J. Mt. Sci. (2020) 17(10): 2459-2484 e-mail: jms@imde.ac.cn http://jms.imde.ac.cn
https://doi.org/10.1007/s11629-019-5890-0

Combined forest and soil management after a catastrophic event

Augusto ZANELLA[1*] https://orcid.org/0000-0001-7066-779X; e-mail: augusto.zanella@unipd.it

Jean-François PONGE[2] https://orcid.org/0000-0001-6504-5267; e-mail: ponge@mnhn.fr

Anna ANDREETTA[3] https://orcid.org/0000-0002-2082-0503; e-mail: anna.andreetta@unifi.it

Michael AUBERT[4] https://orcid.org/0000-0003-4846-1159; e-mail : michael.aubert@univ-rouen.fr

Nicolas BERNIER[5] https://orcid.org/0000-0001-7340-8646; e-mail: bernier@mnhn.fr

Eleonora BONIFACIO[6] https://orcid.org/0000-0003-3488-672X; e-mail: eleonora.bonifacio@unito.it

Karine BONNEVAL[7] https://orcid.org/0000-0002-4765-8737; e-mail: karine@karinebonneval.com

Cristian BOLZONELLA[8] https://orcid.org/0000-0001-5459-1406; e-mail: cristian.bolzonella@unipd.it

Oleg CHERTOV[9] https://orcid.org/0000-0002-5707-3847; e-mail: oleg_chertov@hotmail.com

Edoardo A. C. COSTANTINI[10,11] http://orcid.org/0000-0002-2762-8274; e-mail: eac.costantini@gmail.com

Maria DE NOBILI[12] https://orcid.org/0000-0002-4633-4394; e-mail: maria.denobili@uniud.it

Silvia FUSARO[13] https://orcid.org/0000-0001-8966-8485; e-mail: fusaro.silvia.17@gmail.com

Raffaello GIANNINI[14] https://orcid.org/0000-0001-7029-7944; e-mail: raffaello.giannini@unifi.it

Pascal JUNOD[15] https://orcid.org/0000-0002-1386-0478; e-mail: junod@bzwlyss.ch

Klaus KATZENSTEINER[16] https://orcid.org/0000-0003-0534-8391; e-mail: klaus.katzensteiner@boku.ac.at

Jolantha KWIATKOWSK-MALINA[17] https://orcid.org/0000-0003-2090-8449; email: jolanta.kwiatkowska@pw.edu.pl

Roberto MENARDI[18] https://orcid.org/0000-0002-8721-9958; e-mail: roberto.menardi@unipd.it

Lingzi MO[19] https://orcid.org/0000-0001-5246-4497; e-mail: lingzi.mo@phd.unipd.it

Safwan MOHAMMAD[20] https://orcid.org/0000-0003-2311-6789; e-mail: safwan.mohammad.bcdu@gmail.com

Annik SCHNITZLER[21] https://orcid.org/0000-0003-3189-3684; e-mail: annik.schnitzler@univ-lorraine.fr

Adriano SOFO[22] http://orcid.org/0000-0003-0305-308X; e-mail: adriano.sofo@unibas.it

Dylan TATTI[23] https://orcid.org/0000-0002-5889-0427; e-mail: dylan.tatti@bfh.ch

Herbert HAGER[24*] https://orcid.org/0000-0003-0857-1337; e-mail: herbert.hager@boku.ac.at

**Corresponding author*

1 Università degli Studi di Padova, Dipartimento TESAF, Viale dell'Università 16, 35020 Legnaro (PD), Italy

2 Museum National d'Histoire Naturelle, CNRS UMR 7179, 4 avenue du Petit Château, 91800 Brunoy, France

3 Università degli Studi di Firenze Dipartimento di Scienze della Terra (DST) Piazzale delle Cascine, 15 - 50144 Firenze, Italy

4 URA IRSTEA/EA 1293 – FR CNRS 3730 SCALE, UFR Sciences et Techniques, Université de Rouen, 76821 Mont Saint Aignan cedex, France

5 Museum National d'Histoire Naturelle, CNRS UMR 7179, 4 avenue du Petit Château, 91800 Brunoy, France

6 Università degli Studi di Torino, Dipartimento di Scienze Agrarie, Forestali e Alimentari, Largo P. Braccini 2, 10095 Grugliasco (TO), Italy

7 École supérieure des Arts Décoratifs de Strasbourg, 67082 Strasbourg, France

8 Università degli Studi di Padova, Dipartimento TESAF, Viale dell'Università 16, 35020 Legnaro (PD), Italy

9 Prof. Emeritus, Dr. habil. Ecology, Albert Schweitzer Str. 20, 26129 Oldenburg, Germany

10 Accademia dei Georgofili, Logge degli Uffizi of Florence, 50122 Florence

11 Accademia Nazionale di Agricoltura, Via Castiglione, 11, 40124 Bologna BO, Italy

12 Department of Agricultural, Food, Environmental and Animal Sciences, University of Udine, via delle Scienze 209, 33100 Udine, Italy

13 Università degli Studi di Padova, Dipartimento DAFNAE, Viale dell'Università 16, 35020 Legnaro (PD), Italy

14 Accademia italiana di scienze forestali, Piazza Tommaso Alva Edison, 11, 50133 Firenze, Italy

15 Service de la faune, des forêts et de la nature (SFFN) Route des Chéseaux 9, 2017 Boudry, Switzerland

16 Institute of Forest Ecology, Dept. of Forest and Soil Sciences, University of Natural Resources and Life Sciences (BOKU) Vienna, Peter Jordanstr. 82, 1190 Vienna, Austria

17 Warsaw University of Technology, Faculty of Geodesy and Cartography, Department of Spatial Planning

and Environmental Sciences, Politechniki 1 Sq., 00-661 Warsaw, Poland

18 Università degli Studi di Padova, Centro Studi Ambiente Alpino, Via F. Ossi, 41, 32046 San Vito di Cadore (BL), Italy

19 School of Geographical Sciences, Guangzhou University, Guangzhou 510006, P. R. China

20 Institute of Land Use, Technology and Regional Development- Faculty of Agricultural and Food Sciences and Environmental Management-University of Debrecen, 4032 Debrecen, Böszörményi út 138, Hungary

21 Université de Lorraine, Cité Universitaire, 57000 Metz, France

22 Department of European and Mediterranean Cultures: Architecture, Environment, Cultural Heritage (DiCEM)], Università degli Studi della Basilicata, Via Lanera 20, 75100 Matera, Italy

23 Haute école des sciences agronomiques, forestières et alimentaires HAFL, Länggasse 85, 3052 Zollikofen, Switzerland

24 Institute of Forest Ecology, Dept. of Forest and Soil Sciences, University of Natural Resources and Life Sciences (BOKU) Vienna, Peter Jordanstr. 82, 1190 Vienna, Austria

Citation: Zanella A, Ponge JF, Andreetta A, et al. (2020) Combined forest and soil management after a catastrophic event. Journal of Mountain Science 17(10). https://doi.org/10.1007/s11629-019-5890-0

Abstract: At the end of October 2018, a storm of unprecedented strength severely damaged the forests of the eastern sector of the Italian Alps. The affected forest area covers 42,500 ha. The president of one of the damaged regions asked for help from the University of Padua. After eight months of discussion, the authors of this article wrote a consensus text. The sometimes asper debate brought to light some crucial aspects: 1) even experienced specialists may have various opinions based on scientific knowledge that lead to conflicting proposals for action. For some of them there is evidence that to restore a destroyed natural environment it is more judicious to do nothing; 2) the soil corresponds to a living structure and every ecosystem's management should be based on it; 3) faced with a catastrophe, people and politicians find themselves unarmed, also because they rarely have the scientific background to understand natural processes. Yet politicians are the only persons who make the key decisions that drive the economy in play and therefore determine the near future of our planet. This article is an attempt to respond directly to a governor with a degree in animal production science, who formally and prudently asked a university department called "Land, Environment, Agriculture and Forestry" for help before taking decisions; 4) the authors also propose an artistic

Received: 07-Nov-2019
1st revision: 17-Dec-2019
2nd revision: 19-Apr-2020
Accepted: 14-May-2020

interpretation of facts (uncontrolled storm) and conclusions (listen to the soil). Briefly, the authors identify the soil as an indispensable source for the renewal of the destroyed forest, give indications on how to prepare a map of the soils of the damaged region, and suggest to anchor on this soil map a series of silvicultural and soil management actions that will promote the soil conservation and the faster recovery of the natural dynamic stability and resilience.

Key words: Vaia storm; Wind damages; Soil organic carbon; Soil functioning; Humus form; Climate change

1 Background Introduction

1.1 Science and politics

Scientists have fewer and fewer choices other than engaging scientific knowledge in societal challenges. Yet, is it compatible with "doing science"? This question is worth asking since the future is not precisely fated, and ecological predictions may look like charlatanism. Strengths and weaknesses of ecology hold precisely in the unpredictable dimension of nature. The stochastic aspect brings considerable richness, allowing mechanisms such as interchangeability, founder effects, resilience, etc. System indeterminism is at the origin of ecologist discomfort when meeting requests for recipes. The duty of science holds probably more toward educating the glance than to manipulating nature. If society wishes more life, it should agree to lose some control over it to let every organism filling empty spaces and sharing a variety of ecological niches. In turn, every organism will be (or will construct) a habitat for adding a multitude of other species.

Consequently, the "letting go" philosophy or the will to let nature going by itself is at the core of the educational duty for scientists. Scientists must set up a back control of the way by which spontaneous dynamics serve humanity to check if this "letting go" philosophy brings some fruits, i.e., if the ecosystem goes in the direction of niche sharing and differentiation, that is a promise of biological richness. In this frame, scientists may play an active role in society, explaining the differences between natural wilderness and natural gardening. Both systems may hold a similar level of species diversity, but the former is self-organized while the second needs social skills to stabilize the ecological niche of each component. And the second alternative has an operational cost.

Society and Nature must evolve together. Humans are an outcome of Nature, humans are Nature. Nature exists and lives even without humans. The dynamics of living systems occurs by jumps. Nature essays "prototypes". If they don't work, Nature tries other unlimited in number designs. We need to deconstruct our human-sided view of Nature because the "correct way" stays in the future, and it does not exist a priori.

Humans struggle to distinguish between safe and dangerous progress. The "genetically modified organisms" are an example of ambiguous scientific attitudes: are these organisms the fruit of useful knowledge (a sort of intensified natural evolution) or models of unsafe progress? Back to the Vaia event, does the export of matter from a forest ecosystem influence its consistency in the future? Is it adequate to take away no more than the annual increment? Can we take away something from the wood without giving something in exchange for it? We can change the species composition of forests when economically advantageous. Is this a right or wrong move? When does a forest correspond to a group of living organisms? When does it, instead, correspond to a system of living organisms, with its functioning? Are we able to count the living organisms that make up a forest? Is it essential for humans to take care of this aspect of the story?

The authors of this article want to try a new formula for scientific articles. They propose to list the engaging opinions of a group of scientists and to address them to politicians for putting the views into practice. After presenting official data on the catastrophe, we pondered several publications that suggest some recommendations. The main issues are listed in the Conclusions as a letter addressed to one of the rare politicians who asked for scientific support before making operational decisions.

1.2 Soil As Digestive System (SADS)

SADS is a multinational group (the 23 authors of this article and four anonymous ecologists), composed of minds of diverse and co-evolving scientific opinions. The group took birth after a major storm over the North Veneto region (Italy) that came to the overall destruction of trees.

We know that forests generate from living soil. A forest ecosystem is composed of lasting organisms that use the soil as a secondary source of nutrients, the primary source being photosynthesis. The soil corresponds to a mandatory recycling center necessary for forest survival, in harmony with a local and relatively fixed climate and a geological substrate, in a specific morphology. Soil organisms digest dead organisms or parts of them, allowing reinvesting the products of past biological activities in living structures through the photosynthetic process. As for egg and hen, was soil born before photosynthesis or vice versa? The process of photosynthesis took probably place in the soil, at the origin, in bacteria evolving in algae, but in contrast with the digestive processes, the chloroplast activities are poorly diversified. Regardless of plant species, the photosynthetic function is taken in charge entirely unchanged. The digestive system is, in contrast, highly diversified and unequally distributed among the soil organisms. Fortuitously, it lies beneath the surface and remains quite invisible, and could be the Achille's heel of every ecosystem.

Speciation is a natural mechanism that drives living beings to fill the gaps between occupied ecological niches. Nowadays, world ecosystems have to cope with mundialization that brings new flows and new channels. Increasing mobility brings upheaval in both ecology and society. Species and populations carried away from any places around the world bring disruption of local equilibria. Population dynamics, in an environment with limited resources, are known for a long time (Volterra 1926; Kingsland 2015). A new incoming population increases slowly first, then rapidly and finally reaches an overall equilibrium, oscillating around a relatively stable value of environmental resources. Invasive species may be considered as monopolistic (a factor depleting biodiversity) or on the contrary, as a means to increase local biodiversity. The exportation of a universal model of sociological development upset the equilibrium of a millennium share of resources between humans and Nature. The belief and the system value that support the search for new stability cannot overlook economic constraints and the fact that richness unequally distributes.

On the one hand, an ecological system is ultimately a biological solution to dissipate solar energy (Zanella 2018). On the other hand, a sociological system is a solution to dissipate richness. Putting the analogy to the end, we know that an ecological system also has a hidden face that is soil as a digestive system (SADS), and we may wonder what a SADS could be for society. SADS is the regulatory focus of every ecosystem. From an organizational point of view, the counterpart of SADS to the society could be the dissipative mechanism that corresponds to the process of economic goods consumption. Thus, the instruments of a social SADS regulation could consist of taxes and allow public services to control the consumer society. Unfortunately, this captivating representation may work only in a virtual and with unlimited resources world. As we live in a real and limited resources world, we need to reconcile with Nature. Humans should limit their needs. Living and dead Nature should remain in a long-term balance. Social and natural SADS need to meet themselves and co-evolve.

1.3 Data

The Vaia event was quickly and well introduced (Motta et al. 2018). On October 27-29, 2018, intense sirocco currents, boosted by their passage over the Mediterranean Sea (during a summer season much warmer than average), struck north-eastern Italy. Wind currents channeled along the slopes of many Alpine valleys reaching speeds of over 150 km/h (Figure 1).

The Directorate General Forests of the Ministry of Agriculture, Food and Forestry and Tourism established a technical table with the Regions and Autonomous Provinces of Northern Italy affected by the storm. A few weeks after the disastrous event, the committee released the first quantitative analyses of the extensive damages to the national forest heritage. The analyzes base on local authorities' damage estimates, through field surveys and interpretation of aerial and satellite images, and with the support of numerous universities and forest research institutes.

The forests of 473 municipalities were damaged. The affected forest area covered 42,500 ha, where an almost total knockdown of trees was observed, to which a similar surface having suffered partial damages should be added. Most affected areas were located in the Autonomous Province of Trento with over 18,000 ha of felled forests and Veneto with over 12,000, followed by Alto Adige, Lombardy and Friuli. Slight damages were noticed in Piedmont and Valle d'Aosta.

Figure 1 Left: Centre of Studies for the Alpine Environment (Belluno, Dolomites, Italy) on October 30, 2018, on the day after the event. Notice fallen trees on the roof of the building and part of the damages done in its vicinity. Right: Same position two months later (January 4, 2019), with the first restoration works (Photographs: Roberto Menardi).

The volume of timber on the ground in the 42,500 most damaged areas reaches about 8,300,000 cubic meters. Based on these estimates, the Vaia storm is the most destructive event ever recorded in Italian forests.

This kind of storm in Central Europe has become now quite common and is the cause of about 50% of forest damage in the last 100 years. The average rate of major or critical storms which hit Central Europe is two a year (the most famous cases being Vivian in 1990 and Lothar in 1999 with damages equal to about 200 million cubic meters).

1.4 Criticalities

Downstream damaged forests, the function of protection of settlements, and human activities will be severely affected by falling rocks, avalanches, landslides for a period ranging from a few to tens of years. This situation will last until the post-storm renewal has been established.

Risks of disease to surviving forest stands, primarily dominated by northern spruce (*Picea abies* (L.) Karst), are caused by the proliferation of Scolytidae's insects. They deposit eggs in fallen wood from which the populations can invade the surrounding forest stands, especially in the presence of a climatically favorable spring.

The danger of spreading fires is increased by the high amount of deadwood mixed with grass and shrubs. This can give rise to highly flammable fuel and generates high flame front intensities.

Significant economic damages to the chain of wood products are due to the low price at which wood is sold on the ground, an amount which still decreases rapidly over time because of the alteration of technologic quality. This sharply reduces the opportunity of public and private owners to benefit from the economic value of these highly productive forests. At the same time, harvesting all fallen timber will require 2-3 years, enough to bring down the price of wood in a period of excess supply, with adverse effects on the national forest sector of activity.

Ordinary forest management is abandoned in non-damaged stands, as foreseen by planning tools, following commitment for emergency management of harvested timber.

About the safety of the personnel employed in crashed forest site areas, where the felling and extraction of wood are complicated and dangerous due to strong wood tensile forces, thus there is a high criticality. Some workers have already lost their lives on the worksites in progress. For these activities, the high professionalism of the operators is required.

We expect a significant modification in the structure and composition of habitats of Community interest (Natura 2000, a network of protected areas in Europe), with inevitable repercussions on behaviour, survival, and dispersal of animal and plant species.

1.5 Immediate reaction

From the beginning, the experts correlated the increase in temperature of the Mediterranean Sea with a higher quantity of energy and water vapor, which corresponded to the incredible virulence of the specific meteorological phenomena occurred on October 29, 2018. Was the Vaia storm a perverse fruit of such a climate change on which so much people discuss? The soil “fluidized” reducing the root seal. The strong wind (about 100-130 km/h) produced localized whirlwinds due to roughness and micro-orographic peculiarities, which, allied to canopy rocking, caused the observed damages (Cat

Berro et al. 2018; Barcikowska et al. 2018).

What percentage of vegetation would still be let in place if more responsible forest practices had favored a diversification of forest stands (Bormann and Likens 2012; Arts et al. 2013; Motta et al. 2018)? Besides, great neglect was given meanwhile to the margins of forest stands: compactness of the border vegetation between a meadow and the forest is almost always lacking (Figure 2, Left compared Right pictures).

You can enter immediately in the heart of the forest, too often thinned out by intensive use, more markedly in private forests. In most low and medium mountain forests, in search of higher economic rent, spruce has always been favored, "cultivated" in even-aged pure populations (Indermühle et al. 2005; Gonzalez et al. 2010; Kauppi et al. 2018). This species has a superficial root system (Figure 3 Right), and, in the event of a wind blow, its stands suffer from a domino effect (Merzari et al. 2018), as it also happened this time (Figure 3 Left).

In forest stands where trees were more diversified in age and species, devastating effects of the wind were more restricted, with a better resistance due to different morphology of the root system (white fir, larch, beech, and other deciduous trees). In damaged areas, only some larches (with little "sail effect" causing canopy rocking) and sometimes hardwoods remained standing. They survived the disaster for "intrinsic properties", not only because they bypassed by crashed vegetation (Figure 3 Left). Merzari et al. (2018) reported: "Reasonably if we had mixed woods with different species (like spruce, fir, beech, and other species) of different ages able to better use the vertical space of the foliage, and with younger and more elastic plants, all this would have been limited to some portion of the forest". A more diversified forest was promoted for years, even in books of the founder of the Centre for Studies on Alpine Environment (Figure 1) and President of the School of Forestry Science of the University of Padua (Susmel 1980; Giannini and Susmel 2006).

We hope that management errors will be recognized and, after having removed where and when possible fallen timber, management will follow the principles of close-to-nature forestry. We expect that foresters will concretely apply these principles according to the vocation of individual forest sites to spontaneously evolve in natural succession: from pioneer species of open spaces (for example larch) to the multi-layered uneven, multi-species high forest to which, where allowed by altitude, broadleaved trees like beech or maple conspicuously participate with adequate density (Susmel 1980).

Figure 2 Left: Forest without a mantel, easily subject to wind blows. Cadino Valley, Trento (photograph: Valter Giosele, July 8, 2019). Right: forest with shrubby mantel that resists strong winds. Boite valley, Belluno (Roberto Menardi, July 11, 2019). The two forests are located at nearby altitudes and slopes.

Figure 3 Left: In this population of spruce and larch destroyed by the Vaia storm, only some larches remained standing. The deeper, more solid root system and the lighter foliage probably made the difference (photograph: Roberto Menardi, November 9, 2018). Right: the root system of Picea abies does not allow isolated trees to withstand strong winds (photograph: Roberto Menardi, January 4, 2019).

The hydrogeological defense action of the forest and rainwater regulation can still be carried out, above all, on the steepest and most https://www.pefc.org)/inaccessible areas where it is more difficult and dangerous to collect timber. Compared to an entirely denuded ground, trunks fallen on the ground may protect it (BAFU 2008; Cislaghi et al. 2019). Infestations of xylophagous insects may undoubtedly happen in spring, but they can be opposed in turn by other competitors.

So, in any case, it is preferable, when possible, to prevent landslides. In general, we suggest avoiding the use of forestry machinery that can affect the ground and cause irreparable secondary damages, resulting in gulling erosion figures (Figure 4). Practical solutions to the management of forest stands to prevent soil erosion and landslides can be found in the results of recent research projects (Costantini et al. 2017).

Figure 4 The passage of mechanical machinery necessary for the removal of fallen trees causes important (irremediable?) injuries to the soil. Left: the spatial dimension of the damage can be vast. Right: ground disturbance can also be locally profound. Near Perarolo (Belluno province) (photographs: Augusto Zanella, May 4, 2019).

1.6 Ecological catastrophes and "butterfly effect"

Almost all wind-damaged areas were managed sustainably according to international standards of PEFC (Programme for the Endorsement of Forest Certification: https://www.pefc.org), a non-government organization that certifies the sustainable management of forests and forest products. Therefore, the cause of the lousy state of damaged forests is certainly not attributable to their abandonment. How is it possible that well-kept forests suffer such serious damage? An explanation could be that perpetual disturbance and disequilibrium could be a natural law (Motta 2018). However, without equilibrium a system does not stand up, and this might contradict a thesis of perpetual disequilibrium. It could be the balance covering of a system in "unstable equilibrium", i.e., a continually evolving complex ecosystem. A forest displays century-old cycles, inserted in geological periods of several millennia. A forest includes trees with several-century growth cycles, plants, and animals with 10-yr, annual, or monthly cycles, up to the cycles of micro-organisms that are of days to hours or even minutes. Every sub-system is moving in a changing equilibrium. However, thinking that a world without balance exists, means disregarding ecology. If a catastrophe may stir the pot, there should be a trend, a force that allows recovering a momentarily lost original equilibrium (as in the aging of every natural system, like the growth of a child). Of course, the reference point of such evolution is in the future and remains theoretical. Nevertheless, this "final theoretical forest" will be mobile but measurable after the forest has started to regrow. We are talking about a concept attributable to the chaos theory (Lorenz 1963; Mandelbrot 1983; Gleick and Hilborn 1988; Nottale and Schumacher 1998; Nottale 2003; Ponge 2005; Zanella 2018). Chaos theory does not say that things are out of balance, and that sooner or later they can / must fall into disrepair. On the contrary, it announces an unpredictable but balanced and continuous becoming. And this means studying the forest as a system in the making, with its own and still unknown laws. To do this we need a lot of patience, a lot of research, respect for the future and a lot of prudence. These aspects were addressed with foresight during a historical conference in Italy (Ciancio 2010, 2015). That left the Italian forest managers' society divided, faced with a poorly understood proposal called "systemic silviculture". Unfortunately, however, the consequences of the past forestry are before our eyes, landed. From (Ciancio 2009): "Science has value if it is capable of explaining and predicting. The dominant scientific culture is aimed at planning the future on the basis of data acquired with experiments and observations. Well, in biology and forestry, current knowledge does not allow us to be certain that the change in some conditions does not affect the results. The uncertainty derives from the fact that it operates in a changing environment. As it is easy to guess, this factual datum involves methodological problems, on which, instead of pausing to reflect, one often flies over with great ease".

It is now clear to everyone that we must change our attitude towards the woods. Radical changes need to be made in the scientific approach. The debate on forest management must be resumed on a new basis, otherwise we end up governing the past: what has been acquired is transcribed or repeated in environmental conditions and in socio-economic situations different from the current ones. And to pay the price, needless to say, will always be the forest.

We must be pervaded by the idea that science is made of data, like a forest of trees, but a mass of data is not science just as a set of trees is not a forest.

It is useful to refer to the term "catastrophe" as used in ecology, in the framework of the complexity epistemology.

Nature is a complex system whose components interact in multiple ways and follow local rules, meaning there is no reasonable higher instruction to define the various possible interactions (Prigogine et al. 1974; Nicolis and Auchmuty 1974; Zeeman 1976). René Thom in the 1960s firstly exposed a theory of catastrophes applied to different domains. For us, all this is relevant because we can formulate plans of actions, based on our various pieces of knowledge and experiences, but without having the presumption to provide solutions valid for everywhere. For this reason, we prefer to remain general in our approach and suggestions: i) use part of the accessible timbers, since there is an immediate economic and social interest, besides reducing the risks of fire and landslides, ii) leave all the rest on the ground to protect soil from water erosion. In Long term actions chapter (4.1.), we propose to harmonize this second solution according to the amount and kind of necromass left, the type of soil and humus profile, and other local factors.

1.7 Why is soil so important after a catastrophic event like Vaia?

Soil is a natural body which tends to self-organization (Costantini and Lorenzetti 2013); functionally, it corresponds to a vast digestive and accumulative system fed by organic and/or mineral compounds (Zanella et al. 2018d). The biological processes of demolition, selection, storage, reapplication of energy and building material from transformed mineral and organic matters occur in every living organism (belly, with the meaning of "internal and under control soil"). The evolution of life on Earth generated increasingly complex natural ecosystems, accomplished by breaking down mineral and organic structures and using the resulting elemental pieces and energy for assembling new organisms in new habitats and ecosystems (Gobat and Guenat 2019).

Pedodiversity is important because it is related and probably supports biodiversity (Costantini and L'Abate 2016). The natural self-organization process of the soil profile is highly variable depending on local conditions (Costantini et al. 2013). The response of the soil system to catastrophes depends on the degree and type of self-organization reached by the soil at the time of the catastrophe. The rule is that the more organized the soil, the more resilient it is, and this up to the moment of breakage (landslide, accelerated erosion, artificial excavation). After this break, it is no longer possible to return to the pre-existing state of equilibrium. On the other hand, in the case of young, simple, poorly evolved soils, resilience is less consistent (they change quickly), and also return more quickly to the previous state after the catastrophic event.

Earthworm communities are diverse in various types of European forests (Wandeler 2018); we do not think that the hypothesis that plants and earthworms could coevolve still stuns someone.

Trees seem to speak to each other as in a big family that occupies a whole forest-ecosystem. Also supportive for an audience of non-specialists, we mention two books of worldwide success in which the results of countless scientific works prove the existence of natural systems, not of species with individualistic strategy. To the point of questioning the possibility that species make ecosystems; it would seem that only ecosystems can arise, not single species, or only species as parts of functional sets (Wohlleben 2016, 2018). The means of communication of trees are molecular signals that fly in the air or travel in the soil. This "chemical language" allows trees to face adversity and dangerous parasites as well as to find resources for feeding themselves and their progeniture. Wohlleben's books are founded on scientific truth and may recall the concept of Gaia developed by Lovelock and Marginus (Lovelock and Margulis 1974).

There is a French book entitled "Jamais Seul. Ces microbes qui constituent les plantes, les animaux et les civilisations" (Never Alone. These microbes that build plants, animals and civilizations). Its charming black and white cover exposes in a glance the content of the book (Selosse 2017). Go and look at it here: https://www.actes-sud.fr/node/59704.

Soil is an after storm available seed bank. Forest managers have to expect a shortage of tree seeds in old even-aged forests; on the contrary, a rich bank of tree seeds may be found in the juvenile phases of more natural uneven-aged forests (Alessio Leck et al. 1989; Rees 1994; Thompson 2000). Seed bank densities are higher in nutrient-rich soils (Berger et al. 2004). Nitrate treatments do not promote germination of viable buried seeds (Berger et al. 2004). The spruce forest regeneration starts where light reaches the ground; however, the sunlight will above all favour the development of grass seeds, and it will be necessary to cover the soil (with branches of fallen trees) to favour the growth of trees (Thompson et al. 2003).

No matter how much biomass lies on the ground today, the soil-system will digest everything. Bark beetles can destroy the still living part of the forest system, especially if the standing forest has an anthropic origin and is not in equilibrium with the environment in which it developed. A healthy forest will not let the bark beetles dictate their law (Paoletti 1999; Seidl and Blennow 2012; Morris et al. 2018). If man intervenes as little as possible, the new forest will grow in harmony with the climate and environment of the region. By integrating the carbon of dead trees into new living organisms, the forest will even mitigate ongoing climate change, storing in the soil a part of the carbon that was in the fallen timber. The ramial chipped wood technique seems to be made for our case and deserves a large-scale attempt (Asselineau and Donenech 2013), why do not try at least in areas where rehabilitation requires human intervention?

Tree species identity, particularly N-fixing species, seems to have a stronger impact on soil C stocks than tree species diversity (Mayer et al. 2020). In forests with high populations of ungulate herbivores, reduction in herbivory levels can increase soil C stocks (Mayer et al. 2020). Specific composition of the tree population and humus forms are very correlated (Wandeler 2018). The reason lies in the quality of the bedding produced by trees, which is related to soil biodiversity (Chapter 4.1).

About important ectomycorrhizal and arbuscular mycorrhizae recent discoveries; selected phrases from (Popkin 2019): "Trees, from the mighty redwoods to slender dogwoods, would be nothing without their microbial sidekicks. Millions of species of fungi and bacteria swap nutrients between soil and the roots of trees, forming a vast, interconnected web of organisms throughout the woods. Now, for the first time, scientists have mapped this "wood wide web" on a global scale, using a database of more than 28,000 tree species living in more than 70 countries. Earth has about 3 trillion trees. Each tree is closely associated with certain types of microbes. For example, oak and pine tree roots are surrounded by ectomycorrhizal (EM) fungi that can build vast underground networks in their search for nutrients. Maple and cedar trees, by contrast, prefer arbuscular mycorrhizae (AM), which burrow directly into trees' root cells but form smaller soil webs. The researchers wrote a computer algorithm to search for correlations between the EM-, AM-, and nitrogen-fixer–associated trees and local environmental factors such as temperature, precipitation, soil chemistry, and topography. In cool temperate and boreal forests, where wood and organic matter decay slowly, network-building EM fungi rule. About four in five trees in North America, Europe, and Asia associate with these fungi. By contrast, in the warmer tropics where wood and organic matter decay quickly, AM fungi dominate. These fungi form smaller webs and do less inter-tree swapping, meaning the tropical wood wide web is likely more localized. About 90% of all tree species associate with AM fungi. The findings could, for example, help researchers build better computer models to predict how much carbon forests will squirrel away and how much they will spew into the atmosphere as the climate warms. As the planet warms, about 10% of EM-associated trees could be replaced by AM-associated trees. Microbes in forests dominated by AM fungi churn through carbon-containing organic matter faster, so they could liberate lots of heat-trapping carbon dioxide quickly, potentially accelerating a climate change process that is already happening at a frightening pace".

1.8 Soils affected by VAIA storm

With the aim of developing a strategy of interventions related to soil types, we simply superimposed the map of the areas destroyed by VAIA (Chirici et al. 2019) to that of the soils in the Veneto region (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto 2015). We then listed these soils on a table (Appendix 1), associating each of them with the most likely humus system. A quick and punctual search of sample sites has proven these realities but has not allowed to recognize the most precise mesh of the humus forms. It would have required a more accurate sampling that could possibly be carried out during the research proposed in chapter 4.2., To better define the degradation times related to each humus system.

The VAIA damaged area is characterized by Leptosols, Cambisols, Phaeozems, Luvisols and Podzosols with Mull, Moder, Amphi, Tangel and Mor humus systems.

We will use this knowledge to estimate the duration of biodegradation of wood material on different humus systems.

2 A Crucial Question: Why Not Let Nature Curing Its Wounds by Herself?

Below we summarize the answers of the authors of the present article. A complete version of their thinking is published in an open access draft of the article (Zanella et al. 2019). The answers have been specifically arranged in two opposite categories which correspond to the "for" and "against" of letting Nature heal itself. After reading them it will be necessary to choose an intervention strategy.

2.1 No, damaged forests need management

Consider other similar events as an example (Figure 5) and consequent results of given interventions.

1. Removing fallen trees as quickly as possible increases the possibilities of rational wood management and protects against pest degradation (Directorate-General of the State Forests 2017; Wesołowski and Zmihorski 2018).

2. Do not leave dead wood on the ground; a fast intervention that takes away the timbers will prevent bark beetle damage (Zastocki et al. 2018).

3. An accumulation of necromass on the ground leads to a thickening of the transition from organic to inorganic soil horizons and lowers the CH_4 uptake, reducing the ability of forest soil to lower GHG in the atmosphere (Lorenzetti et al. 2019).

4. Space (dimension of the damaged area) and time (forest cycle) should be considered as well as the origin of the species used in eventual plantations (Motta et al. 2002, 2006; Bottalico et al. 2016; Kulakowski et al. 2017; Motta 2018; Chirici et al. 2019).

5. Eventually, re-create multiplane and multi-age forests. Mixed forests have a more natural structure and more stable vegetation as a consequence. The blowdown areas need to be assessed or classified according to their specific site condition and situation in the landscape (a concerted effort should be started to retrieve old records of local natural forest vegetation). In a second time, differentiated site and landscape adequate reactions (soil potentiality in the context of sites and differentiated priorities) should be planned (Susmel 1980; Giannini and Susmel 2006).

6. Many years (from 57 to 106 years) are needed to achieve an advanced decay for fir and spruce logs, while leaves, needles and small branches will provide an important input of organic matter at the soil surface in the short time (Spears and Lajtha 2005; Přívětivý et al. 2016).

7. Lack of a forest cover will enhance nutrient losses because of lack of biological recycling of element (Jastrow et al. 2007; Smolander et al. 2008; Falsone et al. 2012; Strukelj et al. 2013; Xu and Chen 2016; Magnússon et al. 2016; Zhang et al. 2018).

Figure 5 View of the state forest of Cadino Valley, resumed the day after the storm of November 4, 1966, taken from Aprie (http://www.forestedemaniali.provincia.tn.it/forestedemaniali/cadino/pagina2.html)

8. If a long time passes before revegetation occurs, the new equilibrium between forest and soil will favor a poorly fertile system (Jobbágy and Jackson 2001; Balogh-Brunstad et al. 2008; Stanchi et al. 2012; Bonifacio et al. 2013).

9. Attention should be paid to the role of the storms in the natural dynamics of the forest, a consequence of this should be a departure from the acute elimination of windstorm effects in favour of partially leaving the forest to natural succession and regeneration processes (Directorate-General of the State Forests 2017; Wesołowski and Zmihorski 2018).

10. In cleared areas, leaving branch wood on the ground could be very useful to protect the soil ecosystem (Berhongaray and Ceulemans 2014; Machar et al. 2016; Baran et al. 2018; Barančíková et al. 2018).

11. Fallen trees should be removed (Valinger et al. 2014, 2019).

12. Soil nutrients increase in damaged areas due to reduction of biological demand (McNulty 2002).

13. The new forest should be adapted to incoming extreme events. Climate change is considered as one of the big threats for forestry (IPCC 2014; Keenan 2015; Andersson et al. 2018).

2.2 Yes, forest will recover by itself

1. Wait at least ten years before intervening, letting Nature try something by Herself first (Spurr 1956; Stokland et al. 2012).

2. Do not chip fallen wood (Strom 1985; Taylor and Carmichael 2003; Tang et al. 2004; Machrafi et al. 2006).

3. When regeneration becomes improbable on the ground, it is very often vigorous on the trunks of decaying trees (Attenborough 1995; Szewczyk and Szwagrzyk 1996; Zielonka and Piątek 2001; Zielonka and Piątek 2004; Motta et al. 2006; Zielonka 2006; Génot et al. 2011; Fukasawa 2012; Tsujino et al. 2013; Orman and Szewczyk 2015; Guo 2016; Wohlgemuth et al. 2017; Parisi et al. 2018; Taeroe et al. 2019)).

4. Animals have a substantial impact on plant regeneration: are large herbivores regulated by carnivores?

5. In the case of fragile forests, it would be better to cut batches of trees and abandon them on the site to increase the deadwood mass on the ground (Guo 2016; Diaci et al. 2017).

6. Identify areas with pre-existing forest tree seedlings within the perimeter affected by the storm (Fischer et al. 2002; Motta et al. 2006; Orman and Szewczyk 2015).

7. Identify patches of dense ground vegetation (of ericaceous type, Calamagrostis, etc.) which could shortly show an explosive kind of development and in this case avoid clearing the windthrow (Kuuluvainen 1994; Szewczyk and Szwagrzyk 1996; Zielonka 2006; Ilisson et al. 2007; Tsujino et al. 2013; Martiník et al. 2014).

8. Take a close look at mounds and pits of uprooted trees because they are environments where the bare mineral soil is a micro-site favorable to regeneration. It can be beneficial to bring maximum light to these mounds (Attembourg 1995; Szewczyk and Szwagrzyk 1996; Zielonka and Piatek 2001, 2004; Zielonka 2006; Motta et al. 2006; Génot et al. 2011; Fukasawa 2012; Tsujino et al. 2013; Orman and Szeczyk 2015; Guo 2016; Taeroe et al. 2019).

9. Protected areas could not to be subjected to any interventions (Jackson et al. 2009; Čerevková and Renčo 2009; Bischetti et al. 2009; Vodde et al. 2011; Bell et al. 2014; Cambi et al. 2015; Barančíková et al. 2018; Cislaghi et al. 2019).

10. In other managed state forests, it would be advisable to remove just a part of bigger logs (Siira-Pietikäinen et al. 2001; Faccoli and Bernardinelli 2014).

11. Coppices should be banned from the VAIA area (Gardiner et al. 2013; Clauser 2018).

The forest ecosystem is creative and adaptive. In Switzerland, we knew Lothar, a powerful storm at the end of December 1999. In the 288 ha Creux du Van forest (canton of Neuchâtel), despite the fear and protests of neighboring forest owners (due to a possible rapid reproduction and spread of bark beetles), it was decided to leave all the fallen trees in place on a surface of 102 ha and to build a forest sanctuary (disturbances are opportunities to restore natural processes). Twenty years later, the renewal of this area (Abieti-Fagetum) shows unpredictable vigor (Figure 6 Left).

In managed forests, the adopted scheme of actions after hurricane disasters consist in "clearing up" damaged trees and artificially regenerate post-mortem areas, which from the

Figure 6 Left: the young spruce trees thrive between the trunks of fallen and decaying trees. The trunk on the left touches the ground and is more decomposed than the one on the right, which is held up above the ground by its branches. Right: A vigorous silver fir with 20 cm annual growth. Behind it, a decomposing trunk covered with mosses. Notice that behind the fir branches, beech and lime are composing a mixed forest. Soil: from Rendzic Phaeozems - Entic Hapludolls to Haplic Cambisols - Inceptic Haprendolls; Humus systems: from Amphi to Mull, respectively. The decomposition process appears to be in line with the provisions in Figure 7, between the lines of Mull and Amphi-Moder systems.

point of view of natural forest ecosystems should be considered inappropriate (Seidl et al. 2017).

The population should be informed with the production of leaflets and updated on the situation in itinere (Sadri et al. 2017; Barančíková et al. 2018).

In most of these answers it appears clearly how the soil plays a predominant role in restoring the health and functionality of the destroyed forest. For this reason, we propose below to put it at the center of the recovery actions. The landed forest must be classified according to the soil and the interventions must be based on the answers that we expect from the soil.

3 Short Term Actions (1-5 years): Security, Vulnerability/Sensitivity Analysis and Maps

We know very well what needs to be done immediately after a catastrophe. Manuals have been published and there are examples to imitate. Here is one (Katzensteiner et al. 2016):

In short:

1) Experts on Alpine Natural Hazards/ Torrent- and Avalanche Control) can map critical zones for those disasters (there may be positive effects of residuals as they create surface roughness and prevent snow gliding, there may be negative effects by stems blocking streams, etc.) with priority ranking and, depending on the situation, advices on the degree of intervention.

2) Experts on area types (ownership, accessibility) can map forest type, structure and management, soil and humus types.

3) Bark beetle risk assessment (Baier et al. 2007), resumed here by the Risk Assessment Group of the Institute of Forest Entomology, Forest Pathology and Forest Protection, Department of Forest and Soil Sciences, BOKU - University of Natural Resources and Life Sciences, Vienna: http://ifff-server.boku.ac.at/wordpress/index.php/home/phenips-online/

4) Regeneration, the question of natural regeneration versus planting is an issue and will determine costs. How to make use of that potential?

5) Ungulate browsing will be a serious issue in the future. How to act on that?

I don't have time to come up with a careful DPSIR analysis by now, but I will continue to work along those lines.

6) Set up an Endnote-Web literature database.

7) Mapping: a) Critical zones and SECURITY, b) Accessibility (roads) and c) Regeneration and ungulate pressure.

4 Soil and Forest Rebirth

Before presenting a project of forest recovery, let's spend another two words on the soil and specify the reasons that guide the development of such a type of reforestation plan.

There are no tables with the duration of biodegradation of whole trees in the forest. Instead, the becoming of dead wood on the forest floor and the classification of the material in the evolving phases have been described and published by (Zanella et al. 2018c; Tatti et al. 2018). No estimates were made on the time needed for the biotransformation of wood because the factors that influence the speed of biodegradation are numerous and interdependent (Tatti et al. 2018): geological substrate, soil (particle size, pH, CEC...), climate, topography and contact surface between soil and deadwood, living organisms including microbial organisms, type of surrounding vegetation, tree/shrub species, initial decay stage of the woody material, quantity/volume, type, shape and size of the initial woody material. There are works that link the rate of decomposition to the lignin content or C / N ratio of the litter, the microclimate or the potential evapotranspiration of the sites (Meentemeyer 1978; Melillo et al. 1982; Vitousek et al. 1994; Johansson et al. 1995). Others papers link the litter biodegradation to groups of soil microorganisms (Cleveland et al. 2014). Few works link biodegradation time to humus systems (Zanella et al. 2018) and none to soil type.

We know that: a) there is a negative correlation between lignin content and tree wood formation (Novaes et al. 2010); b) in different tree species the lignin content varies from 15 to 40% (Sarkanen and Ludwig 1971); c) in each species the content varies by only a few units (26% +/- 2% in Picea abies (Raiskila 2008). Since Picea abies is the species that suffered the greatest damage, we think that the biodegradation times can reasonably be enclosed on the graph between the two lines of the Mull and Tangel-Mor, moving downwards in Mull more favorable conditions (high temperature and humidity) and upwards in opposite cases.

In 1966, McFee and Stone (1966) described a forest near New York where dead wood persisted in the soil long after being incorporated. After more than 100 years, the wood incorporated in the upper part of the soil was estimated at 15 or 30% of the initial volume. Even in the soil, these pockets of dead wood of more than 100 years show contents in N and P lower than the surrounding humus. Næsset (1999) states that the degree of contact with humus is one of the factors favoring the decomposition of wood. In particular, the author speaks of moisture rising from the ground ("Cross-section diameter, ground contact, soil moisture, and aspect were all found to have significant impacts on the decomposition rate constant. For different combinations of these characteristics the decomposition rate constant ranged from a minimum of 0.0165 per year to a maximum of 0.0488 per year"). This could mean that in a Mull (richer in organo-mineral aggregates and thus in water), the rise of moisture could be favored compared to a Moder.

However, a study by Bütler et al. (2007) assessed the relationship between the degree of decomposition of dead wood and the humus form but finds no link between the two. They take up the idea that only the rise of humidity counts.

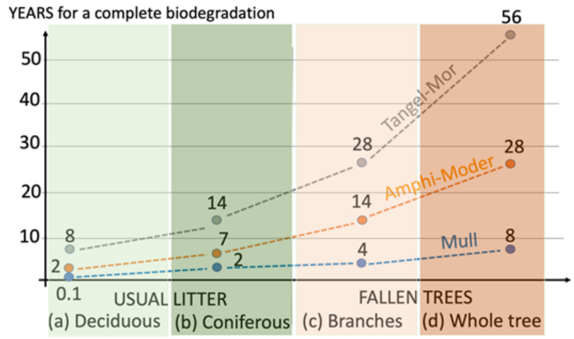

Figure 7 Estimation of the time necessary for a complete biodegradation of the fallen trees in three groups of humus systems (1- Mull; 2- Amphi-Moder; 3- Tangel-Mor). Mor and Tangel systems are very rare in the VAIA area and give an idea of what arrives in sites of slow biodegradation. We started with values (years necessary for a complete degradation; 0.1 means from few days to few months) published for litter: (a) good deciduous litter, (b) coniferous litter. As the time for lignin biodegradation is double compared to cellulose (Berg and McClaugherty 2014), we used a factor 2 from Coniferous litter (b) to Branches, material left in place after removing tree trunks (c) and to Whole tree (d). Consider that: i) lignin nearly doubles in % from leaves-needles to wood; ii) lignin is higher in coniferous than in deciduous material; iii) from Mull to Tangel or Mor, coniferous increases and deciduous decrease in the population of trees. We think we are not very far from the truth, but we are also aware that it is only an empirical estimate that requires control and feed-back. We do not see how we could act otherwise, today, in the face of the fait accompli.

With the study of Heilmann-Clausen (2001), a link between floristic wealth (which is probably associated with a soil richness gradient) and the diversity of wood decomposers, hence the rate of decomposition of wood. There is also talk of rising moisture, but also of pre-existing decomposers in the soil (Couture et al. 1983).

Culliney (2013) followed the decomposition of samples of wood included in different forms of humus and concluded the determining role of the macrofauna. This study shows that once integrated with humus, buried wood decomposes much faster in the mull than in the moder. This is one of the rare studies that goes in the direction of Figure 7 but unfortunately it lacks concrete elements to deduce a generalization to a forest context.

4.1 Soil, humipedon, humus system and humus form

To operate respecting the soil potentialities, we need to map the "biological soil" and to forecast its response to the event. The soil may be parted in three main layers: Humipedon, Copedon and Lithopedon (Zanella et al. 2018b, d). The top part is the more biological and the one that will first react to the event. To recognize the different forest humipedons (called "Humus systems", subdivided in "Humus forms"), we recommend the app TerrHum (free downloadable in the Education section of the App Store). Applied Soil Ecology published three Special Issues (Zanella and Ascher-Jenull 2018a, b, c) on humus forms. Ecologists, foresters and naturalists know that the living soil reacts differently according to the environment in which it develops. The fundamental traits of humus systems, and the main features that allow individuating the humipedons in the field are briefly resumed here down:

Mull system: absence of OH horizon

Moder system: Presence of zoOH horizon pHwater (A horizon) ≤ 5

Amphi system: presence of zoOH horizon, pH (A horizon) > 5; thickness of A ≥ ½ thickness of OH

Tangel system: presence of zoOH horizon, pH (A horizon) > 5; thickness of A < ½ thickness of OH

Mor system: nozOF or/and szoOH present; pH of A or AE or E < 4.5

4.2 Expeted reactions on each humus system

- On Mull system [digestive system of temperate environment and neutral substrate, developed at the top of Cutanic Luvisols - Typic or Inceptic Hapludalfs, or Haplic Cambisols - Typic Udorthepts, or Endogleyic Cambisols – Aquic Eutrudepts, or Luvic Phaeozems – Typic Argiudolls (IUSS Working Group WRB 2015; Soil Survey Staff 2015)] areas: let 1/2 of the material (steams, branches...) to the natural digested; estimated time of material digestion and transformation: 4-8 years (Figure 7). A large (7-40 cm) A organic-mineral horizon is expected to be generated and/or enriched in OC. A permanent or temporary switch to an Amphi system (formation of a zoogenic OH horizon) is possible under thick organic rests.

- On Moder system [digestive system of cold-temperate environment and acidic substrate, developed at the top of Dystric Cambisols – Spodic Dystrudents, or Entic Podzols – Humicryods *(IUSS Working Group WRB 2015; Soil Survey Staff 2015)*] areas: let 1/3 of the material (steams, branches...) to the natural digestion; estimated time of digestion: 14-28 years (Figure 7). We expect the formation of a thick Organic OH horizon (3-20 cm) and a thin organic-mineral A horizon (< 7 cm). A permanent or temporary switch to a Mor system is possible, with the formation of a thick organic layer in which a fungal biodegradation dominates; estimated time of digestion: 28-56 years or more.

- On Amphi system [digestive system of cold-temperate environment and limestone or dolomite substrate, developed at the top of Skeletic Luvisols – Inceptic Hapudalfs, or Epileptic Phaeozems – Lithic Hapludolls, or Rendzic Leptosols – Cryendolls *(IUSS Working Group WRB 2015; Soil Survey Staff 2015)*] areas: let 1/3 of the material (steams, branches...) to the natural digestion; estimated time of digestion: 14-28 years (Figure 7). We expect the formation of a thick Organic OH horizon (3-20 cm) and a thick organic-mineral A horizon (7-40 cm). A permanent or temporary switch to a Tangel system is possible, with the formation of a thick organic layer in which a zoogenic biodegradation dominates; estimated time of digestion: 28-56 years.

In conclusion, woody biomass generated by VAIA will mechanically increase the frequency of a very particular humus system, Legno, with all associated biological diversity. This "Para humus system" (Zanella et al. 2018c; Tatti et al. 2018) is usually "incorporated" punctually into another system. If the original system is a Mull, the biodegradation of wood may be faster than in a Moder (Figure 7). The literature shows that even a hidden Legno humus system, which is incorporated under the soil surface, lasts a very long time and could even be a means of sustainably storing woody carbon in the soil to cope with global warming (Moroni et al. 2010).

It would be very interesting to see what happens with the VAIA material and to compare real data with the forecasts calculated in Figure 7.

5 Long Term Actions (1-100 years)

To give a practical example, we decided to operate in a pragmatic way - a kind of classical method with greater importance assigned to the soil - on the three quarters of the area that suffered damage from Vaia, and to dedicate the remaining quarter to research.

5.1 Sylviculture on 75% of the VAIA surface. To support the forest regeneration.

The preconised measurements are adapted to the response of the biological soil. They can be reported in a few lines if together with the humus system we consider the naturalness of the damaged forest, the damaged surface in every type of forest and the quality of the natuiral renewal. These parameters are coded as follows:

A. Natural forests (reserves, parks...), not cut or very little, not for timber production

B. Forests submitted to natural forestry (no plantation, never clear-cut)

C. Forests subjected to more impacting cutting operations = wood production forests, band and spot cut

D. Forests from which fallen trunks have been removed and which have suffered damage to the soil and on the renewal due to the heavy means used for logging operations

AND

1. damaged by wind in spots or on less than 25% of coverage,

2. damaged on 25-50% of coverage and

3. damaged on 50% or larger surfaces;

AND

y. presence or potentially possible natural regeneration

n. absence or potentially difficult natural regeneration

Examples:

A1y: Natural forest (A), lowly damaged in spots (1) with potential or real natural regeneration (y);

B2n: Forests submitted to natural forestry (B), damaged on 25-50% of coverage (2) and absence or potentially difficult natural regeneration (n).

The silvicultural measures that we recommend on the 75% of the surface that has suffered damage from VAIA are the following:

In A, it is not necessary to detect the humus system:

- A1: do nothing
- A2: remove only the stems easy to take out of the forest without damaging the soil (along the roads);
- A3: remove of the stems easy to take out of the forest without damaging the soil (along the roads and using a light and low-impact cableway);

In B:

- B1y and B2y: where possible with light soil damages, remove only the good-for-sawmill stems;
- B1n, B2n and B3y: do nothing;
- B3n: where possible with light soil damages, remove ½ or 2/3 of the steams in case of Mull or (Moder and Amphi) respectively;

In C:

As in B; in addition, where possible, fragment half the branches let on the soil.

In D:

Fragment half the branches and let the sites to natural evolution. In case of erosion danger, plants with native species in harmony with the surrounding natural forest.

The potential soil types and forms of humus in the areas that underwent the Vaia event are shown on Table 1.

At this point of the analysis, with knowledge of causes and effects, the politician makes decisions for the future of the environment in which his community lives.

5.2 Research on 25% of the damaged area

5.2.1 *Possible research on soil erosion, N cycle, biology and biodiversity*

In slope erosion issues, Battany and Grismer (2000) and Stanko et al. (2011) in an experiment on soil erosion of vineyards, showed that below 16% slope, if erosive processes exist they are minors compared to steeper slopes. Holvoet and Muys (2004), Linser et al. (2018) and Rogers and Schumm (1991) specified that runoff in a forest context becomes intense from 20% slope if there is no ground cover. Runoff is slowed down as soon as 8 to 10% of the area remains afforested by bands parallel to the contours. A more recent synthesis (Gobin et al. 2004; Guerra et al. 2017) mentions that any landscape with a slope > 3-5% is subjected to soil erosion.

In detail, there are questions on the flow of nitrogen especially in the form of nitrates that enrich streams but impoverish forest soils. Törmänen et al. (2018) recently experienced the effect of the contribution of 40 kg/m² of exploitation residues on the N cycle in soil superficial horizons (0 and 0-5cm). They tested it for 3 species, *Betula pendula*, *Picea abies and Pinus sylvestris*. All species combined, 18 months after the intake, between 150 and 200mg/kg o.m. nitrate was produced. There was no nitrification in the control (now input of residues) for which the mineral N production was limited to ammonium. However, in a simple clear-cut without the addition of milling material, Smolander and Heiskanen (2007), Smolander et al. (2008) and Finér et al. (2016), by comparing a clear-cut spruce stand with an existing stand, showed that the net N mineralization rate was low without producing NO_3^- in the stand in place while mineralization and nitrification rates were very high in the cut area. Net nitrification was 29 times higher in the clearcut, in line with Likens' work.

Then there are all the effects on soil biology, we export everything, we do not export everything, it's always the same question. The "cleaning" of the cut area with the export of slash is unfavorable to biodiversity. Indeed according to Landmann et al. (2009, 2014, 2015), wood debris are home to many living species, different from those of large dead wood. They are home to a large part of saproxylic insect and ascomycete communities. They provide shelter for amphibians, reptiles, small mammals, promote colonization by mycorrhizae, and maintain microclimatic conditions favorable to mosses. The few studies available in temperate forests show that compared to a conventional harvest leaving slash on the ground, the export of small wood remains decreases in the short term the diversity of saproxylic insect communities at plot scale, by modifying their composition (Canadian Institute of Forestry 2019).

5.2.2 Possible research on N and C cycles, erosion, leaching, evapotranspiration, nitrate concentration in forest soil solutions after windthrow

Increased levels of nitrate concentration in the soil solution could be expected after forest damages following strong wind events. An increase in nitrate leaching into the deeper soil horizons was observed in previous studies on forests affected by storms (Legout et al. 2009; Hellsten et al. 2015) as well as by clear-cut harvests (Gundersen et al. 2006; Kreutzweiser et al. 2008). Diminished nitrogen uptake by plants and/or increased mineralization rates could be the driving process that explain nitrogen losses by leaching after forest disturbance (Vitousek et al. 1979; Ranger et al. 2007). Changes in the soil climate of forest gaps due to decreased transpiration and increased sun exposure (Kreutzweiser et al. 2008) favor organic matter decomposition and nitrate formation after nitrification. Nitrate concentration in soil water has been found to reach a maximum a few years after the storm, up to 15 years depending on the study case. Indeed, the impact of windthrow on nitrate leaching is modulated by important factors such as the level of nitrogen deposition (Akselsson et al. 2004), the extent of ground vegetation cover (Legout et al. 2009; Hellsten et al. 2015) and the magnitude of the area affected by windthrow.

Nitrate leaching below the rooting zone may potentially contaminate groundwater, cause eutrophication of surface water (Kreutzweiser et al. 2008) and contribute to soil acidification. This could further worsen the already critical situation of the VAIA forest ecosystems. European forests have been exposed to acidifying anthropogenic deposits for several decades and the Alps are still receiving high loads of atmospheric reactive nitrogen due to the proximity of emission sources in the Po Valley (Rogora et al. 2016). High inorganic nitrogen concentrations in soil solutions were found in sites with high N deposition loads (Andreetta et al. 2019), where a regular N flux out of the rooting zone can represent a risk of ground- and freshwater pollution. Increased nutrient availability could also affect tree carbon partition patterns, with a shift of carbon allocation from roots to aboveground woody biomass (Janssens and Luyssaert 2009). This nitrogen-induced carbon allocation pattern could ultimately increase the sensitivity of trees to extreme windstorms, likely leading to an alarming positive feedback loop.

5.2.3 Studies on soil microbial communities

Before considering the whole forest soil as a digestive system or to subdivide the soil in parcels with different "managements", as an agricultural chemist I would recommend observing in the lab the degradation of the fragmented wood by endogenous microorganisms. It could be possible to identify and isolate at least the dominant ones and let them grow under controlled conditions using wood as a substrate. Soil respiration (IRGA), changes in wood composition (LC-MS) and composition of microbial communities (DGGE, 16S/18S-RNA fingerprinting) could be studied. This could be a preliminary basis before infield studies, in order to get an idea about the best strategy to be applied in the whole forest.

Soil microbial communities can play several important ecological and physiological functions in a forest (soil organic matter decomposition and control of its cycle; regulation of mineral nutrient availability for plants; atmospheric nitrogen fixation; formation of mycorrhizae; production of biologically active substances able to stimulate plant growth; etc.), ameliorating soil physical and chemical conditions, and consequently soil habitability for plants, as observed in many soil-plant systems (Sofo et al. 2010, 2012, 2014). There is a growing interest in the maintenance of forest functionality and its connected ecosystem services. It seems that the soil microbiota, particularly its biodiversity, allows forest systems to better overcome natural and anthropic perturbations by improving their recovering capacity (resilience concept). Thus, a survey on soil microbiological data of the forests of North-East Italian Alps, that were strongly damaged by wind on 30 October 2018, is urgent for planning the best strategies for their management in the next future. Particularly, attention should be given to changes in the structure, dynamics and complexity of soil microbial communities, in order to evaluate soil health status before and after planned interventions.

One of the easiest and reliable techniques for defining soil microbiological status is the determination of microbial metabolic/functional diversity by the spectrophotometric Biolog® method, that has a high discriminating power between microbial soil communities from different soil environments. Culture-based and genetic techniques have been used successfully in forests to ascertain the presence of some types of microorganisms. This is particularly important in damaged forests, where soil microorganisms, and particularly fungi, can play an important role for fast forest recovery, as both bacteria and fungi respond to forest perturbation already in the short term. Besides microbiological and genetic analyses, nowadays next-generation sequencing (NGS), coupled with bioinformatic tools and metagenomic approach, made it easier to comprehensively analyze microbial communities in any type of matrix, including soils.

On this basis, short-time effects on microbial functional and genetic diversity of different management systems after the 30th October disaster could be evaluated by a combination of culture-dependent and culture-independent methods, accompanied by microscopy. This is urgent for better understanding the degree of forest resilience in our case study.

5.2.4 Soil studies as a basis for forest renewal

A simple comparison between i) the soils prived of trees due to Vaia, ii) the soils now recovered with different species and processes by the silviculturist, and iii) the other nearby soils that instead continue to support the forest that survived Vaia.

We could make pedofauna inventories twice a year, with associated chemical-physical and biological (example: DNA) analyzes, for n years (the longer, the better). We could classify the forms of humus (with the app TerrHum), we could estimate the natural renewal (counting the seedlings in sample areas), we could collect soil samples, we could extract the animals and make chemical-physical and biological measurements. Then we will compare the data statistically, choosing the factors we want, such as the type of silviculture, the quality of the renewal, the altitude or the type of forest, but also the type of feeding of the soil (nothing, leaves, chips, branches, trunks ...).

6 Additional Economical Consideration

From an economic point of view, VAIA had an interesting dynamic effect on the timber price. After VAIA, the prices of timber had literally dropped (Ebner 2018; Talignani 2019), with the consequent disadvantage of using most of the fallen timber. As a consequence, according to scientists, there were problems related to the spread of insects and fungi harmful even to the living woods that remained standing. However, in a second time the fall in the price of timber attracted unexpectedly forest companies and foreign

European and Chinese buyers, arising the timber price which doubled. Market could be very efficient to use resources.

Figure 8 shows the dynamic of the standing timber price and the logs price in the Trento province.

The collapse of the prices hit in particular the standing timber that fell from 67,6 €/m³ to 29,36 €/m³ (-56.6%) from October to November 2018, while the price decline of logs has been more limited (-16%).

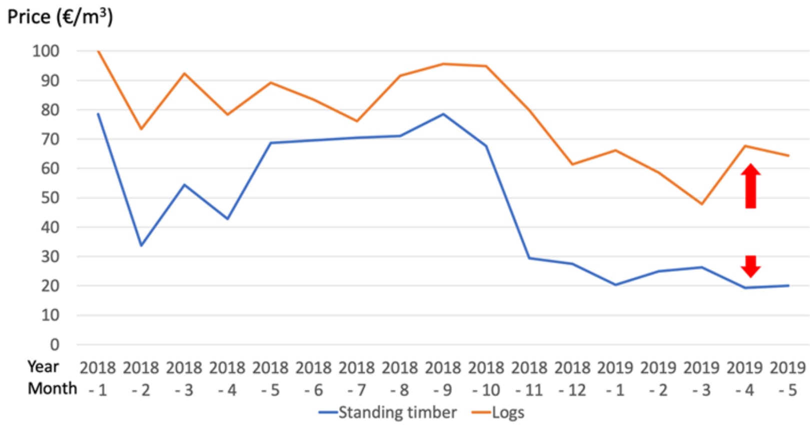

Figure 8 Dynamic of the monthly timber prices (€/m3) in the period January 2018 – May 2019. Source Commerce chamber of Trento (IT), www.legnotrentino.it/asteonline

In the first months of 2019 there has been a recovery in the price of logs (64 – 67 €/m³) due to the effect of foreign buyers, while the price of standing timber remains at very low levels (19 – 20 €/m³).

Currently, the companies are removing all the woody material, without releasing wood on the ground, as if VAIA was an unexpected sylvicultural cut operated a large forest area (as it currently arrives in Canadian, Swedish, Russian woodlands). If we want to let part of the material on the ground for stimulating the soil functionality, it is necessary to intervene rapidly raising artificially the timber price (imposing a minimum price) or establishing artificial constraints in the contract specifications (defined quantities of material to release in the forest), to guarantee the renewal of the woods in the long term.

Another exciting aspect ponders the dynamics of the free market. The storage of timber has a cost that risks not being compensated for by an expected price increase that remains unpredictable in a globalized market. It is sufficient that another catastrophic event arrives elsewhere to defeat the price forecasts. It is, therefore, more prudent to store only the wood that can be used for local activities and to rely on a global market for the rest. With growing domestic demand and booming export industry, China is both a major importer and exporter of wood products. Coupled with an environmental policy to protect the country's remaining natural forests and economic policy, China has not only increased its import of timber products but has tended to import less processed materials.

In 2018, China's logwood imports had increased by 8% compared to the previous year, rising to an overall of 60 million m³, of which about 42 million m³ (+ 9%) were softwood and 19 million m³ (+ 8%) were hardwood logs (Jauk 2019). Zhu (2019) shows (Appendix 2) that imported softwood logs quantity and price of China in 2018, 42% of softwood logs shipments arrived from New Zealand and 19% from Russia, followed by the US (12%), Australia (10%), Canada (6%) and Uruguay (5%), and the average price is about 139 $/m³ (around 125 €/m³).

The 8 million m³ of VAIA's timber correspond to a volume of softwood within reach of Chinese buyers, and the price fluctuations of Trento timber (Figure 8: months 2019-3, 2019-4) could be related to their preferences. To avoid empty export containers back to China, trading companies arrived in Europe would choose to transport logs back to China. Such logs are most likely used to produce medium grade furnishings sold in the country. Therefore, Chinese buyers were likely to buy logs and not standing timber whose prices remain low (Figure 8). The fact that the cost of wood rose to avoid returning to China with empty containers (and not for reasons of competition with European companies) left everyone stunned. The unforeseeable is... not predictable (which corresponds to a first direct feedback of this review). In this case, for example, timber extraction has become economically advantageous even in less accessible parts of the forest, with an additional consequent ecological impact to be taken into account. All this could be an example of unforeseeable behavior to have in mind if it were decided in the future to face global warming seriously.

7 Conclusions and Response to Governor of Veneto Region

Dear Governor of Veneto Region,

Thanks for asking for scientific advice.

Scientists have many solutions that depend on their character, training, intelligence, connection with the territory. Unfortunately, there is a difference of opinion on the question of how to intervene after Vaia. It is not usual to publish contrasts in scientific articles. There was a general agreement on the need to follow a "precautionary principle", to think that the territory you govern should be transmitted with its functional biodiversity to future generations. On how to do this, unfortunately, is where the shoe still pinches. Below you will find the summary of the advice of the authors of this article, and some surprises.

7.1 Is it better to let nature treat its wound?

Yes, it would be better. Where possible, it is better to leave it to nature. The whole discussion can be foound at https://hal.archives-ouvertes.fr/hal-02342793.

There is an article in The Guardian on 15 Oct. 2017: From dead woods to triumph of nature, 30 years after the Great Storm. The devastating winds of 1987 felled 15 million trees but also prompted a radical change to the way we work with the countryside to let it heal itself.

“Scords Wood was left alone,” says Tom Hill, the National Trust’s trees and woodlands specialist. “There’s been no intervention at all, and it’s now a thriving woodland in terms of its diversity.”

“Veteran trees have decay and growth happening at the same time. One of the biggest attitudes that changed was the process of decay being seen as an integrated part of life not just something dirty or rotten.”

“Storms mix things up, they allow light to get in, which is a vital factor. Toys Hill is like a mosaic of different habitats and light and shade, and it has a very diverse structure. That’s exactly what you want if you’re seeking to maintain healthy woodland. Destruction is very important, and nature is self-destructive and self-healing at the same time.”

Link: https://www.theguardian.com/environment/2017/oct/15/british-woodlands-30-years-after-great-storm

7.2 Actions

Examples of short term actions (1-5 years), concerning security, vulnerability/sensitivity analysis and maps, are reported in section 3 . In section 5.1, you dispose of a list of long term actions (1-100 years) that allow renewing the forest on 75% of the damaged surface; in 5.2, you find a list of research projects to place on the remaining 25% of the damaged surface for collecting the necessary feedback and improve the forest restoration action.

8 Artistic Interpretation and Call for Earth’s Climate Protection

Science alone is not enough. The future must also be invented (not only understood). Science and art are two sides of a single vision. Until the 17th century, art referred to any skill or mastery and was not differentiated from crafts or sciences. Because to understand things, one must first imagine them as individual mental creations. This is the reason why each individual understands things in her/his own way. Truth reveals itself in the future, it cannot be known in the present time, only "imagined". It generates itself as an amazing and ever-changing historical collective construction.

8.1 “Listen to the soil”, of Bonneval Karine (FR)

Can we listen to the ground, what sounds could the soil make?

Soil is not a simple and inert material, it is a world in itself, complex and living. The soil is full of many symbols: it is our planet of course, the soil in which we grow our food, a material first, the surface on which we are anchored, the territory on which we live. We walk on a complete universe that it seems important today to give to hear in order to understand the world below us in a different way.

It is the product of decomposing living beings and shelters an immense diversity of animals, plants, fungi, bacteria...

The life of these organisms can be heard (Figure 9): their activity generates sounds. In the ceramic sculptures are played different recordings of different soil biotopes, in order to offer to the audience a sound landscape of the soil.

A soil in good shape is noisy.

8.2 "L'urlo di Vaia", with the permission of the authors Vera Bonaventura (IT) and Roberto Mainardi (IT)

Inside Malga Costa (alpine hut for cows), it will be possible to relive, condensed in 5 minutes, what the populations and trees of Trentino have lived in 5 hours between 28 and 29 October 2018. "We probed the various forms of art we could use ... and we found ourselves with only a sound in our hands ... which, from interviews with people who lived Vaia, was an element tragically imprinted in our memory". A glimpse of this sound, from youtube: https://www.youtube.com/watch?v=SFGWU7gjQ48

8.3 A cell-phone referendum

Even after Covid-19, the climatic situation of our planet leaves no hope for a long period of peaceful coexistence, unless a decision is made to act as a whole humanity. We suggest to put the average air temperature of planet Earth (mean surface air temperature = 15 ± 2 °C) among the humanity's assets (UNESCO Wolrld Heritage List). As if the air temperature was part of our common home, related to our activities, and in need of peculiar protection.

We suggest to organize a first worldwide cell-phone referendum (Figure 10), a first conscious and democratically determined step in the Anthropocene. During the coming Olympic Games in Tokyo (July 2021). Would you help us and sign a petition addressed to the Organising Committee of the Tokyo 2020 Olympic Games?

https://secure.avaaz.org/community_petitions/en/to_the_organsing_committee_of_the_tokyo_2020_olymp_lets_organise_a_worldwide_referendum_and_stop_the_climate_from_warming/.

Figure 9 Left: Listen to the soil, sometimes I hear the plants whisper, Botanical museum Berlin, 2018. An art and science project, in collaboration with Fanny Rybak, bioacoustician in Neuropsi, Paris -Saclay/Rillig Lab, directed by Matthias Rillig, laboratory of plant ecology, freïe Universität, Berlin/Johannes Lehmann, director of the soil and crop sciences section at Cornell University .A project supported by the Diagonale Paris - Saclay, the Drac Centre-Val de Loire, Micro Onde Centre d'Art, Cornell University.

Figure 10 This figure illustrates the evolution of biodiversity on our planet, from: (Zanella 2018). Life develops between the molecular world of the organic substance in the soil and far away to the nearest galaxy clusters. The orange background corresponds to the threat of average rising air temperature. In the middle, two figures with an opposite meaning, the gray spectrum of the first atomic bomb and the "Pioneer plaque" launched in 1972 by NASA in the space to indicate our position in the universe to other extraterrestrial living beings.

Acknowledgements

Our article would like to promote collaboration between politicians and scientists. We thank the Authorities we mentioned without consultation. Thank Valter and Doretta for the photographs-reports and testimonies which helped us understand the extent of the disaster and the seriousness of the loss for the families living in the mountains. Thank Vera and Roberto for reproducing "Scream of Vaia" which causes people a feeling of fear, and at the same time silent and powerful. Authors are particularly grateful to the University of Natural Resources and Life Sciences Vienna (BOKU) which supported the open access publication of the article.

References

Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto (2015) Legenda della Carta dei Suoli del Veneto in Scala 1: 250,000. Versione 2015. Regione Veneto. "Regional Agency for Environmental Prevention and Protection of Veneto (2015) Legend of the Veneto Soil Map in Scale 1: 250,000. Version 2015. Veneto Region".(In Italian).

Akselsson C, Westling O, Örlander G (2004) Regional mapping of nitrogen leaching from clearcuts in southern Sweden. Forest Ecology and Management 202: 235-243. https://doi.org/10.1016/j.foreco.2004.07.025

Alessio Leck M, Parker VT, Simpson RL, et al. (1989) Ecology of soil seed banks. Elsevier.

Andersson E, Keskitalo ECH, Bergstén S (2018) In the eye of the storm: adaptation logics of forest owners in management and planning in Swedish areas. Scandinavian Journal of Forest Research 33: 800-808. https://doi.org/10.1080/02827581.2018.1494305

Andreetta A, Cecchini G, Marchetto A, et al. (2019) Soil-atmosphere interface: the impact of depositions on forest soils in Italy. Geophysical research abstracts 21:

Arts B, Behagel J, van Bommel S, et al (eds) (2013) Forest and Nature Governance. Springer Netherlands, Dordrecht.

Asselineau A, Donenech G (2013) De l'arbre au sol, les Bois Raméaux Fragmentés. ROUERGUE edition

Attenborough D (1995) The Private Life of Plants, 1st editio. Princeton University Press.

BAFU (2008) Sturmschaden-Handbuch. Vollzugshilfe für die Bewältigung von Sturmschadenereignissen von nationaler Bedeutung im Wald. Umwelt-Vollzug Nr. 0801., 3a edn. Umwelt-Vollzug Bundesamt für Umwelt BAFU, Bern. "Storm damage manual. Implementation aid for dealing with storm damage incidents of national importance in the forest. UmweltVollzug No. 0801., 3a edn. Environmental enforcement Federal Office for the Environment FOEN, Bern". In German

Baier P, Pennerstorfer J, Schopf A (2007) PHENIPS—A comprehensive phenology model of Ips typographus (L.) (Col., Scolytinae) as a tool for hazard rating of bark beetle infestation. Forest Ecology and Management 249(3): 171-186. https://doi.org/10.1016/j.foreco.2007.05.020

Balogh-Brunstad Z, Keller CK, Bormann BT, et al (2008) Chemical weathering and chemical denudation dynamics through ecosystem development and disturbance. Global Biogeochemical Cycles 22: n/a-n/a. https://doi.org/10.1029/2007GB002957

Baran J, Pielech R, Bodziarczyk J (2018) No difference in plant species diversity between protected and managed ravine forests. Forest Ecology and Management 430: 587-593. https://doi.org/10.1016/j.foreco.2018.08.052

Barančíková G, Jarzykiewicz M, Gömöryová E, et al. (2018) Changes in forest soil organic matter quality affected by windstorm and wildfire. Journal of Soils and Sediments 18: 2738-2747. https://doi.org/10.1007/s11368-018-1942-2

Barcikowska MJ, Weaver SJ, Feser F, et al (2018) Euro-Atlantic winter storminess and precipitation extremes under 1.5 °C vs. 2 °C warming scenarios. Earth System Dynamics 9: 679-699. https://doi.org/10.5194/esd-9-679-2018

Battany MC, Grismer ME (2000) Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. Hydrological Processe 14: 1289-1304. https://doi.org/10.1002/(SICI)1099-1085(200005)14:7<1289::AID-HYP43>3.0.CO;2-R

Bell DM, Bradford JB, Lauenroth WK (2014a) Early indicators of change: divergent climate envelopes between tree life stages imply range shifts in the western United States. Global Ecology and Biogeography 23: 168-180. https://doi.org/10.1111/geb.12109

Bell DM, Bradford JB, Lauenroth WK (2014b) Mountain landscapes offer few opportunities for high-elevation tree species migration. Global Change Biology 20: 1441-1451. https://doi.org/10.1111/gcb.12504

Berg B, McClaugherty C (2014) Plant Litter. Springer Berlin Heidelberg, Berlin, Heidelberg.

Berger TW, Sun B, Glatzel G (2004) Soil seed banks of pure spruce (Picea abies) and adjacent mixed species stands. Plant and Soil 264: 53-67. https://doi.org/10.1023/B:PLSO.0000047753.36424.41

Berhongaray G, Ceulemans R (2014) Soil organic carbon balance in a bio-energy plantation (POPFULL). In: Communications in Agricultural and Applied Biological Sciences.

Bischetti GB, Chiaradia EA, Epis T, et al. (2009) Root cohesion of forest species in the Italian Alps. Plant and Soil 324: 71-89. https://doi.org/10.1007/s11104-009-9941-0

Bonifacio E, Falsone G, Catoni M (2013) Influence of serpentine abundance on the vertical distribution of available elements in soils. Plant and Soil 368: 493-506. https://doi.org/10.1007/s11104-012-1530-y

Bormann FH, Likens G (2012) Pattern and Process in a Forested Ecosystem: Disturbance, Development and the Steady State Based on the Hubbard Brook Ecosystem Study. Springer New York

Bottalico F, Nocentini S, Travaglini D (2016) Linee guida per la ricostituzione del potenziale forestale nelle aree danneggiate dal vento: il caso dei boschi della Toscana. L'Italia Forestale e Montana 227–238. "Guidelines for the restoration of forest potential in areas damaged by wind: the case of the woods of Tuscany. L'Italia Forestale e Montana 227-238. (In Italian). https://doi.org/10.4129/ifm.2016.4.04

Bütler R, Patty L, Le Bayon RC, et al (2007) Log decay of Picea abies in the Swiss Jura Mountains of central Europe. Forest Ecology and Management 242: 791-799. https://doi.org/10.1016/j.foreco.2007.02.017

Cambi M, Certini G, Neri F, Marchi E (2015) The impact of heavy traffic on forest soils: A review. Forest Ecology and Management 338: 124-138. https://doi.org/10.1016/j.foreco.2014.11.022

Canadian Instituite of Forestry (2019) MICHAEL'S blog. In: Forestry. Contact Information: P.O. Box 99, 6905 HWY. 17

Wes Mattawa, On. Poh 1VO Canada. https://www.cif-ifc.org/2018/09/michaels-blog-2/. (accessed 11 Jun 2019).
Cat Berro D, Acordon V, Claudio C (2018) 2018. 27-30 ottobre 2018: scirocco eccezionale, mareggiate e alluvioni in Italia con la tempesta Vaia. "27-30 October 2018: exceptional sirocco, storm surges and floods in Italy with the Vaia storm" In: NimboWeb. http://www.nimbus.it/eventi/2018/181031TempestaVaia.htm (accessed 19 Jan 201). (In Italian)
Čerevková A, Renčo M (2009) Soil nematode community changes associated with windfall and wildfire in forest soil at the High Tatras National Park, Slovak Republic. Helminthologia 46: 123-130. https://doi.org/10.2478/s11687-009-0024-9
Chirici G, Giannetti F, Travaglini D, et al (2019) Forest damage inventory after the "Vaia" storm in Italy. Forest@ - Journal of Silviculture and Forest Ecology 16: 3-9. (In Italian) https://doi.org/10.3832/efor3070-016.
Ciancio O (2015) Designing the future of the forestry sector. Silvosistemica: to know is to act. In: Atti del Secondo Congresso Internazionale di Selvicoltura = Proceedings of the Second International Congress of Silviculture. Accademia Italiana di Scienze Forestali, pp 23-32. (In Italian)
Ciancio O (2010) La teoria della selvicoltura sistemica, le "sterili disquisizioni" e il sonnambulismo dell'intellighenzia forestale. Accademia Italiana di Scienze Forestali. " The theory of systemic forestry, the "sterile disquisitions" and the sleepwalking of the forest intelligentsia. Italian Academy of Forest Sciences". (In Italian)
Ciancio O (2009) Relaezione introduttiva. Quale selvicoltura nel XXI secolo? In: ATTI del Terzo Congresso Nazionale di Selvicoltura per il miglioramento e la conservazione dei boschi italiani. 16-19 ottobre 2008 TAORMINA (Messina). Accademia Italiana di Scienze Forestali Firenze - 2009 VOLUME PRIMO. Accademia Italiana di Scienze Forestali, Firenze (Italia). Piazza Edison 11 - 50133 Firenze info@aisf.it - www.aisf.it, Firenze, Italy, pp 3–39. " Which silviculture in the 21st century? In: PROCEEDINGS of the Third National Congress of Forestry for the improvement and conservation of Italian woods. 16-19 October 2008 TAORMINA (Messina). Italian Academy of Forest Sciences Florence - 2009 FIRST VOLUME. (In Italian)
Cislaghi A, Vergani C, Chiaradia EA, Bischetti GB (2019) A Probabilistic 3-D Slope Stability Analysis for Forest Management. Recent Advances in Geotechnical Research, pp 11–21. In: Wu W. (eds) Recent Advances in Geotechnical Research. Springer Series in Geomechanics and Geoengineering. Springer, Cham. https://doi.org/10.1007/978-3-319-89671-7_2
Cleveland CC, Reed SC, Keller AB, et al (2014) Litter quality versus soil microbial community controls over decomposition: a quantitative analysis. Oecologia 174: 283-294. https://doi.org/10.1007/s00442-013-2758-9
Costantini EA, Andrenelli MC, Fantappiè M, et al (2017) Management of forest stands to enhance soil ecosystem services: a short review of recent and on-going projects in Mediterranean Europe. In: Roberto Tognetti GSM and TH (ed) Mountain Watersheds and Ecosystem Services: Balancing multiple demands of forest management in head-watersheds. EFI Technical Report 101. European Forest Institute. European Forest Institute, pp 44-51.
Costantini EAC, Barbetti R, Fantappiè M, et al (2013) Pedodiversity. In: Costantini E.A.C. DC (ed) The Soils of Italy, World Soil. Springer, pp 105–178
Costantini EAC, L'Abate G (2016) Beyond the concept of dominant soil: Preserving pedodiversity in upscaling soil maps. Geoderma 271: 243-253. https://doi.org/10.1016/j.geoderma.2015.11.024
Costantini EAC, Lorenzetti R (2013) Soil degradation processes in the Italian agricultural and forest ecosystems. Italian Journal of Agronomy 8:28. https://doi.org/10.4081/ija.2013.e28
Couture M, Fortin J-A, Dapré Y (1983) Oidiodendron griseum (Robak): an endophyte of ericoid mycorrhizas in Vaccinium spp. New Physiologist 95: 375-380
Culliney T (2013) Role of Arthropods in Maintaining Soil Fertility. Agriculture 3: 629-659. https://doi.org/10.3390/agriculture3040629
Diaci J, Rozenbergar D, Fidej G, Nagel TA (2017) Challenges for Uneven-Aged Silviculture in Restoration of Post-Disturbance Forests in Central Europe: A Synthesis. Forests 8: 378.' https://doi.org/10.3390/f8100378
Directorate-General of the State Forests (2017) Forest in Poland 2017. The State Forests Information Centre, Warsaw
Ebner G (2018) More clarity on the consequences of Vaia. In: Timber-online.net. https://www.timber-online.net/rundholz/2019/02/more-clarity-on-the-consequences-of-vaia.html (accessed 10 Jun 2019).
Faccoli M, Bernardinelli I (2014) Composition and Elevation of Spruce Forests Affect Susceptibility to Bark Beetle Attacks: Implications for Forest Management. Forests 5: 88-102. https://doi.org/10.3390/f5010088
Falsone G, Celi L, Caimi A, et al (2012) The effect of clear cutting on podzolisation and soil carbon dynamics in boreal forests (Middle Taiga zone, Russia). Geoderma 177-178: 27-38. https://doi.org/10.1016/j.geoderma.2012.01.036
Finér L, Jurgensen M, Palviainen M, et al (2016) Does clear-cut harvesting accelerate initial wood decomposition? A five-year study with standard wood material. Forest Ecology and Management 372: 10-18. https://doi.org/10.1016/j.foreco.2016.03.060
Fischer A, Lindner M, Abs C, Lasch P (2002) Vegetation dynamics in central european forest ecosystems (near-natural as well as managed) after storm events. Folia Geobotanica 37:17–32. https://doi.org/10.1007/BF02803188
Fukasawa Y (2012) Effects of wood decomposer fungi on tree seedling establishment on coarse woody debris. Forest Ecology and Management 266: 232-238. https://doi.org/10.1016/j.foreco.2011.11.027
Gardiner B, Schuck A, Schelhaas M-J, et al (2013) Living with storm damage to forests. What Science Can Tell Us 3, European Forest Institute. Joensuu, Finland
Génot JC, Poirot J, Vallauri D, et al (2011) La Lettre des forêts Sauvages. Naturalité. Lettre n° 13. WWF. http://www.forets-sauvages.fr/automne_modules_files/pdocs/edited/r108_10_naturalite_13.pdf (accessed 31 August 2020)
Giannini R, Susmel L (2006) Forests, woods, forest plantations. Forest@ - Journal of Silviculture and Forest Ecology 3: 464-487. https://doi.org/10.3832/efor0424-0030464
Gleick J, Hilborn RC (1988) Chaos, Making a New Science. American Journal of Physics 56: 1053-1054. https://doi.org/10.1119/1.15345
Gobat JM, Guenat C (2019) Sols et paysages - Types de sols, fonctions et usages en Europe moyenne, 1st editio. PPUR - Collection: Science et ingénierie de l'environnement
Gobin A, Jones R, Kirkby M, et al (2004) Indicators for pan-European assessment and monitoring of soil erosion by water. Environmental Science & Policy 7: 25-38. https://doi.org/10.1016/j.envsci.2003.09.004
Gonzalez P, Neilson RP, Lenihan JM, et al. (2010) Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography 19: 755-–768. https://doi.org/10.1111/j.1466-8238.2010.00558.x
Guerra AJT, Fullen MA, Jorge M do CO, et al (2017) Slope Processes, Mass Movement and Soil Erosion: A Review. Pedosphere 27: 27-41. https://doi.org/10.1016/S1002-0160(17)60294-7
Gundersen P, Schmidt IK, Raulund-Rasmussen K (2006) Leaching of nitrate from temperate forests – effects of

air pollution and forest management. Environmental Reviews 14: 1-57. https://doi.org/10.1139/a05-015

Guo X (2016) Natural regeneration on coarse woody debris. Univ Br Columbia Open Collect UBC Undergraduate Research 1-22. https://doi.org/10.14288/1.0075522

Heilmann-Clausen J (2001) A gradient analysis of communities of macrofungi and slime moulds on decaying beech logs. Mycological Research 105: 575-596. https://doi.org/10.1017/S0953756201003665

Hellsten S, Stadmark J, Pihl Karlsson G, et al (2015) Increased concentrations of nitrate in forest soil water after windthrow in southern Sweden. Forest Ecology and Management 356: 234-242. https://doi.org/10.1016/j.foreco.2015.07.009

Holvoet B, Muys B (2004) Sustainable forest management worldwide: a comparative assessment of standards. International Forestry Review 6: 99-122. https://doi.org/10.1505/ifor.6.2.99.38388

Ilisson T, Köster K, Vodde F, et al. (2007) Regeneration development 4–5 years after a storm in Norway spruce dominated forests, Estonia. Forest Ecology and Management 250: 17-24. https://doi.org/10.1016/j.foreco.2007.03.022

Indermühle M, Raetz P, Volz R (2005) LOTHAR - Ursächliche Zusammenhänge und Risikoentwicklung. Synthese des Teilprogramms 6. Umwelt-Materialien Nr. 184. Bundesamt für Umwelt, Wald und Landschaft, Bern. 145 S. " Causal relationships and risk development. Synthesis of sub-program 6. Environmental materials No. 184. Federal Office for the Environment, Forests and Landscape, Bern. 145 pp." In German. https://www.waldwissen.net/waldwirtschaft/schaden/sturm_schnee_eis/wsl_lothar_zusammenhaenge/index_DE (accessed August 31 2020)

IUSS Working Group WRB (2015) World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. Food and Agriculture Organization of the United Nations, Rome, Italy.

Jackson ST, Betancourt JL, Booth RK, Gray ST (2009) Ecology and the ratchet of events: Climate variability, niche dimensions, and species distributions. Proceedings of the National Academy of Sciences 106: 19685-19692. https://doi.org/10.1073/pnas.0901644106

Janssens IA, Luyssaert S (2009) Nitrogen's carbon bonus. Nat Geosci 2: 318-319. https://doi.org/10.1038/ngeo505

Jastrow JD, Amonette JE, Bailey VL (2007) Mechanisms controlling soil carbon turnover and their potential application for enhancing carbon sequestration. Climatic Change 80: 5-23. https://doi.org/10.1007/s10584-006-9178-3

Jauk G (2019) Log wood imports at 60 million sm^3 (adapted for holzkurier.com; translated by Eva Guzely). In: Timber-online.net. https://www.timber-online.net/rundholz/2019/02/log-wood-imports-at-60-million-sm-.html (accessed Jun 10 2019).

Jobbágy EG, Jackson RB (2001) The distribution of soil nutrients with depth: Global patterns and the imprint of plants. Biogeochemistry 53: 51-57. https://doi.org/10.1023/A:1010760720215

Johansson M-B, Berg B, Meentemeyer V (1995) Litter mass-loss rates in late stages of decomposition in a climatic transect of pine forests. Long-term decomposition in a Scots pine forest. IX. Canadian Journal of Botany 73: 1509-1521. https://doi.org/10.1139/b95-163

Katzensteiner K, Ewald J and Göttlein A (2016) StratAlp: Wälder der Kalkalpen - Strategien für die Zukunft. Österreichische Gesellschaft für Waldökosystemforschung und Experimentelle Baumforschung an der Univ. f. Bodenkultur Wie. Schriftleitung: Prof. Dr.Herbert Hager Bearbeiterin: Mag. Judith Schaufler. 127 p. " StratAlp: Forests of the Limestone Alps - Strategies for the future". (In German). https://boku.ac.at/fileadmin/data/H03000/H91000/H91200/Schriftenreihe/Band_21.pdf (accessed August 31 2020)

Kauppi P, Hanewinkel M, Lundmark T, et al (2018) Climate Smart Forestry in Europe. European Forest Institute

Keenan RJ (2015) Climate change impacts and adaptation in forest management: a review. Annals of Forest Sciencei 72: 145-167. https://doi.org/10.1007/s13595-014-0446-5

Kingsland S (2015) Alfred J. Lotka and the origins of theoretical population ecology. Proceedings of the National Academy of Sciences of the United States of America 112: 9493-9495. https://doi.org/10.1073/pnas.1512317112

Kreutzweiser DP, Hazlett PW, Gunn JM (2008) Logging impacts on the biogeochemistry of boreal forest soils and nutrient export to aquatic systems: A review. Environmental Reviews 16: 157-179. https://doi.org/10.1139/A08-006

Kulakowski D, Seidl R, Holeksa J, et al (2017) A walk on the wild side: Disturbance dynamics and the conservation and management of European mountain forest ecosystems. Forest Ecology and Management 388: 120-131. https://doi.org/10.1016/j.foreco.2016.07.037

Kuuluvainen T (1994) Gap disturbance, ground microtopography, and the regeneration dynamics of boreal coniferous forests in Finland: a review. Annales Zoologici Fennici 31: 35-51.

Landmann G, Achat D, Augusto L, et al (2015) Projet RÉSOBIO. Gestion des rémanents forestiers : préservation des sols et de la biodiversité. Synthèse de l'étude RÉSOBIO Angers : ADEME, Paris : Ministère de l'agriculture, de l'agroalimentaire et de la forêt - GIP Ecofor. " RESOBIO project. Management of forest residues: preservation of soil and biodiversity. Summary of the RESOBIO study". https://www.ademe.fr/projet-resobio-gestion-remanents-forestiers-preservation-sols-biodiversite (accessed August 31 2020). (In French)

Landmann G, Augusto L, Cabral AS, Saint-André L (2014) Sylvicultural Itineraries and Sustainability of Soil. Report of the workshop 1. Revue forestière française LXVI – hors série 2014.

Landmann G, Gosselin F, Bonhême I (2009) Utilisation de la biomasse forestière, biodiversité et ressources naturelles : synthèse et pistes d'approfondissement : chap 16. Bio2 - Biomasse et Biodiversité Forestière - Augmentation de l'utilisation de la biomasse forestière: implications pour la biodiversité et les ressources naturelles, Landmann G., Gosselin, F., Bonhême, I. (eds), GIP Ecofor, p. 177 - p. 191, 2009. ⟨hal-00498671⟩. https://hal.archives-ouvertes.fr/hal-00498671 (accessed August 31 2020)

Legout A, Nys C, Picard J-F, et al (2009) Effects of storm Lothar (1999) on the chemical composition of soil solutions and on herbaceous cover, humus and soils (Fougères, France). Forest Ecology and Management 257: 800-811. https://doi.org/10.1016/j.foreco.2008.10.012

Linser S, Wolfslehner B, Bridge S, et al (2018) 25 Years of Criteria and Indicators for Sustainable Forest Management: How Intergovernmental C& I Processes Have Made a Difference. Forests 9: 578. https://doi.org/10.3390/f9090578

Lorenz EN (1963) Deterministic Nonperiodic Flow. Journal of the Atmospheric Sciences 20: 130-141. https://doi.org/10.1175/1520-0469(1963)020<0130:DNF>2.0.CO;2

Lorenzetti R, Costantini EAC, Agnelli AE, et al. (2019) Relationships between humus profiles and C cycling, first results from a Mediterranean pine forest. EQA – Environmental quality /Qualité de l'Environnement / Qualità ambientale 33: 37-53.

https://doi.org/10.6092/issn.2281-4485/843537
Lovelock JE, Margulis L (1974) Atmospheric homeostasis by and for the biosphere: the gaia hypothesis. Tellus A 26: 2-10. https://doi.org/10.1111/j.2153-3490.1974.tb01946.x
Machar I, Simon J, Rejsek K, et al (2016) Assessment of Forest Management in Protected Areas Based on Multidisciplinary Research. Forests 7: 285. https://doi.org/10.3390/f7110285
Machrafi Y, Prévost D, Beauchamp CJ (2006) Toxicity of Phenolic Compounds Extracted from Bark Residues of Different Ages. Journal of Chemical Ecology 32: 2595-2615. https://doi.org/10.1007/s10886-006-9157-1
Magnússon RÍ, Tietema A, Cornelissen JHC, et al (2016) Tamm Review: Sequestration of carbon from coarse woody debris in forest soils. Forest Ecology and Management 377: 1-15. https://doi.org/10.1016/j.foreco.2016.06.033
Mandelbrot B. B. (1983) The fractal geometry of nature /Revised and enlarged edition/. New York
Martiník A, Dobrovolný L, Hurt V (2014) Comparison of different forest regeneration methods after windthrow. Journal of Forest Science 60: 190-197. https://doi.org/10.17221/66/2013-JFS
Mayer M, Prescott CE, Abaker WEA, et al (2020) Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. Forest Ecology and Management 466: 118127. https://doi.org/10.1016/j.foreco.2020.118127
McFee WW, Stone EL (1966) The Persistence of Decaying Wood in the Humus Layers of Northern Forests1. Soil Science Society of America Journal 30: 513. https://doi.org/10.2136/sssaj1966.03615995003000040032x
McNulty SG (2002) Hurricane impacts on US forest carbon sequestration. Environmental Pollution 116:S17–S24. https://doi.org/10.1016/S0269-7491(01)00242-1
Meentemeyer V (1978) Macroclimate and Lignin Control of Litter Decomposition Rates. Ecology 59: 465-472. https://doi.org/10.2307/1936576
Melillo JM, Aber JD, Muratore JF (1982) Nitrogen and Lignin Control of Hardwood Leaf Litter Decomposition Dynamics. Ecology 63: 621-626. https://doi.org/10.2307/1936780
Merzari M, Amicarelli A, Lucchi S (2018) Devastazione forestale sulle Alpi – Analisi metereologica e aspetti forestali. Reportage – 12 Novembre 2018. " Forest devastation in the Alps - Meteorological analysis and forest aspects. Reportage - 12 November 2018."In: Meteo4. http://www.meteo4.com/mt/index.php (accessed Jan 19 2019). In Italian
Moroni MT, Hagemann U, Beilman DW (2010) Dead Wood is Buried and Preserved in a Labrador Boreal Forest. Ecosystems 13: 452-458. https://doi.org/10.1007/s10021-010-9331-8
Morris JL, Cottrell S, Fettig CJ, et al (2018) Bark beetles as agents of change in social-ecological systems. Frontiers in Ecology and the Environment 16: S34-S43. https://doi.org/10.1002/fee.1754
Motta R (2018) The balance of nature does not exist (and has never existed!). Forest@ - Journal of Silviculture and Forest Ecology 15: 56-–58. https://doi.org/10.3832/efor2839-015
Motta R, Ascoli D, Corona P, et al (2018) Silviculture and wind damages. The storm "Vaia." Forest@ - Journal of Silviculture and Forest Ecology 15: 94-98. https://doi.org/10.3832/efor2990-015
Motta R, Berretti R, Lingua E, et al. (2006) Coarse woody debris, forest structure and regeneration in the Valbona Forest Reserve, Paneveggio, Italian Alps. Forest Ecology and Management 235: 155-163. https://doi.org/10.1016/j.foreco.2006.08.007
Motta R, Nola P, Piussi P (2002) Long-term investigations in a strict forest reserve in the eastern Italian Alps: spatio-temporal origin and development in two multi-layered subalpine stands. Journal of Ecology 90: 495-507. https://doi.org/10.1046/j.1365-2745.2002.00685.x
Næsset E (1999) Decomposition rate constants of Picea abies logs in southeastern Norway. Canadian Journal of Forest Research 29: 372-381. https://doi.org/10.1139/x99-005
Nicolis G, Auchmuty JFG (1974) Dissipative Structures, Catastrophes, and Pattern Formation: A Bifurcation Analysis. Proceedings of the National Academy of Sciences of the United States of America 71: 2748-2751. https://doi.org/10.1073/pnas.71.7.2748
Nottale L (2003) Scale-relativistic cosmology. Chaos, Solitons & Fractals 16: 539-–564. https://doi.org/http://dx.doi.org/10.1016/S0960-0779(02)00222-9
Nottale L, Schumacher G (1998) Scale relativity, fractal space–time and gravitational structures. Fractals Beyond Complexities Sci World Sci London, UK 0: 149-160.
Novaes E, Kirst M, Chiang V, et al (2010) Lignin and Biomass: A Negative Correlation for Wood Formation and Lignin Content in Trees. Plant Physiology 154: 555-561. https://doi.org/10.1104/pp.110.161281
Orman O, Szewczyk J (2015) European beech, silver fir, and Norway spruce differ in establishment, height growth, and mortality rates on coarse woody debris and forest floor—a study from a mixed beech forest in the Western Carpathians. Annals of Forest Science 72: 955–965. https://doi.org/10.1007/s13595-015-0492-7
Paoletti MG (1999) Invertebrate Biodiversity as Bioindicators of Sustainable Landscapes. Elsevier Science.
Parisi F, Pioli S, Lombardi F, et al (2018) Linking deadwood traits with saproxylic invertebrates and fungi in European forests - a review. iForest - Biogeosciences and Forestry 11: 423-436. https://doi.org/10.3832/ifor2670-011
Ponge J-F (2005) Emergent properties from organisms to ecosystems: towards a realistic approach. Biological Reviews 80: 403-411. https://doi.org/10.1017/s146479310500672x
Popkin G (2019) 'Wood wide web'—the underground network of microbes that connects trees—mapped for first time. Science (80). Posted in: Plants & Animals. May. 15, 2019, 1:20 PM. https://doi.org/10.1126/science.aay0516
Prigogine I, Nicolis G, Babloyantz A (1974) Nonequilibrium Problems in Biological Phenomena. Annals of the New York Academy of Sciences 231: 99-100. https://doi.org/10.1111/j.1749-6632.1974.tb20557.x
Přívětivý T, Janík D, Unar P, et al (2016) How do environmental conditions affect the deadwood decomposition of European beech (Fagus sylvatica L.)? Forest Ecology and Management 381: 177-187. https://doi.org/10.1016/j.foreco.2016.09.033
Raiskila S (2008) The effect of lignin content and lignin modification on Norway spruce wood properties and decay resistance. Dissertationes Forestales 2008. The Finnish Society of Forest Science Finnish Forest Research Institute Faculty of Agriculture and Forestry of the University of Helsinki. https://doi.org/10.14214/df.68
Ranger J, Loyer S, Gelhaye D, et al (2007) Effects of the clear-cutting of a Douglas-fir plantation (Pseudotsuga menziesii F.) on the chemical composition of soil solutions and on the leaching of DOC and ions in drainage waters. Annals of Forest Science 64: 183-200. https://doi.org/10.1051/forest:2006103
Rees M (1994) Delayed Germination of Seeds: A Look at the Effects of Adult Longevity, the Timing of Reproduction, and Population Age/Stage Structure. The American Naturalist 144: 43-64. https://doi.org/10.1086/285660
Rogers RD, Schumm SA (1991) The effect of sparse vegetative cover on erosion and sediment yield. Journal of Hydrology 123: 19-24.

https://doi.org/10.1016/0022-1694(91)90065-P
Rogora M, Colombo L, Marchetto A, et al (2016) Temporal and spatial patterns in the chemistry of wet deposition in Southern Alps. Atmospheric Environment 146: 44-54. https://doi.org/10.1016/j.atmosenv.2016.06.025
Sadri AM, Ukkusuri SV, Gladwin H (2017) The Role of Social Networks and Information Sources on Hurricane Evacuation Decision Making. Natural Hazards Review 18: 04017005. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000244
Sarkanen K, Ludwig C (1971) Lignins: Occurrence, Formation, Structure and Reactions. John Wiley and Sons, New York.
Seidl R, Blennow K (2012) Pervasive Growth Reduction in Norway Spruce Forests following Wind Disturbance. PLoS One 7: e33301. https://doi.org/10.1371/journal.pone.0033301
Seidl R, Thom D, Kautz M, et al (2017) Forest disturbances under climate change. Nature Climate Change 7: 395-402. https://doi.org/10.1038/nclimate3303
Selosse M-A (2017) Jamais Seul - Ces microbes qui construisent les plantes, les animaux et les civilisations. Actes Sud
Siira-Pietikäinen A, Pietikäinen J, Fritze H, Haimi J (2001) Short-term responses of soil decomposer communities to forest management: clear felling versus alternative forest harvesting methods. Canadian Journal of Forest Research 31: 88-99. https://doi.org/10.1139/cjfr-31-1-88
Smolander A, Heiskanen J (2007) Soil N and C transformations in two forest clear-cuts during three years after mounding and inverting. Canadian Journal of Soil Science 87: 251-258. https://doi.org/10.4141/S06-028
Smolander A, Levula T, Kitunen V (2008) Response of litter decomposition and soil C and N transformations in a Norway spruce thinning stand to removal of logging residue. Forest Ecology and Management 256: 1080-1086. https://doi.org/10.1016/j.foreco.2008.06.008
Sofo A, Ciarfaglia A, Scopa A, et al (2014) Soil microbial diversity and activity in a Mediterranean olive orchard using sustainable agricultural practices. Soil Use and Management 30: 160-167. https://doi.org/10.1111/sum.12097
Sofo A, Milella L, Tataranni G (2010) Effects of Trichoderma harzianum strain T-22 on the growth of two Prunus rootstocks during the rooting phase. The Journal of Horticultural Science and Biotechnology l 85: 497-502. https://doi.org/10.1080/14620316.2010.11512704
Sofo A, Nuzzo V, Tataranni G, et al (2012) Berry morphology and composition in irrigated and non-irrigated grapevine (Vitis vinifera L.). J Plant Physiology 169: 1023-1031. https://doi.org/10.1016/j.jplph.2012.03.007
Soil Survey Staff (2015) Illustrated guide to soil taxanomy, version 2. U.S. Department of Agriculture, natural resources Conservation Service, National Soil Survey Center, Luncoln, Nebraska
Spears JDH, Lajtha K (2005) The imprint of coarse woody debris on soil chemistry in the Western Oregon Cascades. Biogeochemistry 71: 163-175. https://doi.org/10.1007/s10533-005-6395-1
Spurr SH (1956) Natural Restocking of Forests Following the 1938 Hurricane in Central New England. Ecology 37: 443-451. https://doi.org/10.2307/1930166
Stanchi S, Freppaz M, Zanini E (2012) The influence of Alpine soil properties on shallow movement hazards, investigated through factor analysis. Natural Hazards and Earth System Sciences 12: 1845-1854. https://doi.org/10.5194/nhess-12-1845-2012
Stanko V, Anton I, Borut P, Janez V (2011) Effect of soil management systems on erosion and nutrition loss in vineyards on steep slope. Journal of Environmental Biology 32: 289-294.
Stokland JN, Siitonen J, Jonsson BG (2012) Biodiversity in Dead Wood. Cambridge University Press, Cambridge.
Strom PF (1985) Effect of temperature on bacterial species diversity in thermophilic solid-waste composting. Applied and Environmental Microbiology 50: 899-905.
Strukelj M, Brais S, Quideau SA, et al (2013) Chemical transformations in downed logs and snags of mixed boreal species during decomposition. Canadian Journal of Forest Research 43: 785-798. https://doi.org/10.1139/cjfr-2013-0086
Susmel L (1980) Normalizzazione delle foreste Alpine: basi ecosistemiche, equilibrio, modelli colturali, produttività : con applicazione alle foreste del Trentino. Liviana, Padova, Italy. " Normalization of Alpine forests: ecosystem basis, balance, crop models, productivity: with application to the forests of Trentino". (In Italian)
Szewczyk J, Szwagrzyk J (1996) Tree regeneration on rotten wood and on soil in old-growth stand. Vegetatio 122: 37-46. https://doi.org/10.1007/BF00052814
Taeroe A, de Koning JHC, Löf M, et al (2019) Recovery of temperate and boreal forests after windthrow and the impacts of salvage logging. A quantitative review. Forest Ecology and Management 446: 304-316. https://doi.org/10.1016/j.foreco.2019.03.048
Talignani G (2019) Alberi venduti ai cinesi e filiera solidale. Così si recuperano i tronchi della tempesta di Vaia (17 maggio 2019). La Repubblica. " Trees sold to the Chinese and solidarity chain. This is how the trunks of the Vaia storm are recovered (17 May 2019)" https://www.repubblica.it/ambiente/2019/05/17/news/alberi_venduti_ai_cinesi_e_filiera_solidale_cosi_si_recuperano_i_tronchi_della_tempesta_di_vaia-226527680/?refresh_ce (accessed Jun 10 2019).
Tang J-C, Kanamori T, Inoue Y, et al (2004) Changes in the microbial community structure during thermophilic composting of manure as detected by the quinone profile method. Process Biochemistry 39: 1999-2006. https://doi.org/10.1016/j.procbio.2003.09.029
Tatti D, Fatton V, Sartori L, et al (2018) What does 'lignoform' really mean? Applied Soil Ecology 123: 632-645. https://doi.org/10.1016/j.apsoil.2017.06.037
Taylor BR, Carmichael B (2003) Toxicity and chemistry of aspen wood leachate to aquatic life: field study. Environmental Toxicology and Chemistry 22: 2048-2056.
Thompson K (2000) The Functional Ecology of Soil Seed Banks. In: Fenner M (ed) Seeds. The Ecology of Regeneration in Plant Communities. 2nd Edition. School of Biological Sciences University of Southampton, UK - CABI Publishing International, pp 218-221.
Thompson K, Ceriani RM, Bakker JP, Bekker RM (2003) RESEARCH OPINION. Are seed dormancy and persistence in soil related? Seed Science Research 97-100. https://doi.org/10.1079/SSR2003128
Törmänen T, Kitunen V, Lindroos A-J, et al (2018) How do logging residues of different tree species affect soil nitrogen cycling after final felling? Forest Ecology and Management 427: 182-189. https://doi.org/10.1016/j.foreco.2018.06.005
Tsujino R, Matsui K, Yamamoto K, et al (2013) Degradation of Abies veitchii wave-regeneration on Mt. Misen in Ohmine Mountains: effects of sika deer population. Journal of Plant Research 126: 625-634. https://doi.org/10.1007/s10265-013-0551-9
Valinger E, Kempe G, Fridman J (2014) Forest management and forest state in southern Sweden before and after the impact of storm Gudrun in the winter of 2005. Scandinavian Journal of Forest Research 29: 466-472. https://doi.org/10.1080/02827581.2014.927528
Valinger E, Kempe G, Fridman J (2019) Impacts on forest management and forest state in southern Sweden 10 years after the storm Gudrun. Forestry: An International Journal of Forest Research 92: 481-489. https://doi.org/10.1093/forestry/cpz005
Vitousek PM, Gosz JR, Grier CC, et al (1979) Nitrate Losses from Disturbed Ecosystems. Science (80)204: 469-474. https://doi.org/10.1126/science.204.4392.469

Vitousek PM, Turner DR, Parton WJ, Sanford RL (1994) Litter Decomposition on the Mauna Loa Environmental Matrix, Hawai'i: Patterns, Mechanisms, and Models. Ecology 75: 418-429. https://doi.org/10.2307/1939545

Vodde F, Jõgiste K, Kubota Y, et al (2011) The influence of storm-induced microsites to tree regeneration patterns in boreal and hemiboreal forest. Journal of Forest Research 16: 155–167. https://doi.org/10.1007/s10310-011-0273-6

Volterra Vi (1926) Fluctuations in the Abundance of a Species considered Mathematically1. Nature 118: 558-560.

Wandeler H De (2018) Earthworm communities in relation to tree communities in European forests. PhDmanuscript_DeWandelerHans.pdf [freely available]: https://limo.libis.be/primo-explore/fulldisplay?docid=LIRIAS2000486&context=L&vid=Lirias&search_scope=Lirias&tab=default_tab&lang=en_US&fromSitemap=1 (accessed August 31 2020)

Wesołowski T, Zmihorski M (2018) Lasy po huraganach: uczmy się na błędach. "Ziemia na crossroads" portal. Published: March 7, 2018 in the Climate and economy category by Hubert. "Hurricane forests: let's learn from mistakes". https://ziemianarozdrozu.pl/artykul/3791/lasy-po-huraganach-uczmy-sie-na-bledach (accessed August 31 2020). (In Polish)

Wohlgemuth T, Moser B, Brändli U-B, et al (2008) Diversity of forest plant species at the community and landscape scales in Switzerland. Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology 142: 604-613. https://doi.org/10.1080/11263500802410975

Wohlleben P (2016) The Hidden Life of Trees: What They Feel, How They Communicate – Discoveries from a Secret World. Greystone Books, Canada.

Wohlleben P (2018) The Secret Network of Nature. The Delicate Balance of All Living Things. Penguin Random House UK, London SW1V 2SA

Xu GL, Chen WY (2016) Two new species of Sinella from Guangdong Province, China (Collembola: Entomobryidae). Zookeys 611: 1-10. https://doi.org/10.3897/zookeys.611.9025

Zanella A (2018) Humans, humus, and universe.Applied Soil Ecology 123: 561-567. https://doi.org/10.1016/j.apsoil.2017.07.009

Zanella A, Ascher-Jenull J (2018a) Editorial. Humusica 1 - Terrestrial Natural Humipedons.Applied Soil Ecology 122: 1-9. https://doi.org/10.1016/J.APSOIL.2017.11.029

Zanella A, Ascher-Jenull J (2018b) Editorial. Humusica 2 - Histic, Para, Techno, Agro Humipedons.Applied Soil Ecology 122: 139-147. https://doi.org/10.1016/j.apsoil.2017.12.006

Zanella A, Ascher-Jenull J (2018c) Editorial. HUMUSICA 3 - Reviews, Applications, Tools.Applied Soil Ecology 123: 297-298. https://doi.org/10.1016/j.apsoil.2018.05.016

Zanella A, Berg B, Ponge J-F, Kemmers RH (2018a) Humusica 1, article 2: Essential bases - Functional considerations.Applied Soil Ecology 122: 22-41. https://doi.org/10.1016/j.apsoil.2017.07.010

Zanella A, Bolzonella C, Lowenfels J, et al (2018b) Humusica 2, article 19: Techno humus systems and global change - Conservation agriculture and 4/1000 proposal.Applied Soil Ecology 122: 271-296. https://doi.org/10.1016/j.apsoil.2017.10.036

Zanella A, Ponge J-F, Andreetta A, et al (2019) Forest Biodiversity, Soil Functions and Human Behavior - A case study: the October 29 2018 catastrophe in North-East Italian Alps. Centre pour la Communication Scientifique Directe - CNRS. hal-02342793v4. https://hal.archives-ouvertes.fr/hal-02342793

Zanella A, Ponge J-F, Fritz I, et al (2018c) Humusica 2, article 13: Para humus systems and forms.Applied Soil Ecology 122: 181-199. https://doi.org/10.1016/j.apsoil.2017.09.043

Zanella A, Ponge J-F, Gobat J-M, et al (2018d) Humusica 1, article 1: Essential bases – Vocabulary.Applied Soil Ecology 122: 10-21. https://doi.org/10.1016/j.apsoil.2017.07.004

Zastocki D, Lachowicz H, Sadowski J, Moskalik T (2018) Changes in the Assortment and Species Structure of Timber Harvested from the Polish Managed Part of Białowieża Forest. Sustainability 10: 3279. https://doi.org/10.3390/su10093279

Zeeman EC (1976) Catastrophe Theory. Sci Am 234:65–83

Zhang X, Xin X, Zhu A, et al (2018) Linking macroaggregation to soil microbial community and organic carbon accumulation under different tillage and residue managements. Soil & Tillage Research 178: 99-107. https://doi.org/10.1016/j.still.2017.12.020

Zhu G (2019) Changes and Problems in China's Import and Export Market of Wood and Wood Products in 2018. International Wood Industry 49: 18-22. In Chinese. https://doi.org/10.3969/j.issn.1671-4911.2019.01.006.

Zielonka T (2006) When does dead wood turn into a substrate for spruce replacement? Journal of Vegetation Science 17: 739-746. https://doi.org/10.1111/j.1654-1103.2006.tb02497.x

Zielonka T, Piątek G (2001) Norway spruce regeneration on decaying logs in subalpine forests in the Tatra National Park. Polish Botanical Journal 46: 251-260.

Zielonka T, Piątek G (2004) The Herb and Dwarf Shrubs Colonization of Decaying Logs in Subalpine Forest in the Polish Tatra Mountains. Plant Ecology 172: 63-72. https://doi.org/10.1023/B:VEGE.0000026037.03716.fc

The following Appendixe (Appendixes 1) is the Electronic Supplementary Material of the article entitled "Combined forest and soil management after a catastrophic event" at https://doi.org/10.1007/s11629-019-5890-0

Appendix 1 European soil regions and subregion (EDGI 2016), altitude, soil references (IUSS Working Group WRB 2015; Soil Survey Staff 2014) and humus systems (Zanella et al. 2018e) examples. From Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto (2019), synthetic overview.

Soil region	Soil subregion	Soil subregion description	Altitude (m)	Examples of common soils	Soil diagnostic horizons	Humus system (diagnostic horizons)
37.1	MA1	Soils formed from moderately competent silicate lithotypes. They are located on high slopes and at the top of the main mountain ranges, at medium energy of the relief, with common coverings of glacial and slope deposits.	1900-2500	Moderately deep, stony soils, with moderate profile differentiation and locally with moderate translocation of aluminium and iron sesquioxides in depth (Dystric Cambisols - Dystrudepts) and moderately deep, stony soils, with high profile differentiation, with sesquioxides and organic substance translocation in depth (Entic Podzols - Humicryods)	A(AE)-Bs-CO; A-Bhs-Bs-BC-C	Moder (OL, zoOF, zoOH or szoOH, sgA) or Mor (OL, nozOF or szoOH, msA or sgA or absence of A horizon)
	MB1	Soils formed from moderately competent silicate lithotypes. They are located on medium and low slopes of main mountain ranges and secondary chains, at medium energy of the relief, with extensive coverage of glacial and slope deposits	1000-1900	Moderately deep, stony soils, with moderate profile differentiation and moderate translocation of aluminium and iron sesquioxides in depth (Dystric Cambisols - Dystrudepts)	AE-Bs-BC-C	Moder (OL, zoOF, zoOH, miA)

(-To be continued-)

Appendix 1 European soil regions and subregion (EDGI 2016), altitude, soil references (IUSS Working Group WRB 2015; Soil Survey Staff 2014) and humus systems (Zanella et al. 2018e) examples. From Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto(2019), synthetic overview.
(-Continued-)

Soil region	Soil subregion	Soil subregion description	Altitude (m)	Examples of common soils	Soil diagnostic horizons	Humus system (diagnostic horizons)
34.3	DA1	Soils formed from very competent carbonate lithotypes. They are located on high slopes and at the top of the main mountain ranges, high-energy relief, with common coverings of glacial and slope deposits.	1700-2800	Thin, very stony soils with low profile differentiation and accumulation of organic matter on surface (Rendzic Leptosols - Cryrendolls)	OA-AC-C	Tangel (OL, zoOF, zoOH or szoOH, meA or absence of A)
	DA3	Soils formed from moderately competent carbonate lithotypes. They are located on high slopes and at the top of the main mountain ranges, at medium energy of the relief, with common coverings of glacial and slope deposits.	1700-2500	Thin, very stony soils, with low profile differentiation, on steep and / or eroded surfaces (Rendzic Leptosols - Cryrendolls) and moderately deep, stony soils, with high profile differentiation, with leaching of clays on stable morphologies (Skeletic Luvisols - Inceptic Hapludalfs).	OA-AC-C; A-E-Bt-BC-C	Tangel (OL, zoOF, zoOH or szoOH, meA or absence of A) or Amphi (OL, zoOF, zoOH, meA or maA)
		Soils formed from moderately competent carbonate lithotypes. They are located on high slopes and at the top of the main mountain ranges, at medium energy of the relief, with common coverings of glacial and slope deposits.	1700-2500	Thin, very stony soils, with low profile differentiation, on steep and / or eroded surfaces (Rendzic Leptosols - Cryrendolls) and moderately deep, stony soils, with high profile differentiation, with leaching of clays on stable morphologies (Skeletic Luvisols - Inceptic Hapludalfs).	OA-AC-C; A-E-Bt-BC-C	Tangel (OL, zoOF, zoOH or szoOH, meA or absence of A) or Amphi (OL, zoOF, zoOH, meA or maA)

(-To be continued-)

Appendix 1 European soil regions and subregion (EDGI 2016), altitude, soil references (IUSS Working Group WRB 2015; Soil Survey Staff 2014) and humus systems (Zanella et al. 2018e) examples. From Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto(2019), synthetic overview.
(-Continued-)

Soil region	Soil subregion	Soil subregion description	Altitude (m)	Examples of common soils	Soil diagnostic horizons	Humus system (diagnostic horizons)
34.3	DB1-2	Soils formed from very competent carbonate lithotypes. They are located on medium and low slopes of main mountain ranges and secondary chains, high-energy relief, with extensive coverage of glacial and slope deposits.	500-2100	Thin, very stony soils with low profile differentiation (Rendzic Phaeozems - Typic Haprendolls).	A-(AC)-C	Mull (OL, zoOF, maA) or Amphi (OL, zoOF, zoOH, meA or maA)
	DB3	Soils formed from moderately competent silicate lithotypes. They are located on medium and low slopes of main mountain ranges and secondary chains, at medium energy of the relief, with extensive coverage of glacial and slope deposits.	1000-2000	Moderately deep, stony soils, with moderate profile differentiation and moderate translocation of aluminium and iron sesquioxides in depth (Dystric Cambisols- Spodic Dystrudepts).	AE-Bs-BC-C	Mull (OL, zoOF, maA) or Moder (OL, zoOF, zoOH, miA)
	DB4	Soils formed from moderately competent carbonate lithotypes. They are located on steep surfaces and / or subject to erosive phenomena, of medium and low slopes of main mountain ranges and secondary chains, at medium energy of the relief, with extensive coverage of glacial and slope deposits	400-2300	Deep, stony soils with high profile differentiation, with clay accumulation in depth (Skeleti-Cutanic Luvisols - Inceptic Hapludalfs) and moderately deep, stony soils with moderate profile differentiation (Haplic Cambisols -Typic Udorthents)	A-E-Bt-BC-C; (OA)-A-Bw-BC-C	Mull (OL, zoOF, maA) or Amphi (OL, zoOF, zoOH, meA or maA)

(-To be continued-)

Appendix 1 European soil regions and subregion (EDGI 2016), altitude, soil references (IUSS Working Group WRB 2015; Soil Survey Staff 2014) and humus systems (Zanella et al. 2018e) examples. From Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto(2019), synthetic overview.

(-Continued-)

Soil region	Soil subregion	Soil subregion description	Altitude (m)	Examples of common soils	Soil diagnostic horizons	Humus system (diagnostic horizons)
34.3	DB5-6	Soils formed from competent carbonate lithotypes. They are located on stable surfaces of medium and low slopes of main mountain ranges and secondary chains, at medium energy of the relief and with extensive coverage of glacial and slope deposits	400-2000	Soils from moderately deep to deep, stony, with high profile differentiation, with accumulation of clay in depth (Cutanic Luvisols - Typic Hapludalfs), or with moderate profile differentiation with evident hydromorphy (Endogleyic Cambisols - Aquic Eutrudepts)	A-(BE)-Bt-C; A-Bw-(BCg)-Cg	Mull (OL, zoOF, maA)
	SA1-2-3-4	Soils on surfaces from sub-floors to undulating and slopes, in hard limestone, locally affected by karst phenomena	600-1800	Moderately deep soils, on rock, with high profile differentiation, with deep clay accumulation (Leptic Luvisols - Inceptic Hapludalfs) on wooded surfaces and thin soils, on rock, with moderate profile differentiation, with accumulation of organic substance on the surface (Leptic Cambisols - Typic Eutrudept); Soils on weakly concave surfaces affected by colluvial and alluvial troughs. Deep, stony soils with high profile differentiation and clay accumulation in depth (Luvic Phaeozems - Typic Argiudolls)	A-Bt-R; A-Bw-BC-R; A-(EB)-Bt	Mull (OL, zoOF, maA) or Amphi (OL, zoOF, zoOH, meA or maA)
	SD1	Soils on high-slope slopes formed by hard limestone with abundant debris deposits on the foot and in the watersheds.	300-1400	Thin soils, on rock, with low profile differentiation, with accumulation of organic substance on the surface (Epileptic Phaeozems - Lithic Hapludolls)	OA-A-R	Amphi (OL, zoOF, zoOH, meA or maA)

(-To be continued-)

Appendix 1 European soil regions and subregion (EDGI 2016), altitude, soil references (IUSS Working Group WRB 2015; Soil Survey Staff 2014) and humus systems (Zanella et al. 2018e) examples. From Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto(2019), synthetic overview.
(-Continued-)

Soil region	Soil subregion	Soil subregion description	Altitude (m)	Examples of common soils	Soil diagnostic horizons	Humus system (diagnostic horizons)
34.3	SD2	Soils on slopes and on narrow ridges developed on marly limestone with medium-high slopes and dense drainage network.	300 -1700	Thin soils, on rock, with low profile differentiation, with accumulation of organic substance on the surface, partial decarbonation (Endoleptic Phaeozems - Entic Hapludolls) on very steep eroded slopes and moderately deep soils, on rock, with high profile differentiation, with clay accumulation in depth (Cutanic Luvisols - Typic Hapludalfs), on stable morphologies	A-AC(AB)-(Bw)/R; A-Bt-BC-C	Amphi (OL, zoOF, zoOH, meA or maA) or Mull (OL, zoOF, maA)
	SI1	Soils on valley incisions in dolomite with predominantly steep slopes.	300-2000	Thin soils, on rock, with moderate profile differentiation, with accumulation of organic substance on the surface (Haplic Cambisols - Inceptic Haprendolls)	A-Bw-(BC) -C	Mull (OL, zoOF, maA)
	SI2	Soils on valley incisions in limestones, with steep slopes	200 -2000	Very thin soils, on rock, with low profile differentiation, with accumulation of organic substance on the surface (Rendzic Phaeozems - Entic Hapludolls) on steep slopes, and moderately deep soils, very stony, with moderate profile differentiation, with accumulation of organic substance on the surface (Haplic Cambisols - Inceptic Haprendolls) on scree slopes	A-AB(Bw)-R; A-Bw-(BC) -C	Amphi (OL, zoOF, zoOH, meA or maA) or Mull (OL, zoOF, maA)
34.3	SI3	Soils on valley incisions, escarpments, small basins in marly limestone (Biancone) and subordinately to marls with regular rounded slopes with strong slope.	300-1300	Thin soils, on rock, with low profile differentiation, with accumulation of organic substance on the surface, partial decarbonation (Epileptic Phaeozems - Lithic Hapludolls) on very steep eroded slopes and moderately deep soils, on rock, with high profile differentiation, with clay accumulation in depth (Cutanic Alisols - Ultic Hapludalfs) on stable morphologies	A-R; A-EB-Bt	Amphi (OL, zoOF, zoOH, meA or maA) or Mull (OL, zoOF, maA)

Appendix 2 Countries of production, quantity and price of softwood imported to China in 2018 (Zhu 2019)

Countries	Softwood quantity (million m^3)	Softwood price (\$/m^3)
New Zealand	17.29	141
Russian	7.95	117
The United States	5.03	166
Australia	4.13	126
Canada	2.53	184
Japan	0.92	134
Uruguay	2.09	124
Others	1.64	-
Total	41.6	139

References

Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto (2019) Legenda della Carta dei Suoli del Veneto in Scala 1: 250,000. Versione (2019). Regione Veneto. En: Regional Agency for Environmental Prevention and Protection of Veneto. Soil Map Legend 2019. https://www.arpa.veneto.it/temi-ambientali/suolo/conoscenza-dei-suoli/carta-1-250.000/leg_250k.pdf/view

The legend briefly describes all the cartographic units. These are inserted in a hierarchical structure that includes four levels, in accordance with what is proposed at the national level for the "Map of the Soils of Italy on a scale of 1: 250,000". The first level is that of soil regions (L1 -soil regions), represented in the map in a box on a scale of 1: 5,000,000; these are the result of the national re-elaboration of the map of the soil regions of Europe, prepared by the European Soil Bureau and attached to the "Manual of Procedures for a Georeferenced Database of European Soils". The second level, represented in a box on a scale of 1: 1,000,000, corresponds to the provinces of soils (L2 - soil subregions). The third level, soil systems (L3 - great soilscapes), is identified by different colors in the legend of the 1: 250,000 scale map. The fourth level, which corresponds to that of the cartographic units (L4 - soil subsystems - soilscapes), is shown on the map only as an abbreviation within the individual delineations as the high number does not allow unambiguous identification through different colors.

The classification system used is the World Reference Base for Soil Resources, 2006 version, and the 2010 USDA Soil Taxonomy.

EDGI (2016) EuroGeoSurvey. European Geoscience for Society [WWW Document]. Geol. Surv. Organ. Eur. URL http://www.europe-geology.eu/soil/soil-map/soil-regions/ (accessed on 2020-09-11)

IUSS Working Group WRB (2015) World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps., World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations, Rome, Italy. https://doi.org/10.1017/S0014479706394902

Soil Survey Staff (2014) Keys to Soil Taxonomy by Soil Survey Staff, 12th edition., 12th ed, Soil Conservation Service. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

Zanella A, Ponge JF, Jabiol B, et al. (2018) Humusica 1, article 5: Terrestrial humus systems and forms - Keys of classification of humus systems and forms. Applied Soil Ecology 122: 75-86. https://doi.org/10.1016/j.apsoil.2017.06.012

Zhu GQ (2019) Changes and problems in China's import and export market of wood and wood products in 2018. International Wood Industry (1): 18-22. (In Chinese). https://doi.org/10.3969/j.issn.1671-4911.2019.01.006