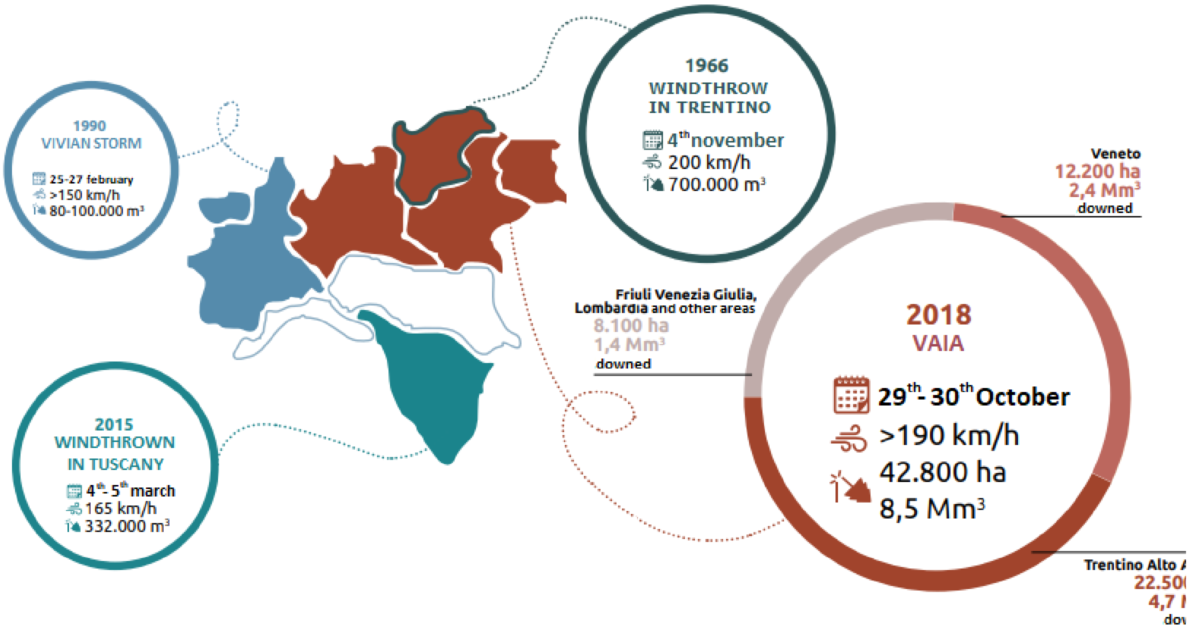


Figure 2.2: Comparison between *Vaia* storm effects and other disturbance events that has occurred in Italy during the last 70 years. (Reference: Regione Lombardia, ERSAF (2019) Tempesta Vaia: Cosa è successo alle foreste alpine? Come ricostruire boschi più resistenti?)

On the contrary, these past events together with *Vaia* storm are a nothing if compared to those windthrows happened in Europe in the same period (figure 2.3); in fact, since the '50s more than 900 million of m^3 of wood has been downed in European forests, while in Italy this amount is a little more than 1 million of m^3.

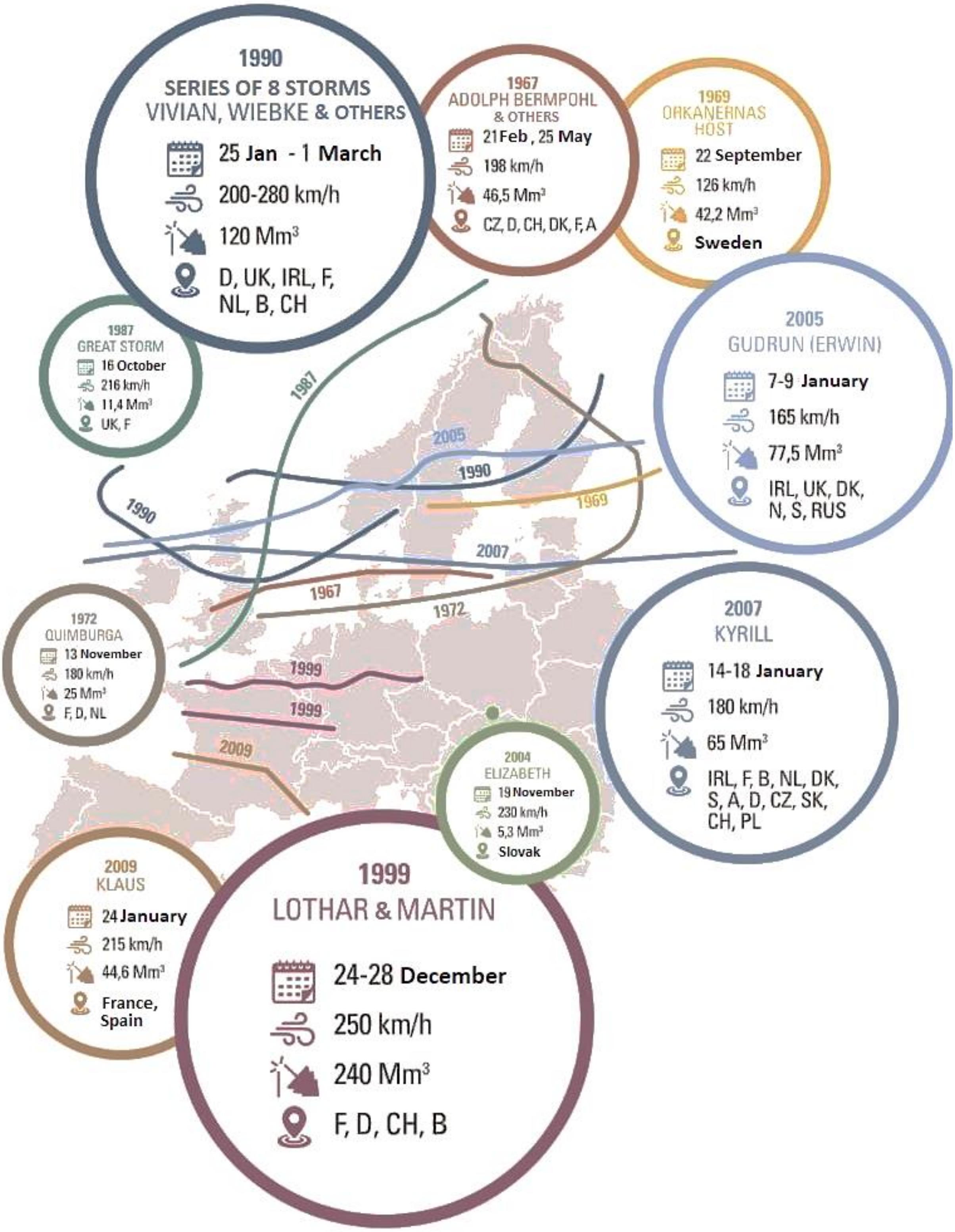


Figure 2.3: Main windthrow events that have occurred in Europe during the last 70 years
(Reference: Torreggiani L. (a cura di) (2019), Sherwood – Foreste e Alberi oggi, 238:16-17)

2.2 FOREST RECOVERY AFTER A WINDTHROW

According to Jonsson (1993), to understand how forest recover from disturbance effects, it has to be clear what this disturbance actually has caused.

As a consequence of a windthrow, huge amounts of wood lie on the ground; this scenario lead forest owners to the need of "clean up", by recouping economically valuable timber before deterioration (Morisette et al. 2002); this operation is called *salvage logging*, that is defined as the removal of commercially valuable timber from a stand after the occurrence of a natural disturbance such windthrow (Lang et al. 2009, Lindenmayer & Noss 2006).

This common management practice in following the occurrence of a disturbance causes the removal and alteration of significant amounts of biological legacies (BOX 1), on which the damaged forest relies on for its recovery (Franklin et al. 2000, Van Nieuwstadt et al 2001, Lang et al. 2009).

In fact, according to many authors (Turner et al. 1998, Ulanova 2000, Lindenmayer & Noss 2006, Lang et al. 2009), patterns of ecosystem recovery and revitalization following any kind of disturbance are influenced by the types, numbers and spatial arrangements of biological legacies remaining after the event.

BOX 1 **- WHAT ARE BIOLOGICAL LEGACIES?**

Biological legacies are organisms, organic matter, organically derived structures and organically produced patterns that survive from the pre-disturbance system (Franklin et al. 2000).

ORGANISMS – Among organisms are included complete organisms (varying in size and degree of sexual maturity); perennating parts (some roots, rhizomes, hyphae); propagules (seeds, spores, eggs).

ORGANIC MATTER – Fine litter and particulate material is that organic matter, that will provide an abundant energy and a nutrient base for the advancing of forest succession.

ORGANICALLY DERIVED STRUCTURES – For organically derived structures are intended all the standing dead trees (also known as snags), downed trees and other coarse woody debris, as well as root wads and pits from uprooted trees.

ORGANICALLY DERIVED PATTERNS – Soil chemical, physical and microbial properties, forest understory composition and distribution are what is meant for organically derived patterns.

Specific biota (plant, animal and fungal species), plant communities and biotic processes, can generate strong and persistent spatial patterns in environmental resources, including chemical, physical and biological properties of soils (Franklin et al. 2000); think for example to nitrogen-fixing species which can enrich the soil of nitrogen.

After salvage logging on a windthrow area, woody debris of all size such as snags, stumps, roots and sometimes branches (e.g. when full-tree harvesting system is not adopted) can be particularly abundant (Lang et al. 2009, De Grandprè et al. 2018); these legacies together with the microtopography originated by the tree fall (i.e. pits and mounds), represent the basis on which the damaged and salvaged forest will rely on for its recover (Sirèn 1955, Kuuluvainen 1994).

According to Everham & Brokaw (1996) forest recovery after a disturbance occur through one or more of these paths: regrowth, release, recruitment or repression (BOX 2).

BOX 2 - **WHICH ARE THE PATHS OF FOREST RECOVERY?** (Everham & Brokaw 1996)

REGROWTH – Regrowth is the vegetative recovery of surviving stems, i.e. the sprouting of surviving trees.

Actually, this system in alpine forests is limited to beech *(Fagus sylvatica)* forests and to pioneer species such as birch and grey alder, since the most of forests are composed of conifers.

RECRUITMENT – Recruitment is the recovery of the forest through the establishment of seedlings, that includes three basic processes: seed germination, seedling survivorship, and seedling growth.

The rate and seed of this process is strongly affected by the survived trees that act as seed-producers (Halpern et al. 1990).

RELEASE – Release is the rapid growth of suppressed subcanopy trees or saplings, that follow the first stage after the disturbance occurrence (Ulanova 2000, Szwagrzyk et al. 2018); this happen because of the sudden availability of resources (e.g lights, water and nutrients), as a consequence of tree mortality (Szwagrzyk et al. 2018).

REPRESSION – Repression refers to the secondary succession that is suppressed by the invasion of herbaceous growth or by a heavy litter, that restricts the regrowth or recruitment of trees.

In the Alps, where forests are dominated by conifers, regrowth process is limited to broadleaves such as birches *(Betula pendula)* and grey alder *(Alnus viridis)*, that are usually found along avalanche gullies; release may occur when advanced regeneration has not been seriously damaged by the fallen trees, but since the amount of survived vegetation is low, secondary succession is oriented to the re-establishment of vegetation through regeneration.

2.2.1 REGENERATION ESTABLISHMENT

In areas affected by large disturbance events such as windthrow, biological legacies provide numerous microsites for ecosystem recovery (Franklin et al. 2000), whose distribution affect seedlings distribution (Kuuluvainen 1994, Ulanova 2000).

According to Aaltonen (1919) and Ulanova (2000) seedlings and small saplings in windthrow areas are concentrated in uprooting sites (i.e. pits and mounds) and along or above decomposing woody debris (e.g. logs, stumps, roots).

2.2.1.1 PITS AND MOUNDS

Pits and mounds (also known as *tree tip-up*) are an important structural legacies that originates as a consequence of a tree throw (Waldron et al. 2014); the "*pit"* is the depression within the forest floors that is formed by the uprooted mass, while the "*mound"* is the mass composed of the root system and earth (figure 2.4).

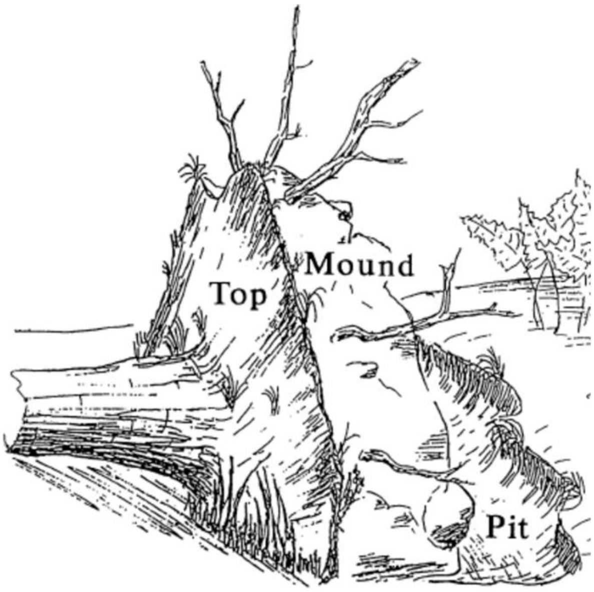


Figure 2.4: Pit and mound microtopography
(Reference: Carlton et al. 1998)

This legacy typical of windthrow represents an important microsite for regeneration development (Kuuluvainen 1994, Peterson 2000, Lang et al. 2009).

Pits and mounds increase structural complexity of forest floor (Peterson & Pickett 1990) above and below ground, by disrupting soil horizons, exposing organic and mineral soil (Ulanova 2000, Waldron et al. 2014), creating gradients of soil water content, generating small-scale temperature differences and altering soil development (Lang et al. 2009).

New seedlings establish better in pits (Ulanova 2000) rather than on mounds, mainly because of the different moisture conditions, that is considered a primary factor contributing to their establishment (Peterson & Pickett 1990); in fact, on mounds temperature and moisture conditions are subjected to rapid variations (Peterson & Pickett 1990).

Moreover, on mounds seed retention is lower than in pits, since soil can detach leaving seedlings without a growing substrate (Peterson & Pickett 1990); however, the detaching soil, especially during heavy rains, often kills seedlings in the pits (Ulanova 2000).

On the contrary, mounds represent a favourable site for fast-growing pioneer species that are able to establish a good root system (Peterson & Pickett 1990).

Therefore, pits are characterized by a greater species richness, a higher species diversity, greater total biomass per unit area and greater tree seedling density (Peterson & Pickett 1990).

Lang et al. (2009) and Spicer et al. (2018) have observed that, although tip-up mounds naturally wear down over time through erosional processes and pits fill with sediment and debris, salvage practices augment this levelling by further exposing, moving and compressing soil during harvest.

2.2.1.2 WOODY DEBRIS

Woody debris, when significantly decomposed, constitute a preferred establishment microsite for some tree species (Harmon et al. 1986, Titus 1990, Zanin 2001, Marzano et al. 2013, Leverkus et al. 2019); growing on woody debris offer some advantages.

1. In the first period after the disturbance, they are characterized by a certain structural stability (Franklin et al. 2000); moreover, in case of high slopes, seedlings are protected from the risk of being buried by material moving downslope (Harmon et al. 1986).

2. In water-rich forest floor woody debris represent the only site where seedlings can grow out of the water (Harmon et al. 1986), thus they establish even though decomposition process is in the first phases (McCullough 1948).

3. They provide water and nutrients to young seedlings through their decomposition (Harmon et al. 1986, Halpern et al. 1990); moreover, it has been observed that to advanced decay stage corresponds higher water-holding capacity (Harmon et al. 1986, Kuuluvainen & Kalmari 2002), that seems to be even better than the humus ones (Harmon et al. 1986, Minore 1972).

4. Growing next to fallen trunks and crown allow to benefit from the change in microclimate (e.g. increased moisture) and from an increased nutrient availability from the decomposing litter (e.g. from bark, needles, small branches) (Kuuluvainen 1994).
5. Woody debris allow to grow at a higher position than forest floor, with a consequent lengthening of the vegetative season, because of the earlier snowmelt and the higher temperatures (Baldwin 1927).
6. Growing at a higher position eliminates competition with forbs and grasses (Kuuluvainen & Kalmari 2002), increasing the survival rate of regeneration and speeding up the process of forest succession (Kuuluvainen 1994).

   In fact, during the first stages after the disturbance, especially where salvage logging has been carried out, understory cover regrowth vigorously, because of both the more open canopy conditions that change light balance to the soils and the additional amount of mineral soil exposed during the salvage operation (Lang et al. 2009); therefore forest regeneration has to compete with forbs and grasses (Eis 1981, Kokkonen et al. 2018), fostering the development in height that will be reduced once the seedling will be able to withstand competition (Eis 1981, Ramming et al. 2005).
7. Plants grown on large logs and stumps are more difficult for animals to reach (Castro 2013), as well as high concentration woody debris can work as natural exclosures allowing the development of patches of not grazed vegetation (Harmon et al. 1986).

Moreover, woody debris are significant for biodiversity as numerous organisms are dependent on deadwood (Harmon et al. 1986), contributing to community assembly (Thorn et al. 2015).

On the other hand, it has to be considered that rotting wood has lower concentrations of nutrients rather than those of the forest floor, therefore regeneration grow slower (Harmon et al. 1986); in addition, when woody debris are too high, they may become quite dry reducing the suitability for regeneration development (Titus 1990).

Concerning this, Minore (1972) observed that tree seedlings grew faster when they were rooted in needle litter than in rotten wood; however, he observed that seedlings were more abundant on rotten logs, since duff layer is thicker than that on mineral soil.

Minore (1972) observed also that when the overstory is completely removed, hence seedlings are exposed to full sunlight, neither rotten wood nor duff-covered soil are good seedbed; therefore, after large disturbance events, that creates large canopy gaps, woody debris are no more preferred establishment microsite for regeneration.

Another criticism of woody debris as a regeneration microsite is that they are not stable in the long-term (Ruel et al. 2010)., thus, by time, decay process will reduce the survival rate of seedlings (Harmon et al. 1986).
Moreover, it has to be considered that just a few tree species are able to grow on woody debris, such as Spruce *(Picea spp.)*; many authors (Baldwin 1927, Jones 1945, Harmon et al. 1986 Ulanova 2000, Kuuluvainen & Kalmari 2002, Kupferschmid & Bugmann 2005) observed that *Picea* often establishes on rotten wood.
The ability of this species can be explained by the fact that since it grows where snowfalls are consistent, those seedlings that establish on rotten wood start before the growing season rather than those that grow on the forest floor, that are buried for longer; however, Kupferschmid & Bugmann (2005) observed that in the subalpine level, *Picea* saplings on woody microsites showed a very low height increment, that may be caused by a lower availability of nutrients required for plant growth (Harmon et al. 1986).

2.3 LIMITATIONS TO REGENERATION ESTABLISHMENT

Seedling establishment is affected by many factors, such as seeds and microsites availability, diseases and herbivore attacks (Ulanova 2000).

According to Frehner (1989), Ott et al. (1991) and Brang (1998), especially in mountain forests, recruitment is mainly limited by germination and survival of seedlings, that in turn is limited by the supply of seeds and the availability of suitable microsites for germination (Kuoch 1965).
In particular, Ramming et al. (2005) sustain that seed supply seems to play a major role for the speed of reforestation; hence, the absence of survived mature trees as well as a far forest edge is limiting for seedling establishment, resulting in an overall slowing of forest recovery.
Moreover, also regeneration microsites availability, i.e. structural legacies (Halpern et al. 1990, Peterson 2000) is considered a limiting factor for regeneration development.
Therefore, although, in the common imagination, salvage logging is a way for assisting ecosystem recovery (Session et al. 2004), actually the effects are opposite to the intention (Lindenmayer & Noss 2006), because of the removal and alteration of significant amounts of biological legacies, i.e. of microsites (Franklin et al. 2000, Van Nieuwstadt et al 2001, Lang et al. 2009, Morimoto et al. 2011).

However, tree regeneration is limited not only spatially by favourable microsites and seed propagules availability, but also by Ungulates browsing, that is often reported as one of the major hazards for tree regeneration, e.g. in sites disturbed by windthrow and bark beetles (Kupferschmid & Bugmann 2005).

2.3.1 UNGULATES IMPACTS

Forest ungulates such as red deer *(Cervus elaphus)*, roe deer *(Capreolus capreolus)* and chamois *(Rupicapra rupicapra)* affect woody plant species in many ways, e.g. by removing shoots and leaves (i.e. browsing), by stripping bark, fraying and trampling (Kupferschmid & Bugmann 2005).

Ungulate browsing as an issue for regeneration establishment has been firstly studied in the United States (Aldous 1944).

In Europe most of the studies have been carried out within the Alps, focusing on red deer *(Cervus elaphus)*, whose browsing action has become a problem in the second half of the ’70s (Pedrotti & Bragalanti 2008).

These studies have been carried out in Piedmont, Aosta valley, Trentino (Natural parks) and South Tyrol (Motta & Quaglino 1989, Motta 1996, Motta & Franzoi 1997, Provincia Autonoma di Bolzano 1997, Armani & Franzoi 1998); further researches have been done in other Alpine regions such as *Tyrol* (1995), *Baviera* (1994) and Switzerland (Kupferschmid et al. 2015).

According to these studies, shoots and buds represent an important food resource (Kupferschmid et al. 2015, Motta & Quaglino 1989) during winter season, where snow cover reduces the amount of food resources available (Aldous 1944, Bergquist & Orlander 1998, Motta 1996, Carmignola 2001); in particular, these areas are located on sunny slopes where snow melts before, increasing the chances for Ungulates to find something to eat (Carmignola 2001).

This means that in wintering areas the impact on regeneration is heavier than that in those areas occupied only in summer (Pedrotti & Bragalanti 2008), also because in summer there is a higher availability of food resources, e.g. grass.

An intense regeneration browsing implies an overall slowing of regeneration process (Motta 1996, Kupferschmid & Bugmann 2005, Abderhalden & Campel 2006, Kupferschmid et al. 2015), because of both the increased mortality of established seedlings and the reduction in height development as a consequence of shoot apex browsing (Carmignola 2001, Gómez-Aparicio et al. 2008) (Figure 2.5).

Figure 2.5: Browsed shoot apex
(Picture: Francesca Michelon, 13.10.2019, Valiselle, 1860 m asl)

This slowing of recovery process, in the long-period will have negative effects also on forest yield, thus on forest harvesting; moreover, the altered stem structure due to browsing (such as double stem or stem crook) results in lower timber quality (Switzenberg et al. 1955, Rea 2011, Wallgren et al. 2014).
Ungulates browsing affects also forest species composition, since these animals are extremely selective (Frelich 2002, Gómez-Aparicio et al. 2008); in fact, it has been observed that the most affected species are silver fir *(Abies alba)* (Motta 1996, Kupferschmid et al. 2015, Carmignola 2001) and broadleaves (Motta 1996, Carmignola 2001, Szwagrzyk et al. 2018), in particular rowan *(Sorbus aucuparia)* in the subalpine district (Kupferschmid et al. 2015).
Moreover, also underbrush species such as blueberry *(Vaccinium myrtillus)* and Juniper *(Juniperus communis* subsp. *nana)* are intensively browsed (Provincia Autonoma di Bolzano 1997); this leads to another indirect effect on Grouse *(Tetraonidae)* population, because of the reduced availability of food resources (Angeli & Brugnoli 2005).
Therefore, there is an overall negative effect on ecosystem biodiversity.

Antler fraying occurs in spring (because of roe deer) and in summer (because of red deer), in order to remove the velvet that cover antlers during its grown; according to

Carmignola (2001), the most damaged species are those that grow first during forest regeneration process, i.e.as European larch and Swiss stone pine

Usually, antler fraying is not a problem for forest regeneration process, when regeneration density is very high; on the contrary, when regeneration density is low, this type of damage may have long-term effects on forest regeneration process (Carmignola 2001).

Bark stripping damages regards young trees of Norway spruce characterized by a diameter of 10-20 cm, Swiss stone pine trees with diameter lower than 15 cm and broadleaves trees; European larch is not affected because, very early, it is able to develop a thick bark (Carmignola 2001).

2.3.1.1 FACTORS AFFECTING UNGULATE IMPACTS IN WINDTHROW AREAS

The high habitat complexity generated by woody debris spread on the ground as a consequence of a windthrow, could hamper the movement of large herbivores; in fact, this biomass acts as a physical barrier that protect seedlings from Ungulates (Kuuluvainen 1994, Franklin et al. 2000, Relva et al. 2009, Castro 2013).

In fact, deer avoid areas with deep slash, because they would not be able to escape easily if a predator does attack (White et al. 2003); moreover, when the material is higher enough to make deer jump, the energetic costs of locomotion increases dramatically (Hanley et al. 1989, Nyberg 1990), thus Ungulates avoid the area, fostering recruitment.

However, this protection decreases by time because of wood decaying, increasing again the accessibility to the disturbed area (Relva et al. 2009).

However, since after a windthrow salvage logging is carried out, the removal of fallen log accelerate deer entrance (Relva et al. 2009) increasing browsing pressure; however, when trees are harvested with the tree length system (i.e. felling the tree, cutting the main branches and leaving all the biomass *in situ*), the forest benefit at least from a minimal protection (Castro 2013).

However, Bergquist & Örlander (1998) found that *Picea abies* browsed by roe deer *(Capreolus capreolus)* did not vary in sites with different amounts of slash in the forest; thus, according to this author slash treatment had no effect on the level of browsing damage, nor was the gradual decrease in slash with clear-cut age related to the level of browsing damage.

The same findings have been reported by Kupferschmid & Bugmann (2005), who found that fallen trees do not constitute a barrier to chamois *(Rupicapra rupicapra)* browsing *Picea abies* saplings.

Moreover, according to these authors, logs (lying and hanging stems) do not protect *Picea* saplings from browsing, nay close to logs or underneath logs saplings are more often browsed than saplings without logs in their neighbourhood; this is probably due to the thinner snow cover and the faster snow melt near or under logs than in gaps.

In addition, the removal of wood material lead to the development a vigorous grass cover (Lang et al. 2009), that could constitute a secondary attraction to herbivores (Baraza et al. 2006, Leverkus et al. 2019), but that, in turn, may constitute an alternative food resource (Szwagrzyk et al. 2018), with a consequent reduction of the impacts on regeneration.

Another aspect to be mentioned is that, regeneration is also able to protect itself.

In fact, many trees have developed defences against browsing, including unpalatability and thorniness (Savill et al. 1997); the spatial distribution of palatable and unpalatable plants can influence the foraging behaviour of herbivores (Baraza et al. 2006), thus indirectly reduce browsing pressure over patches of forests.

3.THE STUDY AREA

Peio valley (*Val di Peio*) is a small mountain valley located in the north-west part of Trento province, under the jurisdiction of Peio municipality, to which refer seven villages: *Celentino, Strombiano*, *Comasine, Celledizzo, Cogolo, Pejo fonti* and *Pejo paese*.

The valley extends over about 17 000 hectares, from an altitude of about 1100 m a.s.l. up to 3765 m a.s.l among the peaks and glaciers of Ortles-Cevedale mountain range (figure 3.1).

The valley was originated by the scouring action of glaciers that nowadays are still present onto the peaks of the mountains that delimit the valley to the north; this arch-shaped mountain range oriented north-west, is composed of the highest peaks of the entire Trento province.

Starting from north there are *Cevedale* (3769 m a.s.l.), *Viốz* (3665 m a.s.l.), *San Matteo* peak (3678 m a.s.l.) and *Corno dei tre signori* (3360 m a.s.l).

These mountains are mainly composed of metamorphic rocks, mainly of micaschists and gneiss, sometimes rich in quartz; moreover, these rocks are rich in iron minerals, which used to be economically extracted for obtaining metallic iron (e.g. Magnetite mines of Comasine).

From these rocks originates brown soils, that are acidic soils characterized by good fertility; moreover, they are rich in iron, that is responsible for its rust colour.

The valley is very rich in water, because of the abundance of glaciers, snowfields and alpine lakes; in fact, water resources have been exploiting for hydroelectric power production, by the construction of *Càreser* dam (1928-1933) and *Pian Palù* dam (1955-1959).

The valley is furrowed by *Noce* stream that flows from north to south, after the confluence of the two streams that delineate the branches in which Peio valley is structured.

Noce bianco stream originates from *Cevedale* glacier and flows through *Val del la Mare* (Figure 3.2) from north to south; in Cogolo this stream flows into *Noce stream* that originates from San Matteo glaciers for then running through Val del Monte (also known as *Val del Palù*) (Figure 3.3) from the north-west to east.

At the confluence of these two valleys (Figure 3.4), *Noce bianco* and *Noce nero* join together in *Noce* stream, that flows to the south, for then leaving Peio valley and flowing toward Adige river.

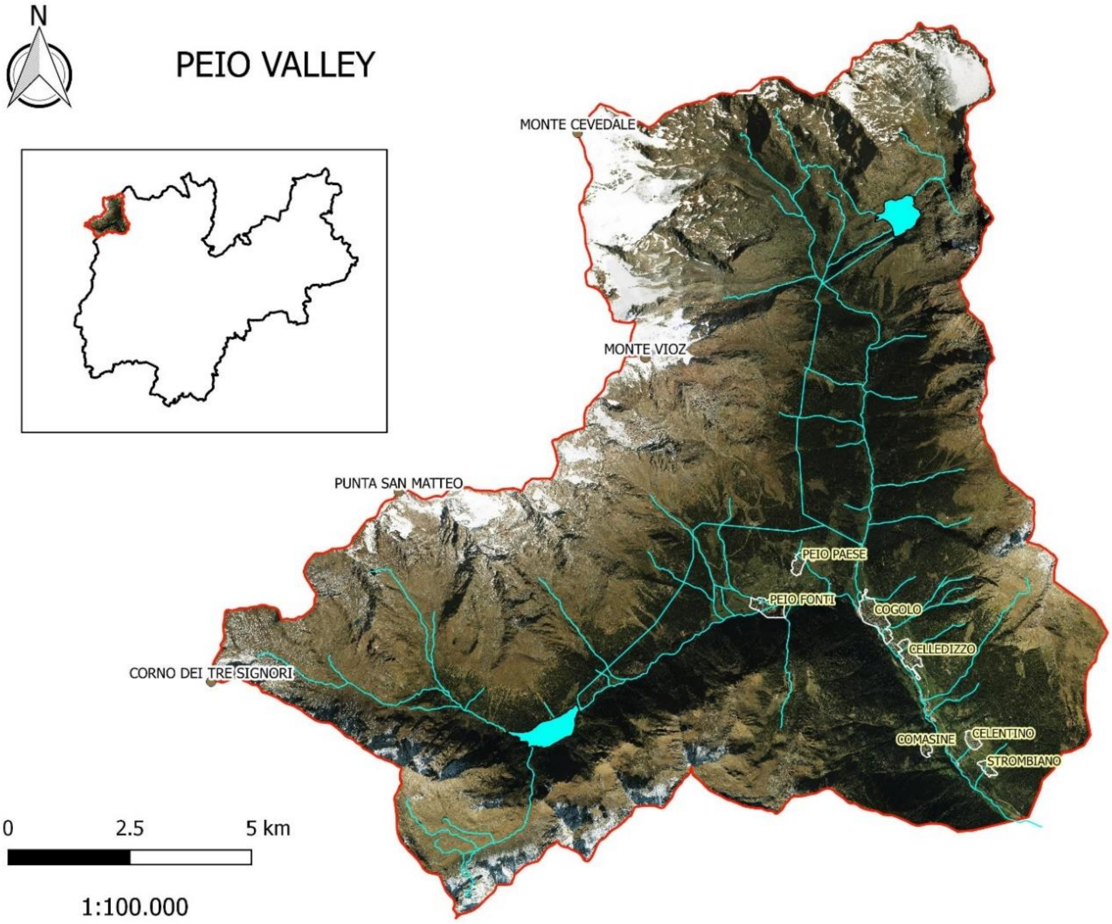


Figure 3.1: Map of Peio valley, showing the hydrographic network, human settlements and the main mountains peaks.

Figure 3.2: A view of *Val del la Mare*; at the end of the valley there is Cogolo, where *Noce bianco* flows to *Noce* that comes from *Val del Monte* (Picture: Francesca Michelon, 01.09.2019, Cavaion, 2350 m asl)

Figure 3.3: A view of *Val del Monte*; at the end of the valley there is the villages of Pejo (right side) and of Pejo fonti (left side). (Picture: Francesca Michelon, 16.06.2019, Alpe Levi, 2100 m asl)

Figure 3.4: A view of *Val di Peio* from the slopes of *Cima Taviela:* at the valley bottom there are villages of Cogolo and Celledizzo, slightly higher villages of Celentino and Strombiano; on the right there is Pejo fonti village. (Picture: Francesca Michelon, 02.08.2013, 3200 m asl)

3.1 CLIMATIC CONDITIONS

The climate is a typical alpine climate, characterised by very cold winters and mild summers. More specifically it is defined as an endalpic climate, with high continentality that results in a significant temperature excursion not only between the seasons, but also between day and night; in addition, there high variation in elevation between the valley bottom and the top of the mountains is responsible for significant differences in temperature.

Precipitations are around 1000 mm/y, concentrated in summer, while winters are very dry; usually from November to march precipitation are represented by snowfalls, thus avalanches may occur.

1888 and 1916 are remembered as the snowiest winter ever, with the occurrence of many avalanches (Gabrielli 1974, Gabrielli 1972).

According to the data of meteorological stations of Peio village (T0366), Careser (T0065) and Pian Palù (T0063) for the period 2002-2019 Table 3.1 reports the mean value of mean temperature, maximum and minimum temperature and mean annual precipitation.

	MEAN T°	**MAX T°**	**MIN T°**	**PRECIPITATION**
PEJO *1565 m asl*	+6.5 °C	+28.1 °C	-13.9 °C	945.8 mm/y
CARESER *2600 m asl*	+0.4 °C	+22.4 °C	-19.6 °C	1056.3 mm/y
PIAN PALÙ *1800 m asl*	+4.5 °C	+27.8 °C	-19.3 °C	1061.4 mm/y
MEAN	**+3.8 °C**	**26.1 °C**	**-17.6 °C**	**1021.2 mm/y**

Table 3.1: Data of mean, minimum and maximum temperature and precipitation for three meteorological stations located in Peio valley (Data reference. Meteotrentino)

Figure 3.5 represents the mean seasonal snowpack depth obtained as a mean of maximum snow cover measured for each month between December and April at Pejo Tarlenta Nivometric station, located at 2010 m asl.

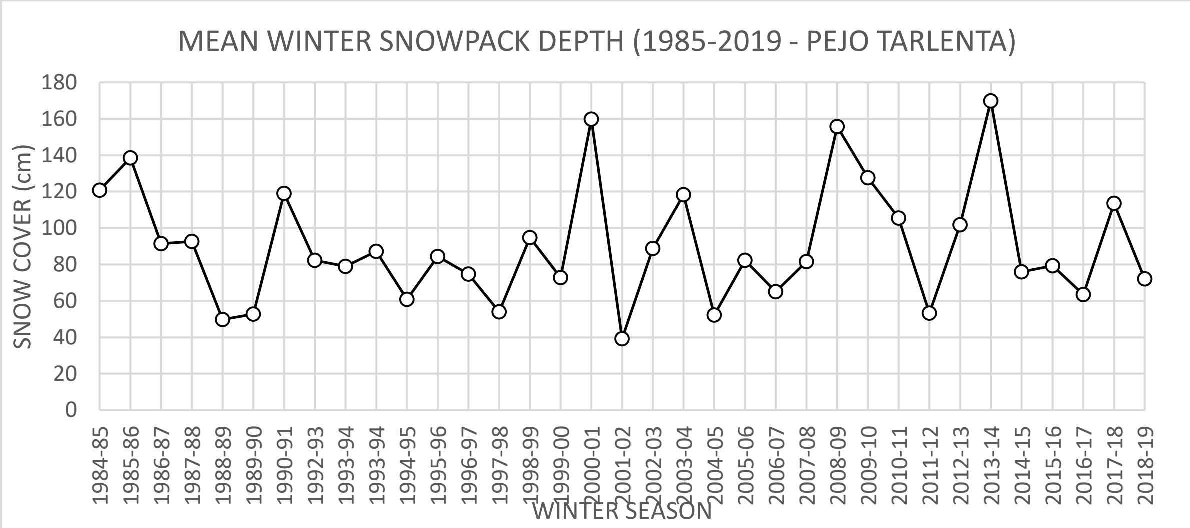


Figure 3.5: Mean winter snowpack depth between 1985 and 2019 measured at Pejo Tarlenta Nivometric station (Data reference. Nivology handbooks 1984-2015 and data about snow profiles and stratigraphy 2015-2019 by Meteotrentino)

Figure 3.6 reports the maximum snowpack depth in April, obtained as a mean of maximum snow cover measured for that month between 1985 and 2019 at Pejo Tarlenta Nivometric station located at 2010 m asl.

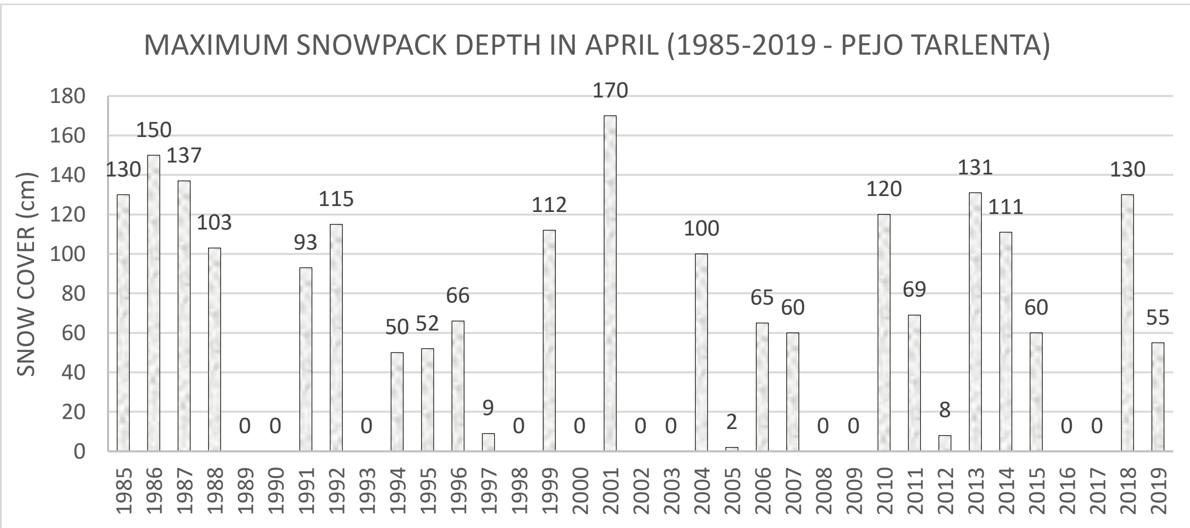


Figure 3.6: Maximum snowpack depth in April between 1985 and 2019 measured at *Pejo Tarlenta* Nivometric station (Data Reference: Nivology handbooks 1984-2015, snow profiles and stratigraphy 2015-2019 - Meteotrentino)

Thanks to its orography the valley is well defend from winds, but sometime wind gusts happen; in particular, cold winds come from the north (figure 3.7), i.e. from the peaks of the high mountain chain that delimit the valley.

PEJO PAESE (T0366) – *1565 m asl*

CARESER DIGA (T0065) - *2600 m asl*

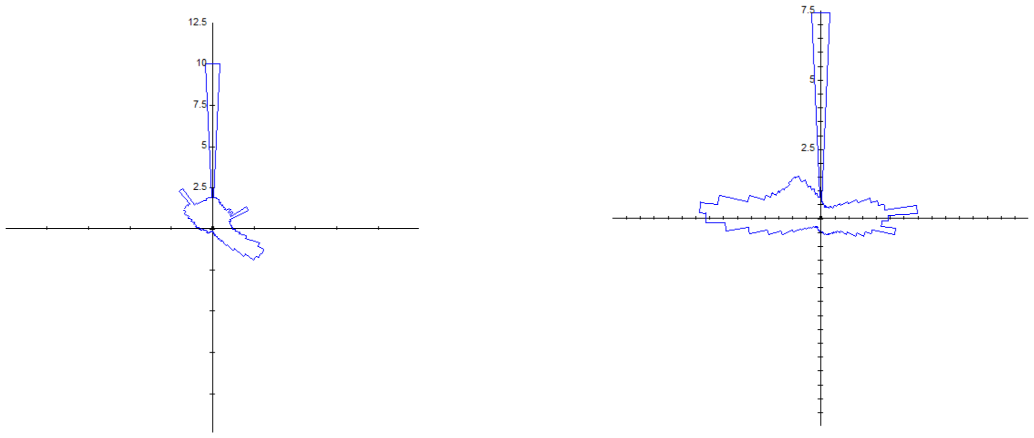


Figure 3.7: Wind roses of Pejo (on the left) and Càreser (on the right) metoerological stations; the length of each spoke (boue line) around the center indicates the amount of time that the wind blows from a particular direction; in both cases the prevalent direction is from the north.
The direction of the wind is expressed in percentage and it is reffered to a period of observation of 10 years (2009-2019). (Data reference: Meteotrentino)

3.2 FORESTS

In Peio valley productive forests extents over about 4 495 hectares, that are under the administration of the *Separate Administration of "civic uses"* (ASUC) of Celentino, Comasine, Celledizzo, Cogolo, Pejo and Termenago (Figure 3.8); moreover, there is a little share owned by other institutions *(e*.g. *3 comuni)* and privates.

Harvesting operations, from the authorization side, are under the jurisdiction of Ossana Forest station, that is coordinated by the Forest District of Malè.

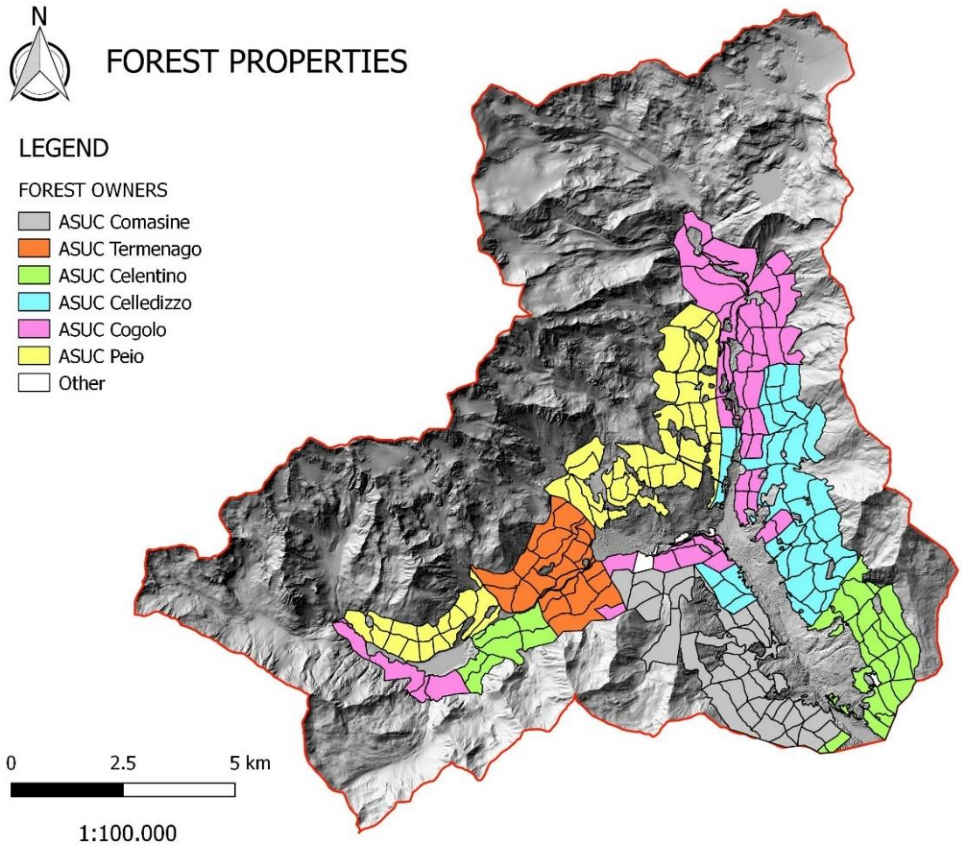


Figure 3.8: Forest coupes and their owners in Peio valley

Thanks to the "mass effect", for which the heat absorbed by the mountains is spread in the surrounding environment, allow to have forests at very high elevation; according to a research carried out by the Trentino forest service in the '90s (Provincia Autonoma di Trento 1992), forests in Peio valley are the highest of the entire province, since they extend up to 2400 m a.s.l., with single trees that has grown up to 2550 m a.s.l..

At these high elevations, forests are composed of mainly Swiss stone pine *(Pinus cembra)*, that is the indicator species of endalpic climate; European larch *(Larix decidua)* is very often associates to this species (Figure 3.9), but pure stands are also present, with a underbrush composed of juniper *(Juniperus communis)* and alpenrose *(Rhododendron ferruggineum)*.

Figure 3.9: Swiss stone pine forest with European larch
(Picture: Francesca Michelon, 14.10.2017, sentiero SAT O123, 2200 m a.s.l.)

However, the most of forests are composed of Norway spruce *(Picea abies)* (Figure 3.10), associated to European larch according to aspect, humidity and fertility of the soil.

The underbrush is mainly composed of either bluberry *(Vaccinium myrtillus)* or lingonberry *(Vaccinium vitis-idaea)*.

Single trees of silver fir *(Abies alba)* can be found within these forests, but regeneration is completely absent; in fact, despite there are the conditions for this species to grow, its regeneration is almost impossible because of the intense deer browsing.

Also, single trees of scots pine *(Pinus Sylvestris)* are present in the outermost part of the valley.

Among broadleaves, grey alder *(Alnus incana)* is well represented, especially alongside mountain brooks and streams, as well as on screes and shallow stony slopes.

Figure 3.10: Grey alder without leaves on a shallow stony slope, within a Norway spruce forest
(Picture: Francesca Michelon, 25.11.2019, *Val de la Mare*, 1300 m a.s.l.)

Moreover, broadleaves such as rowan (*Sorbus aucuparia*), goat willow *(Salix caprea)* and sycamore *(Acer pseudoplatanus)*, are present as single trees or in small clusters within conifer forests; other pioneer species such as silver birch *(Betula pendula)* aspen (*Populus tremula)* and green alder *(Alnus viridis)* colonize recent disturbed areas, in particular avalanche gullies. Within abandoned farmland and close to the villages it is also common to find common hazel *(Corylus avellana)* and ash *(Fraxinus excelsior)*.
As happen for silver fir, also broadleaves are suffering red deer browsing.

In terms of percentage, Norway spruce represents the 43.7% of the total wood volume, European larch the 41.9%, Swiss stone pine the 4.9% and broadleaves the 9.5% (figure 3.11).

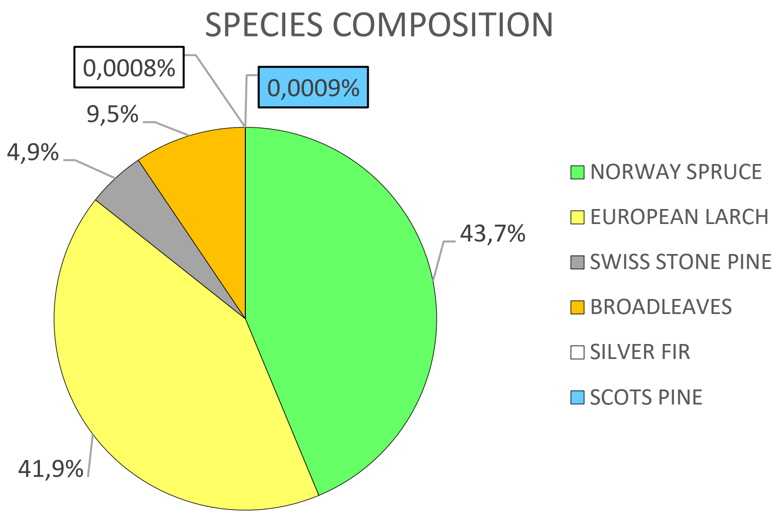


Figure 3.11: Species composition of forests in Peio valley
(Reference: Data from the most recent forest management plans)

Forests in Peio valley have always been intensively exploited.

Farming silviculture and animal breeding were the economic activities from which locals got their livelihoods (Gabrielli 1970, Gabrielli 1971, Gabrielli 1972, Gabrielli 1973, Gabrielli 1974). Therefore, forests were intensively grazed, litter was taken away from forest for being used in barns and trees were cut for getting fuelwood, that was the only source available for heating and cooking; in fact, in Peio village electric power came on the 6th of January 1925 (Gabrielli 1974).

Moreover, around villages forests was clear-cut in order to increase agricultural land for vegetable farming, pasturing the cattle and mowing the hay.

Starting from the XV century, mining became a very important activity for local populations, increasing forests exploitation, because of the demand of charcoal from conifers, in particular from European larch.

During the Great war (1914-1918) in Peio valley was located the front line, thus forests were heavily damaged, because of clear-cuts made for defence reasons, as well as for extracting wood for building barrack huts and to be used as fuelwood; many of these surfaces have been artificial regenerated after the end of the war.

In the ‘50s, thanks to forest policies that aimed at forests recovery, regulation on forest harvesting were introduced, in order to increase forest biomass and surface; in fact, in mountain areas like this, the presence of forest is fundamental for protection from natural disturbances such as avalanches and rockfalls.

Nowadays, forests have increased their surface, but this has happened not only thanks to the choices made in the '50s, but also for the progressive abandoning of mountain farming that occurred from the '70-'80s on, as a consequence of the economic improvement of life of locals during the last decades.

3.3 PROTECTED AREAS: STELVIO NATIONAL PARK

Peio valley is partially included in Stelvio National Park, that is one of the largest protected area of the entire Alps that extends between Trentino (Figure 3.12), Alto Adige and Lombardia.

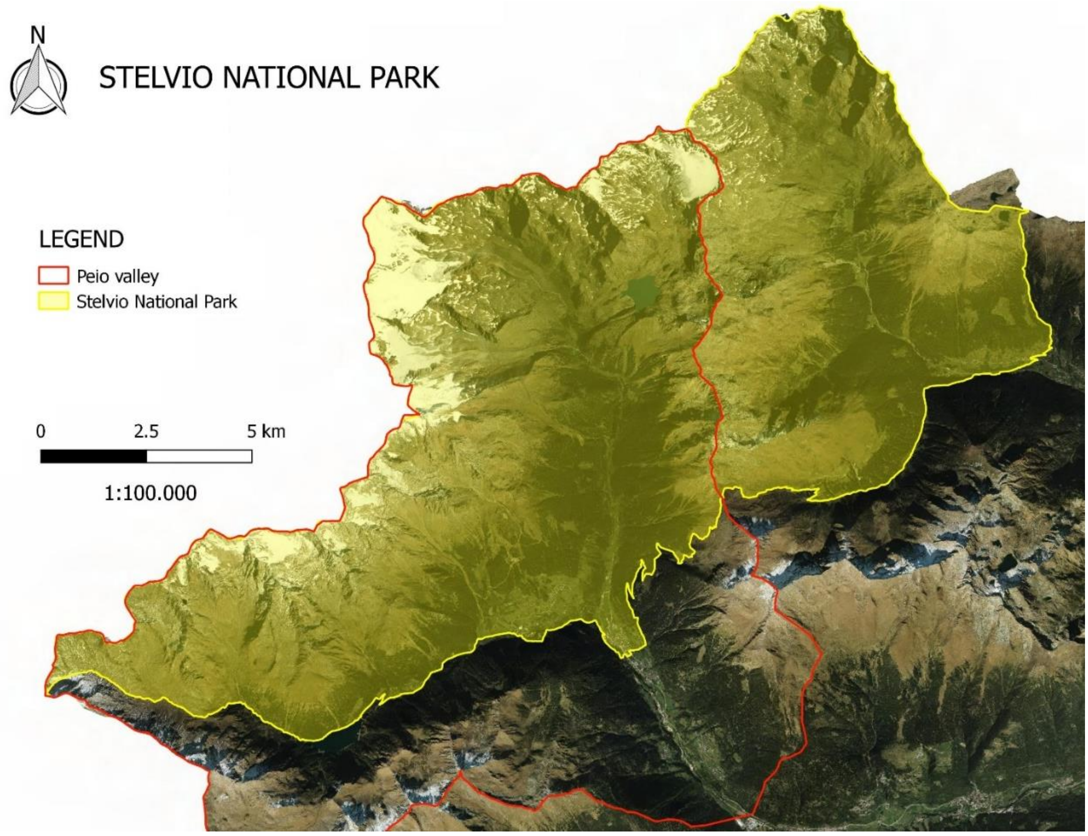


Figure 3.12: Map of Stelvio National park area in Trento province (yellow area)

It was established the 24th April 1935, with the aim of protecting all the components of the alpine environment on which it extends, characterized by glaciers and high altitude mountain meadows as well as forests; by establishing a protection regime, it was wanted to improve *flora*, to foster the development of wildlife populations and to preserve particular geologic formations, valorise the amenities of the landscape and to forest tourism development.

Within this protected area are present many species of wildlife among which birds such as golden eagle *(Aquila chrysaetos)* and bearded vulture *(Gypaetus barbatus)* and ungulates such as Alpine ibex *(Capra ibex)*, chamois *(Rupicapra rupicapra)* and red deer *(Cervus elaphus).*

3.4 WILDLIFE: RED DEER

According to Mustoni et al. (2002), red deer gradually became extinct from the Alps between the XVIII and the XIX century; its return back to the Alps happened thank to both dispersal of individuals from Austria, Slovenia and Switzerland and reintroduction projects carried out in western Alps.

In *Val di Sole*, this species became extinct due to human pressure during the half of the XIX century; it had returned back thanks to dispersal of a few individuals from Switzerland and South Tyrol at the beginning of the XX century.

In fact, in 1916 a female red deer was found dead in the surroundings of *Mezzana*, but for the next observation it had to be waited 1929, when a big male red deer was observed in the same area.

However, until the ‘60s there was not a stable population of red deer within *Val di Sole*; in that period in Stelvio National park red deer were still rare and it was so until the ’80s.

In those years winter foraging was carried out within the park, in order to help Ungulates in surviving to the harsh winter conditions that characterize this alpine environment; this practice attracted red deer toward Peio valley (and Rabbi valley), creating that relationship between the animal and the territory typical to winter foraging.

Very soon it has understood that this practice led to an excessive concentration of animals in a small area, fostering also browsing and bark stripping damages; this is the reason why winter foraging has been abandoned (within the whole national park was carried out until 1991).

However, red deer were by that time stably present within the park and because of the absence of their natural predator and the hunting ban imposed by the park authority, red deer population has been increasing.

In *Val di Sole*, during the ‘90s red deer population within the park has exponentially increased and has maintained to high densities until winter 2008-09 where because of a very snowy winter (the mean snowpack at Pejo Tarlenta nivometric station was 160 cm – Figure 3.5) many red deer died for starvation; however, despite this event and the following ones (e.g. 2017-2018) red deer population has maintained to high densities (figure 3.13).

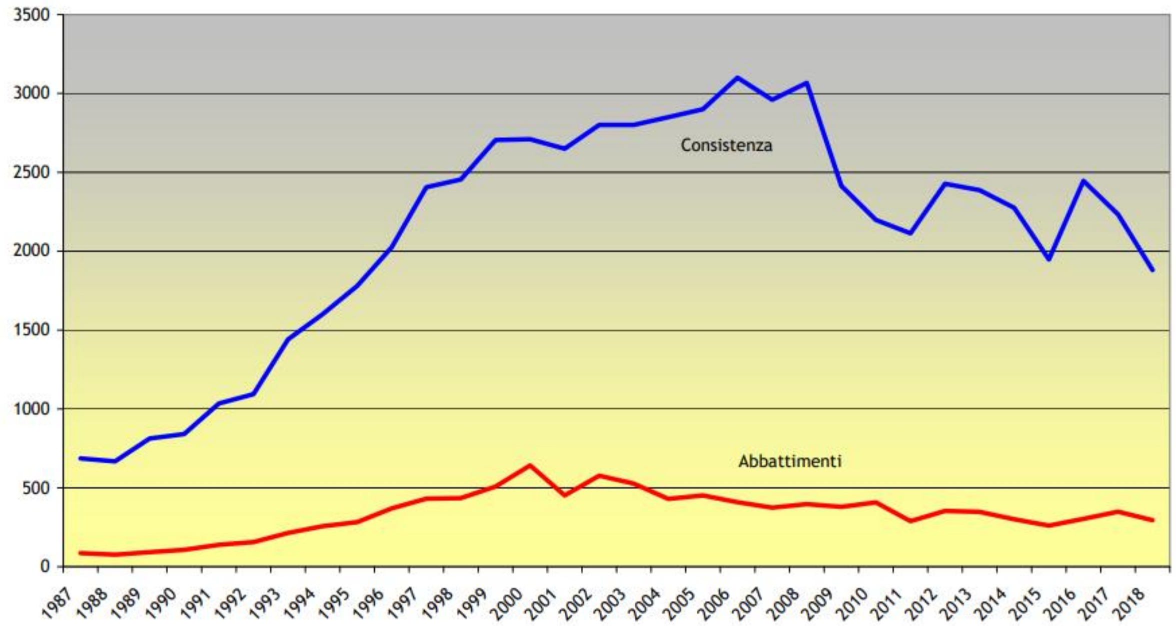


Figure 3.13: The blue line shows the trend of red deer population of the entire *Val di Sole* district, while the red line expresses the amount of red deer hunt (Reference: Valutazione dei Treofei della Val di sole 2018)

During winter, the most of red deer move outside the valley to *Val di sole*; however, wintering areas are present on the east slope of Peio valley starting from the outermost part of *Val de la Mare* to the outermost part of the valley, on grassland, shrubland and forest under Pejo village and on the left side of *Val del monte* above the artificial lake of *Pian Palù* (Figure 3.14).

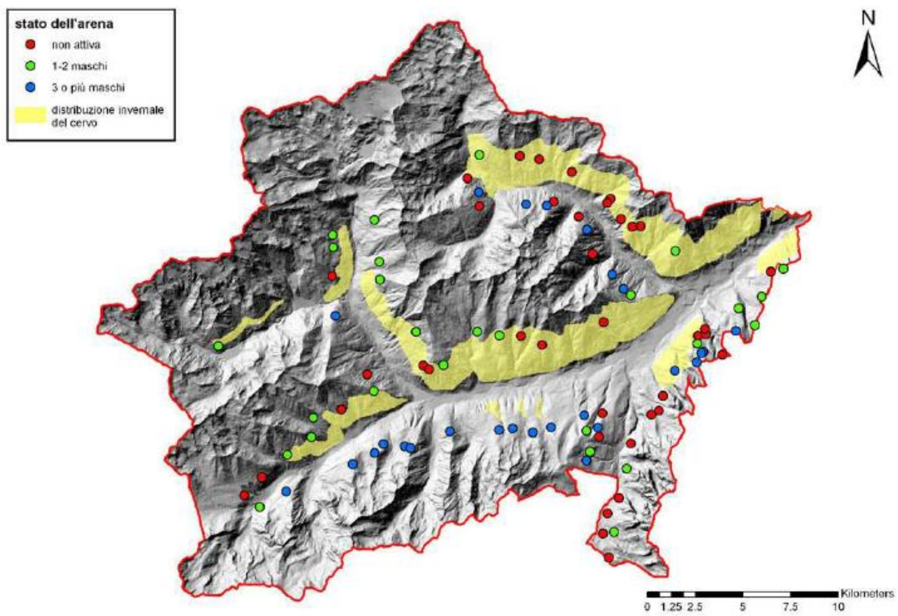


Figure 3.14: Wintering areas of red deer in *Val di sole* (yellow area)
(Reference: Pedrotti & Bragalanti 2008)

During summer and the reproductive period, red deer moves inside the National park area, both in *Val de la Mare* and *Val del Monte* for feeding on mountain meadows.

4. MATERIAL AND METHODS

4.1 DATA COLLECTION AND ANALYSIS

Starting from the historical series of forest management plans, it has been individuated the areas where disturbance events have occurred, extracting the location and volume of salvaged wood; these 33 forest management plans cover the period between 1952 and 2017 and refers the principal forest owners in Peio valley, represented by the A.S.U.C. of Celentino, Comasine, Celledizzo, Cogolo and Pejo (Table 4.1).

A.S.U.C. CELENTINO	A.S.U.C. CELLEDIZZO	A.S.U.C. COGOLO	A.S.U.C. COMASINE	A.S.U.C. PEJO	A.S.U.C. TERMENAGO
2011-2020	2011-2020	2017-2036		2017-2036	2015-2024
2001-2010	2001-2010	1997-2016	1998-2017	1997-2016	2005-2014
1987-2001	1987-2001	1982-1996	1983-1997	1982-1996	1995-2004
1977-1986	1977-1986	1972-1981	1973-1982	1972-1981	1985-1994
1967-1976	1967-1976	1962-1971	1963-1972	1962-1971	1975-1984
1956-1965	1956-1965	1952-1971			1955-1974

Figure 4.1: Forest management plans available for each forest owner.

The preliminary information extracted from forest management plans have been reported on an *Excel* worksheet structured as follows:

PLAN CODE	FOREST OWNER	F.M.P DECADE	COUPE NUMBER	YEAR OF THE EVENT	SALVAGED VOLUME	TYPE OF EVENT

Then, these data have been georeferenced as a *shapefile* using *QGis 2.18.25 software*, with the aim of having a visual representation of the areas where salvage logging has been carried out; thanks to the graduated style function of QGis it has been possible to colour the forest coupes individuated according to the amount salvaged wood volume.

It has to be remembered that the amount of wood is referred to the entire forest coupe and not to the exact point where it was located.

At this point a first data analysis has been carried out in order to select the most important events on which concentrate the fieldwork; the analysis focused on the amount of salvaged wood in each forest coupes, considering the location and the year.

In this way it has been possible to select a few areas in which carry out the fieldwork with the objective to study regeneration development after the disturbance; these areas are referred to disturbance events attributable to three different years.

For this purpose, 28 transects, with a surface of 40 m^2 (20x2m), have been individuated in the upper montane level, at an elevation between 1560 and 1945 m a.s.l (figure 4.1).

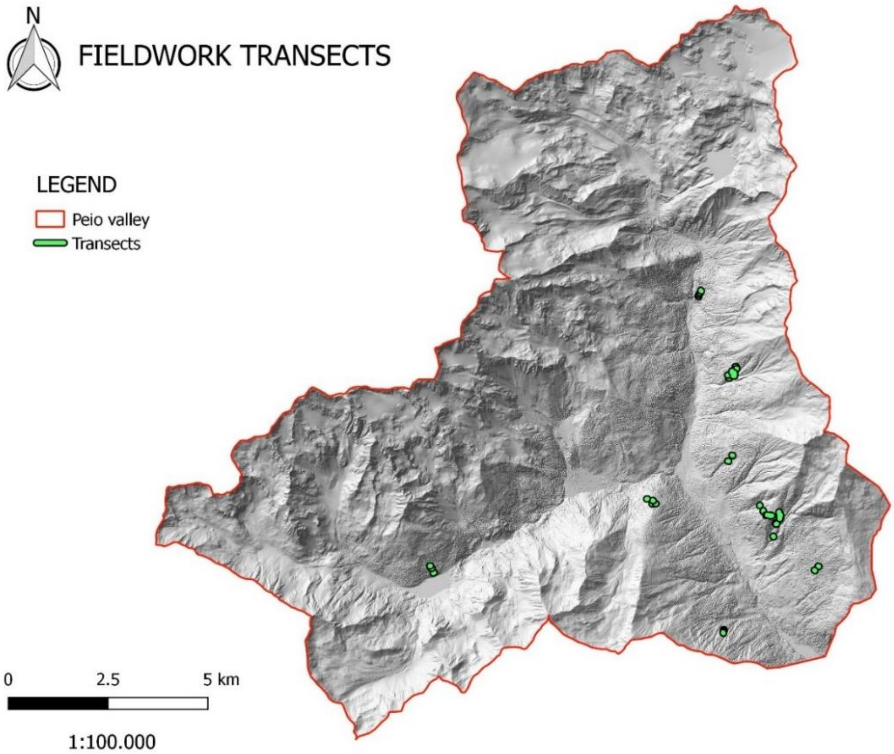


Figure 4.1: Placement of the 28 transects on which the fieldwork has been carried out

Transects refers to a specific disturbance event (year) and their placement according to Stelvio National park (SNP).

TRANSECT	1	2	3	4	5	6	7	8	9	10	11	12	13	14
YEAR	90	90	90	90	03	03	03	03	03	90	90	15	15	15
SNP	x	x	x	x	x	x	x	x	x					

TRANSECT	15	16	17	18	19	20	21	22	23	24	25	26	27	28
YEAR	15	15	15	15	90	90	03	03	03	03	03	15	15	15
SNP												x	x	x

Within each transect regeneration process has been analysed considering the aspects reported in table 4.2.

SAMPLE AREA	• ADMINISTRATION		
	• FOREST COUPE NUMBER AND TOPONYM		
	• INSIDE OR OUTSIDE STELVIO NATIONAL PARK		
	• YEAR OF THE EVENT		
(each) **TRANSECT**	• ELEVATION		
	• AMOUNT OF DEADWOOD		1 – Single stumps, no logs an no limbs 2 – A few stumps and logs, traces of limbs 3 – Many stumps, logs and limbs
	• AMOUNT OF FORBS AND GRASSES		1 – Patches of short grass (< 10 cm) 2 – Grass cover complete or not, but height < 50 cm 3 – Complete cover, height > 50 cm
	REGENERATION CHARACTERISTICS	• SPECIES	Norway spruce, European larch, Swiss stone pine, *r*owan, *b*irch, goat willow, grey alder
		• HEIGHT (cm)	
		• BROWSING SIGNS	
		• LOCATION	- Stumps, Uprooted stumps, Logs, Rocks, Ground - On wood, on the clod of earth - Above, on a side
		• HEIGHT FROM THE GROUND (cm)	
	CHARACTERISTICS OF DEADWOOD	• DIAMETER (cm)	
		• LENGTH/HEIGHT (cm)	
		• DECOMPOSITION STAGE	**0** – Any evidences of decay **1** – First evidences of decay (no rot, but sings of decomposition process) **2** – Evidences of decay (lower structural resistance, brown/white rot) **3** – Advanced decay stage (any structural resistance, brown/white rot) **4** – Remains

Table 4.2: Table reporting the data collected about regeneration during the fieldwork

Then, a second analysis of forest management plans have been carried out in order to extract other information relative to forest structure.
For each forest coupe of each administration for all the 33 forest management plan available the following information have been extracted:

- Productive forest surface (ha)
- Species composition (% of each species present)
- Basal area (m^2/ha)
- Growing stock (m^3)
- Yield (m^3)
- Total harvested volume (m^3)
    - Ordinary harvested volume
    - Salvaged volume

GIS data concerning *Vaia* storm have been provided by Trentino forest and wildlife service (Servizio Foreste e Fauna); further fata have been extracted from the *new action plan for the management of Vaia damages to forests* (Piano d'azione per la gestione degli interventi di esbosco e di ricostruzione dei boschi danneggiati dagli eventi eccezionali nei giorni dal 27 al 30 ottobre 2018).
Other GIS data used for maps making have been obtained by the *Portale Geocartografico del Trentino*.

Data concerning red deer counts have been provided by Trento forest and wildlife service; these data have been collected during spring nocturnal census of red deer population for the period 1995-2018; the entire area of Malè district is structured in sub-areas in which the operators are moving by car on fixed routes and using a light red deer are counted.
These operations are repeater for three times, for each spring season.
In this study, just the sub-areas included in Peio valley have been taken into account and just the maximum number of deer counted have been considered; this means that the results of data elaboration refer to a part of the Stelvio national park area.
Since data obtained are underestimated because of the methodology followed, to the datum referred to each year of the census operations has been added the underestimation percentage, by dividing for 0.67.

4.2 STATISTICAL ANALYSIS

Since data collected for the purposes of this research are referred to random samples of the entire population represented by the overall regeneration amount in windthrow areas, it is very likely the existence of errors of the estimates; this is why it is necessary to verify the hypothesis referred to the observations of sample data through *statistical hypothesis testing*. *Statistical hypothesis testing* is a statistical method that is used in making statistical decisions using experimental data and assumptions relative to a selected population parameter; for the purposes of this research, the population parameter chosen is the mean.

For applying this method, it is necessary to define a null hypothesis and an alternative hypothesis.

The null hypothesis *(H_0)* is a statistical hypothesis that assumes the observation is due to a chance factor, thus that there is no difference between the two samples; the alternative hypothesis *(H_1)* is contrary to the null hypothesis, i.e. the observation is the result of a real effect, thus there is a difference between the two samples.

The acceptance or rejection of the null hypothesis *(H_0)* will be done comparing the *p-value (p)* computed by means of a statistical test with the significance level *(α)*, that could be either 0.1 or 0.05 or 0.01.

If the calculated *p-value* is below the threshold chosen for statistical significance *(α)*, then the null hypothesis *(H_0)* is rejected in favour of the alternative hypothesis *(H_1)*; therefore, the comparison is deemed statistically significant.

For the purposes of this study, the minimum significance level has been set to 0.05; moreover, a significance level of 0.01 has been used as a threshold to define that the comparison is highly significant.

P-values have been computes using *PAST* 3.26 statistic software, that is a free software for scientific data analysis, with functions for data manipulation, plotting, univariate and multivariate statistics, ecological analysis, time series and spatial analysis, morphometrics and stratigraphy.

In particular, *Mann–Whitney U test* has been applied for computing *p-values* of two or more than two data sets; this is a nonparametric test that gives the most accurate estimates of significance, especially when sample sizes are small and/or when the data do not approximate a normal distribution.

5. RESULTS AND DISCUSSION

5.1 MAJOR DISTURBANCE EVENTS

5.1.1 VAIA STORM

According to the estimates reported in the *new action plan for the management of Vaia storm damages to forests* (Provincia Autonoma di Trento, Giugno 2019), in Trento province *Vaia* storm has damaged more than 20 000 hectares of forests, for an overall downed wood volume of more than 4 million cubic meters; this amount of wood is equal to what on average is harvested in the whole Province in 8 years.

As shown by figure 5.1, the north-east part of the Province has been also the most damaged; there, the maximum wind speed has been measured: 190 km/h at *Passo Manghen* (2035 m asl).

To enforce the exceptionality of this event, the mean overall precipitation on the whole Province in those three days has been 275 mm, that is ¼ of the annual mean precipitation of around 1 100 mm/y.

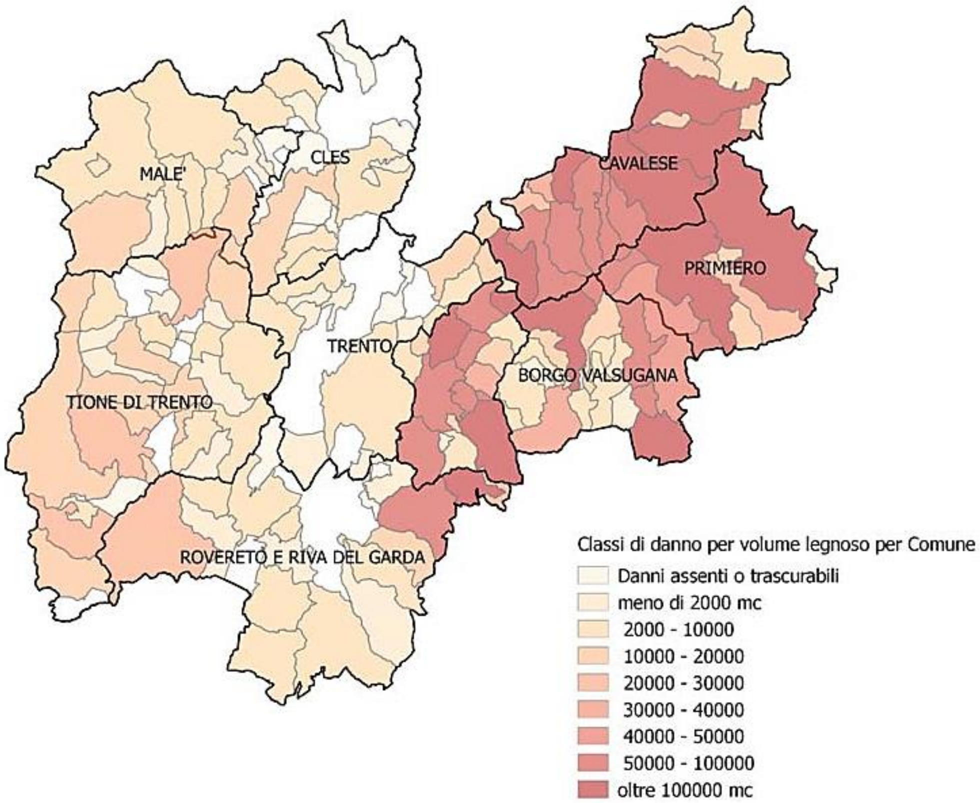


Figure 5.1: Distribution of downed wood volume (m^3 = mc) among municipalities of Trento province (Reference: Provincia Autonoma di Trento (2019) Piano d'azione per la gestione degli interventi di esbosco e di ricostruzione dei boschi danneggiati dagli eventi eccezionali nei giorni dal 27 al 30 ottobre 2018, p.10)

Within the forest district of *Malè*, the first estimates of damaged forests reported a total wood volume of 60 624 m^3, of which around the 16.3% (9895 m^3) refers to Peio valley (Figure 5.2).

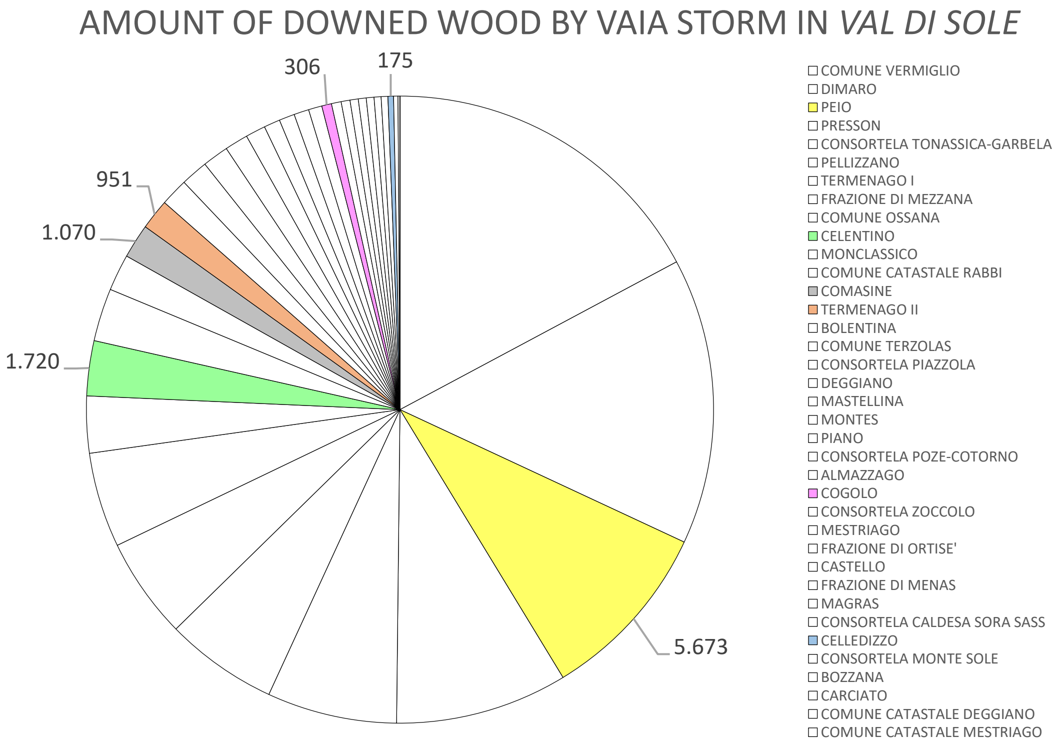


Figure 5.2: Amount of wood downed because of *Vaia* storm in *Val di Sole*
(Reference: Servizio Foreste e Fauna)

One year after the event, these estimates have grown considerably as a consequence of salvage logging operations and the subsequent roundwood measurements.

As regard Peio valley, the total amount of salvaged wood until nowadays (November 2019) has been 13 122 m^3, that for more than a half are located within the forest properties of *A.S.U.C.* Pejo (7578 m^3); the left part regards forest proprieties of the other *A.S.U.C.* as follows: *A.S.U.C.* Celentino 1 750 m^3, *A.S.U.C.* Termenago 1602 m^3, *A.S.U.C.* Comasine 992 m^3, *A.S.U.C.* Cogolo 856 m^3 and *A.S.U.C.* Celledizzo 344 m^3 (Figure 5.3).

Therefore, up to now (November 2019) the first estimates of *Vaia* storm damages in Peio valley have increased of the 32.6% and are likely to increase with the prosecution of salvage logging, that has not ended yet.

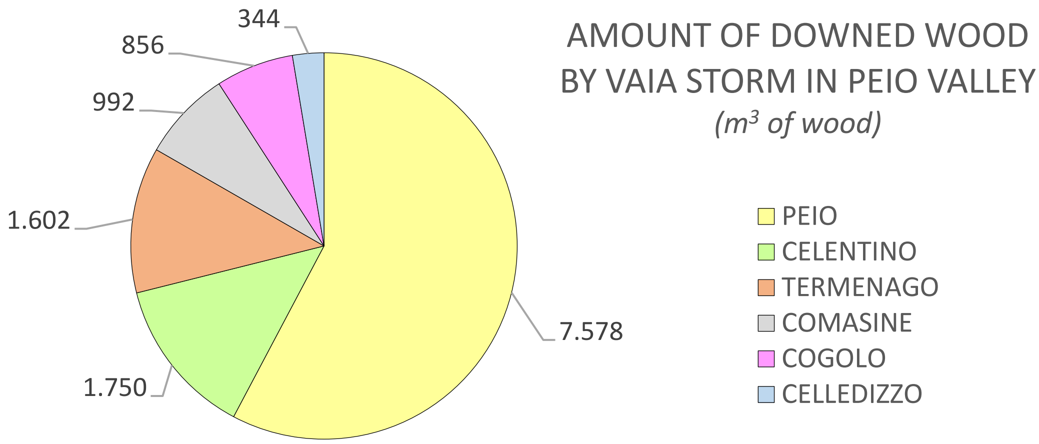


Figure 5.3: Amount of wood downed because of *Vaia* storm in *Peio valley*
(Reference: Servizio Foreste e Fauna)

Vaia storm heavily impacted the south-facing slope of *Val del Monte (Pian Palù)*, downing about 8 000 m^3 of timber (Figure 5.5, Figure 5.6); around 2 000 m^3 have been downed on the west side of *Val del la Mare*, while the left part (around 4 000 m^3) have been downed on the outermost slopes of Peio valley (Figure 5.4).

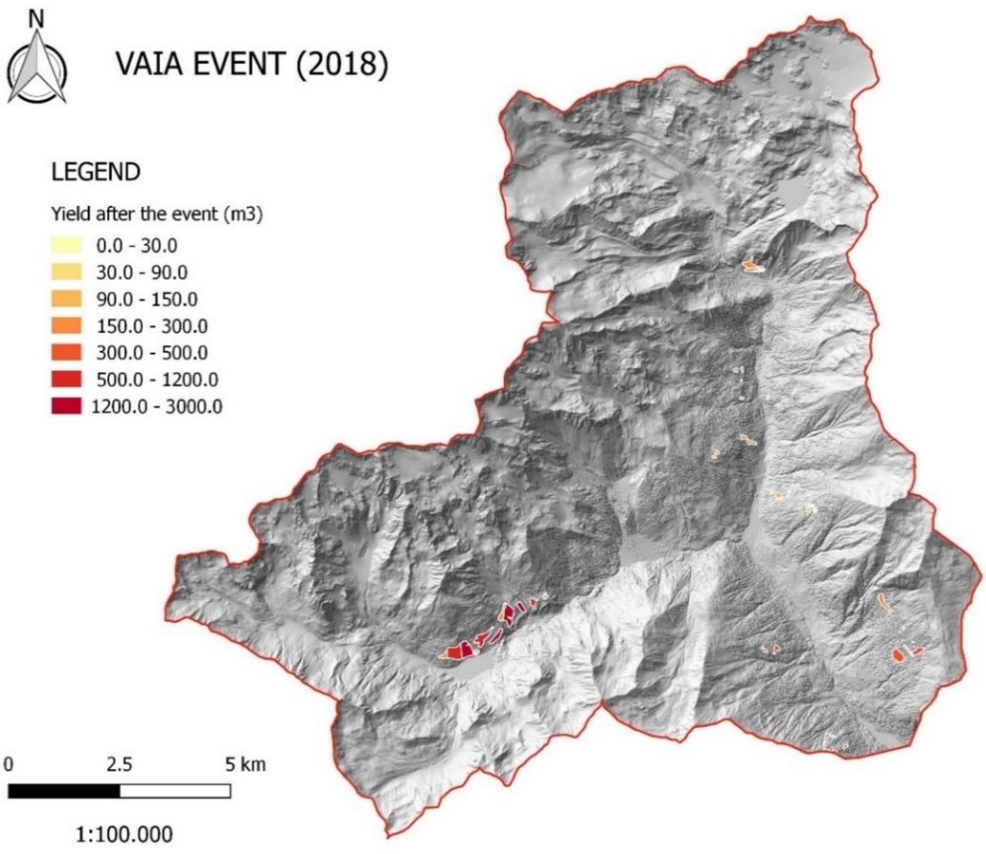


Figure 5.4: Areas damaged by *Vaia* storm in Peio valley
(Reference: Servizio Foreste e Fauna)

Figure 5.5: *Pian palù* area before *Vaia* storm
(Picture: Francesca Michelon, 19.09.2018, 2450 m asl)

Figure 5.6: Pian palù area after *Vaia* storm
(Picture: Francesca Michelon, 13.09.2019, 2450 m asl)

5.1.2 MAJOR PAST DISTURBANCE EVENTS

Despite *Vaia* storm is remembered as the worst large disturbance event within Trento Province, Peio valley has already faced other important disturbance events during the last century.

Thanks to forest management plans available for the six forest owners (A.S.U.C.) within Peio valley, it has been possible to reconstruct the distribution of salvage logging from the '50s to nowadays, in order to find out the occurrence of other large disturbance events in the last 70 years.

From the analysis it emerges that in 1960, 1976, 1990, 2003 and 2015 significant quantities of wood have been salvaged, suggesting the occurrence of five major disturbance events (Figure 5.7).

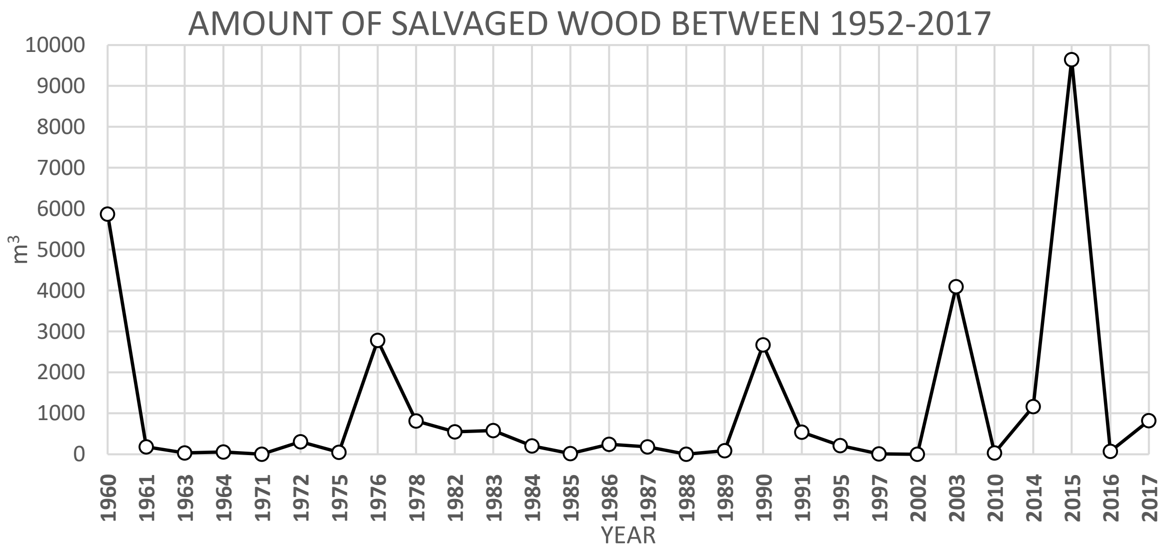


Figure 5.7: Amount of salvaged wood between 1952 and 2017

By data reported on management plans, as well as thanks to memories of locals (Panizza 2005, *Mauro Zambelli* and *Antonio Vicenzi in verbis*), it has been possible to reconstruct the characteristics of these five events (Table 5.1).

YEAR	SALVAGED WOOD *(m^3)*	LOCATION (FOREST OWNER)	CAUSE
1960 *4th September*	6 033	Eastern slope of *Val de la Mare* and outermost slopes of the valley (A.S.U.C. Celledizzo and A.S.U.C. Celentino)	Storm
1976 *Autumn*	2 788	Northern slope at the confluence of *Val del Monte* e *Val de la Mare* (A.S.U.C. Cogolo)	Storm
1990	2 924	East slope of *Val de la Mare* and the outermost slopes of the valley (A.S.U.C. Celledizzo and A.S.U.C. Celentino)	Storm
2002 *25-26th November*	4 100	East slope of *Val de la Mare* and the outermost slopes of the valley (A.S.U.C. Celledizzo and A.S.U.C. Celentino)	Storm
2013 *26th December*	11 705	Outermost west slope of the valley (A.S.U.C. Comasine and A.S.U.C. Celledizzo)	Snow
2014 *February*			Snow
2015 *10th January* *18th August*			Storm

Table 5.1: Characteristics of the main disturbance events in Peio valley over the last 70 years

5.1.2.1 1960, 1990 and 2002 EVENTS

The events occurred in 1960, 1990 and 2002 hit the east slope of *Val de la Mare* and the outermost slopes of the valley, damaging mostly forest properties of A.S.U.C. Celledizzo and A.S.U.C. Celentino; the 1990 event impacted also A.S.U.C. Cogolo, while A.S.U.C. Celentino has not been damaged significantly.

Focusing on 1960 event (Figure 5.8), the total amount of salvaged wood has been 6033 m^3, of which the 32.8% A.S.U.C. Celentino and the 67.2% on A.S.U.C. Celledizzo forest properties.

For the period 1956-1965, for A.S.U.C. Celentino it was planned to harvest 4900 m^3; the total harvested volume has been 5234 m^3 of which 1967 m^3 (37.6%) derived from salvage logging (Figure 5.11).

For the same period, for A.S.U.C. Celledizzo it was planned to harvest 5380 m^3; the total harvested volume has been 9010 m^3 of which 4023 m^3 (44.7%) derived from salvage logging (Figure 5.12).

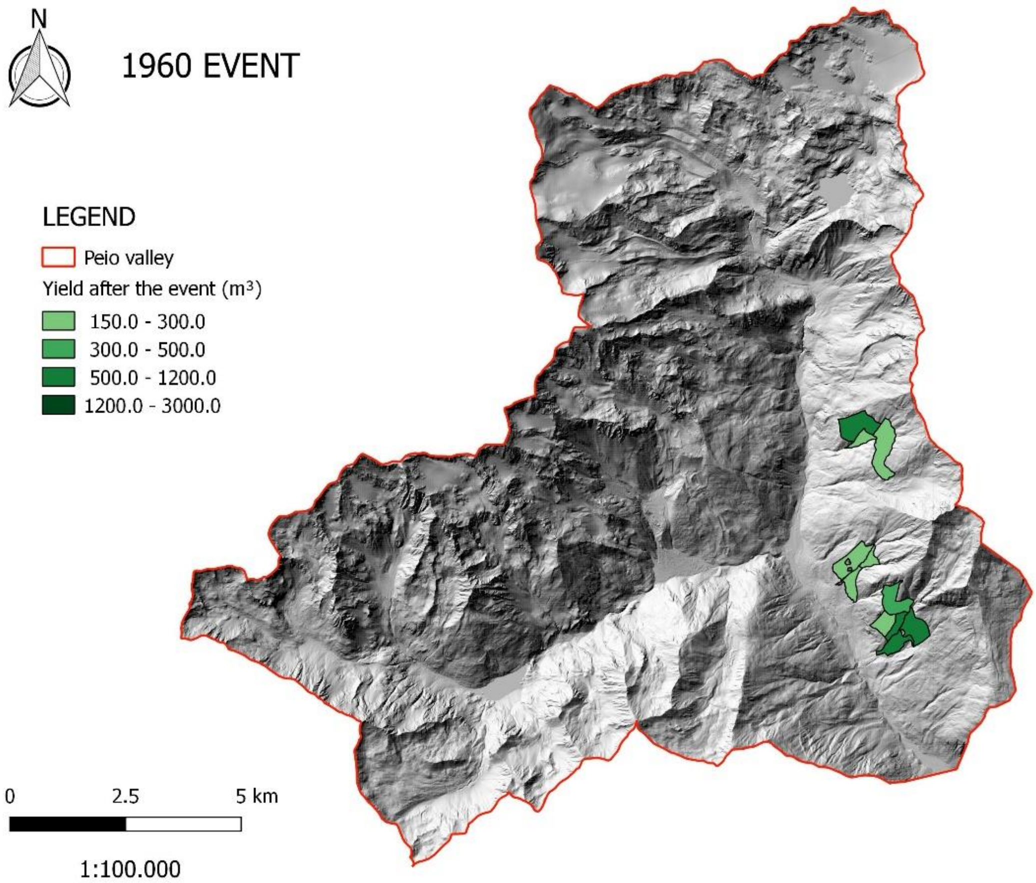


Figure 5.8: Forest coupes damaged by the 1960 storm event

Focusing on 1990 event (Figure 5.9), the total amount of salvaged wood has been 2924 m^3, more or less half on A.S.U.C. Celledizzo and half on A.S.U.C. Cogolo forest properties. For the period 1987-2001, for A.S.U.C. Celledizzo it was planned to harvest 19 500 m^3; the total harvested volume has been 17706 m^3, of which 1447 m^3 (8.1%) derived from salvage logging.

For the period 1982-1996, for A.S.U.C. Cogolo, it was planned to harvest 18 600 m^3; the total harvested volume has been 18178 m^3, of which 1963 m^3 (10.8%) derived from salvage logging (Figure 5.14).

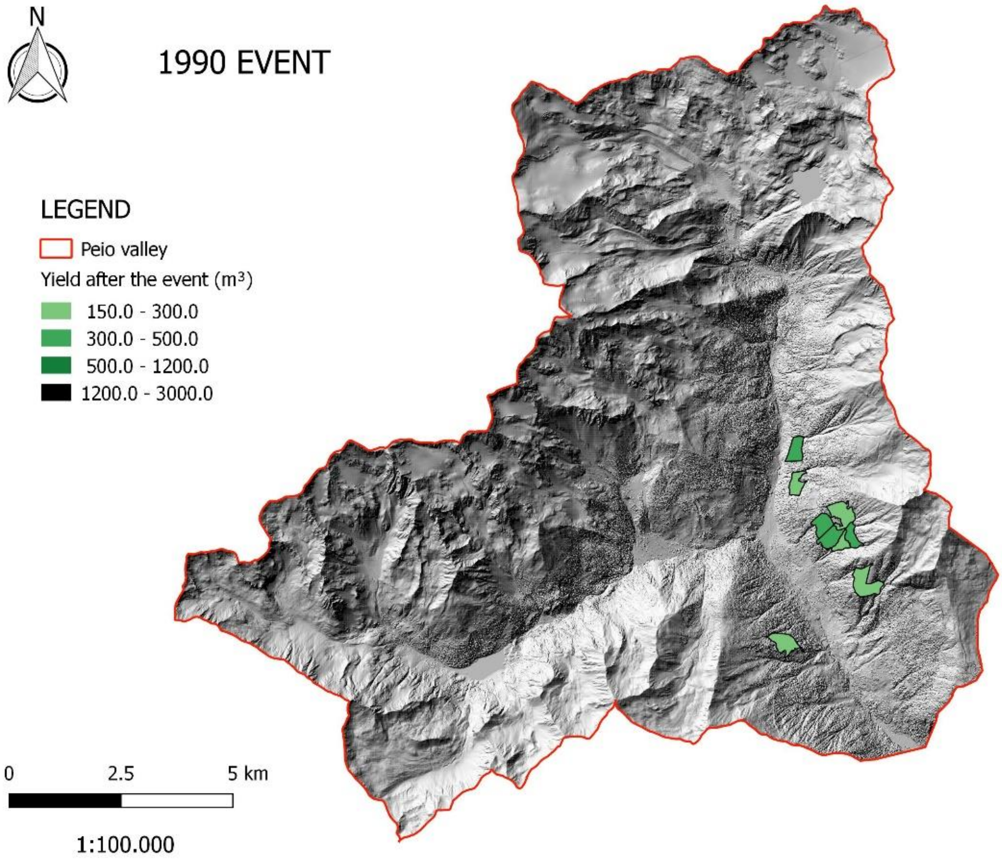


Figure (5.9): Forest coupes damaged by the 1990 storm event

Focusing on 2002 event (Figure 5.10), the total amount of salvaged wood in 2003 has been 4100 m^3, of which the 76.5% on A.S.U.C. Celentino and the 23.5% on A.S.U.C. Celledizzo forest proprieties.

For the period 2001-2010, for A.S.U.C. Celentino it was planned to harvest 8400 m^3; the total harvested volume has been 8678 m^3 of which 3138 m^3 (33.9%) derived from salvage logging.

For the same period, for A.S.U.C. Celledizzo it was planned to harvest 11350 m^3; the total harvested volume has been 11000 m^3 of which 934 m^3 (8.5%) derived from salvage logging (Figure xx).

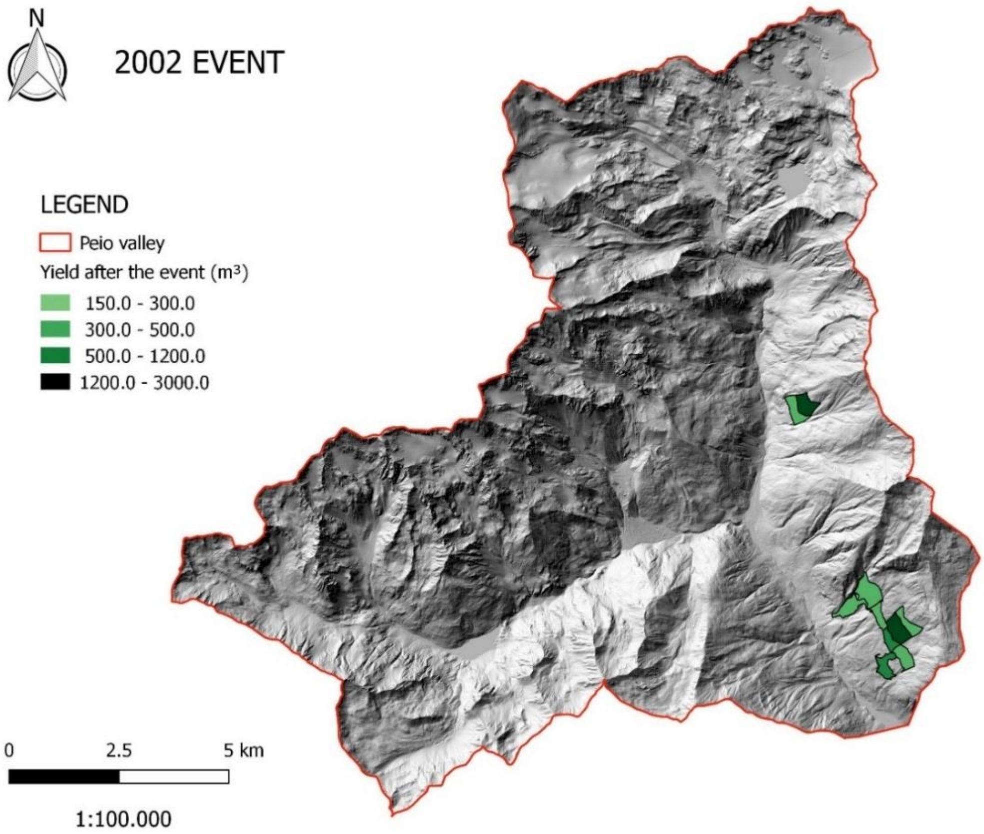


Figure 5.10: Forest coupes damaged by the 2002 storm event

For 1960 for both A.S.U.C. the total harvested volume has significantly overcome the yield planned, for a total exceeded volume of 3 964 m^3; for 1990 and 2002 events total harvested volume was lower or slightly above the total yield planned for the period considered by the management plan.

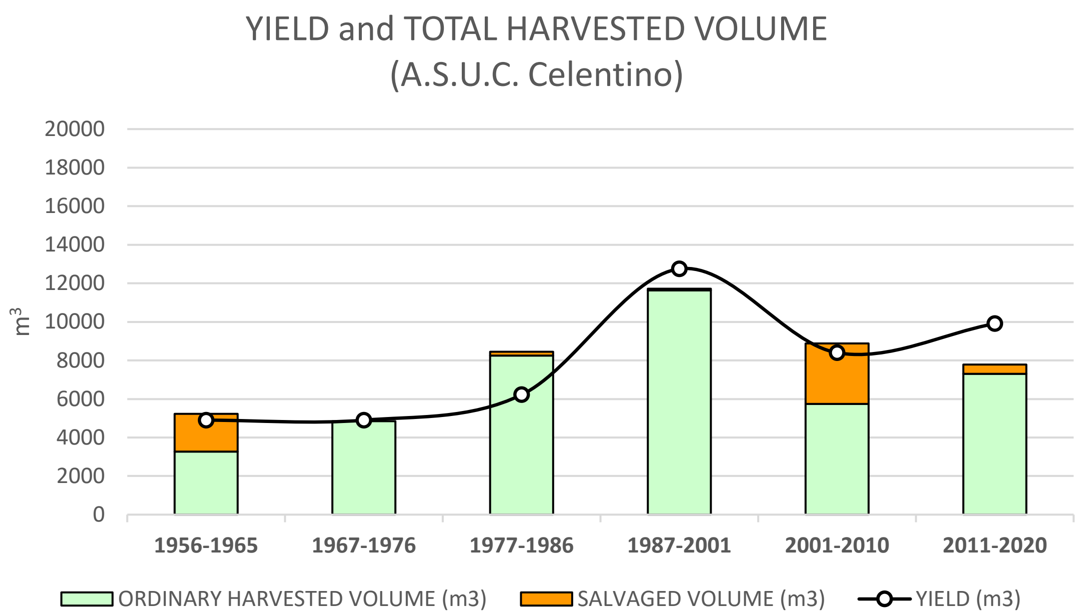


Figure 5.11 Comparison between yield and harvested volume for A.S.U.C Celentino between 1956 and 2017

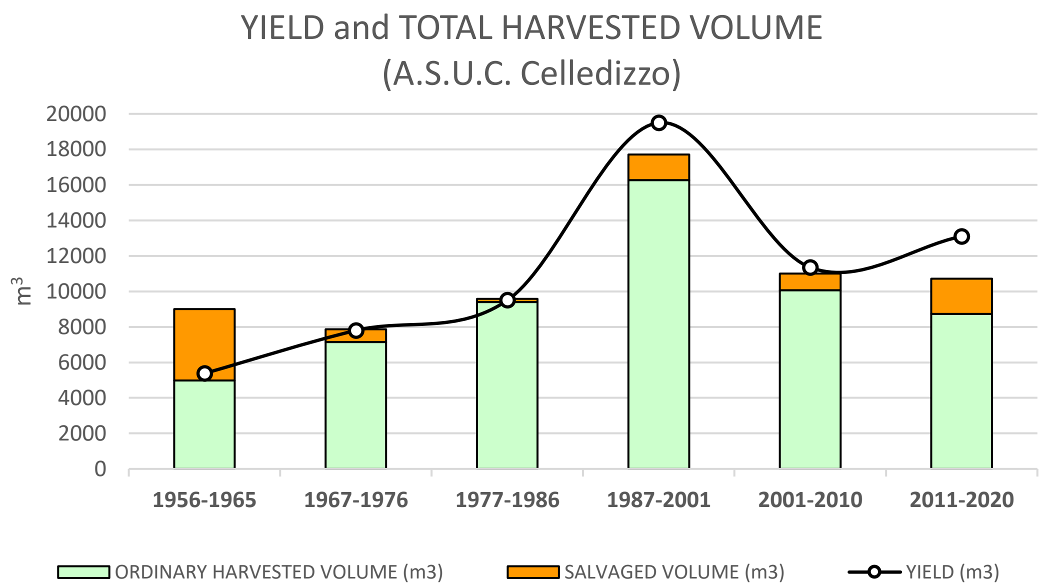


Figure 5.12 Comparison between yield and harvested volume for A.S.U.C Celledizzo between 1956 and 2017

5.1.2.2 1976 EVENT

The 1976 events hit the north facing outermost slope of *Val del Monte* (Figure 5.13), damaging mostly forest properties of A.S.U.C. Cogolo.

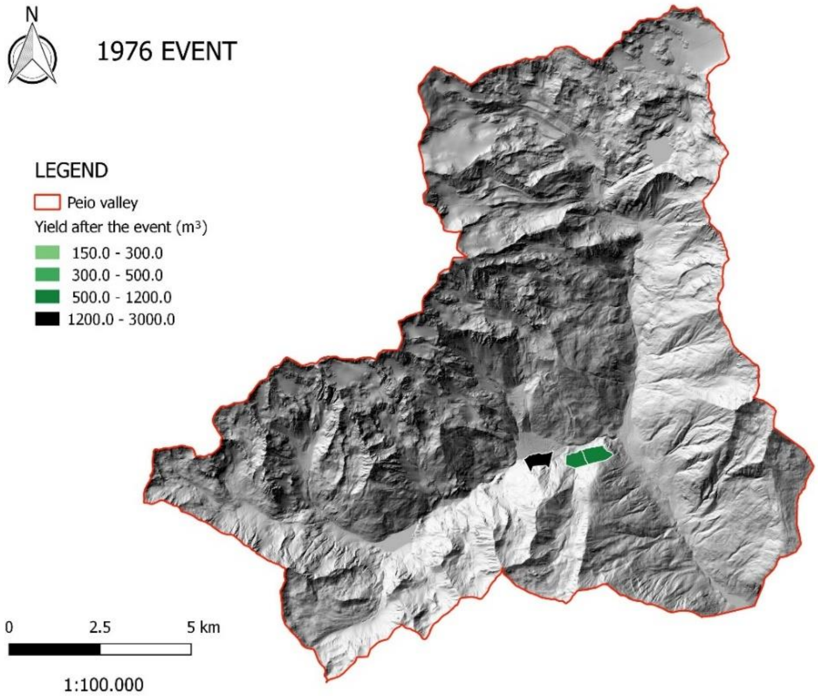


Figure 5.13: Forest coupes damaged by the 1976 storm event

The total amount of salvaged wood has been 2788 m^3.

For the period 1972-1981, it was planned to harvest 10 700 m^3; the total harvested volume has been 10868 m^3 of which 3605 m^3 (33.2%) derived from salvage logging (Figure 5.14).

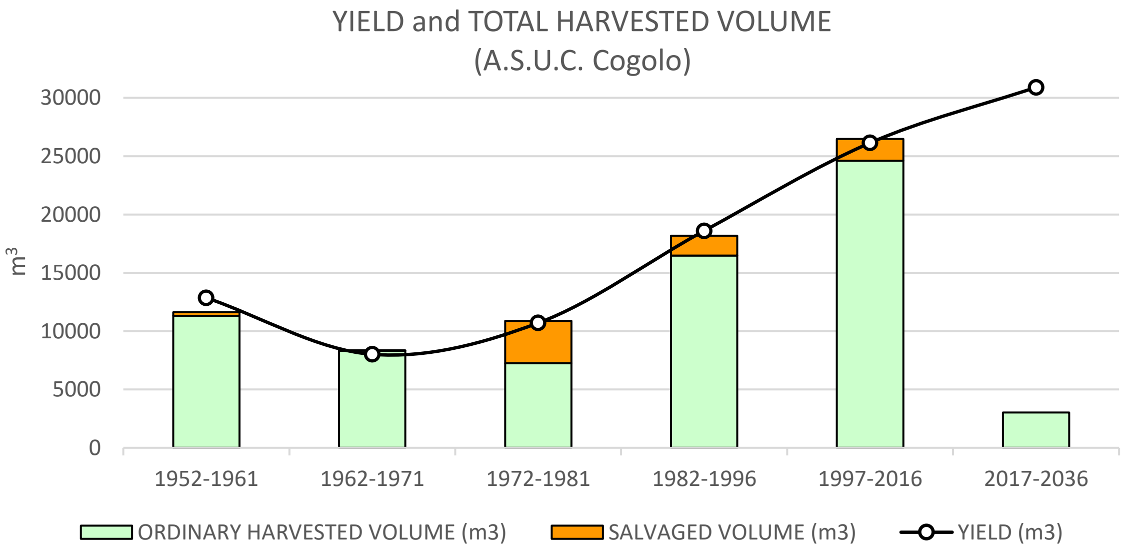


Figure 5.14: Comparison between yield and harvested volume for A.S.U.C Cogolo between 1952 and 2017

Therefore, for the period considered the total harvested volume has not significantly overcome the yield planned, since the quantity exceeded has been 168 m^3.

5.1.2.3 THE RECENT EVENTS BETWEEN 2013 AND 2015

The most recent events of 2013, 2014 and 2015 have damaged mostly forests of A.S.U.C. Comasine, on the outermost western slope of the valley, as well as the north-facing slope at the confluence of *Val del Monte* and *Val de la Mare* (figure 5.15).

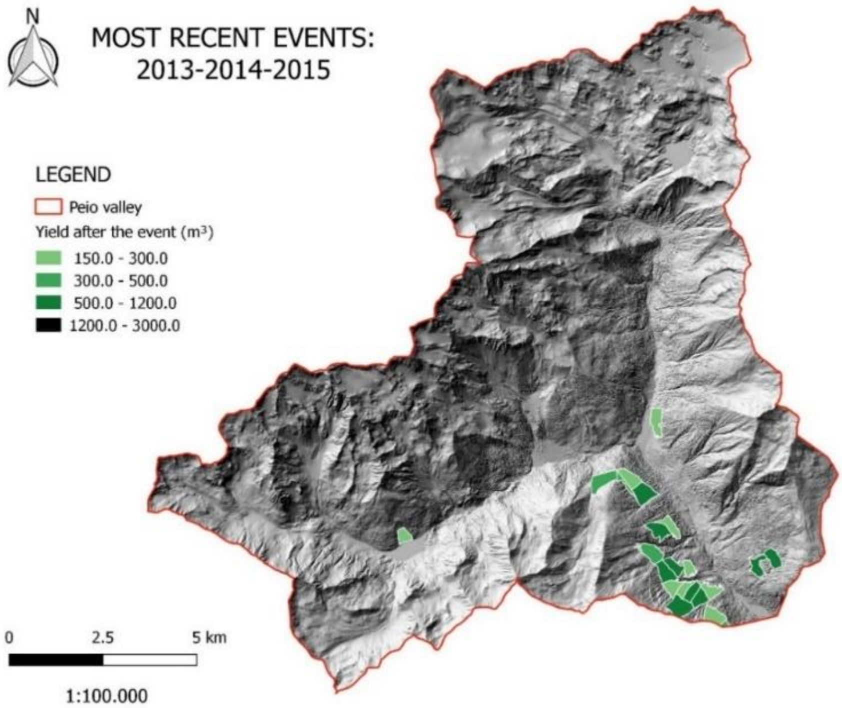


Figure 5.15: Forest coupes damaged by the events of 2013, 2014 and 2015

For these events 11 705 m^3 of wood have been salvaged logged; more than a half of this volume (73.6%) was logged on A.S.U.C. Comasine, for a total volume of 8 501 m^3.

For the period 1998-2007 (it has to be considered this management plan, since the validity of the forest management plan has been extended to 2017), it was planned to harvest 9 650 m^3, that actually are 19 300 m^3 because of the extension for other 10 years of the validity of the forest management plan; the total harvested volume for this period (1998-2017) has been 22 088 m^3 of which 8 501 m^3 (38.5%) were salvage logged (Figure 5.16).

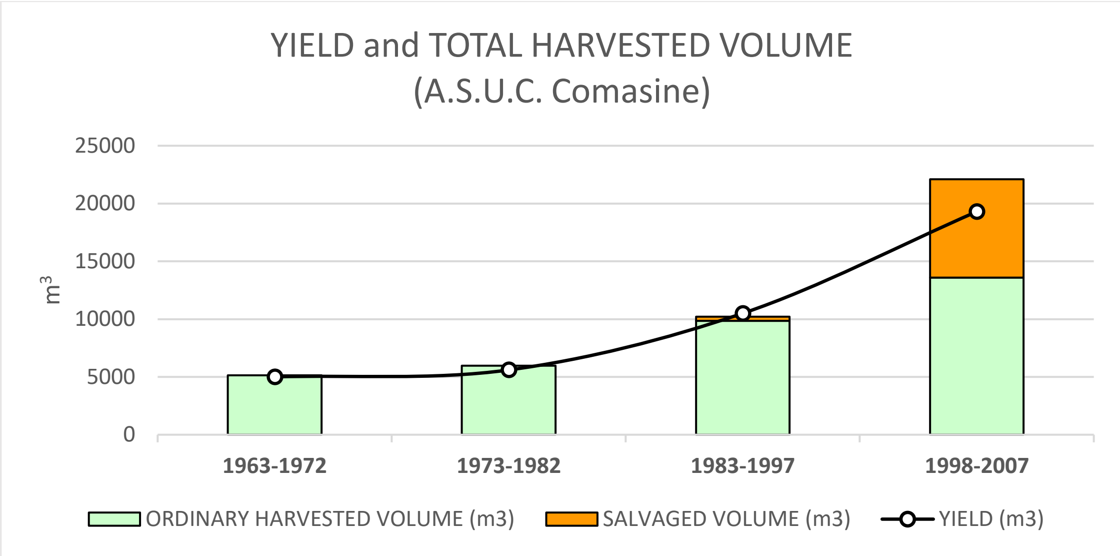


Figure 5.16: Comparison between yield and harvested volume for A.S.U.C Comasine between 1963 and 2017

Therefore, for the period considered the total harvested volume has overcome the yield planned of 2788 m^3.

5.1.3 EFFECTS OF PAST MAJOR DISTURBANCES ON FOREST HARVESTING

A total volume of 32 899 m^3 have been salvaged logged between 1952 and 2017 (Figure 5.17), that represents the 11.3% of the total amount of wood harvested in that period, that has been 290 877 m^3.

This quantity is the 99.2% of the total yield planned for Peio Valley for that period whose amount was 293 100 m^3; therefore, there is just a 0.8% left, that corresponds to 2 223 m^3 of planned yield that has not been harvested.

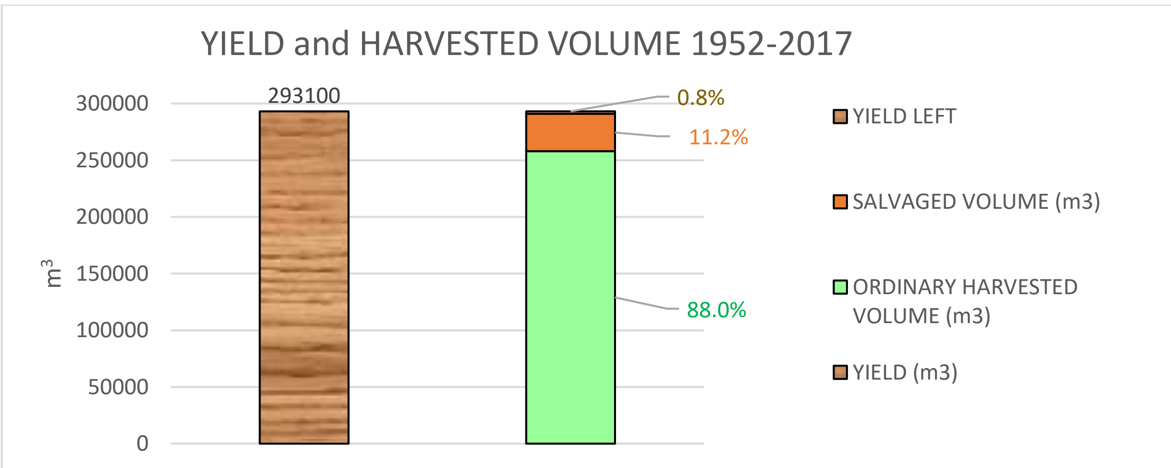


Figure 5.17: Comparison between yield and total harvested volume between 1952-20017; the total harvested volume has been characterized according to the type of harvesting (ordinary or salvage logging)

It is evident that despite these major events, planned yield has been respected; moreover, forests in Peio valley have been growing, as highlighted by the increase of basal area and growing stock through the last seventy years.

In fact, according to the data available, basal area in the ‘60s was 19.3 m^2/ha, in the ‘90s it was 26.2 m^2/ha, while according to the most recent management plans it is 32.0 m^2/ha (Figure 5.18); this means that it has grown of the +68.4% in the last 70 years.

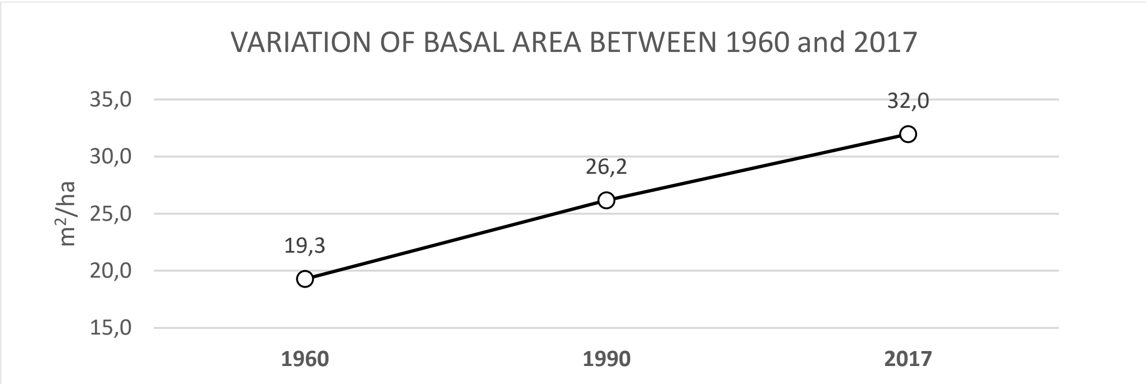


Figure 5.18: Variation of basal area between 1960 and 2017

As regards growing stock, in the ‘60s it was 131.0 m^3/ha, in the ‘90s was 167.7 m^3/ha, while according to the most recent management plans it is 218.9 m^3/ha (Figure 5.19); this means that it has grown of the +67.1% in 70 years.

According to these results, the growth of productive forest surface is linearly correlated to the increase of growing stock, suggesting that the entire forest system in Peio valley has not been compromised by these large disturbance events.

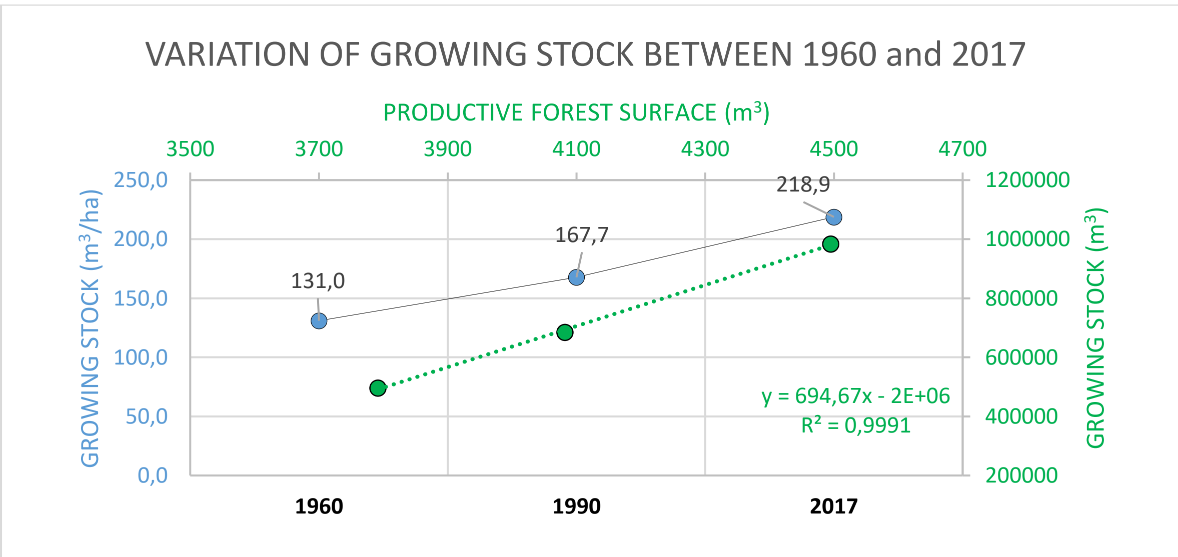


Figure 5.19: Variation of growing stock between 1960 and 2017

Moreover, an increased value of yield has been assigned between the ‘60s and nowadays (Figure 5.20); however, between the ‘50s and the ‘60s there has been a decreasing of the yield, probably as a consequence of the 1960 events.

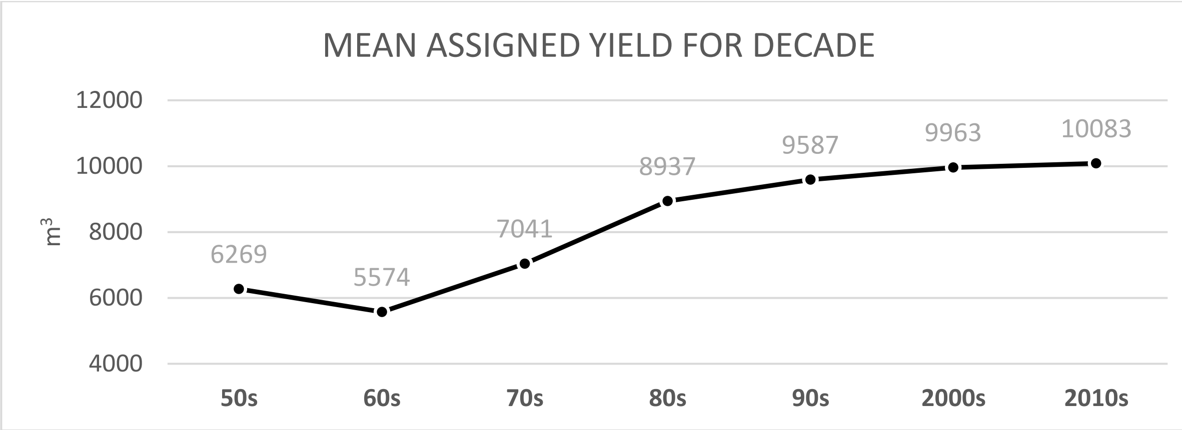


Figure 5.20: Mean assigned yield for decade, considering the yield planned for each of the six A.S.U.C.

Analysing the assigned yield for each forest owner (A.S.U.C.), this trend is confirmed, with some exception (Figure 5.21).

A.S.U.C. Celledizzo has faced a decreasing of the yield between the ‘80s and the ‘90s, but this is not due to disturbance event, since in the ‘80s no significant events have been occurred. Also A.S.U.C. Termenago has faced a decreasing of the assigned yield after the ‘90s; this reduction is probably the obligation put on half of the property as a mitigation measure for the construction of *Val dela Mite* ski facility; the agreement states that a share of forest will be left to the natural evolution, thus any kind of harvesting operation can be carried out in the forest coupes individuated by this agreement.

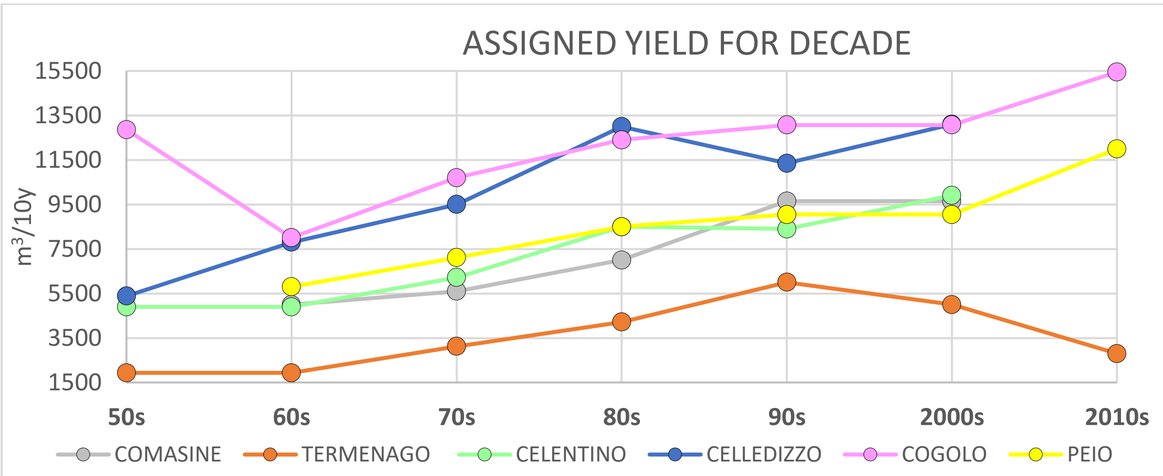


Figure 5.21: Assigned yield for decade for each of the six A.S.U.C.

5.1.4 COMPARISON BETWEEN MAJOR PAST DISTURBANCES AND VAIA STORM

Comparing the total salvaged volumes of past events to *Vaia* storm, it is evident the high severity of the latter, since, by now (November 2019), the salvaged wood volume is roughly equal to the 40.0% of the total salvaged wood volume between 1960 and 2017 (Figure 5.22); it has to be remember that this value is likely to increase, since salvage logging operations have not been completed yet.

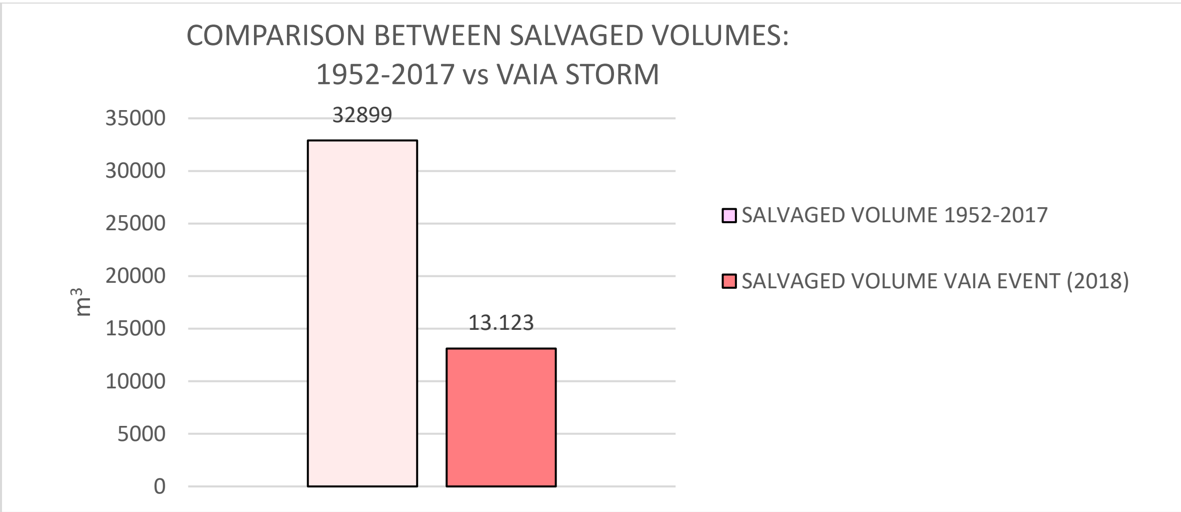


Figure 5.22: Comparison between salvaged volumes between past events (1952-2017) and *Vaia* storm

However, associating to each past event the salvaged volume, it emerges that the amount of wood salvaged in 2015 (relative to 2013, 2014 and 2015 events) is very close to the amount of wood salvaged as a consequence of *Vaia* storm (Figure 5.23).

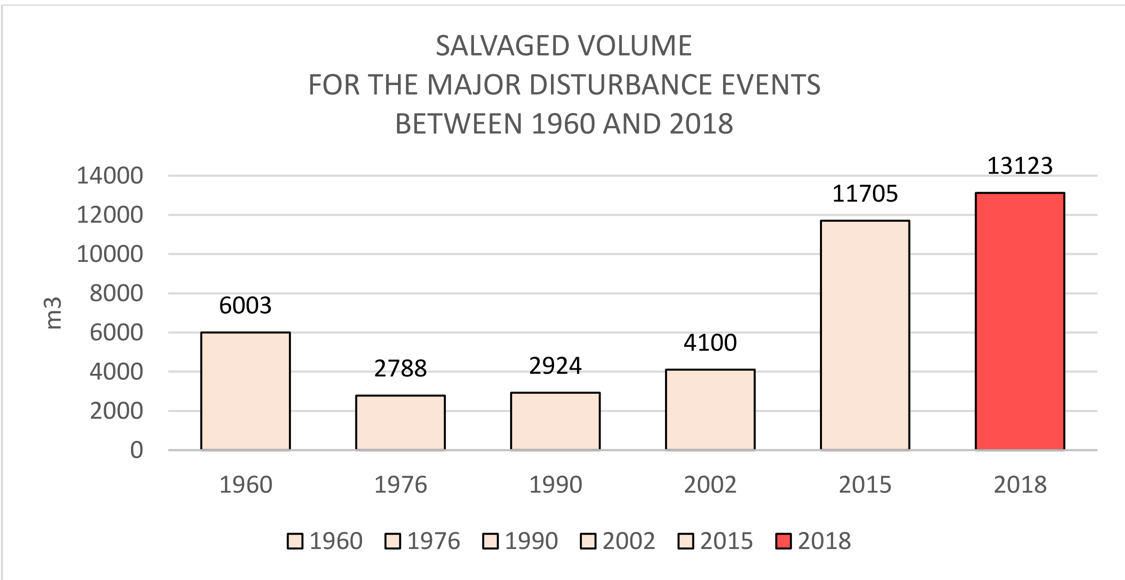


Figure 5.23: Salvaged wood volume for the main disturbance events between 1960 and 2018

Another interesting point is that *Vaia* storm has heavily damaged those forest owners where small amounts of wood have been salvaged since the ‘50s (figure 5.24).

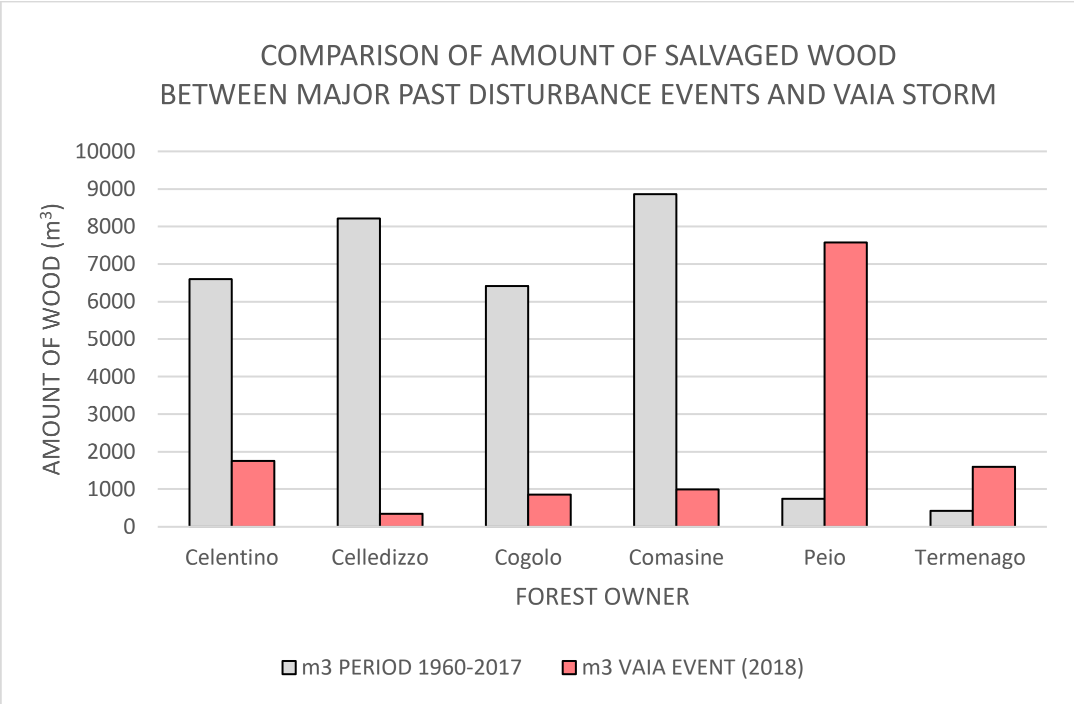
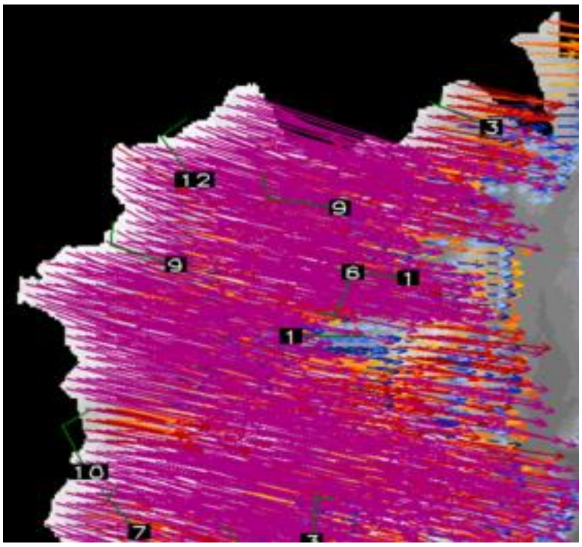


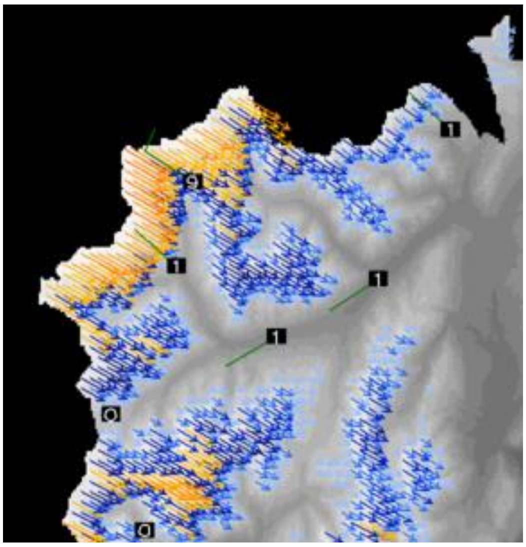
Figure 5.24: Comparison between salvaged wood of past events (1952-2017) and *Vaia* storm for each A.S.U.C.

Actually, the most impacted area by *Vaia* storm (*Pian Palù* in *Val del Monte*) usually it is not subjected to this kind of disturbance, since this area is not directly exposed to winds that normally blow from the north (Angeli F. *in verbis*).

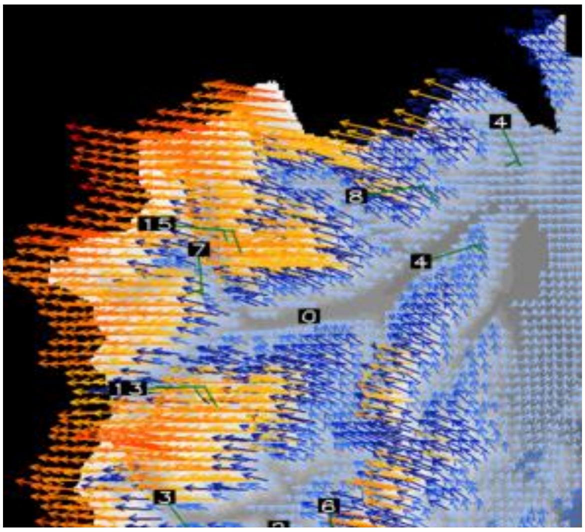
In fact, wind maps witnesses that for the other past events, winds blew from the north-west, while during *Vaia* storm wind blew from the south-east; however, it is interesting to notice that two hours after *Vaia* storm hit the valley, strong wind blew from the north (Figure 5.25).



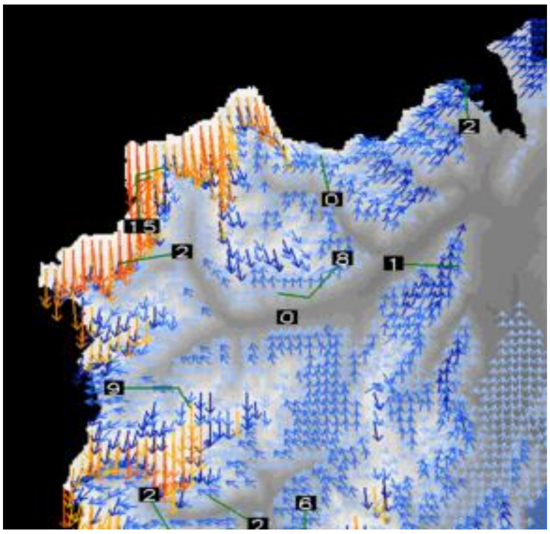
Wind map of windthrown event of 10.01.2015 (h 06.00)
Wind comes from north-west



Wind map of windthrown event of 26.12.2013 (h 21.00)
Wind comes from north-west



Wind map of *Vaia* storm (29.10.2018, h 21.00)
Wind come from the south-east



Wind map of *Vaia* storm (29.10.2018, h 23.00)
Wind come from north

Figure 5.25: The coloured scale expresses wind velocity in m/s: blue corresponds to velocity below 10 m/s, while purple to velocity higher than 30 m/s (Reference: Meteotrentino)

Moreover, there is another aspect to consider, that is the most impacted area by *Vaia* storm (*Pian Palù* in *Val del Monte*) used to be an important pasture for cattle, that nowadays is progressively disappearing together with many other pastures within the valley, as a consequence of the abandoning of mountain farming started from the '70s (Figure 5.26, Figure 5.27).

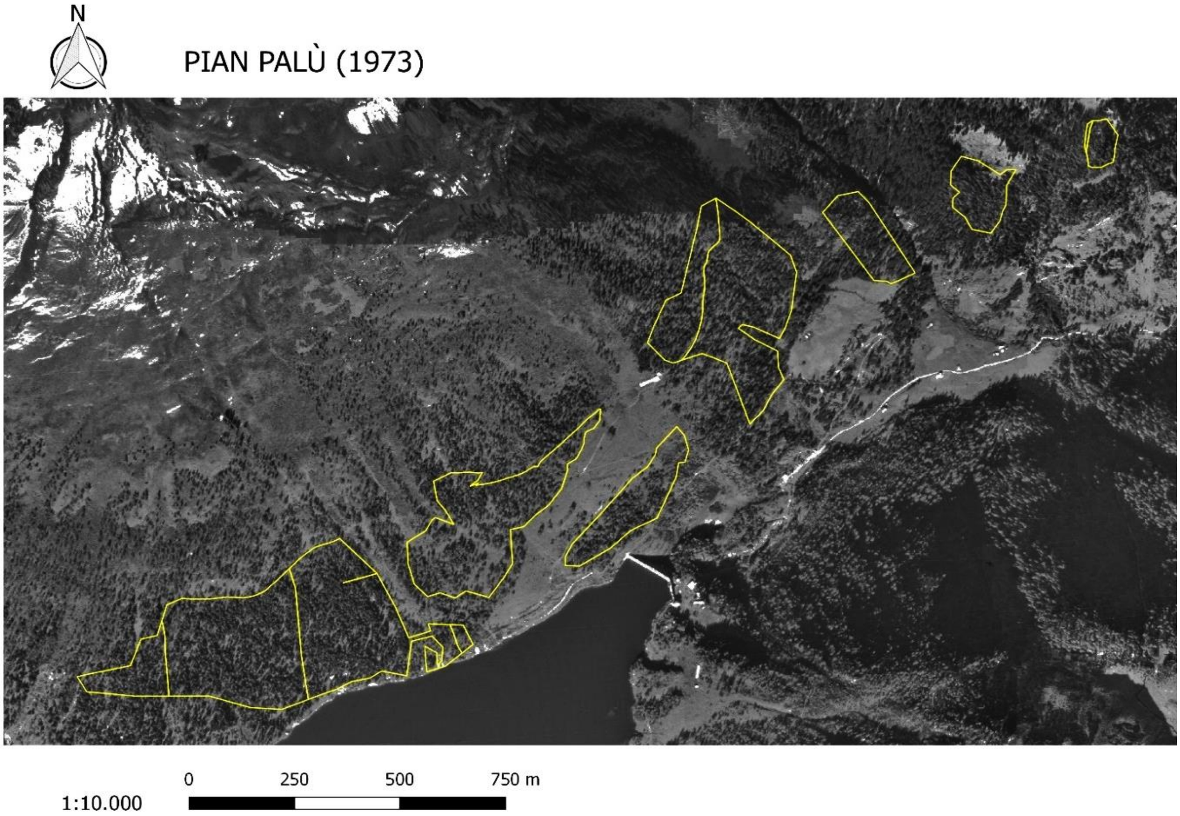


Figure 5.26: Aerial photo of *Pian palù* area referred to year 1973, with areas damaged by *Vaia* storm

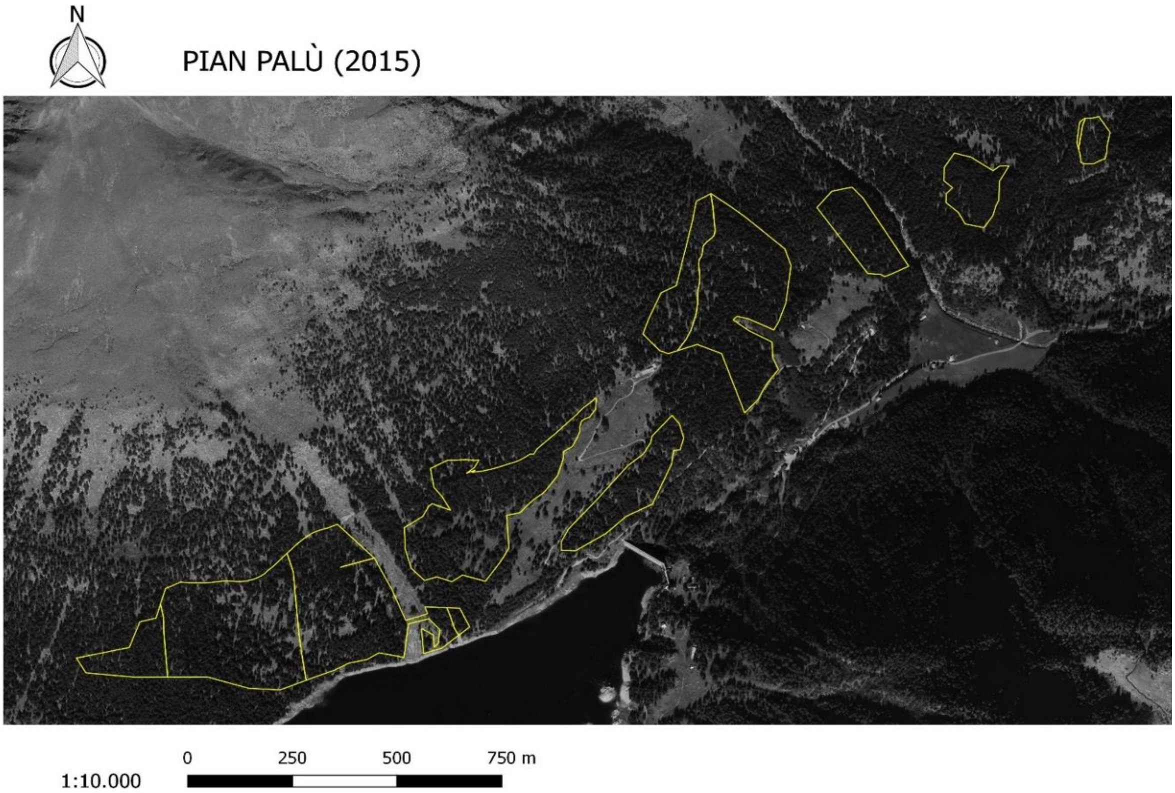


Figure 5.27: Aerial photo of *Pian palù* area referred to year 2015, with areas damaged by *Vaia* storm

According to Schelhaas et al. (2003) the amount of damaged forests by storm has increased over the last seventy years, attributing this process to the changes in forest management, which reflects on forest structure (e.g. age, composition); in particular, he observed that the average growing stock and the age of forests has increased considerably from the '50s to nowadays.

In Peio valley, the changes in forest management due to the abandoning of an economy based on mountain farming, have been responsible for the increase of forest surface (+17.6% of productive forest surface), as well as of growing stock (+67.1% of growing stock – m^3/ha). Because of this process, Schelhaas et al. (2003) sustain that forests can be considered more vulnerable, since there are also more resources that can be damaged.

Considering that according to the current trend, forest resources are expected to continue to increase, Schelhaas et al. (2003) believe that damages from disturbances will also increase in future; to support this view, there is what has been observed for Peio valley by this research (figure 5.28).

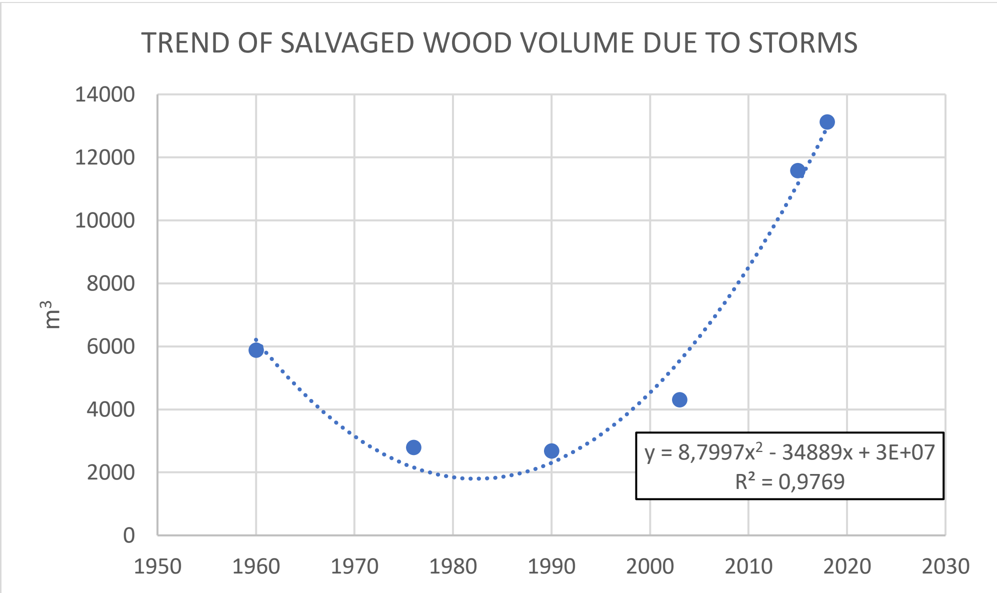


Figure 5.28: Trend of salvaged wood volume due to storm in Peio valley between 1960 and 2019

5.1.5 EFFECTS OF VAIA STORM ON FUTURE FOREST HARVESTING

Vaia storm has completely set to zero forest yield for many years of many forest properties in Trentino.

Table 5.2 and figure 5.29 reports the current situation of forest management plans of each A.S.U.C. in Peio valley, highlighting the left yield, that has been computed through the difference between the yield planned and the total harvested volume for the period of validity of the plan.

FOREST OWNER	F.M.P. PERIOD	YIELD *(m³)*	ORDINARY HARVESTED *(m³)*	SALVAGED WOOD *(m³)*	VAIA STORM *(m³)*	TOTAL HARVESTED *(m³)*	YIELD LEFT *(m³)*
TERMENAGO	2015-2024	2800	1324	0	1602	2926	-126
COMASINE	2018-2037	12650	501	0	992	1493	11157
CELENTINO	2011-2020	9900	7298	481	1750	9529	371
CELLEDIZZO	2011-2020	13100	8737	1978	344	11059	2041
COGOLO	2017-2036	30900	3028	0	856	3884	27016
PEJO	2017-2036	24000	1827	0	7578	9405	14595
TOTAL		93350	22715	2459	13123	38297	55053

Table 5.2: Data about yield and harvested volumes for each forest management plan currently valid of the six forest owners in Peio valley; the last column reports the amount of yield left until the expiry of the management plan.

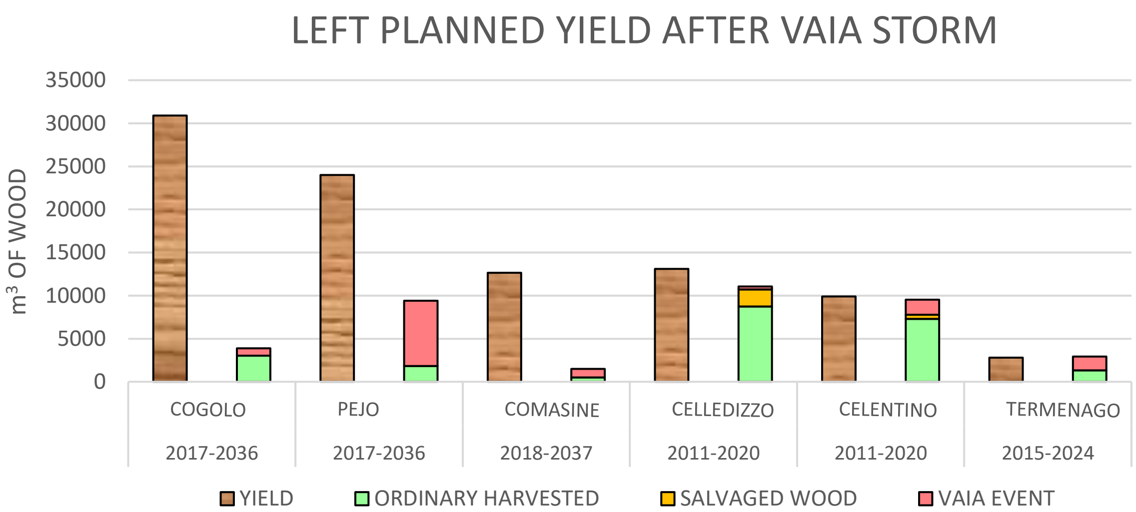


Figure 5.29: Comparison between yield and harvested volume classified considering the reason of harvesting, referred to the current forest management plans for each forest owner in Peio valley.

In Peio valley yield has been set to zero just for A.S.U.C. Termenago, whose management plan is expiring in 2024; actually, this forest owner has just a little share of its property in Peio valley, since the most of the forests owned are outside the valley.

A.S.U.C. Celentino and A.S.U.C. Celledizzo have a left yield of respectively 371 m^3 and 2041 m^3; however, since their forest management plans are expiring next year (2020), forest harvesting will not be compromised.

For A.S.U.C. Cogolo and A.S.U.C. Pejo have just entered in force a new forest management plan; according to the volume harvested since 2017, the left yield is respectively 27016 m^3 and 14595 m^3, that corresponds to an overall annual yield (calculated on the 17 years left) of about 1590 m^3/y for A.S.U.C. Cogolo and 860 m^3/y for A.S.U.C. Pejo.

A.S.U.C. Comasine is drafting its new forest management plan that has expired in 2017; estimating a yield of 12650 for the next 20 years on the basis of the old forest management plan, just the 11.8% of the yield planned has been harvested by now (1493 m^3); therefore, the overall annual yield for the next 18 years will be of about 620 m^3/y.

The following table (table 5.3) resume the amount of annual yield for each forest owner, computed by the ratio between the left yield and the amount of years left before the expiring of the management plan for each A.S.U.C..

	TERMENAGO	**CELENTINO**	**CELLEDIZZO**	**COGOLO**	**PEJO**	**COMASINE**
YEARS LEFT	4	1	1	17	17	18
LEFT YIELD	/	371 m^3/y	2041 m^3/y	1590 m^3/y	860 m^3/y	620 m^3/y

Table 5.3: Left annual yield according the validity of the management plan from 2020 onwards, computed considering the yield left net of the volume harvested until 2019.

5.2 FOREST SURFACE AND SPECIES COMPOSITION VARIATION

In general, forest surface has increased from the '60s to nowadays of the +17.6% (Figure 5.30); in fact, the total productive forest surface in the 60s was *3823.5 ha*, while nowadays it is *4495.0 ha*

Considering the single species, there has been a general increase of Norway spruce *(Picea abies)* cover in terms of woody mass, that in the '60s was 221 083 m^3, while nowadays is 429 337 m^3; however, in terms of percentage, it has increased from 44.7% of 1960 to 52.3% of 1990, for then decreasing between 1990 and nowadays to 43.7%, even though the total woody mass has increased of around 70 000 m^3.

European larch *(Larix decidua)* cover, instead, has also increased in terms of woody mass from the 254 0855 m^3 of the '60s to the 411 789 m^3 of nowadays; however, in terms of percentage it has decreased from a 51.5% of 1960 to the 41.9% of nowadays.

Swiss stone pine *(Pinus cembra)* has slightly increased from 3.5% of the '60s to 4.9% of nowadays, that in terms of woody mass has consisted in an increase of more than a double of the total mass there was in the '60s (from 18 171 m^3 to 47 907 m^3).

According to figure xx Broadleaves, such as silver birch *(Betula pendula)*, goat willow *(Salix caprea)* and rowan *(Sorubus aucuparia)*, has increased their presence within the forests.

Moreover, Scots pine *(Pinus Sylvestris)* and Silver fir *(Abies alba)* are present in small amounts within these forests; however, nowadays they may be found as single trees, representing an important element of biodiversity.

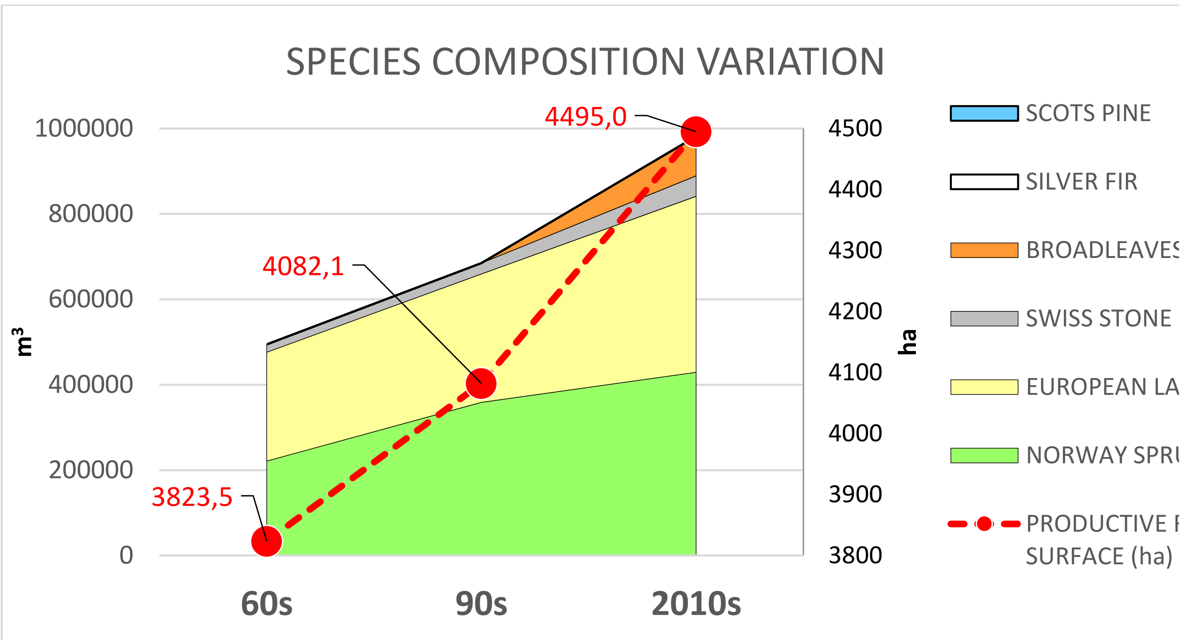


Figure 5.30: Forest species composition variation between the '60s and nowadays in Peio valley

The trend in forest surface and species composition variation within the six different forest properties within Peio valley are shown in figure 5.31, figure 5.32, figure 5.33, figure 5.34, figure 5.35, figure 5.36.

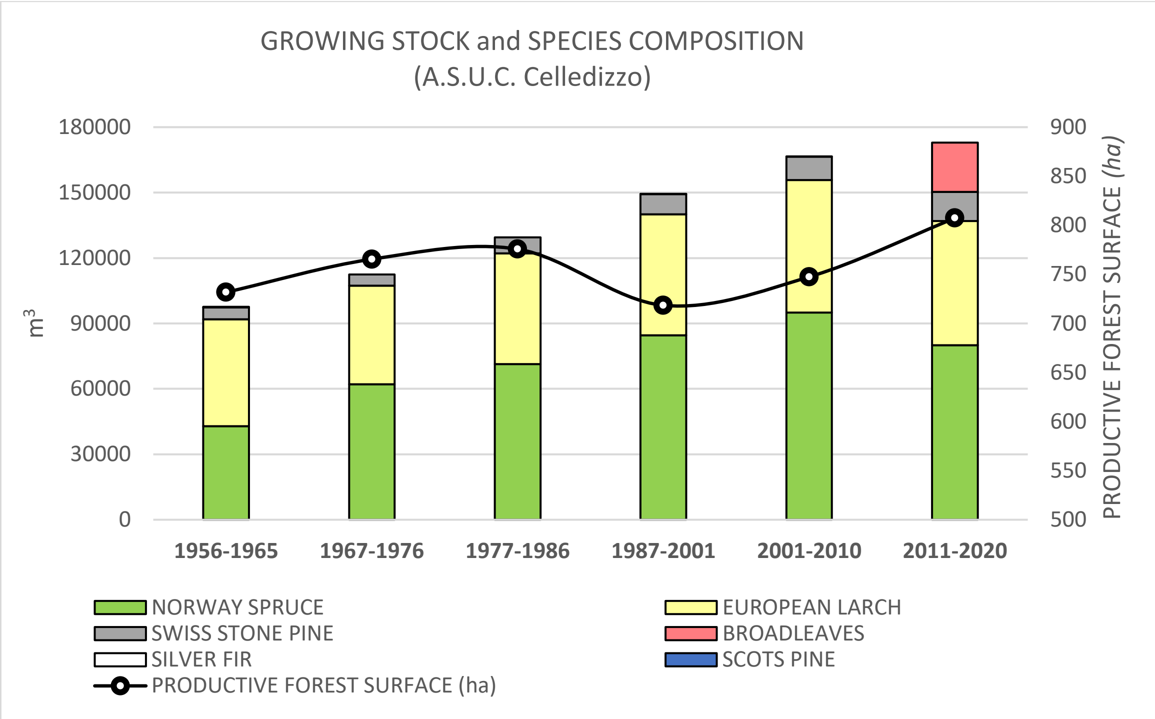


Figure 5.31: Comparison between forest surface and species composition variation for A.S.U.C Celledizzo between 1956 and 2019

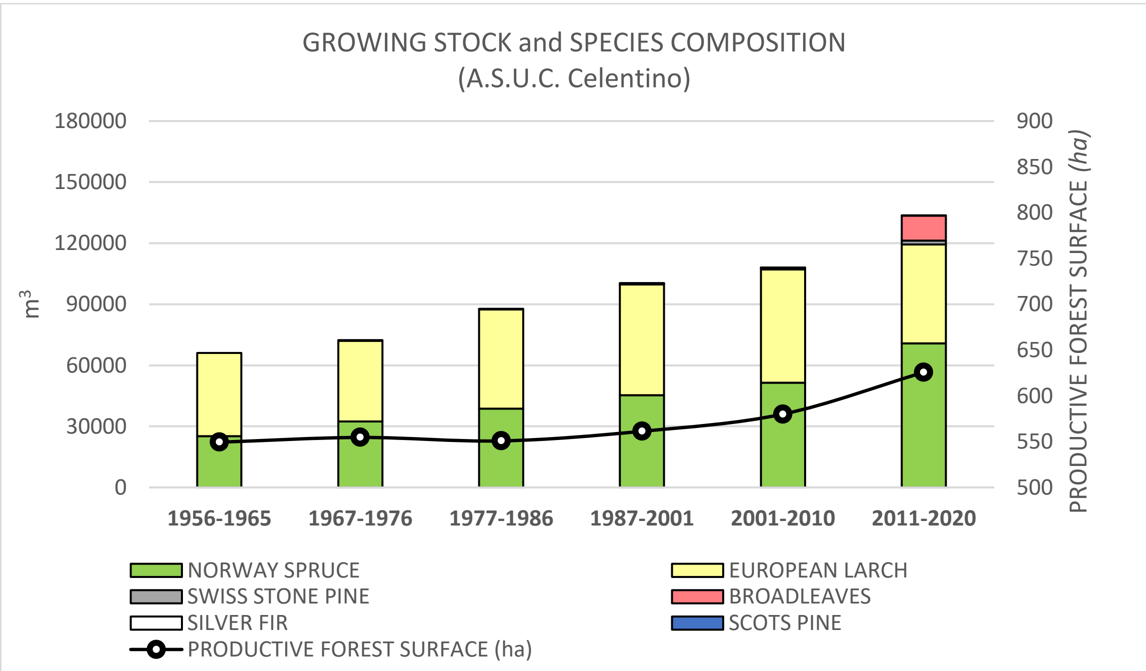


Figure 5.32: Comparison between forest surface and species composition variation for A.S.U.C Celentino between 1956 and 2019

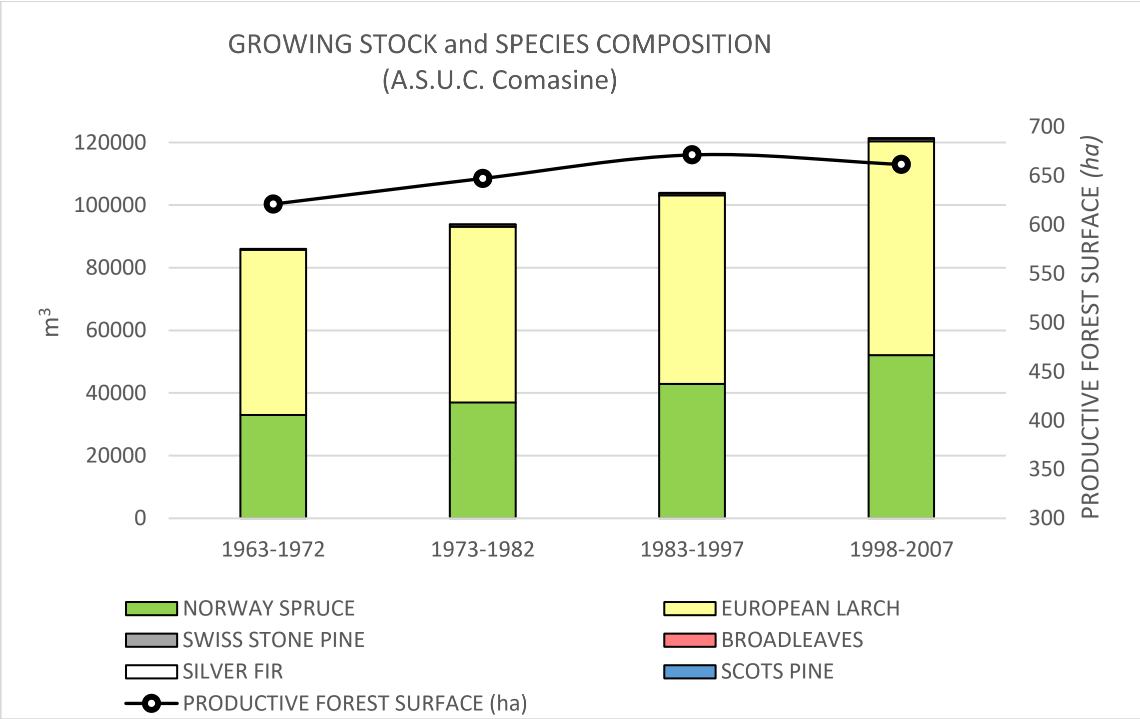


Figure 5.33 Comparison between forest surface and species composition variation for A.S.U.C. Comasine between 1963 and 2019

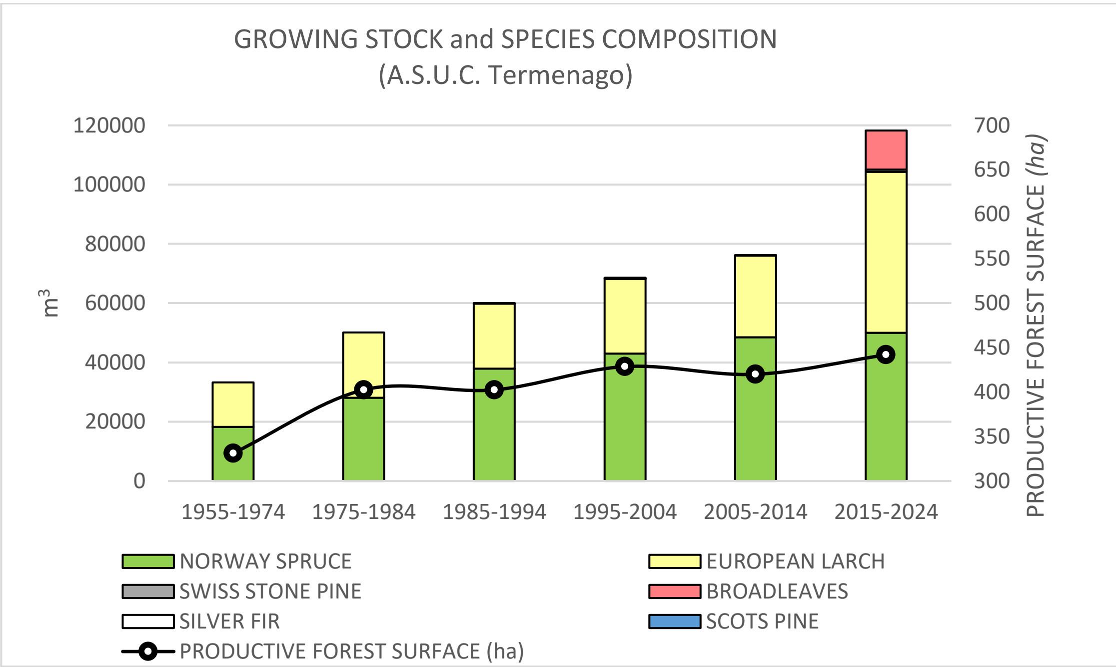


Figure 5.34: Comparison between forest surface and species composition variation for A.S.U.C Termenago between 1955 and 2019

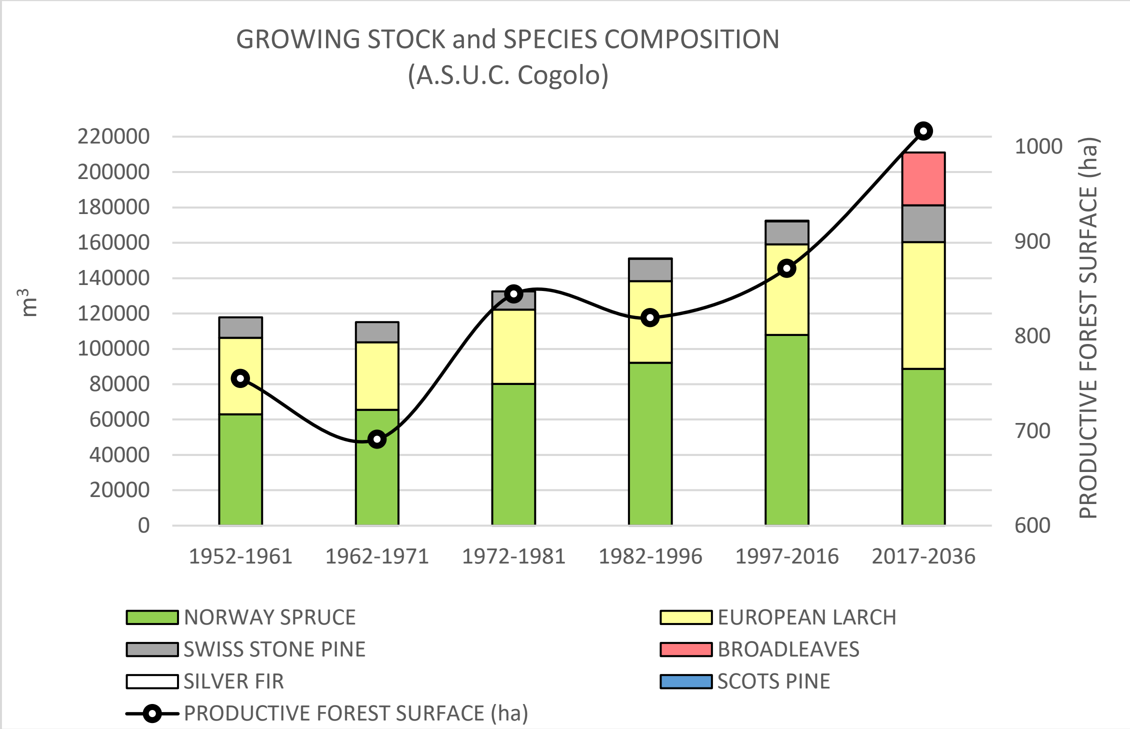


Figure 5.35: Comparison between forest surface and species composition variation for A.S.U.C Cogolo between 1952 and 2019

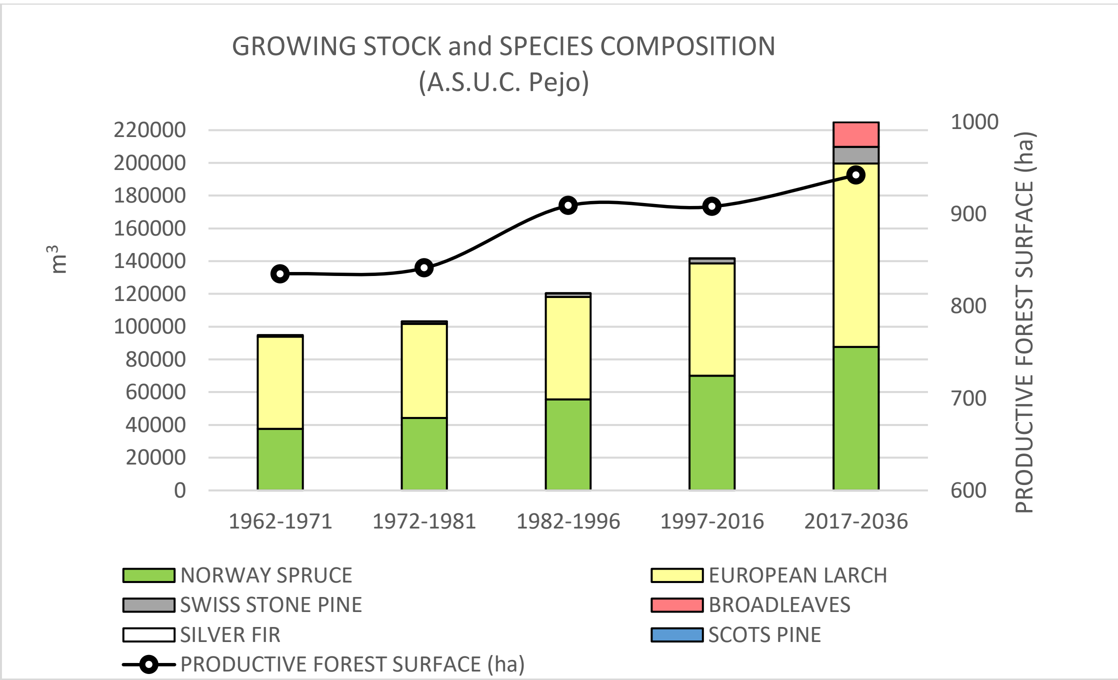


Figure 5.36: Comparison between forest surface and species composition variation for A.S.U.C Pejo between 1962 and 2019

What was expected to observe as a consequence of large disturbance occurrence was an increase of broadleaves (pioneer species) and European larch, which are the first to colonize the gap created in forest canopy; according to data analysis, it has been observed this trend, with the overall increasing also of Norway spruce in terms of volume; in terms of percentage, instead, the amount of European larch has decreased while Norway spruce and broadleaves has increased.

However, it has to be considered that at least until 2010s, broadleaves presence has been underestimated, since in the past field survey for management plan design focused just on the high forest; with the most recent techniques for management plant design, instead, also shrub vegetation is detected and this is why broadleaves amount seems to be increased, if compared to the past.

Despite these results, there are no unequivocal evidences that this trend is due to past disturbance events occurrence; in fact, these observations are more likely the result of two other process.

Firstly, the expansion of forest are the result of forest policies that after the end of the second world wars aimed at promoting the recovery of forests; in fact, forests were seriously damaged at the beginning of the XX century because of the Great war, that was fought on the ridges of these mountains and because of the intensive exploitation due to locals for getting their livelihoods.

Secondly, forest surface has increased as a consequence of the abandoning of mountain farming (e.g. mowing and pasture) starting from the ‘70s-‘80s (figure 5.37, figure 5.38, figure 5.39, figure 5.40).

Figure 5.37: A view of Peio valley from Pejo (year ‘60-70s)
(Reference; Gabrielli (1973) Cogolo e le fonti di Peio, p. 16)

Figure 5.38: A view of Peio valley from Pejo (year 2019)
(Picture: Francesca Michelon, 29.09.2019)

Figure 5.39: A view of Pejo from Cogolo (year: '70-80s)
(Reference: Lucietti Elvira)

Figure 5.40: A view of Pejo from Cogolo (year 2019)
(Picture: Francesca Michelon, 08.12.2019)

5.3 REGENERATION DEVELOPMENT IN WINDTHROW AREAS

5.3.1 REGENERATION SPECIES

It has been analysed the composition of regeneration species (figure 5.41).

In general, the most of regeneration is represented by Norway spruce (49.9%), followed by European larch (45.8%) and Swiss stone pine (0.3%); among broadleaves silver birch is the most abundant (2.3%), followed by rowan (1.0%), goat willow (0.5%) and grey alder (0.1%).

In 2015 areas the 67.1% of the regeneration was represented by European Larch while Norway spruce regeneration represents the 26.0%; moreover, it has been found a 3.3% of silver birch, a 2.2% of rowan and a 1.4% of goat willow.

In 2003 areas, the 52.3% of regeneration present was Norway spruce, while European larch regeneration represents the 43.7%; moreover, it has been found a 3.5% of silver birch, a 0.3% of goat willow and another 0.3% of grey alder.

In 1990 areas, the 71.4% of the regeneration present was Norway spruce, while European larch regeneration represents the 26.5%; moreover, it has been found a 1.0% of Swiss stone pine *(Pinus cembra)*, a 0.7% of rowan and a 0.3% of grey alder *(Alnus incana)*.

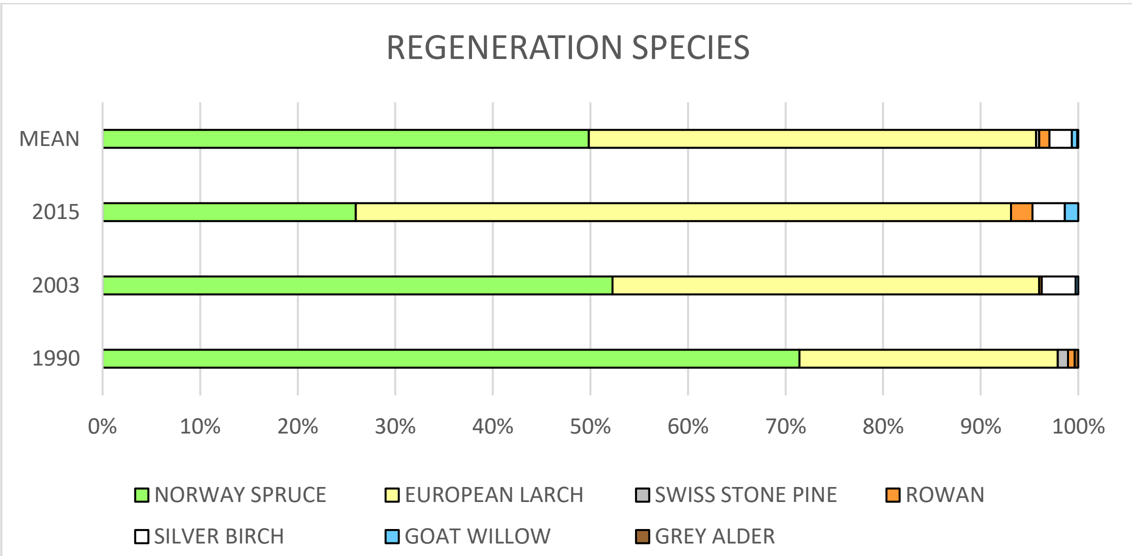


Figure 5.41: Overall species composition of regeneration and for each event year

Considering the temporal scale, it is expected that right after the event, the first species to develop is European larch because of its pioneer characteristics, while Norway spruce will increase its presence as time from the event passes.

In fact, these expectations meets the field observations, since in the most recent areas of 2015 the 67.1% of regeneration is represented by European larch, while in the oldest ones

Norway spruce is the predominant species (71.4%); in 2003 areas, instead, European larch and Norway spruce regeneration are present with roughly equal quantities, slightly unbalanced toward Norway spruce.

Moreover, the presence of Swiss stone pine just in 1990 areas meets the expectation for which this species is the last that appears in plant succession (*"climax species"*), because of its slow growth and low competition capacity (Ulber et al. 2004).

Broadleaves are present, but with very few plants.

This may be explained by the fact that transects were located a mean elevation of 1741 m a.s.l. (between 1560 and 1945 m a.s.l.), where conifers are the dominant species; however, broadleaves such as silver birch and rowan are adapted to these elevations, thus a such low presence has to be due to some other factors that are affecting ecosystem dynamics.

5.3.2 DEADWOOD CHARACTERISTICS

In terms of quantity the amount of deadwood within the areas surveyed has been classified with a scale from 1 to 3 from , where 1 indicates the presence of a small amount of deadwood, whereas 3 correspond to the presence of significant quantities of deadwood within the site (Figure 5.42, Figure 5.43).

The mean deadwood amount value, considering the 28 sample areas surveyed, is 1.64; more specifically, it is 1.50 for 1990 areas, 1.90 for 2003 areas and 1.50 for 2015 areas.

Figure 5.42: Sample area on A.S.U.C. Celledizzo, 2003 event; Grass cover = 3; Deadwood = 3
(Picture: Francesca Michelon, Strente, 15.10.2019, 1750 m asl)

Figure 5.43: Sample area on A.S.U.C. Celentino, 2003 event; Grass cover = 2; Deadwood = 2
(Picture: Francesca Michelon, 16.10.2019, 1750 m asl)

Focusing on the type of deadwood, in total 140 pieces of deadwood have been measured, of which 51 stumps, 50 uprooted stumps and 39 logs, roughly equally distributed for the three different time period (Figure 5.44).

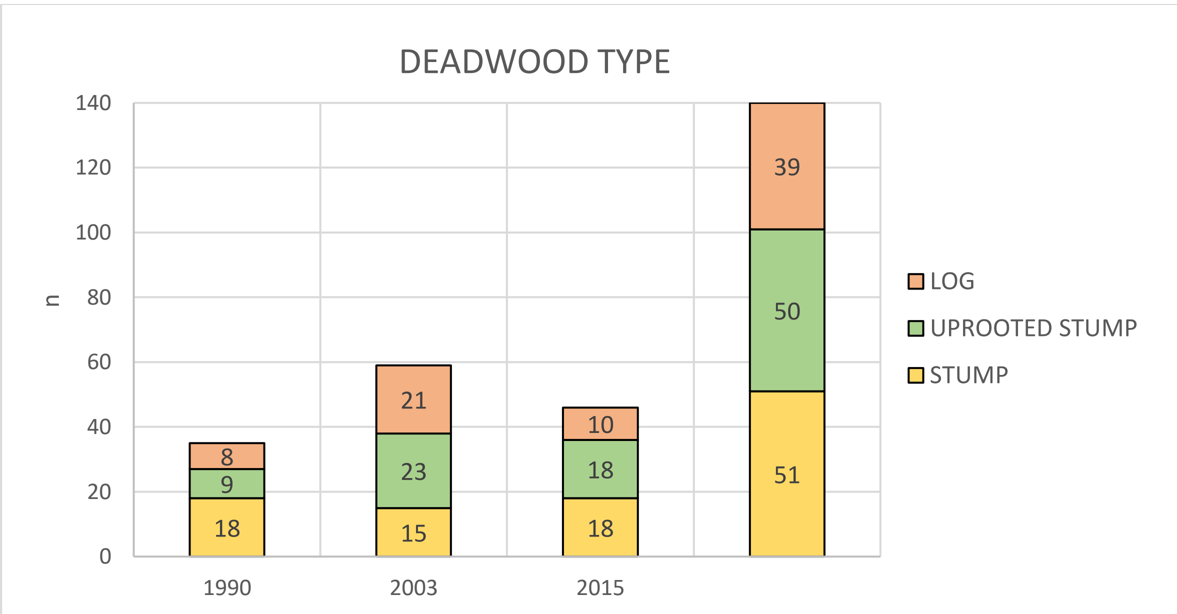


Figure 5.44: Type of deadwood measured for each of the three events and the overall amount

For each event, deadwood has been classified according to the decomposition stage, on a scale from 0 to 4.

In 1990 areas, 35 deadwood pieces have been measured of which 18 stumps, 9 uprooted stumps and 8 logs (figure 5.45); the prevalent decomposition stage degree was 3.

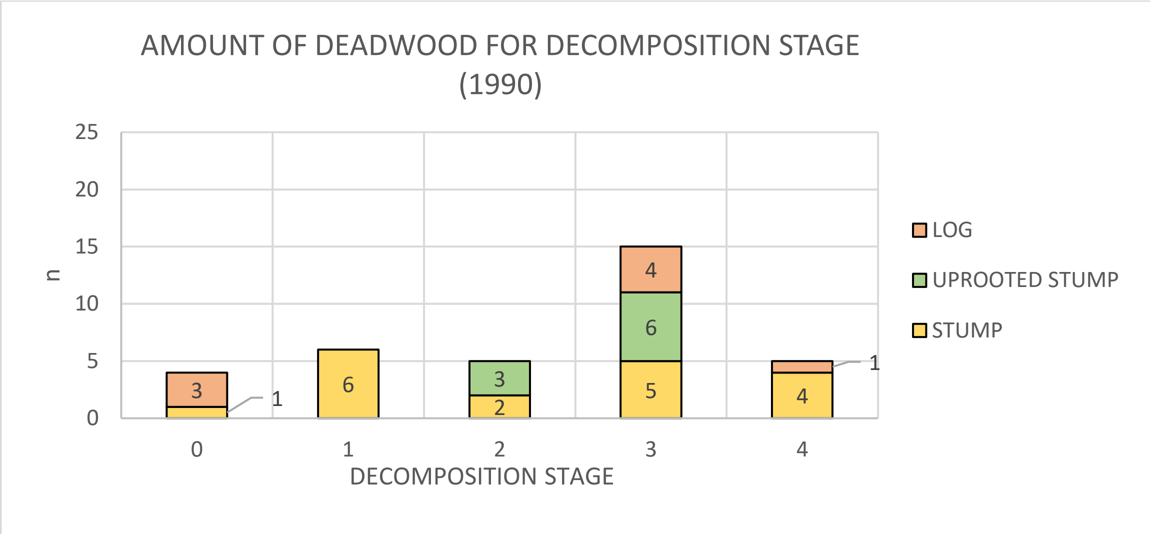


Figure 5.45: Amount of deadwood for decomposition stage for each type for areas sample of 1990 event

In 2003 areas, 59 deadwood pieces have been measured, of which 15 stumps, 23 uprooted stumps and 21 logs (figure 5.46); the prevalent decomposition stage degree is between 2 and 3.

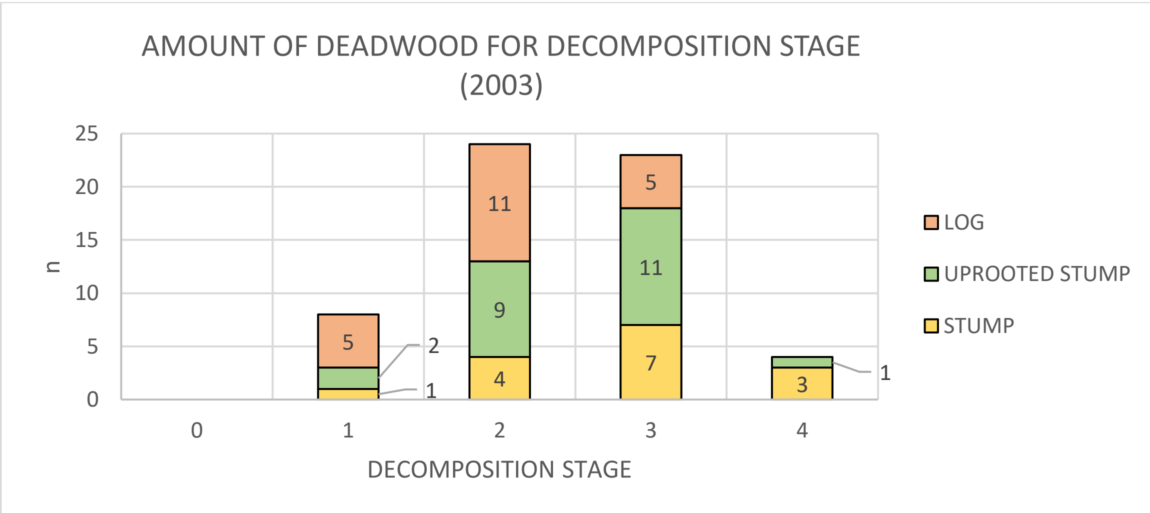


Figure 5.46: Amount of deadwood for decomposition stage for each type for areas sample of 2003 event

In 2015 areas, 46 deadwood pieces have been measured, of which 18 stumps, 18 uprooted stumps and 10 logs (figure 5.47); the prevalent decomposition stage degree is between 0 and 1.

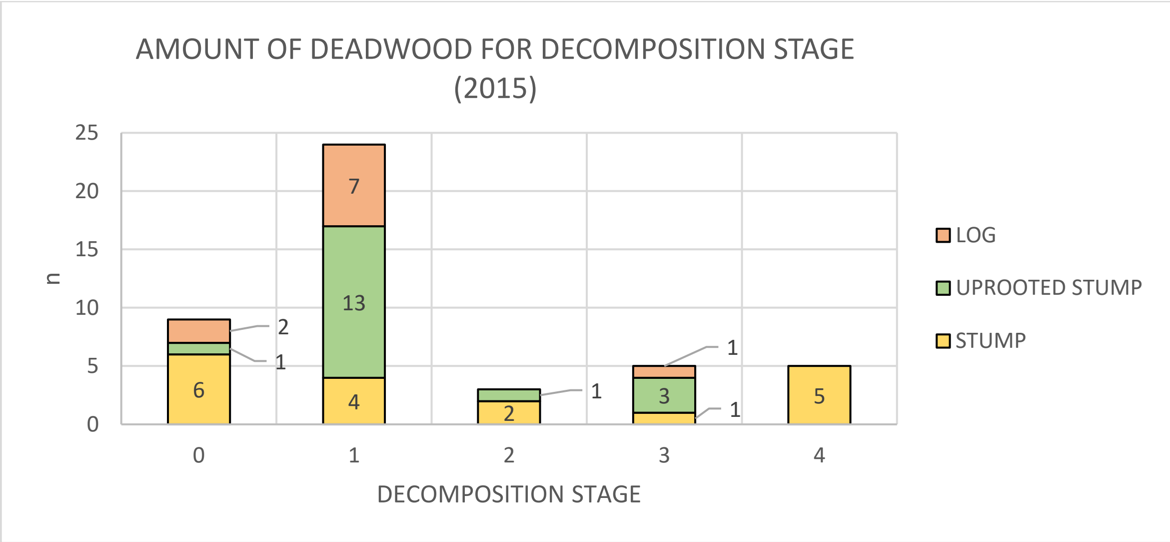


Figure 5.47: Amount of deadwood for decomposition stage for each type for areas sample of 2015 event

The presence of decomposition stage 0 in 1990 areas is probably due to the fact that recently trees have been downed; on the same way, deadwood characterized by a decomposition stage of 4 in 2015 areas, is due to the presence of deadwood before the disturbance event occurrence.

In 1990 areas, the amount of deadwood measured is lower also because after 30 years, it is very likely that most of the material has already been completely decomposed.

5.3.3 REGENERATION LOCATION

According to field observations, deadwood is chosen as a site for regeneration to grow; in fact, according to many authors (Harmon et al. 1986, Titus 1990, Zanin 2001, Marzano et al. 2013, Leverkus et al. 2019), woody debris, when significantly decomposed, constitute a preferred establishment microsite for some tree species, because of the many advantages offered.

In fact, after salvage logging, grass and forbs grow vigorously (Bergquist & Orlander 1998), thus regeneration has to compete for resources (Eis 1981, Kokkonen et al. 2018).

Grass cover within the sample areas has been classified with a scale from 1 to 3, where 1 represents a not significant grass cover with short forbs and grass, while 3 corresponds to a complete grass cover with tall forbs and grasses (figure 5.48).

Figure 5.48: Sample area on A.S.U.C. Comasine; Grass cover = 3; Deadwood = 2
(Picture: Francesca Michelon, 15.10.2019, 1600 m asl)

The mean grass cover resulted to be 2.36; in 1990 areas it is 2.0, in 2003 areas 2.4 and in 2015 2.6.

As expected, grass cover is highest in the more recent areas, for then decreasing as time from the disturbance passes; in fact, in 1990 areas the grass cover is the lower if compared to the other sampled areas.

To verify whether grass cover influences regeneration development, it has been investigated where regeneration has grown (figure 5.49) distinguishing between on the ground and on deadwood.

For 2015 areas the 70.7% of the regeneration measured was located on the ground and the 29.2% on deadwood (5.2% on stumps, 22.9% on the clod of earth of the uprooted stumps and 1.1% on logs).

For 2003 areas the 51.7% of the regeneration measured was located on the ground and the 48.3% on deadwood (4.8% on stumps, 39.5% on the clod of earth of the uprooted stumps and 4.0% on logs).

For 1990 areas the 71.7% of the regeneration measured was located on the ground and the 29.0% on deadwood (9.8% on stumps, 15.7% on the clod of earth of the uprooted stumps, 3.5% on logs).

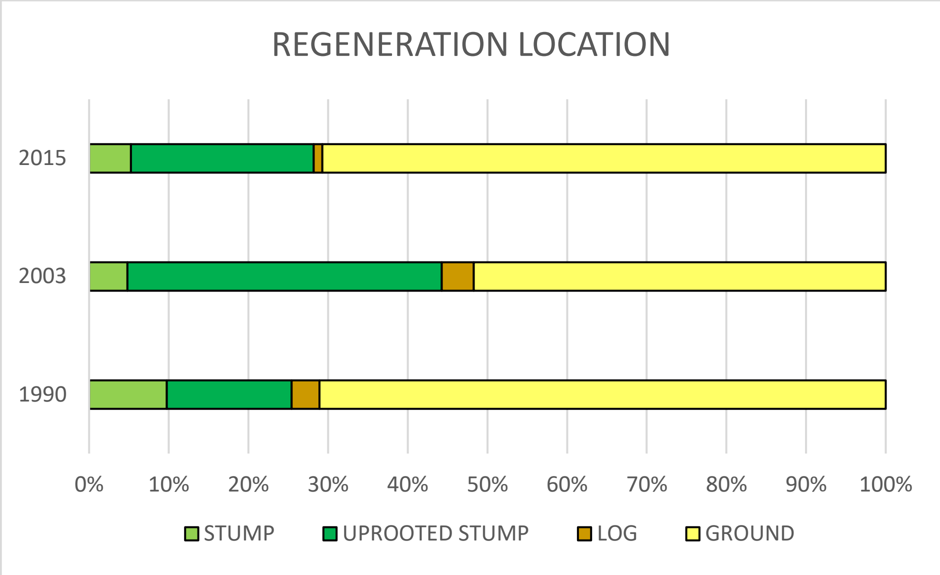


Figure 5.49: Location of regeneration for each event year

Then also the amount of regeneration grown on deadwood and on the ground for the three different grass cover has been examined (figure 5.50).

For a limited and medium grass cover, the most of regeneration is located on the ground, while with a high grass cover, the amount of regeneration is roughly half on the ground and half on deadwood.

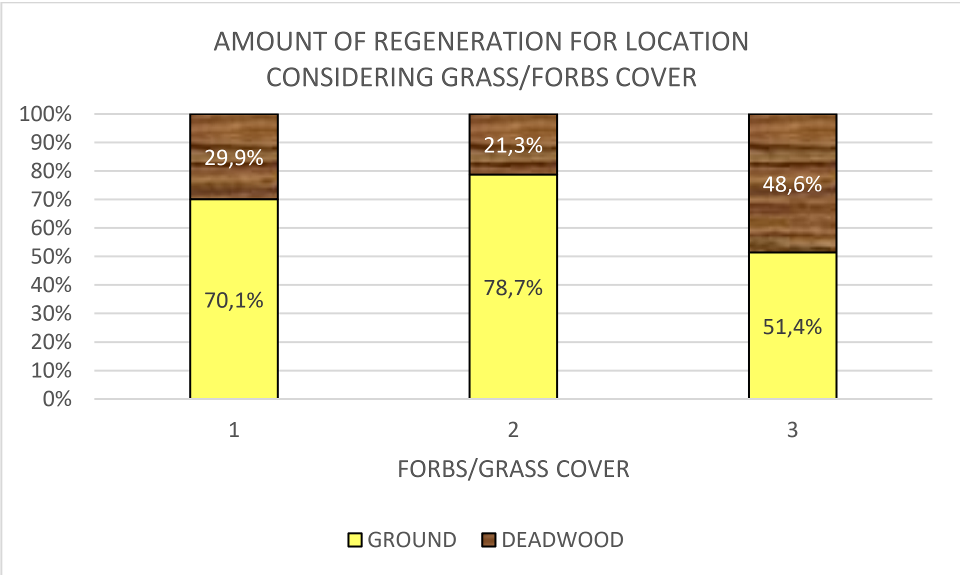


Figure 5.50: Amount for location of regeneration considering forbs/grass cover

In accordance with the results, the most of regeneration was located on the ground for all the three different events, where in all the three cases the mean grass cover is above 2.

Moreover, according to the expectation, where there is a high grass and forbs cover, it is likely the most of regeneration grow at a higher position than on the ground, i.e. on deadwood or rocks.

Considering the amount of regeneration for each grass cover regardless the event, it emerges that for a high grass cover (level of 3) regeneration seems to seek for an elevated position to grow, in order to avoid competition; however, the share of regeneration growing on the ground is still significant (roughly half of the total).

However, basing on the results, it is not possible to affirm that the higher is the grass cover, the higher is the share of regeneration that grow on deadwood; in fact, for a grass cover of 2, the ¾ of regeneration is located on the ground.

This may be an effect of the *operator error* since the grass cover has been attributed by the operator on the basis of a personal visual assessment, i.e. on an subjective base, that is very likely to give rise to an error, especially in defining what is an intermediate grass cover.

Anyway, for all the events the 36.1% of regeneration has grown on deadwood, i.e. at a higher position with respect of the ground; according to field observation this higher position is more frequently represented by the clod of earth of uprooted stump for all the three events. This happens because organic and mineral soil is exposed, that is known representing a preferential microsite for regeneration establishment (Ulanova 2000, Waldron et al. 2014).

To support this view the is also the fact that the highest regeneration density has been observed on uprooted stumps, with a density of 6.73 plants/each; on stump this density is 2.60, while for each log density was 3.63 (table 5.4).

A little share of regeneration on the ground has been observed to be slightly elevated because of the presence of a rock, that in most of the cases was covered by a moss-litter carpet; according to field observation the density of regeneration on rocks is on average 2.60 plants for each rock surveyed, suggesting the significant role of this element for forest regeneration as observed also by Ulanova (2000).

	STUMP	UPROOTED STUMP	LOG	ROCK
regeneration/location	**2,60**	**6,73**	**3,63**	2.60

Table 5.4: Regeneration density for each deadwood type and for rocks

Norway spruce regeneration on a stump
(Picture: Francesca Michelon, 13.10.2019, Gatùs, 1490 m asl)

Norway spruce and European larch regeneration on an uprooted stump
(Picture: Francesca Michelon, 13.10.2019, Valiselle, 1810 m asl)

Norway spruce regeneration on a log
(Picture: Francesca Michelon, Valiselle, 13.10.2019, 1800 m asl)

European larch regeneration on a rock
(Picture: Francesca Michelon, Cavaion, 30.09.2019, 2300 m asl)

5.3.4 REGENERATION MEAN HEIGHT

Regeneration height has been analysed, in order to be used as an indicator of forest recovery process assessment.

Considering the sample of 1024 plants measured, the mean regeneration height is 47.8 cm.

In 2015 areas the mean height is 13.1 cm, in 2003 areas the mean height is 56.7 cm, while in 1990 areas mean height is 79.6 cm (figure 5.51).

From a statistical point of view, there is a very significant difference between mean height value of regeneration in areas 1990-2015 and areas 2003-2015, because of a *p-value* < 0.001; on the contrary, the mean height value of 1990-2003 areas, there is not a significant difference because of a *p-value* of 0.2636.

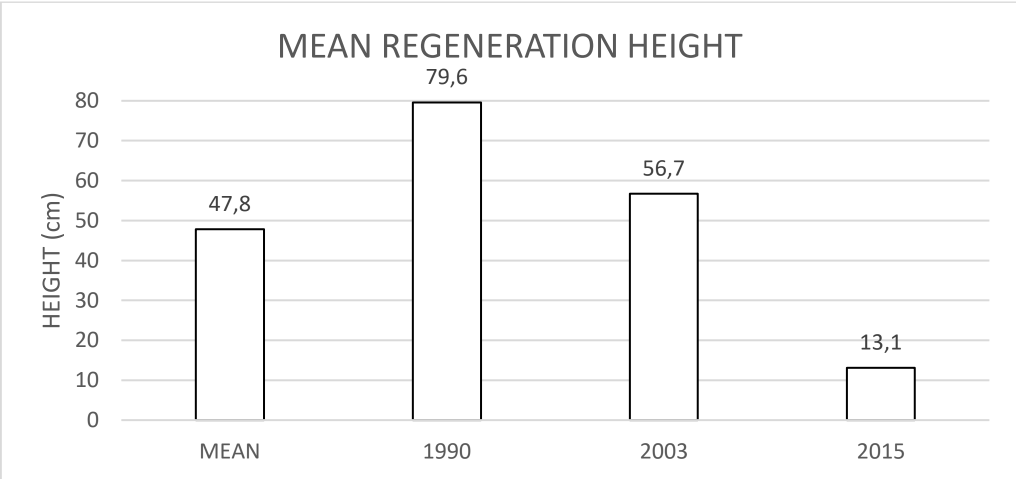


Figure 5.51: Mean regeneration height of regeneration

The mean height according to where it has grown has been analysed, firstly distinguishing between on the ground and on deadwood (figure 5.52), for then analysing more in detail the different location described in paragraph 5.3.3 (figure 5.53).

The overall mean height on plants on the ground is 46.4 cm, while that grown on deadwood is 50.0 cm; according to statistics, these value are not significantly different *(p-value = 0.674)*.

For 1990 event mean height of regeneration on the deadwood was 96.4 cm and 72.8 cm for regeneration on the ground; from a statistical point of view there is not a significant difference between the two height values *(p-value = 0.334).*

For 2003 event mean height of regeneration on deadwood was 52.7 cm and 60.5 cm for regeneration on the ground; from a statistical point of view there is not a significant difference between the two height values *(p-value = 0.0996)*.

For 2015 event mean height of regeneration on the deadwood was 9.01 cm and 14.8 cm for regeneration on the ground; from a statistical point of view there is a highly significant difference between the two height values *(p-value < 0.001).*

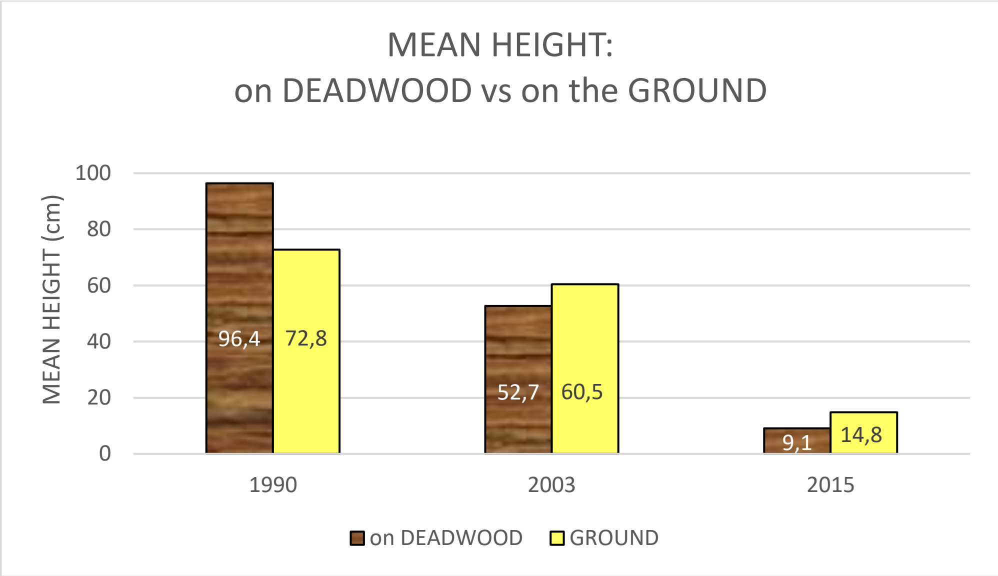


Figure 5.52: Mean regeneration height according to its location

For 1990 event the mean height of the regeneration, on stumps was 83.4 cm, on uprooted stumps 109.9 cm and on logs 71.6 cm; according to statistics, there is not a significant difference between these values *(p-values > 0.05)*.

For 2003 event the mean height of the regeneration on stumps was 64.6 cm, on uprooted stumps 54.7 cm and on logs 18.6 cm.

According to statistics, there is a highly significant difference between mean height of regeneration grown on uprooted stumps and logs *(p-value < 0.001)* and on logs and on the ground *(p-value < 0.001)*; moreover, there is a significant difference between mean height of regeneration grown on stumps and logs *(p-value < 0.05)*.

There is no significant difference between regeneration grown on stumps and uprooted stumps *(p-value = 0.94)*, stumps and on the ground *(p-value = 0.7971)*, on uprooted stumps and on the ground *(p-value = 0.4011)*.

For 2015 event the mean height of regeneration on stumps was 9.4 cm, on uprooted stumps 9.3 cm and on logs 4.0 cm.

According to statistics, there is a highly significant difference between mean height of regeneration grown on stumps and on the ground *(p-value < 0.001)* and regeneration grown on uprooted stumps and on the ground *(p-value < 0.001)*; moreover, there is a significant

difference between mean height of regeneration grown on stumps and uprooted stumps *(p-value = 0.04159)* and regeneration grown on stumps and logs *(p-value = 0.01084)*.
There is no significant difference between regeneration grown on uprooted stumps and logs *(p-value = 0.3903)* and on logs and on the ground regeneration *(p-value = 0.5224)*.

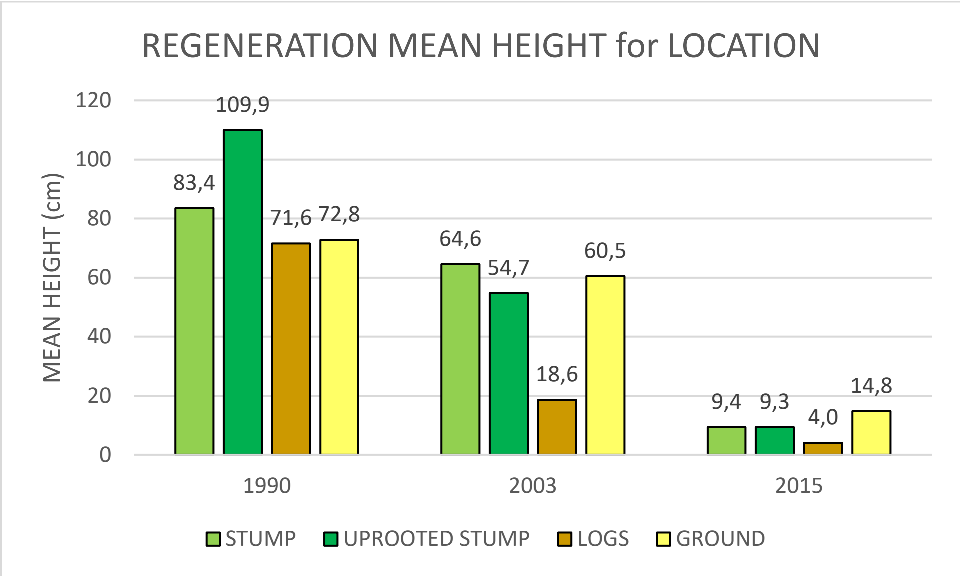


Figure 5.53: Regeneration mean height considering its location

For 1990 event, regeneration grown on deadwood is the highest, in particular that grown on uprooted stumps, followed by regeneration grown on stumps; regeneration grown on logs and on the ground are characterized by a similar mean height, as confirmed also by statistics for which there is not a significant difference.
For 2003 event, regeneration grown on stumps is the highest, followed by that grown on the ground and that grown on uprooted stumps; however, from a statistical point of view there is not a significant difference between these values.
For 2015 event, also according to statistics, there is not highly significant difference in mean height between regeneration grown on deadwood and on the ground.

As expected, the mean regeneration height increases as time from the disturbance event passes.
Moreover, considering where regeneration has grown, it has been observed that for 2003 and 2015 events, regeneration grown on deadwood is shorter than that grown on the ground; for 1990 event, instead, regeneration grown on deadwood is higher than that grown on the ground.

These results meet the expectations.

In fact, in the first stage of development, regeneration on the ground has to win the competition for resources especially with forbs and grasses; as a result, young seedlings invest much of their energy in growing in height (Eis 1981, Ramming et al. 2005).

For this reason, it is expected that in more recent areas (2003 and 2015) the mean height of regeneration grown on the ground is higher than that grown on deadwood; in fact, this is what has been observed for 2003 and 2015 areas, as well as confirmed by statistics for 2015 areas, while for 2003 areas statistics do not confirm the significance of the difference between the two values.

For 1990 areas, regeneration grown on the ground is shorter, because tree height growth decreases once the competition with forbs and grasses has been overcome; in fact, what has been observed in these areas are survived saplings to natural selection, for which the dominant ones succeed while the dominated ones will die.

This hypothesis has been tested by the analysis of the mean height of regeneration on the ground and on deadwood related to grass cover (Figure 5.54).

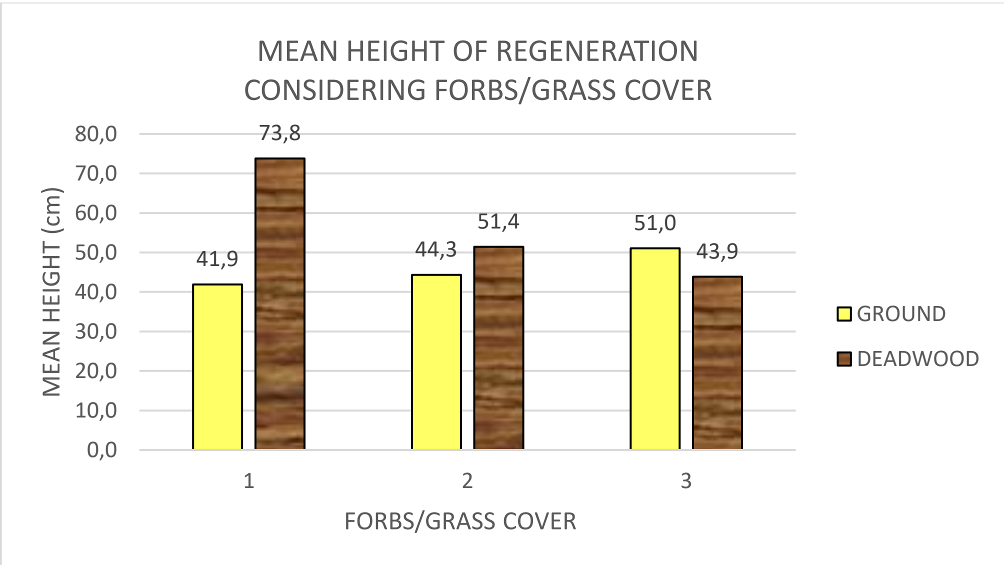


Figure 5.54: Mean height of regeneration considering forbs/grass cover

What emerged is that when grass and herbs cover is the highest (level 3), regeneration on the ground is higher than that grown on deadwood; this difference is highly significant also from a statistical point of view *(p-value* < 0.001*)*.

With a lower grass and herbs cover (level 1) the observation has been the opposite, i.e. regeneration on the ground is shorter than regeneration on deadwood; this difference is highly significant also according to statistics *(p-value* > 0.001*)*.

For a medium grass and herbs cover (level 2), the trend is the same observer for a grass and herbs cover level of 3, but from a statistical point of view, there is not a significant difference *(p-value = 0.7425)*.

Moreover, growing at an higher position to the forest floor allow to anticipate the starting of the growing season, that is a very important advantage for plants, especially in alpine environment where snow cover lasts until late spring; the depth of snowpack varies from winter to winter, but considering snowpack depth data available for Peio valley of the last 35 years, on average in April snow cover at 2000 m asl was 60.0 cm (figure 3.5).

The mean elevation from the ground for all the regeneration measured considering the whole amount of regeneration measured is 95.0 cm.

Therefore, anticipating the beginning of the growing season, means a longer period for plants to grow, thus a faster development of seedlings; therefore, in absence of a dense grass cover, it is expected that regeneration grown on deadwood is higher than that grown on the ground. This is exactly what has been observed also by this research, where for a low grass cover (level 1) regeneration on deadwood (71.3 cm) is the 76.1% higher than that grown on the ground (41.9 cm).

However, it has to be considered that in the long period an intraspecific competition will occur on deadwood; therefore, by time the number of individuals for each deadwood piece will decrease, whereas their dimension will increase.

It has been observed that the density of regeneration grown on deadwood decreases linearly as time passes (figure 5.55); this trend is confirmed also by statistics, because of a value of R^2 close to 1.

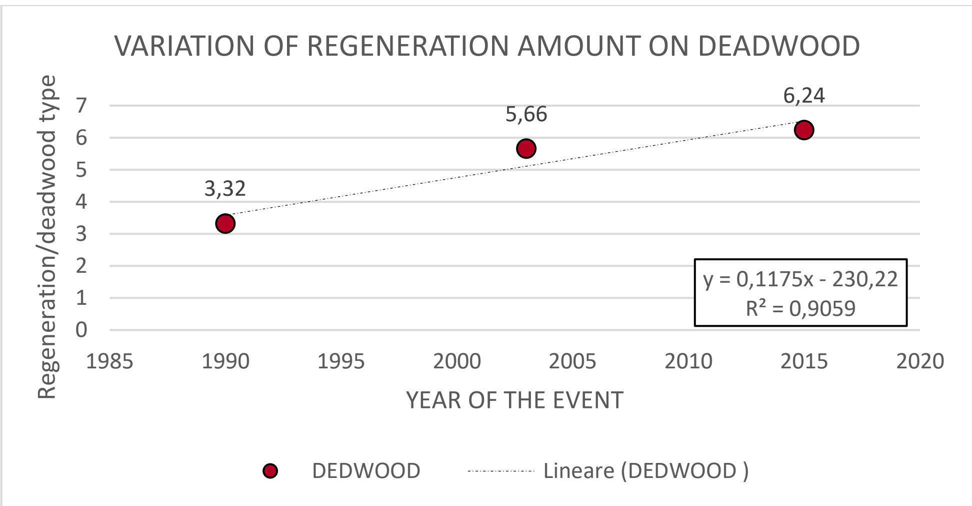


Figure 5.55: Variation of regeneration density on deadwood as time passes

Table 5.5 shows the regeneration density according to each deadwood type for each of the three events considered; except for stumps, the regeneration density decreases as time from the disturbance event passes.

	STUMPS	UPROOTED STUMPS	LOGS
1990	6,43	3,33	3,32
2003	7,05	3,75	5,66
2015	6,38	4,00	6,24

Table 5.5: Regeneration density according to each deadwood type for each event

5.4 WILDLIFE IMPACTS ON REGENERATION

During filed survey it has been observed a significant amount of browsed regeneration, that according to the characteristics of the study area is due to Ungulates and in particular to red deer *(Cervus elaphus)*; moreover, also antler fraying on young saplings has been detected.

5.4.1 BROWSING

5.4.1.1 BROWSED SPECIES

By data analysis it has emerged that the 30.6% of the regeneration was browsed.

Examining the phenomenon of browsing for each of the three different time period considered, the results show that for 2015 event the 15.7% of regeneration was browsed, for 2003 areas the 47.5% and for 1990 areas the 27.2% (Figure 5.56).

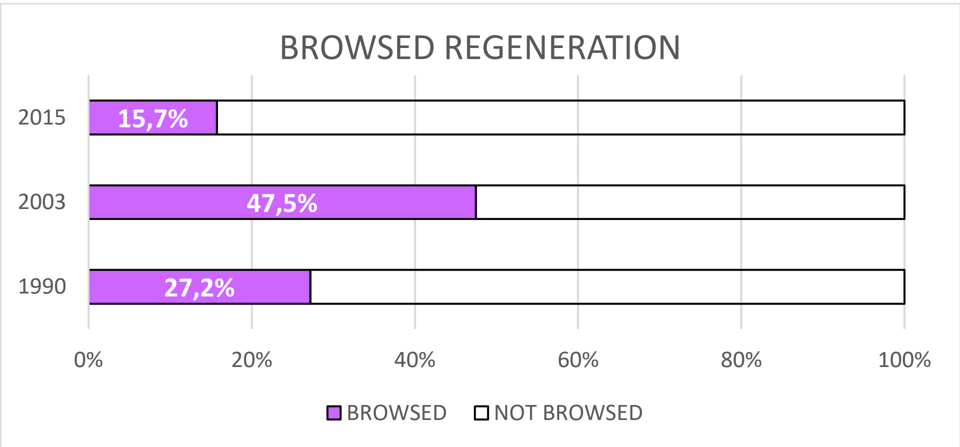


Figure 5.56: Percentage of browsed regeneration according to the event year

Regardless the species, the lowest percentage of browsed regeneration (15.7%) has been observed in 2015 areas; in 2003 event, this percentage is more than the double (47.5%) if compared to 2015 event, while for 1990 event, is between the 2003 and 2015 ones (27.2%). The most browsed is European larch (55.3%), followed by Norway spruce (38.7%), silver birch (2.6%), rowan (1.9%), goat willow (1.0%) and Swiss stone pine (0.3%) (Figure 5.57).
More specifically, for the 2015 event, European larch is more browsed (66.7%) than Norway spruce (21.1%); for the 2003 event, the trend is the same (56.7% European larch and 43.6% Norway spruce).
For the 1990 event, Norway spruce (51.3%) is more browsed than European larch (43.6%).

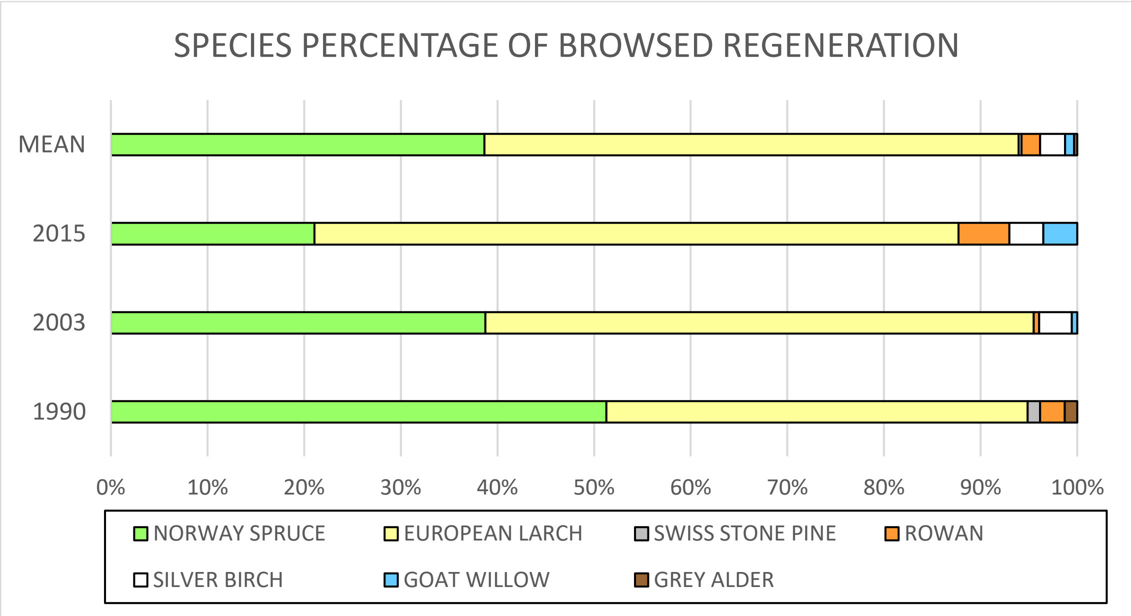


Figure 5.57: Regeneration browsed for each species and for each event year

Therefore, European larch is the most browsed species, even more than Norway spruce, mainly because of its tender leaves that are more palatable for Ungulates.
However, despite Norway spruce is less browsed than European larch, the browsed amount (38.7%) is higher than the mean provincial one, that has been determined to be 19.0% by a research of the provincial forest service in 2001.
It has also been observed that the amount of European larch regeneration browsed decreases by time, probably because either its presence within the forests decreases as time passes with the consequent increase of Norway spruce regeneration, that in turn is more browsed in the oldest areas, or because this species has been so intensively browsed that just a few of them have survived; this trend follow the species composition variation shown

in paragraph 5.2, suggesting that regeneration browsing has not significantly affected the ecosystem dynamic observed.
However, considering the results of a research of Trentino forest service in 2001, that by means of exclosures highlighted that in absence of deer browsing regeneration density is higher and species composition involves more species (in particular broadleaves), it is suggested that the percentage of deer browsing on broadleaves is higher than that detected by the results; however, it is not possible to give a precise estimation, since it is very likely that pressure exerted by Ungulates is responsible for the disappearing of a species (Szwagrzyk et al. 2018), thus the impossibility of detecting its presence, do not allow to estimate its browsing percentage.
This is the case of silver fir, that used to be present in Peio valley forest; however, it is very likely that its disappearance is due to high red deer density, since there are many areas suitable for the growth of this forest species within the valley.
To support this hypothesis, forest management plan of A.S.U.C. Cogolo for the period 1972-1981 reports on forest n. 26 the presence of a few trees of silver fir, that in the following management plans have not been detected anymore; however, nowadays single trees are present on forest property of A.S.U.C. Comasine.

According to many authors (Aldous 1944, Pedrotti & Bragalanti 2008, Motta 1996, Carmignola 2001) the most of regeneration browsing occurs during winter (i.e. in wintering areas), where the ground is covered by a snowpack, whose depth varies during winter as a consequence of the alternance of snowfalls and snow melting.
The low percentage of browsed regeneration in 2015 areas can be explained taking into consideration the mean regeneration height that is 13.1 cm; in fact, for the whole winter period, regeneration is protected by the snowpack, thus browsing occurs just where snow melts soon, as it happen on south-facing slopes; according to Carmignola (2001) regeneration shorter than 40 cm benefits from protection provided by snow.
On the contrary, in 2003 areas, where the mean height of regeneration is 56.7 cm, the protection offered by the snowpack come less or anyway, there will be always a share of regeneration that emerges from the snowpack that, thus, can be browsed; since the protection threshold suggested by Carmignola (2001) is 40 cm, it is evident that in these areas regeneration is more browsed.

The same process happens in 1990 areas, but since the higher mean height (79.6cm) and because of the fact that when the plant exceeds one meter in height browsing the shoot apex is difficultly browsed (Carmignola 2001), it is very likely that browsing percentage is lower than 2003 event, but higher than 2015 event because of the "double protection" that regeneration benefits in these areas.

However, the protection provided by the snow can come less also during no snowy winters, that increases the deer survival and expose more regeneration to the potential browsing damage; this potential exists also during the summer, but actually in this season Ungulates feed mainly on grass.

5.4.1.2 THE ROLE OF DEADWOOD IN PROTECTING FROM BROWSING

However, it is believed that deadwood offers protection to regeneration from browsing.

To verify this hypothesis, it has been analysed the location of browsed regeneration, distinguishing between browsed regeneration *"on the ground"* and *"on deadwood"* (Figure 5.58).

In general, the 21.3% of regeneration browsed was on the ground, while just the 9.3% was on deadwood.

In 1990 areas the 21.3% of regeneration browsed was on the ground, while the 5.9% on deadwood.

In 2003 areas the 29.3% of regeneration browsed was on the ground, while the 18.1% on deadwood.

In 2015 areas the 13.0% of regeneration browsed was on the ground, while the 2.8% on deadwood.

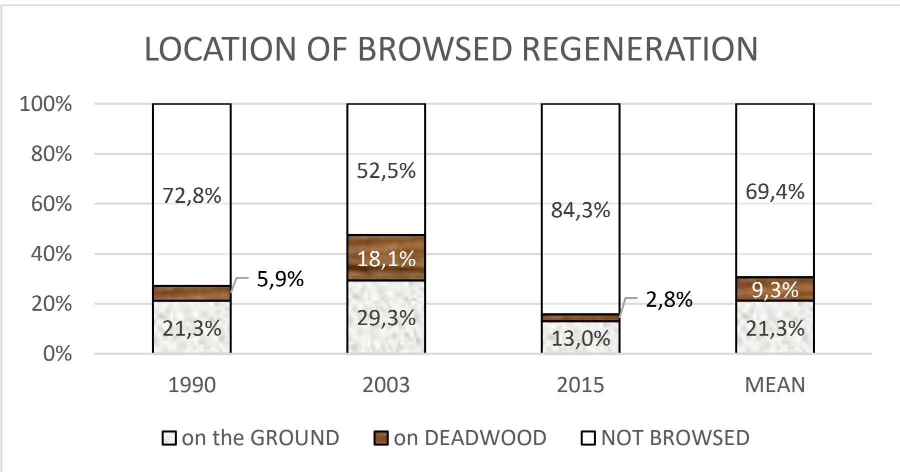


Figure 5.58: Location of browsed regeneration

According to these results, the most of the regeneration browsed was located on the ground, suggesting that regeneration grown on deadwood is more protected from browsing damages, in particular the shoot apex from which depend the vertical growth of the tree; therefore, it is very likely that browsed regeneration is on average shorter than the not browsed one.

In fact, according to Gómez-Aparicio et al. (2008) protection of saplings by ungulates significantly affect sapling growth, with evident effects on sapling height.

However, in the light of the data collected, browsed regeneration (58.4 cm) is on average higher than the not browsed one (43.0 cm) (figure 5.59); also statistics confirms that there is a highly significant difference between these two values *(p-value < 0.001)*.

Only for 1990 event it has been observed that browsed regeneration is shorter than the not browsed one and this difference is significant also from a statistical point of view *(p-value = 0.02671)*.

For 2003 and 2015 areas, height differences are also statistically significant *(p-value < 0.001)*.

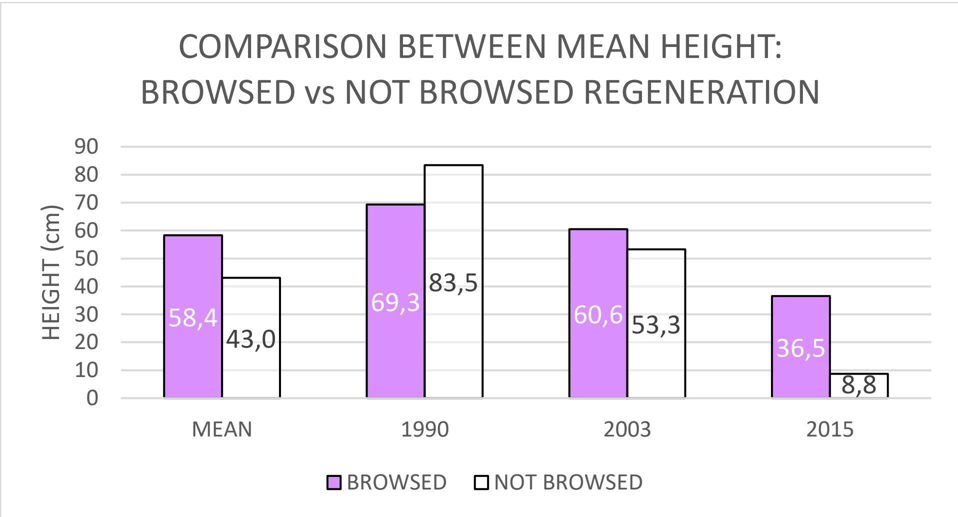


Figure 5.59: Comparison between mean height of browsed and not browsed regeneration

To find an explanation to these findings, it has been analysed the mean height of browsed regeneration considering its location, distinguishing between regeneration on deadwood and regeneration on the ground (figure 5.60).

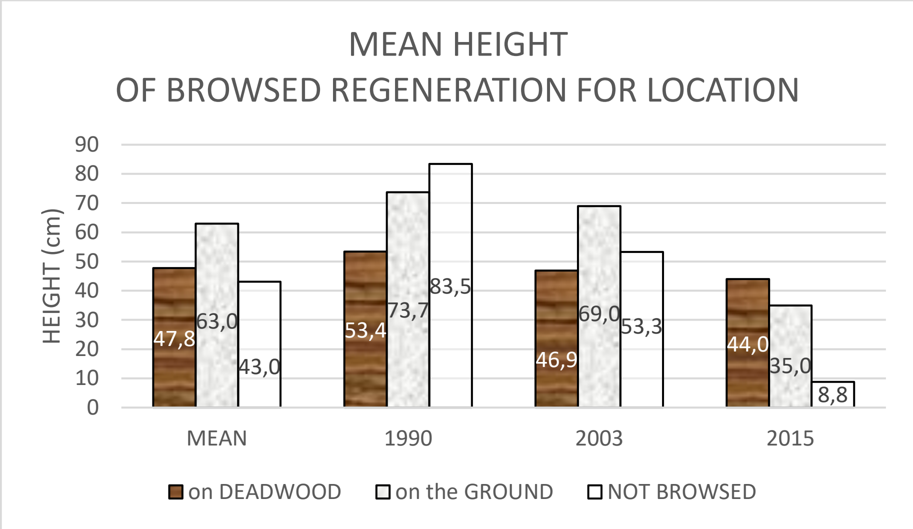


Figure 5.60: Comparison between mean height of browsed for location for each event

On average, browsed regeneration on the ground is higher than that grown on deadwood, but both are higher than that not browsed; these differences are considered significant from a statistical point of view (*p-value* < 0.05 among browsed regeneration, *p-value* < 0.001 between browsed and not browsed).

Focusing on the 1990 event, not browsed regeneration is higher than that browsed, but for this last category, again that on the ground is higher than that grown on deadwood; however, from a statistical point of view, these differences are not significant (*p-value* > 0.1), except for the difference between regeneration grown on the ground and not browsed regeneration (*p-value* < 0.05).

For 2003 event, browsed regeneration grown on the ground is the highest, while that grown on deadwood is shorter than the not browsed one; from a statistical point of view, there is a significant difference between browsed regeneration (*p-value* < 0.01) and between browsed regeneration on the ground and not browsed regeneration (*p-value* < 0.001), while between browsed regeneration on deadwood and not browsed regeneration there is not a significant difference (*p-value* $= 0.06323$).

For 2015 areas it has been observed that browsed regeneration is considerably higher than that not browsed, in particular that grown on deadwood; from a statistical point of view, there is not a significant difference between browsed regeneration (*p-value* $= 0.2194$), but there is a highly significant difference between not browsed regeneration and browsed ones (*p-value* < 0.001).

The fact that browsed regeneration on deadwood is on average shorter than that browsed on the ground may be attributed by two aspects.

Firstly, for what has been discussed above, i.e. that regeneration grown on the ground, in the first stages of forest succession, invest more in growing in height to win the competition with the herbaceous layer.

Then, another explanation is that, despite it is true that deadwood protect regeneration by elevating it from the soil, this protection may come less during winter, because of snow cover. In fact, in particular climatic conditions, the snowpack may be able to support the weight of an ungulate, cancelling the advantage of regeneration on deadwood of being grown at a higher position than on the ground.

This theory would explain why for 1990 and 2003 areas browsed regeneration on deadwood is shorter than browsed regeneration on the ground; for 2003 areas this difference is also statistically significant, while for 1990 areas that is not.

For 2015 areas, instead, browsed regeneration on deadwood is higher than the browsed one grown on the ground, probably because since the event is very recent compared to the others, regeneration on the ground is more stressed because of both browsing and competitions with grasses and forbs; this difference is also statistically highly significant.

However, despite different grass cover, the mean height of browsed regeneration on the ground has resulted to be the same (figure 5.61); also for statistics there is not a significant difference between the two *(p-value = 0.7015)*.

However, as already observed by the comparison between mean height of browsed and not browsed regeneration, also in this case not browsed regeneration is shorter than the browsed one; also from a statistical point of view, this difference is highly significant *(p-value < 0.001)*.

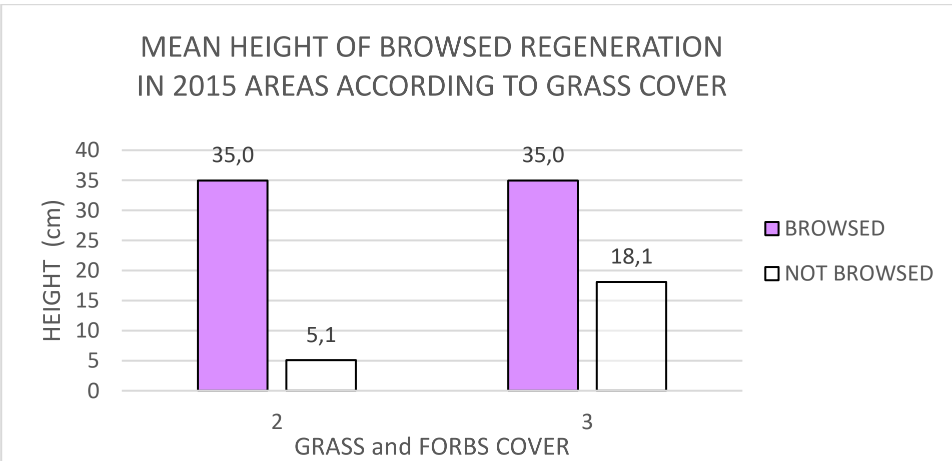


Figure 5.61: Comparison between mean height of browsed regeneration in 2015 according to grass cover

Therefore, there should be some other factor that has not been understood that is responsible for a higher mean height in browsed regeneration than in the not browsed one in the first development stage, since this trend has not been observed for the oldest areas.
It has to be considered that mean height is affected just if the shoot apex is browsed and since this study has not classified the type of browsing, this in some way affects the results obtained and until now discussed.
In fact, if browsing damages regarded lateral shoots rather than the shoot apex, due to the data collection method, it would be not possible to detect any differences in mean height.
In addition to have more precise data it should have been measured also the intensity of browsing, because when browsing of shoot apex is occasional, regeneration is able to recover and grow normally (Carmignola 2001).

5.4.2 ANTLER FRAYING

During field survey, it has been observed damages due to antler fraying (Figure 5.62).
11 damaged saplings have been counted, of which 10 saplings of European larch and just one of Norway spruce; this supports the view for which antler fraying occurs more often on European larch (Carmignola 2001).
Considering the total amount of regeneration sampled, just the 1.0% of regeneration has been damaged due to antler fraying.

Figure 5.62: Antler fraying damage on a European larch
(Picture: Francesca Michelon, 13.10.2019, Valiselle, 1940 m asl)

5.5 BROWSING IMPACT WITHIN STELVIO NATIONAL PARK

Peio valley is partially included in Stelvio National park area.

It has been observed that the 44.5% of the regeneration measured during field survey within Stelvio National park area was browsed (figure 5.63); this amount is much more of what reported by Carmignola (2001), that in 2001 assessed a 28.0% of browsed regeneration within the area of Peio valley included in Stelvio National park.

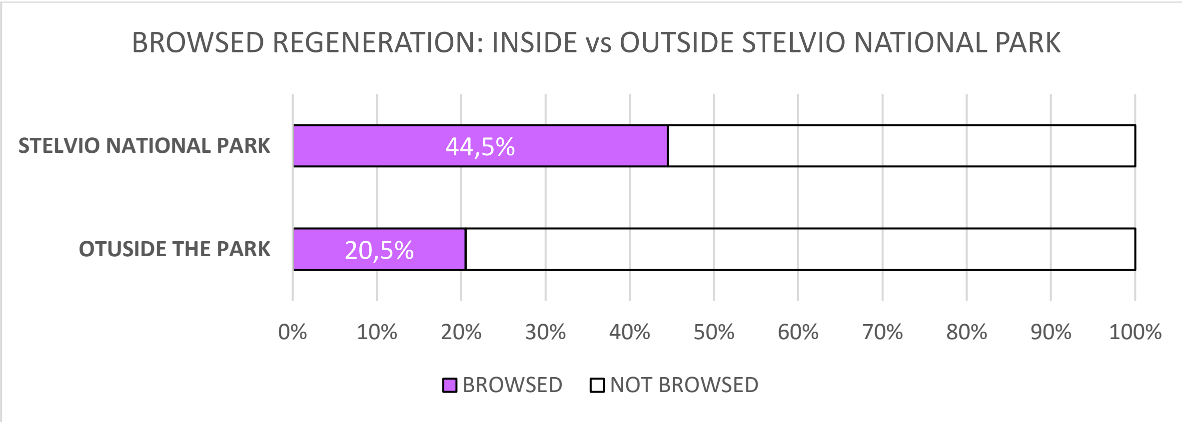


Figure 5.63: Browsing regeneration percentage within and outside Stelvio National park

Considering the single species (5.64), the most browsed species is European larch (57.6%), followed by Norway spruce (37.7%) and broadleaves such as silver birch (3.1%) and rowan (1.6%).

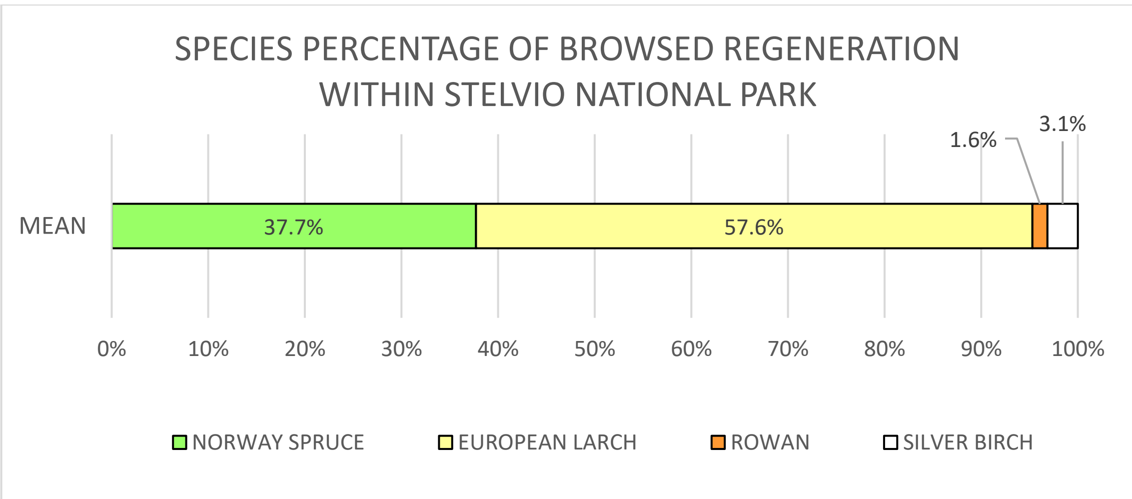


Figure 5.64: Browsed regeneration for each species within Stelvio National park

Norway spruce browsing percentage is slightly higher (37.7%) than what observed by Carmignola (2001) 20 years ago, who reported within national park area in Peio valley a 32% of browsed regeneration of Norway spruce.

The same author, reports that twenty years ago the 21% of European larch regeneration was browsed, while nowadays browsing percentage of European larch is much more browsed (57.6%).

Concerning broadleaves, the most browsed are silver birch and rowan; according to the observation, the 27.3% of rowan and the 24.0% of silver birch measured for the purposes of this study was browsed.

Carmignola (2001) reports that in the whole Stelvio National park, the 84% of rowan and the 78% of silver birch was browsed; there are no specific considerations for Peio valley, since it was estimated that broadleaves represents less than 1.0% of the forest species composition.

The effect of deer browsing within the national park is expressed also by mean regeneration height (figure 5.65); the mean height of browsed regeneration is higher outside the national park area (71.4 cm) than inside (50.0 cm); this difference is highly significant also from a statistical point of view *(p-value < 0.001)*.

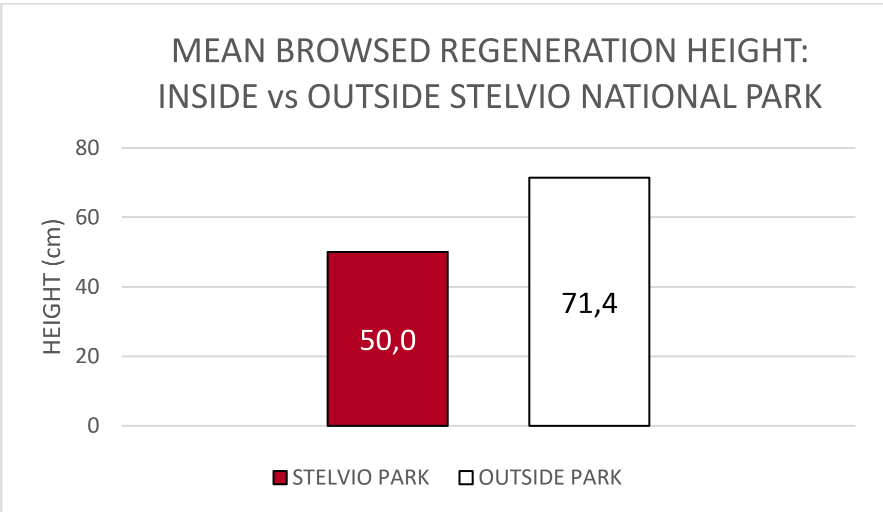


Figure 5.65: Comparison of mean height of browsed regeneration within and outside Stelvio National Park

The different mean height for browsed regeneration within and outside the national park area is very likely attributable to the different browsing pressure that regeneration undergoes in these two contexts, i.e. to the different population densities.

In fact, by analysing population counts over the last 25 years, it is evident that deer counted within the National Park are at least the double than those counted outside (figure 5.66).

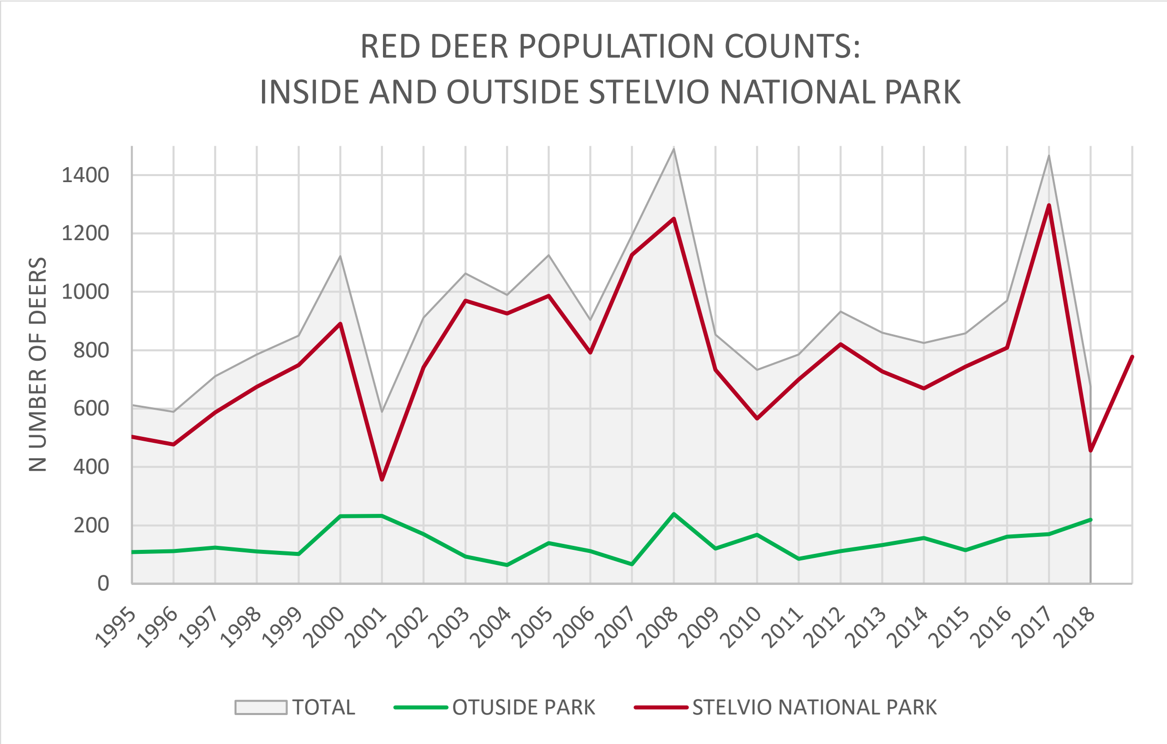


Figure 5.66. Red deer population counts inside (red line) and outside (green line) the area of Peio valley included in Stelvio National park; data for each year have been obtained by taking into account just the maximum number of deer counted, corrected with the underestimation factor (see chapter xx)
(Reference: Data from Servizio Foreste e Fauna 2019)

According to what reported by Pedrotti & Bragalanti (2008), Stelvio National park is recognized as the area where red deer population density is the highest of the entire Alps, not only because of the favourable environmental conditions, but basically because hunting is forbidden and predators are absent; in fact, in some areas during winter season red deer density can reach highest of 40 deer/km^2, when the average value should be 2-4 deer/km^2. Considering that an adult red deer eats between 9 and 14.5 kg of fresh food every day (Carmignola 2001), it is easy to understand the impact of such high densities on forest ecosystem.

For these reasons, forest regeneration development in Stelvio National Park is suffering more than in other alpine regions (Figure 5.67).

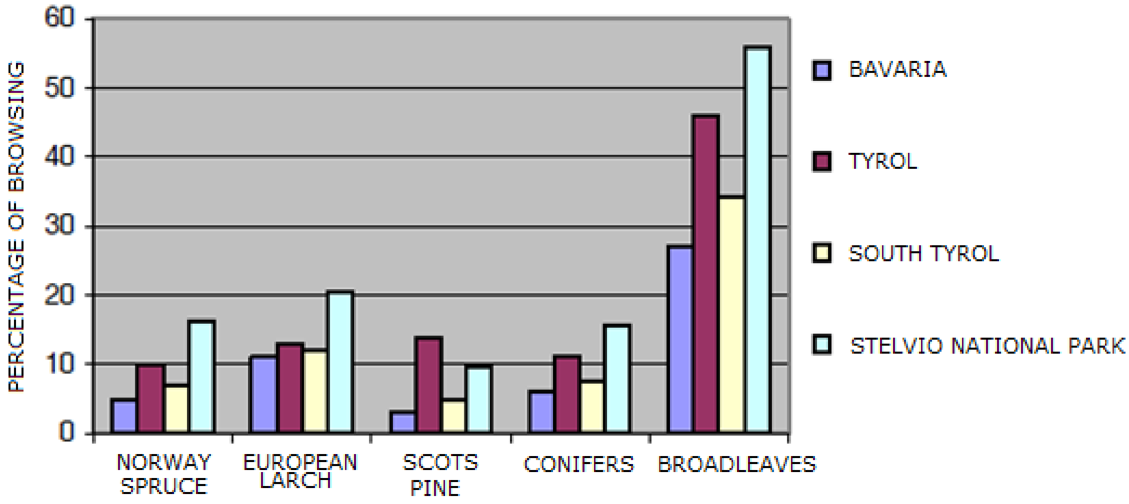


Figure 5.67: Percentages of browsing in Bavaria, Tyrol, South Tyrol and Stelvio National park: comparison between annual regeneration browsing percentages examined in other areas. The values of Tyrol are referred to a period of 1.5 year (Reference: Pedrotti & Bragalanti 2008, p. 173)

The intense browsing is evidenced also by the fact that in most of the oldest sample areas (e.g. 1990), saplings are in very bad conditions.

It has to be considered that such high densities have effects not only on forest regeneration, but also on other wildlife species.

In fact, Gabrielli (1973) reports that roe deer *(Capreolus capreolus)* used to be very abundant within the valley, while nowadays they are very rare within the park (Pedrotti & Bragalanti 2008); moreover, also chamois *(Rupicapra rupicapra)* population is negatively affected by red deer presence (Corlatti et al. 2019) (Figure 5.68).

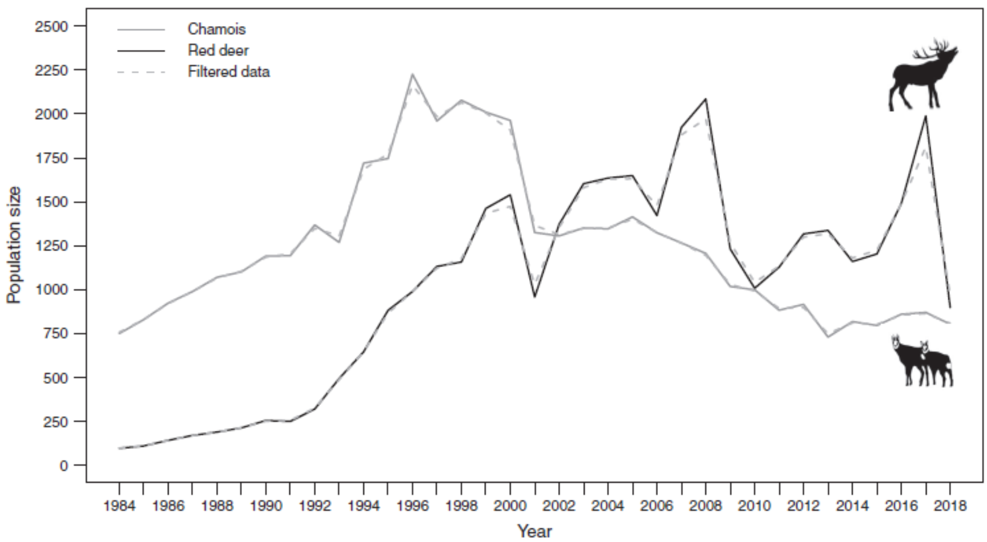


Figure 5.68: Temporal trends of red deer and chamois in the Stelvio National Park between 1984-2018. Count data (solid lines) were filtered using a state-space model (dashed lines) (Corlatti et al. 2019)

6. CONCLUSIONS

According to this study, major windthrows are a frequent natural disturbance in Peio valley, as demonstrated by the occurrence of five major events in the last seventy years.

Consistent with the results concerning regeneration status in the disturbed areas during the last thirty years, forest recovery seems to be a challenging process, mainly because of the intense red deer browsing; in fact, the area is characterized by a high population density, that within Stelvio National park reaches the highest values of the entire Alps.

As a consequence, forest recovery is slowed down further than it is already, due to the climatic conditions of the area.

This scenario sets an alarm bells ringing about how and how much time will take for forests to recover in areas damaged by *Vaia* storm.

Moreover, it has to be considered that due to climate change the frequency of extreme events, such as *Vaia* storm, will increase (Einzmann et al. 2017); in addition , climate change that is altering snowfall regime will increase red deer survival during winter season, where starvation represents a natural selection pathway for red deer population in this alpine environment.

For these reasons, it arises the question not only of which will be the future recovery of those forests affected by natural disturbances, but also how mature forests will respond to these extreme events.

Since it is not possible to modify climatic conditions (at least in the short-term), it is necessary to adapt to them, through what is called an adaptive management of forest ecosystem; according to Dale et al. (1998), mangers can choose to influence either the system prior the disturbance, or the disturbance itself, or the system after the disturbance or the recovery process.

PRE-DISTURBANCE MANAGEMENT – It aims at reducing the vulnerability of forest ecosystem toward those disturbances that may occur in a specific environmental context and which factors contribute to them.

In the case of windthrow risk, management should be oriented to increase the stability of clusters, working on edges and considering wind exposure; wind direction as a factor that requires a cautious management was recognized also by previous regulation concerning forests operations, which stressed the importance of considering wind exposure in the choice of which trees harvest (art. 42 *Prescrizioni di Massima e di polizia forestale*).

POST-DISTURBANCE MANAGEMENT – Practically always, after a disturbance the economically valuable timber is harvested with salvage logging operations, leaving behind stumps, under-dimensioned logs, branches and other woody debris

According to the results of this research, these features are fundamental for the subsequent forest recovery process; moreover, as observed by many authors (Relva et al. 2009, Castro 2013), as well as from this study, woody debris offer also protection to young seedling from browsing.

As suggested also by Relva et al. (2009), policies concerning salvage logging should recognize the role of these biological legacies in promoting forest recovery and protecting from browsing damages.

Artificial regeneration certainly would accelerate forest recovery, but, in absence of a proper management, it will result in the development of an even-aged stand (Baldwin 1927), characterized by an intrinsic vulnerability to disturbance such as windthrow; moreover, protective structures should be built in order to avoid deer browsing, increasing costs.

This may worth in protective forests (Ramming et al. 2005), also if the intervention is not economically convenient, since the need to speed up the forest recovery process for re-establishing its protective role goes beyond the economic aspect.

In the past, instead, forest regulation imposed to the owner the obligation to artificial regenerate forests that have been partially or totally impacted by any natural disturbance; moreover, this was imposed also when four years after ordinary forest harvesting operations, Forest Authority had declared that the forest would not be able to self-recover from the cut (i.e art. 39 *Prescrizioni di Massima e di polizia forestale*).

Moreover, in the study area it has to be addressed the issue of red deer population density, that is very challenging because of the hunting ban imposed within Stelvio National park and the absence of the natural predator, i.e. wolves *(Canis lupus).*

In this scenario, only the return of this species will be able to regulate the population density of red deer; by the way, this animal has been sporadically detected in the last few years, because of a few predations on cattle.

However, a possible return of wolves would lead also to conflicts with mountain farming, since in summer the cattle graze freely on pastures.

On the other hand, hunting would respond more rapidly to this issue, but this choice would clash with public opinion, seen the sensitivity of the topic (there has already been an attempt in this sense), as well as for the importance that red deer have for tourism within the park;

anyway, considering that among the objective of Stelvio National park there is the aim at conserving ecosystem in stable conditions, when a component is altering its stability, it would be lawful to apply measures to deal with the issue (Carmignola 2001).

The need of addressing forest recovery in areas affected by natural disturbances such as windthrows, as well as of adapting to changing climate is particularly important in alpine environment like Peio valley.

In fact, here forests are important for hydrogeological stability, as well as for protecting human settlements and infrastructures from gravity driven processes such as avalanches, rockfalls and landslides (Carmignola 2001, Kupferschmid et al. 2015); therefore, the absence of an adequate forest cover will result in an increase of the expenditures for public administration (Kupferschmid et al. 2015) for building structures that makes up for this lack.

Further to this, also the potential effects on forest economy have to be considered.

Firstly, these kind of large disturbances cause the congestion of timber market, since huge amount of wood are suddenly available and sold at bottom prices, since the fear of wood deterioration triggers speculative mechanisms.

Secondly, after salvage logging and timber trade have been completed, in the long-term the slowing of recovery process due regeneration browsing will lead to a reduction of forest yield, with not negligible consequences on the earnings of forest owners; this aspect heavily affects small forest owners such as the A.S.U.C. in Peio valley, for which forests represent the principal source of income, of which benefits the community.

In fact, A.S.U.C. is a particular type of institution that is responsible for the administration of the collective properties of a community (i.e. of a village), such as forests, pastures and mountain huts/alms.

Moreover, it has to be considered that this kind of events are able to set to zero planned forest yield for the period of validity of the management plan (usually 10 years), setting a new challenge for the future of these institutions.

Fortunately, *Vaia* storm has not altered significatively the future forest yield of each A.S.U.C. in Peio valley, but the occurrence of other events like this may represent a risk.

Considering that many of the heavily impacted forests in Peio valley are predominantly productive forests, it is evident the importance of monitoring the subsequent ecosystem dynamics after the disturbance occurrence, with the aim of taking actions on limiting factors, in order to overcome the challenge of forest recovery.

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sogno che,
dopo 16 anni di sacrifici,
è diventato realtà, perché
così ho voluto:
"Non lasciare mai che la paura di perdere,
ti impedisca di partecipare."

Molini di Nogaredo, 27 Marzo 2011

"Sono sempre stata una persona che in fatto di scelte ha continuamente avuto delle difficoltà.
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"voglio fare l'astronauta!" "e io il carabiniere!" "e io la maestra!"
che con la crescita sono solo delle parole al vento. Non so se fosse il mio carattere o qualcos'altro ma da allora io non ho più cambiato idea.
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IPCC – Intergovernmental panel on climate change
https://www.ipcc.ch/

Storico eventi meteo significativi
https://www.meteotrentino.it/#!/content?menuItemDesktop=73

LAWS

Prescrizioni di massima e di polizia forestale per I boschi e terreni di montagna sottoposti a vincolo nella Provincia di Trento ai sensi degli artt. 8, 9, 10 del R.D. 30.12.1923 n 3267 e approvate con Decreto del Ministero dell'Agricoltura e delle foreste del 07.02.1930.

FOREST MANAGEMENT PLANS

- A.S.U.C. COMASINE: 1998-2017; 1983-1997; 1973-1982; 1963-1972
- A.S.U.C. TERMENAGO: 2015-2024; 1985-1994; 1975-1984; 1955-1964
- A.S.U.C. CELENTINO: 2011-2020; 2001-2010; 1987-2001; 1977-1986; 1967-1976; 1956-1965
- A.S.U.C. CELLEDIZZO: 2011-2020; 2001-2010; 1987-2001; 1977-1986; 1967-1976; 1956-1965
- A.S.U.C. COGOLO: 2017-2036; 1997-2016; 1982-1996; 1972-1981; 1962-1971; 1952-1971
- A.S.U.C. PEJO: 2017-2036; 1997-2016; 1982-1996; 1972-1981; 1962-1971

DATA

Meteorological data: STATION T0366 (Pejo paese) from 2002-2019
http://storico.meteotrentino.it/web.htm?ppbm=T0366&rs&1&df

Meteorological data: STATION T0063 (Pian palù) from 2002-2019
http://storico.meteotrentino.it/web.htm?ppbm=T0063&rs&1&df

Meteorological data: STATION T0065 (Careser) from 2002-2019
http://storico.meteotrentino.it/web.htm?ppbm=T0065&rs&1&df

Snow data 1984-2015 (Quaderni di nivologia)
https://www.meteotrentino.it/index.html#!/content?menuItemDesktop=71

Snow profiles and stratigraphy 2015-2019 (Profili nivometrici e stratigrafia)
https://www.meteotrentino.it/#!/content?menuItemDesktop=117

Wind maps
https://www.meteotrentino.it/#!/content?menuItemDesktop=137

SOFTWARE

The data analysis relied on **Microsoft Excel 2016**.

Statistics have been computed using **PAST: Paleontological Statistics Software Package for Education and Data Analysis**, realized by *Hammer, Ø., Harper, D.A.T., and P. D. Ryan,* 2001**.** Palaeontologia Electronica 4(1): 9pp. https://folk.uio.no/ohammer/past/

For GIS data elaboration has been used **Quantum Gis**.
QGIS Development Team, 2009, version 2.18.25, QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.org