VAIA-FROm lessons LearNT to future option

FINAL REPORT

WP3

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WP3 – Framework for forest SES hazard and vulnerability assessment

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1. Introduction to WP3 objectives, structure (tasks), resources and activities

The WP3 of the Vaia FRONT projects deals with the assessment of different impacts of the windstorm Vaia in the alpine environment, with a special focus on Rocca Pietore municipality, in the middle of the Dolomites, Belluno province.

The first task is dealing with tree-wind interaction. The objective is to deepen the current knowledge about it and to apply some existing tools (for instance physically based models) for assessing susceptibility of alpine forests to wind damages. The final goal is to obtain a map that could be a support for researchers, forest managers and local communities. This map should help to identify susceptible areas where to carry more detailed analysis and field surveys, so to target any forest operation that may enhance forest resistance against wind.

The second task is dealing with some of the multiple ecosystem services that are provided by mountain forests. In this WP3 we focused on the protective function of mountain forests, that is particularly important for the safety of local communities. In this Task we also discussed about the importance of deadwood in regeneration dynamics, a topic that is very important and has direct consequences on management strategies after a natural disturbance.

The third task is about safety for local communities, with a focus on roads and linear infrastructures. It is strictly connected with the first task and, also in this case, the goal is to produce some maps about susceptibility to wind damages of linear infrastructures.

Finally, the fourth task is related to local communities and their vulnerability to natural disturbances.

2. WP3 research methodology (by Task)

2.1 Assessment of the vulnerability of trees and forest stands to wind forcing

Wind-tree interaction is a topic that has been widely studied at many scales, from single tree to the landscape level, this has led to the development of many predictive models that can assess the vulnerability of forest stands to wind forcing.

Among these models, in the VaiaFront project we decided to adopt ForestGALES (Hale et al. 2015). We selected ForestGALES since it has been widely adopted, it is parametrized for different tree species and different soil types. ForestGALES has been initially developed in the United Kingdom as a management tool to assess the susceptibility of plantations to windstorm damage. This semi-empirical, process-based wind risk model has since been expanded and used in other contexts, both European and non-European.

In order to run the model several inputs are needed, concerning trees and site characteristics. In Table 1, the input data are listed according to Locatelli et al. (2017), as well as the main outputs.

Table 1. Inputs and outputs of ForestGALES (or fgr) model.

Inputs	Main outputs
Tree data (dbh, height, density)	Minimum critical wind speed (CWS)
Species parameters	Critical wind speed for overturning
Soil type	Critical wind speed for breakage
Wood characteristics (MOE, MOR)	Wind risk classes

Recently ForestGALES has been updated and developed in the R framework (fgr package), to be easily applicable to different scenarios. However, the original ForestGALES reference database used to derive empirical coefficients of tree anchorage is limited to a relatively flat area and small size trees (Diameter at Breast Height -DBH- less than 30 cm). The alpine forests that have been affected by storm Vaia were often characterised by tree with larger diameter and the stands were located in sloped terrains.

The first objective of WP3 was thus to investigate the anchorage of standing trees with large diameters in order to update the database and calibrate the model. To obtain the new data, pulling test experiments have been set up. In the Cansiglio forest, 44 Norway spruce trees (*Picea abies* (L.) Karst.), an important species for alpine silviculture and particularly susceptible to wind damage (most damages due to storm Vaia were on this species), were subjected to destructive pulling tests. These tests were aimed to calibrate the model in order to use it to analyse Vaia storm damages on the alpine forests.

Using a load cell, inclinometers, and strain gauges the tree felling was monitored in all its phases. Of the 44 plants tested (DBH> 40 cm), 13 were selected in sloped terrain to test if slope may affect stability, in a comparison with trees with similar characteristics on flat terrain (Figure 1). The first results showed that trees on a slope have a higher overturning coefficient and are therefore more resistant to uprooting.

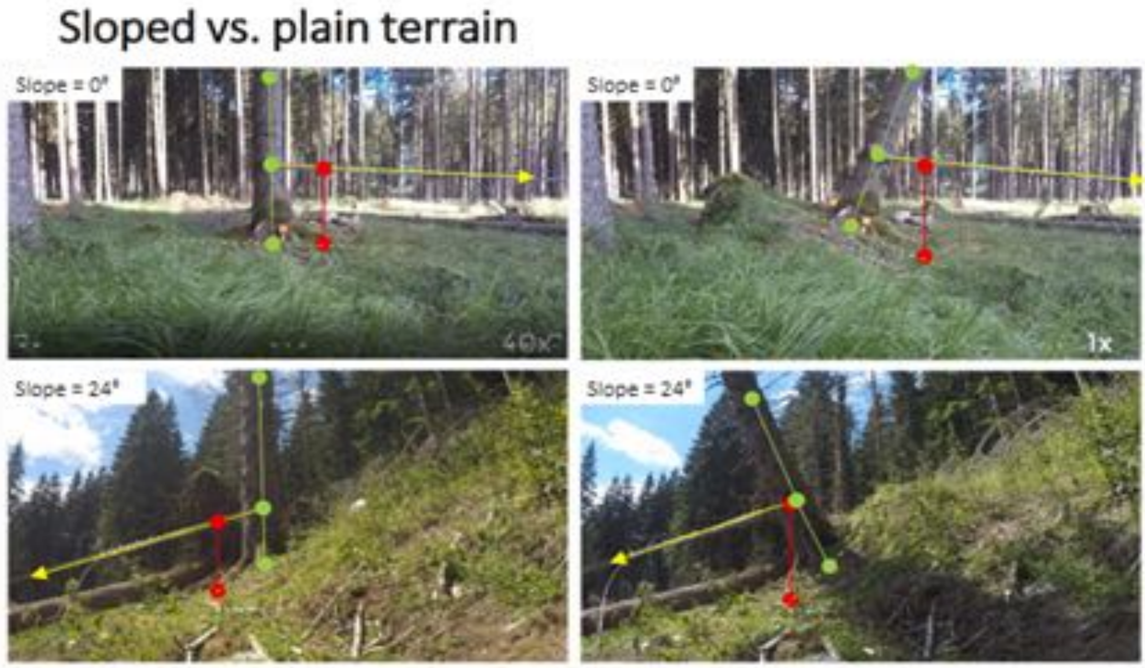

Figure 1. Settings for pulling tests with a differentiation between sloped and flat terrain (Marchi et al, sub)

The data obtained from the field were translated into input parameters for ForestGALES model, allowing to differentiate the parameters for spruce according to the slope of the terrain. The parameterization was further complemented with physical parameters (MOE and MOR) typical of spruce trees grown in the mountain/dolomitic environment. Using these new parameterizations, wind risk assessment maps were created for a case study area located in the north-eastern Italian Alps. This area was strongly affected by storm Vaia in October 2018, the mapping, therefore, aims to observe the susceptibility of stands before and after the disturbance event.

The introduction of new parameters in the fgr model raise the necessity of a validation for the new calibrated model. To do so, a validation process was designed based on the work done by Hale et al (2015), it is summarized in Figure 2.

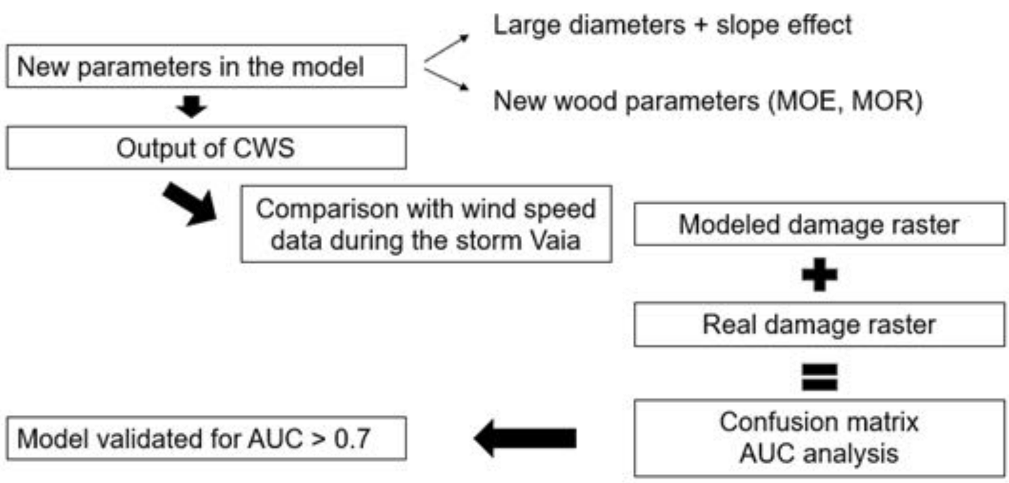

Figure 2. Validation flow-chart for fgr, based on a work by Hale et al (2015)

The idea of the validation process is to compare modelled damages and real damages, so to create a confusion matrix and run an AUC analysis. LiDAR data from the 2015 flight were used to obtain the output of the model for a pre-storm scenario, doing this it was possible to compare the values of critical wind speeds with the wind speed reached during the storm Vaia. This was needed for the computation of the modelled damages raster. Different methodologies were used to calculate the wind speed reached during the storm leading to different modelled damage rasters, among the different outputs the model was considered validated for a final value of AUC higher than 0.7 (Bennett et al, 2013).

Last step of this task is the production of wind susceptibility maps. For doing so, LiDAR data from the 2019 flight were used, in order to observe the post storm susceptibility of alpine forests in the Dolomites. Maps were produced for the Rocca Pietore municipality. In this phase it was also observed the difference between 2019 susceptibility map and the same map from 2015, that allowed us to observe where the storm impacted more tree stability and, on the other hand, where susceptibility increased.

A final note: these maps are static maps, they strictly depend from input data, if there are any substantial changes in forest structure the model should be run again, using updated data (for instance using a more recent LiDAR flight).

2.2 Assessment of the vulnerability of forest ecosystem services (ESS) to wind disturbance

Windstorms may affect ecosystem services that are normally provided by mountain forests such as protection against natural hazards, conservation of biodiversity or erosion mitigation. However, after a disturbance event, structural biological legacies, like deadwood, may enhance or maintain some of these ecosystem services. After a stand-replacing event, the conservation or fast restoration of all these services should be the target of post disturbance management, but currently traditional practices (mainly salvage logging) are often leading to their depletion. The study of the impact of salvage logging (i.e. the removal of almost all the biological legacies) on the protective function of mountain stands has been poorly addressed. Structural biological legacies (i.e. snags, logs, stumps) may provide protection for the natural regeneration as well as they may increase the terrain roughness, providing a shielding effect against gravitative hazards like rockfall. In this WP we investigated how biological legacies affect the multifunctionality of mountain forests, focusing on the protective function. To observe the role of biological legacies we performed software simulations of rockfall activity on windthrown areas located in the Dolomites, with a particular focus on Rocca Pietore municipality, the main study area of the project (Figure 3).

Figure 3. Rocca Pietore municipality, fraction of Boscoverde

We worked with the model Rockyfor3D and we run different simulation scenarios: the first one, used as a reference, without forest influence, than a scenario before the storm and one after the storm, in this last case we considered the terrain roughness created by biological legacies. To evaluate the terrain roughness we used LiDAR data (Figure 4) from a flight that was performed in 2019. LiDAR data had to be validated through field data collection (Figure 5), in order to do a comparison of these field data with the raster obtained through LiDAR.

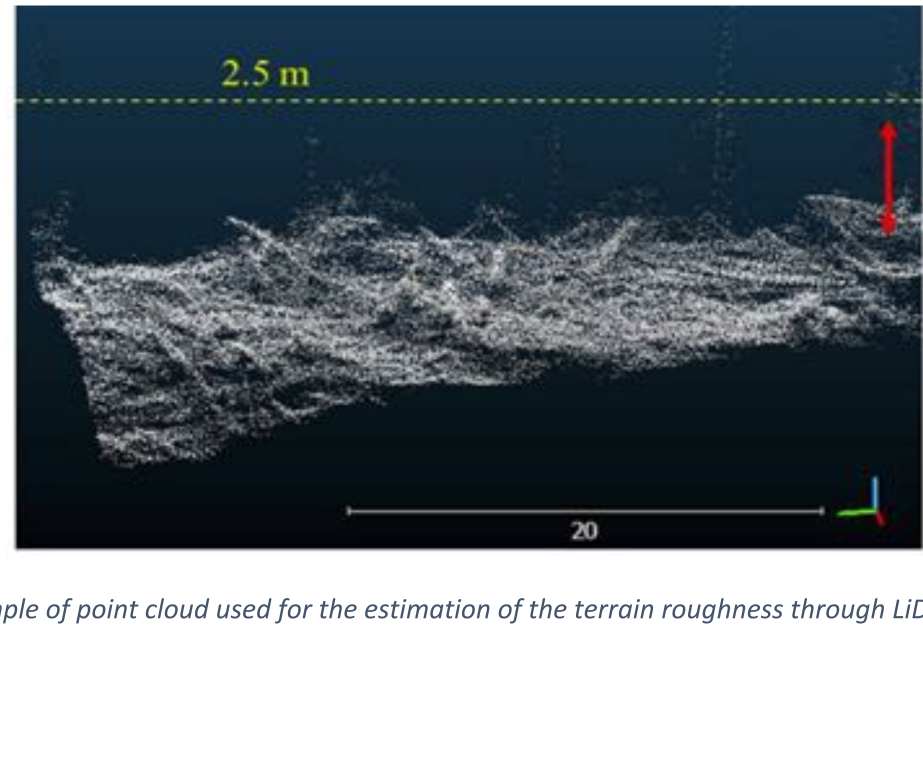

Figure 4. Example of point cloud used for the estimation of the terrain roughness through LiDAR source data

Figure 5. Field surveys aimed to the evaluation of the terrain roughness created by biological legacies

Moreover, using the outputs of the model, some indices were computed. These indices (Figure 6), introduced by Dupire et al (2016) provide an evaluation of the protective efficiency of the forest (with or without damages). The first index, the BARI index, is related to the barrier effect played by trees or logs, the second index, the MIRI index, regards the reduction of kinetic energy of falling blocks caused by trees or logs, the last index, the ORPI index, is a synthesis of the previous two.

Protective efficiency indices

BARrier effect Index

$$BARI(x) = 100 \times \left(1 - \frac{N_{rock_{forest}}(x)}{N_{rock_{no-forest}}(x)}\right)$$

Maximum Intensity Reduction Index

$$MIRI(x) = 100 \times \left(1 - \frac{E95_{forest}(x)}{E95_{no-forest}(x)}\right)$$

OveRall Protection Index

$$ORPI(x) = 100 \times \left(1 - \frac{\sum_{i=1}^{n\,forest} E(x)}{\sum_{k=1}^{n\,no-forest} E(x)}\right)$$

Figure 6. Indices of protection efficiency of forests against rockfall, according to Dupire et al (2016)

The role of biological legacies is important for the restoration and the maintenance of many different ecosystem's services like protection from gravitative hazard. Particularly, coarse woody debris (CWD) can also have another significative impact, specifically on forest regeneration and restoration. After extensive disturbance, the large amount of deadwood lying on ground and the necessity for restoring the forest cover with natural regeneration are two critical issues to be dealt with. specifically, we aim to analyse how CWD contributes to creating favourable microsites for regeneration, increasing seedling establishment probability. We focused on two different facilitative mechanisms provided by CWD, microsite amelioration and seedling protection, by planting a set of seedlings in the surroundings of deadwood elements. The former has been analysed measuring temperature and SWC in the proximity of seedling planted in the surrounding of deadwood elements, the latter by recording browsing evidence at the end of the season. To infer the CWD contribution, control sites have been established in empty sites where no CWD presence was detected in the surroundings (Figure 7).

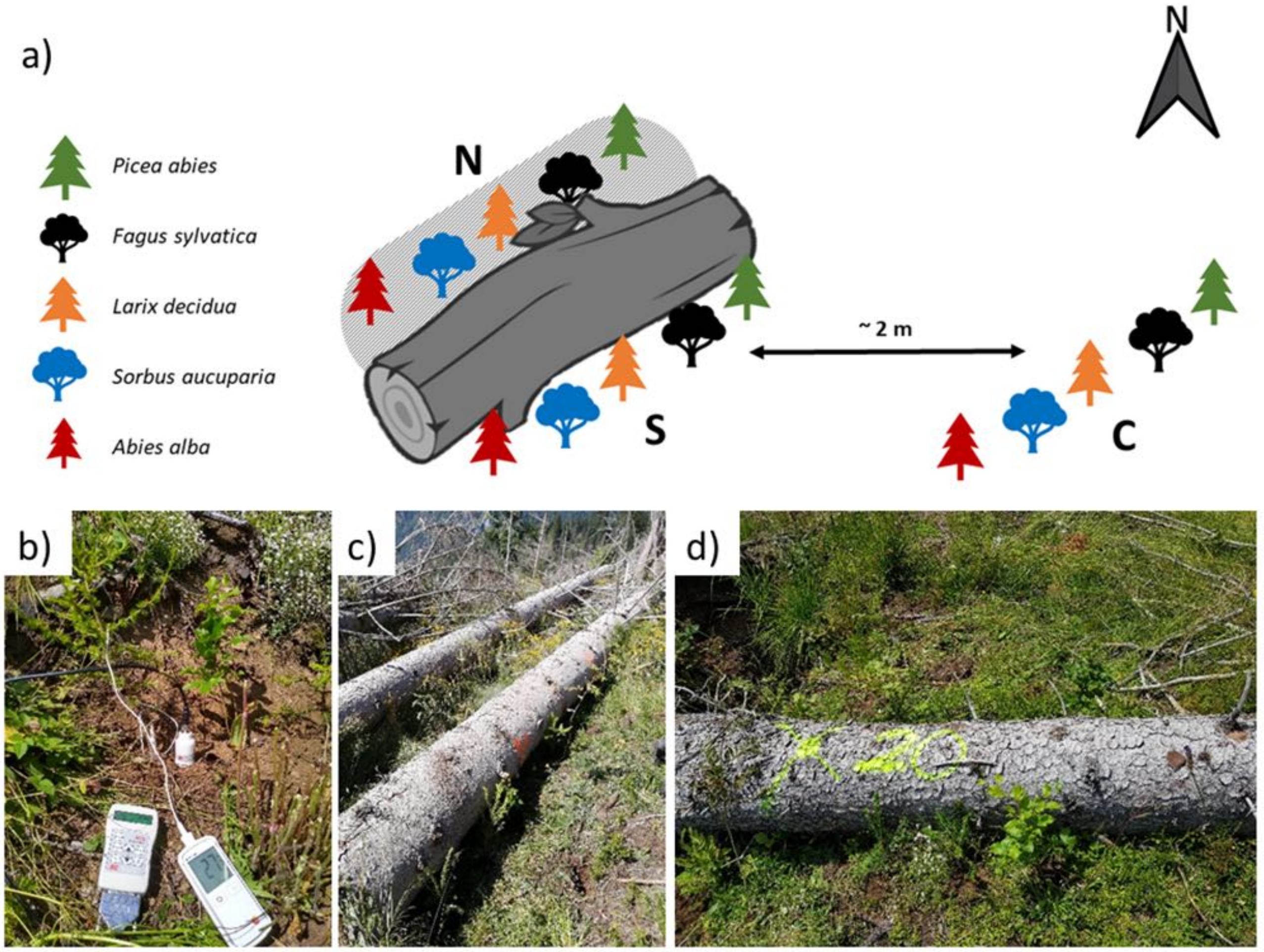

Figure 7. (a) Block structure and disposition of microsites. Three microsites have been identified: north (N) to CWD, south (C) to the element of CWD and control (C) in open field around 2 m from CWD element and with negligible effect of CWD. (b) temperature and control (C) in open field around 2 m from CWD element and with negligible effect of CWD. (b) temperature and soil water content collection. (c – d) example of blocks and microsites (from Marangon et al., 2022).

The latter was estimated by calculating the Cost to Distance Rate (CDR). The CDR is calculated on the difference between two diverse distances from each block and the nearest open areas:

Euclidean-distance and cost-distance. Euclidean distance is the shorter distance between a block and the limit of the windthrown areas. Cost distance is the shorter distance between a block and the limit of the windthrown areas, calculated considering the roughness of CWD, on a digital surface model (DSM). Such difference can be used as an indicator of the effort that an animal needs to make to reach the target seedlings.

2.3 Assessment of the vulnerability of linear infrastructures to wind disturbances

The results of this task are strongly related with results of Task2.2. The objective of this task is to evaluate how, after the storm Vaia, the susceptibility of forests around roads and infrastructures changed.
Official data for roads and powerlines were downloaded from the regional website. To evaluate the susceptibility to wind damages of these infrastructures we created a buffer of 50m around linear infrastructures. Within this buffer we extracted the mean susceptibility (mean critical wind speed) where the presence of forest was detected using the susceptibility map created in Task2.2. Once that each segment of road or infrastructure had a value of susceptibility it was possible to create a map on the municipality scale. The target municipality was Rocca Pietore.

2.4 Assessment of the human vulnerability during storm events

This activity aimed at understanding how individuals affected by the storm: i) detected the potentially dangerous circumstances, ii) reacted to the storm, iii) adapted their routine to cope with the consequence of the event, iv) changed their risk awareness and perception after the event.
To achieve these objectives, we developed a web-based survey addressing 1,388 inhabitants of the Veneto and Trentino Alto Adige regions. The survey quantitatively documented behavioural responses associated with the Vaia event and included questions related to: i) whether respondents changed their normal routine during the storm and if so for what reason; ii) information received before and during the event and how respondents reacted to it; iii) damage suffered during the event; iv) risk awareness and how it changed after the event; v) personal protection measures adopted before and after the event; vi) respondents' attitudinal and psychological traits. Collected data was analysed via regressions (linear, binary logistic and ordinal logistic).

3. Scientific results by task

3.1 Assessment of the vulnerability of trees and forest stands to wind forcing

Forty-four pulling tests, including twelve trees that were growing on steep terrain and two stumps, were carried out in the Cansiglio Forest, in the north-eastern Italian Alps (Figure 8). A high load capacity pulley was designed and used to perform tests on Norway spruce trees, with average DBH equal to 0.50 m, by applying the pulling force at the base, thus neglecting the influence of the stem deflection-related issues typical of more traditional pulling techniques.

Figure 8. Some phases of the tree pulling tests in Valmenera, Cansiglio forest (ph. Matteo de Mayda)

All tests ended up with a failure due to overturning typical of shallowly rooted trees (Achim and Nicoll, 2009; Blackwell et al., 1990). Although no specific instruments were set at the soil level, the video analysis confirmed the pattern reconstructed by Lundström et al. (2007) and Sagi et al. (2019) with a development of the rotational hinge point at a distance between one to two times the DBH. However, in steep terrain the shape of the root–soil plate was likely more a truncated cone rather than an elliptical cross-section (Lundström et al., 2007). Nevertheless, even for large DBH specimens, provided with some massive lateral roots, a relatively small amount of soil has been mobilized (Dupuy et al., 2005), which confirms the unsuitable root morphology to provide high resistance to overturning.

The mechanical resistance of large DBH trees in steep conditions with respect to flat terrain was found to be considerably increased (see Figure 9). On the opposite, the stem base rotational stiffness appears to be less affected by the terrain inclination. The combination of these two concurring factors produces a different pattern of bending moment vs. rotation relations (explicated via adimensional M_0-ϑ_0 curves), thus possibly requiring a more precise adaptation of actual semi-mechanistic models used in decision making risk tools. It's also been proven that the tree self-weight (i.e., crown and stem weight) provides a great contribution to the overturning resistance especially for large diameter trees.

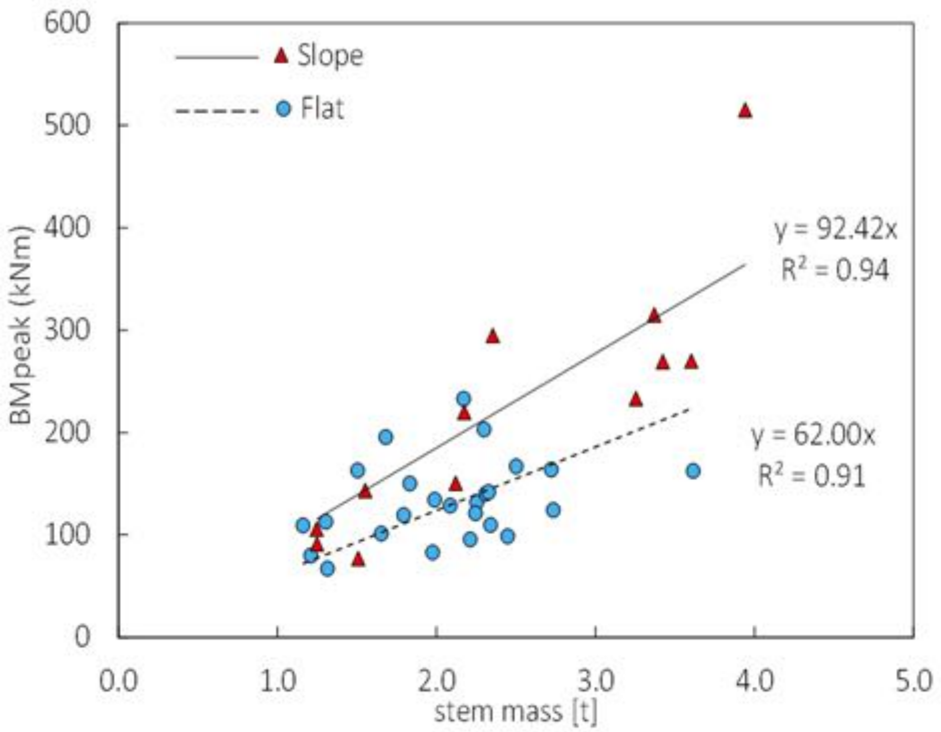

Figure 9. Stem mass (t) against Bending Moment (kNm), blue dots are referring to trees growing in flat conditions, red dots are referring to trees growing in steep terrain (figure from Marchi et. al, sub)

The next step of this Task consisted into the implementation of these new parameters in the fgr model.

The model was run differentiating Norway spruce trees in four categories, represented in Tab 2. These four categories were based on the two factors that we considered when running the field tests: trees DBH and steepness of the growing site, we decided to operate this differentiation once that we so that trees growing on steep terrain had a significantly higher overturning coefficient.

Table 2. Settings of the parameters according to trees dimension and steepness of the growing site

Norway spruce, DBH < 40cm	fgr default parameters
Norway spruce, DBH <40 cm + steep terrain	fgr default parameters corrected for steep conditions
Norway spruce, DBH > 40 cm	New parameters
Norway spruce, DBH > 40 cm + steep terrain	New parameters

Within the new parameters we also introduced new values of wood properties (MOE and MOR) obtained through lab tests (Figure 10)

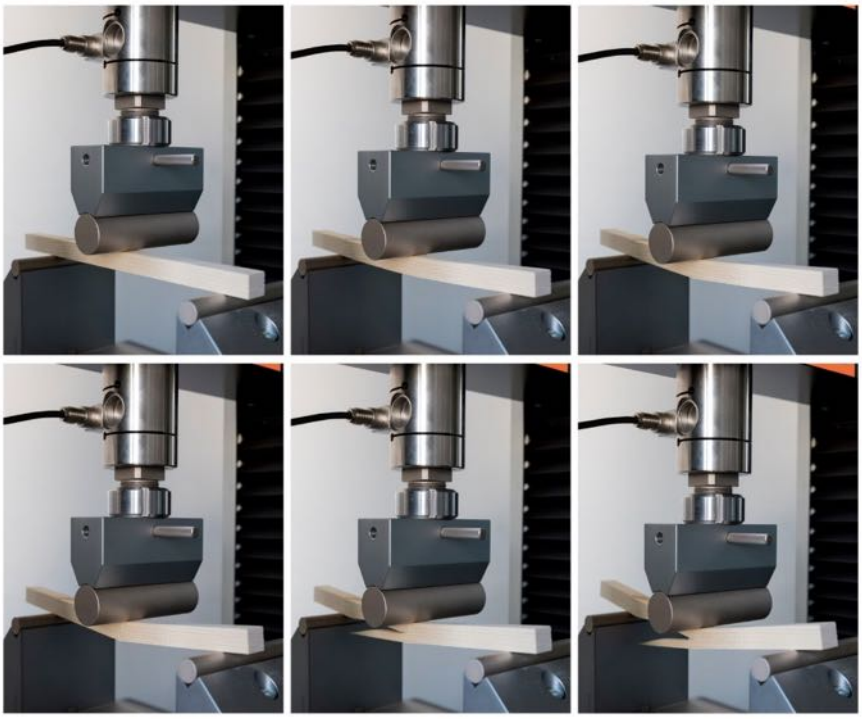

Figure 10. Procedure for the evaluation of MOE and MOR of wood samples. Samples were coming from the tested trees in Valmenera. (ph. Matteo de Mayda)

The workflow of the model is synthetised in Figure 11, starting from a CHM and a DTM a tree file was created, here all input data were computed, then the model was run to obtain a final raster with the critical wind speed values. Fgr model can be run in two methods, TMC (based on single trees information) and Roughness (based on stand information), for this work the TMC method was used.

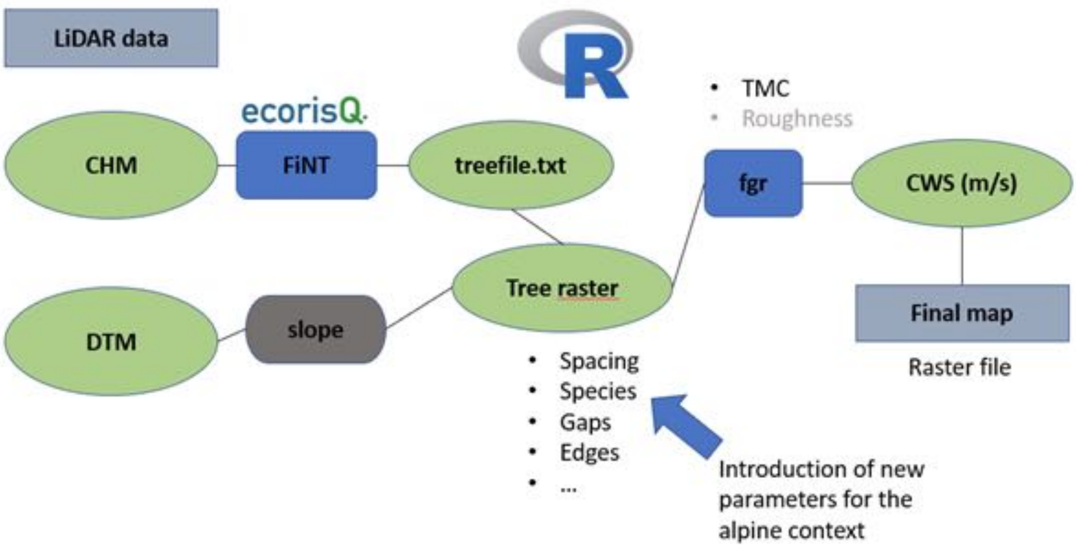

Figure 11. Workflow for wind susceptibility mapping that was applied. It is possible to observe where it was possible to use the new parameters of fgr model, it is also highlighted that fgr model was run with the TMC method.

Firstly, the model was run using Lidar data from 2015, creating a pre-storm susceptibility map (see Figure 12). This map was then used to create a modelled damage raster, comparing the speed reached during storm Vaia with the CWS obtained by fgr. To do so, TOPEX indices were used, they were found to be more accurate than other airflow models (for instance WASP model). The final AUC was 0.73 so the model was considered validated.

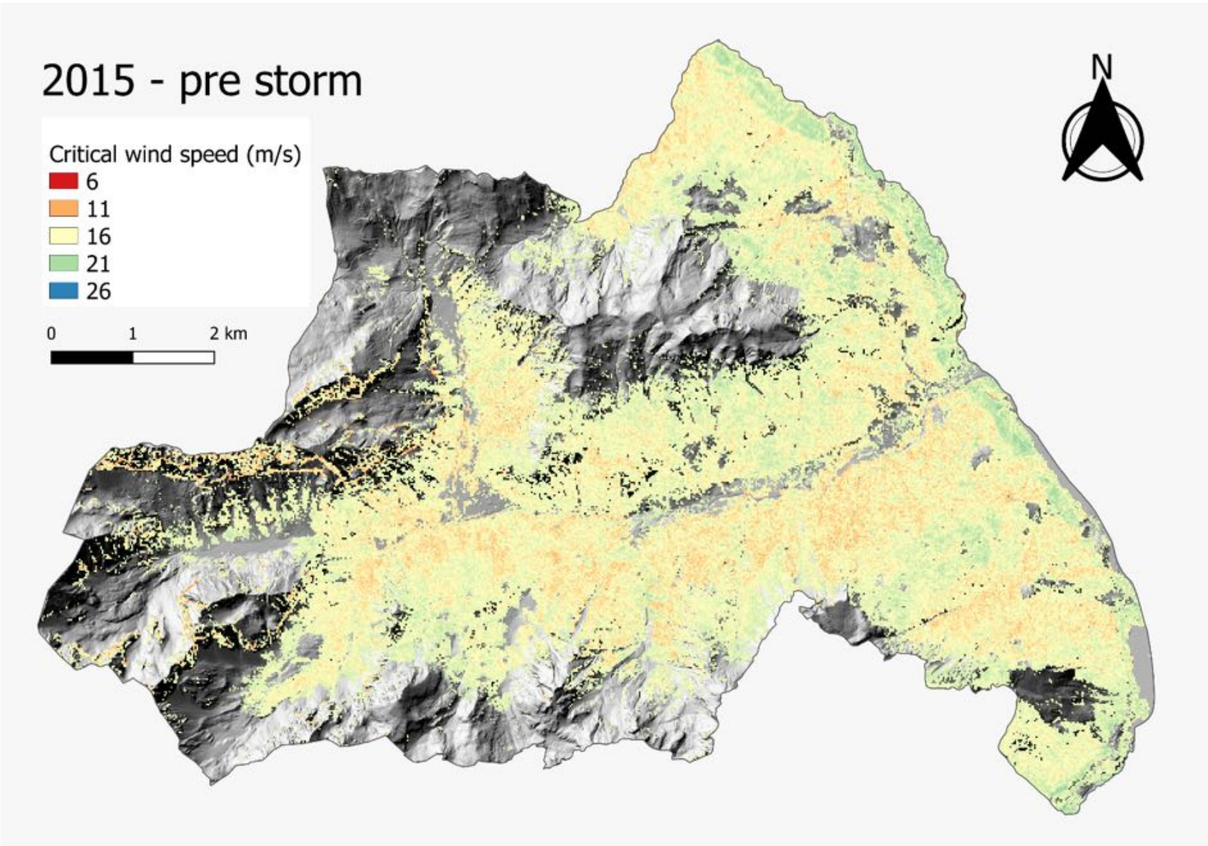

Figure 12. Wind susceptibility for Rocca Pietore municipality in 2015, before the storm Vaia.

Once the model has been validated, it was run again using inputs coming from a LiDAR flight acquired in July 2019, such as after the storm Vaia. These are the most recent data available so they were used to create a susceptibility map that should represent the actual situation, the map is shown in Figure 13. This susceptibility map takes also into account the presence of new brown edges, consequences of storm Vaia. It must be underlined that fgr (and ForestGALES as well) is a static model, it should be run again each time that forest structure changes substantially.

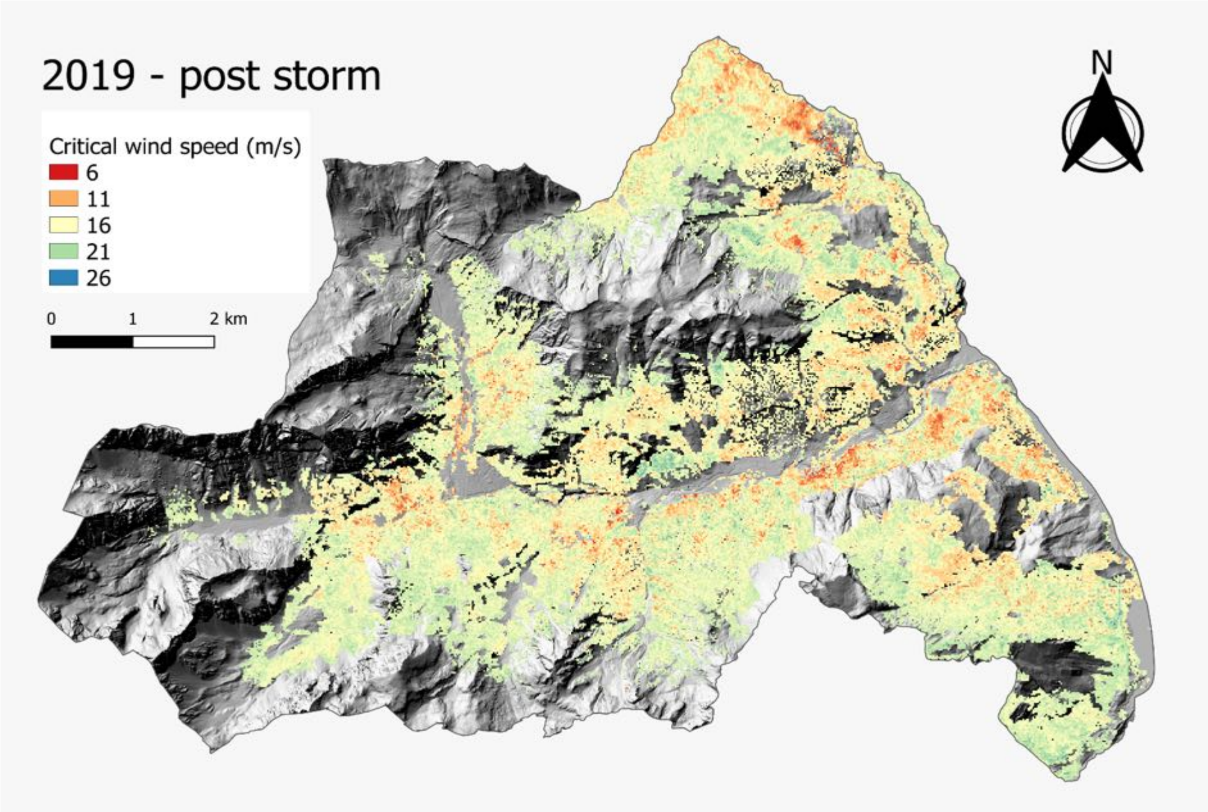

Figure 13. Wind susceptibility for Rocca Pietore municipality in 2019, after the storm Vaia.

Having susceptibility maps for both after and before the storm it is possible to create a raster of the difference (Figure 14), to observe changings in susceptibility to wind damages. This new raster may be useful to support management decision when targeting silvicultural interventions that are aimed to increase forest resistance against wind damages. The raster can help to identify areas in which susceptibility decreased, those are the areas where further analysis, preferably strongly connected with fieldwork, should be run.

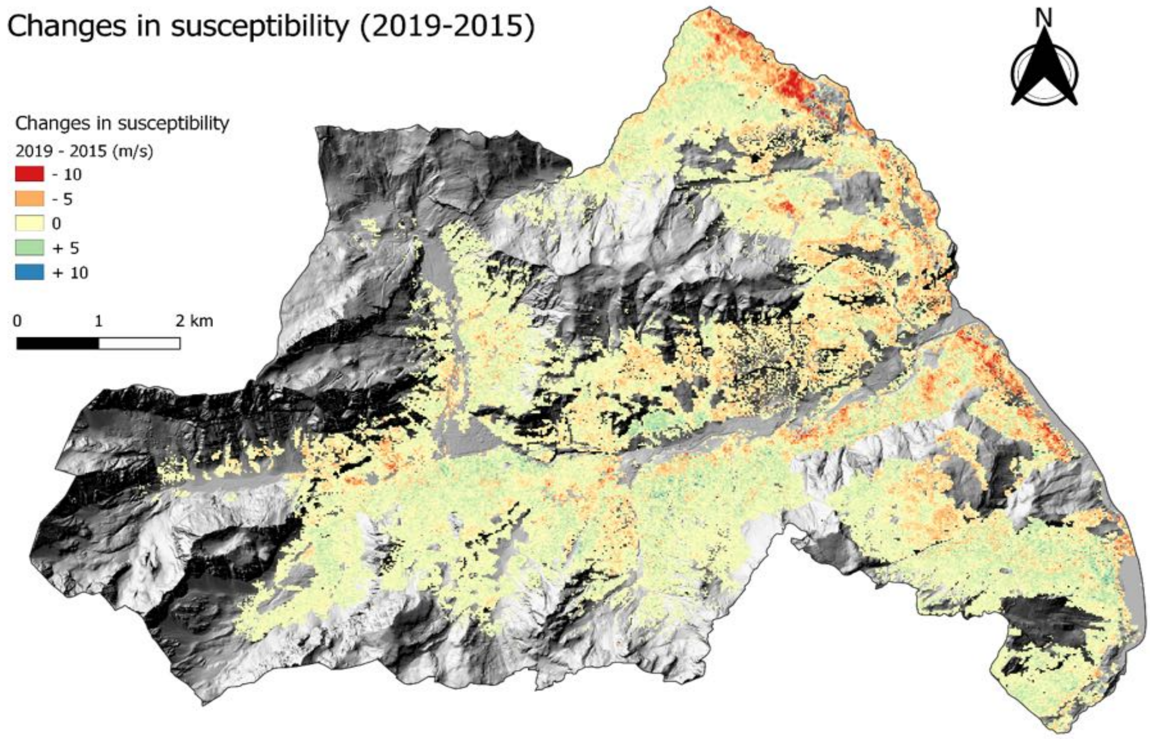

Figure 14. Changes in wind susceptibility due to the storm Vaia, the map was obtained subtracting 2015 from 2019 data

3.2 Assessment of the vulnerability of forest ecosystem services (ESS) to wind disturbance

Thanks to the validation of LiDAR data, it was possible to know the spatial arrangements of deadwood, so to define the protection efficiency of the windthrown stand in the different scenario, as reported by the indices in Figure 15 and in the simulations' outputs in Figure 16. We observed a significantly improvement of protection efficiency after the storm. This improvement of the protective role is due to the barrier effect played by lying logs. This effect could last for a few years, before lying logs start to rot and the height of the logs from the ground starts to decrease, as observed by Wohlgemuth et al. (2017). Moreover, with a reduction of deadwood height above the ground and with a higher portion of logs in direct contact with the soil, the wood decaying processes may accelerate leading to lower protective efficiency of biological legacies. For what concern the salvage logging scenario it is possible to observe that the removal of logs nullifies the protective efficiency of the stand.

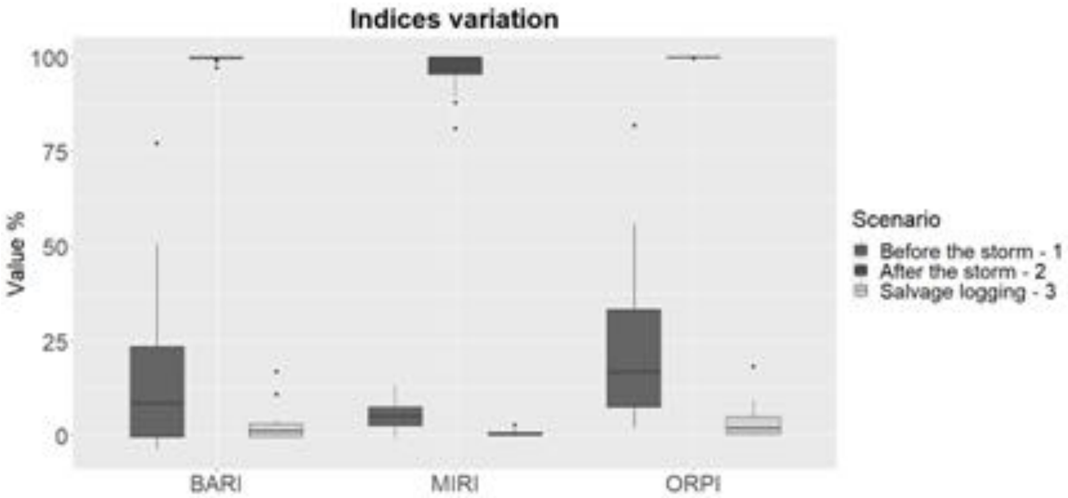

Figure 15. Boxplot of protective efficiency indices (value expressed in percentage) for the three simulations scenarios: 1 before the storm (grey), 2 after the storm (dark grey), 3 after salvage logging (light grey).

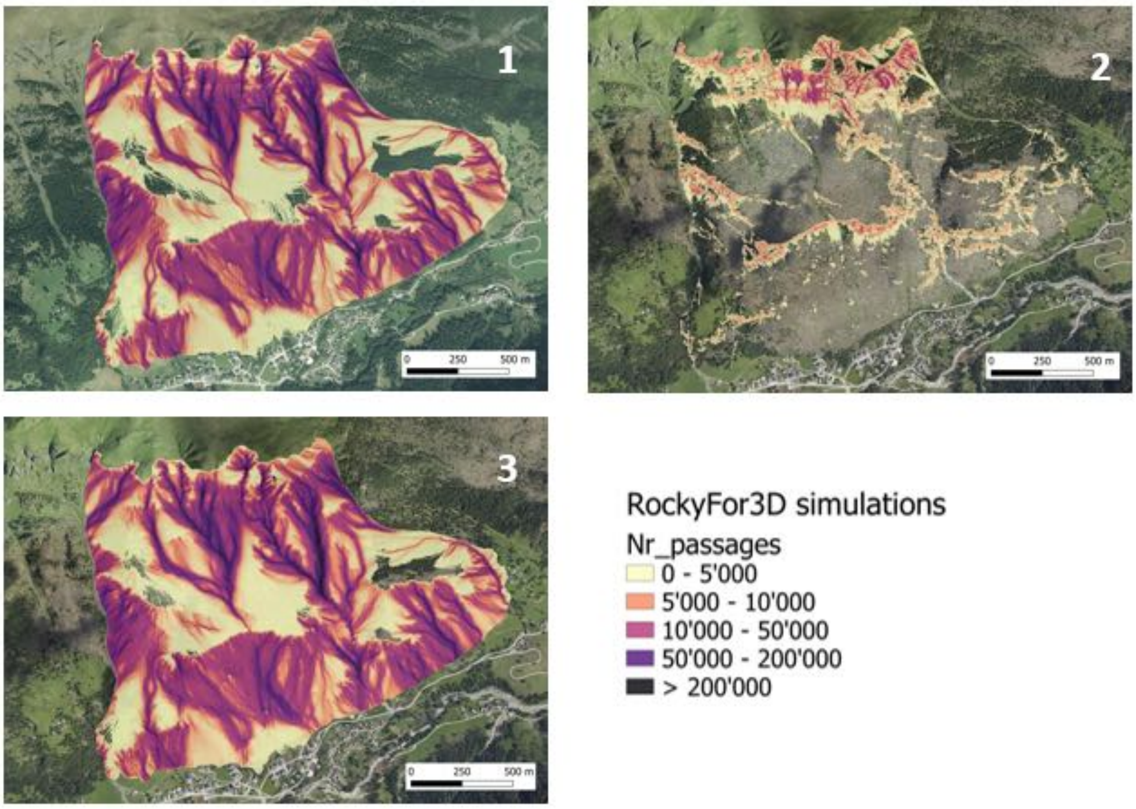

Figure 16. Simulations outputs for BoscoVerde, fraction of Rocca Pietore municipality. Simulations scenarios are 1) before the storm, 2) after the storm, 3) after salvage logging

Finally, from an operative point of view, we would suggest avoiding traditional practices like salvage logging. Where a gravitational hazard is present, forest managers should consider other options with the target of enhancing the natural restoration of protection forests.

For what concerns deadwood, our results show that CWD helps in creating favourable regeneration microsites, shading the ground, and maintaining a lower soil surface temperature. This mitigation effect can help in reducing drought stress for the juvenile stage. Additionally, CWD contributes efficiently to protecting seedlings from browsing. This protective effect is often anisotropic but, especially during the winter period, the sole presence of CWD can help seedlings' survival, making the protective effect isotropic. The contribution of CWD in protecting seedlings and ameliorating regeneration microsites could last at least for the first critical years, as long as the regeneration is better established and becomes taller than CWD. Despite the greater complexity of reforestation operations within windthrown areas, taking advantage of favourable regeneration microsites and the protective effects provided by CWD can be a valuable option in many situations. In mountain protection forests, where it is crucial to reduce the protection gap, the use of favourable regeneration microsites created by CWD can allow forest cover to regenerate with artificial reforestation and at the same time take advantage of the protective effect of the increased roughness provided by CWD. To make better use of microsite amelioration, a lower seedling height makes the influence of deadwood on sapling survival higher after transplantation. Furthermore, given the ability of CWD to decrease temperature and drought stress, on southern slopes or relatively dry sites, favourable microsites created by CWD can significantly increase the survival probability of both natural and artificial regeneration.

3.3 Assessment of the vulnerability of linear infrastructures to wind disturbances

The analysis on the vulnerability of linear infrastructures to wind-related forest impacts has been evaluated in this specific task, accordingly to the forest susceptibility model (v.3.1) and the localization of linear infrastructures. The results are thus presented separately for the two main linear infrastructures in the area, roads and power lines. The output for road susceptibility to wind damages are represented in Figure 17. The average susceptibility for roads in the Rocca Pietore municipality is relatively low, however generalizing this data it is possible to lose local spatial information that may indicate where to carry further analysis, with a more site-specific approach.

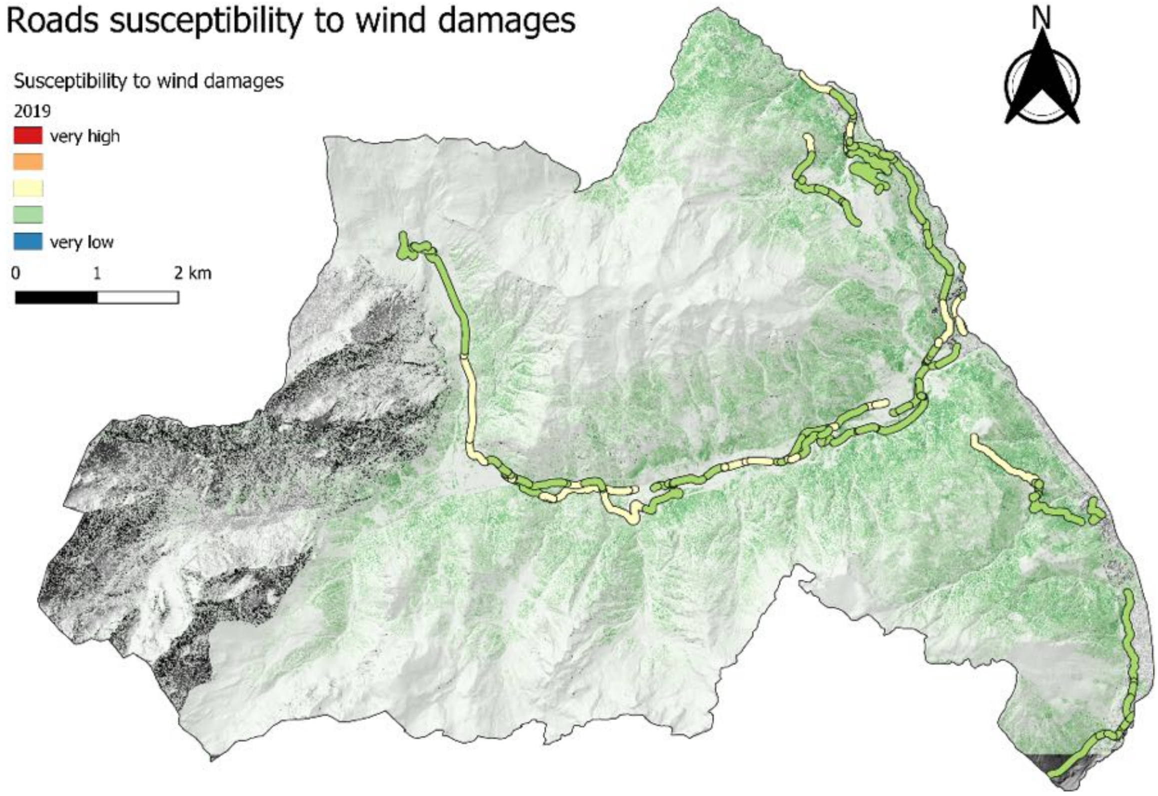

Figure 17. Road susceptibility to wind damages for Rocca Pietore municipality

For what concerns powerlines susceptibility, results are shown in Figure 18. Also in this case the average susceptibility is relatively low.

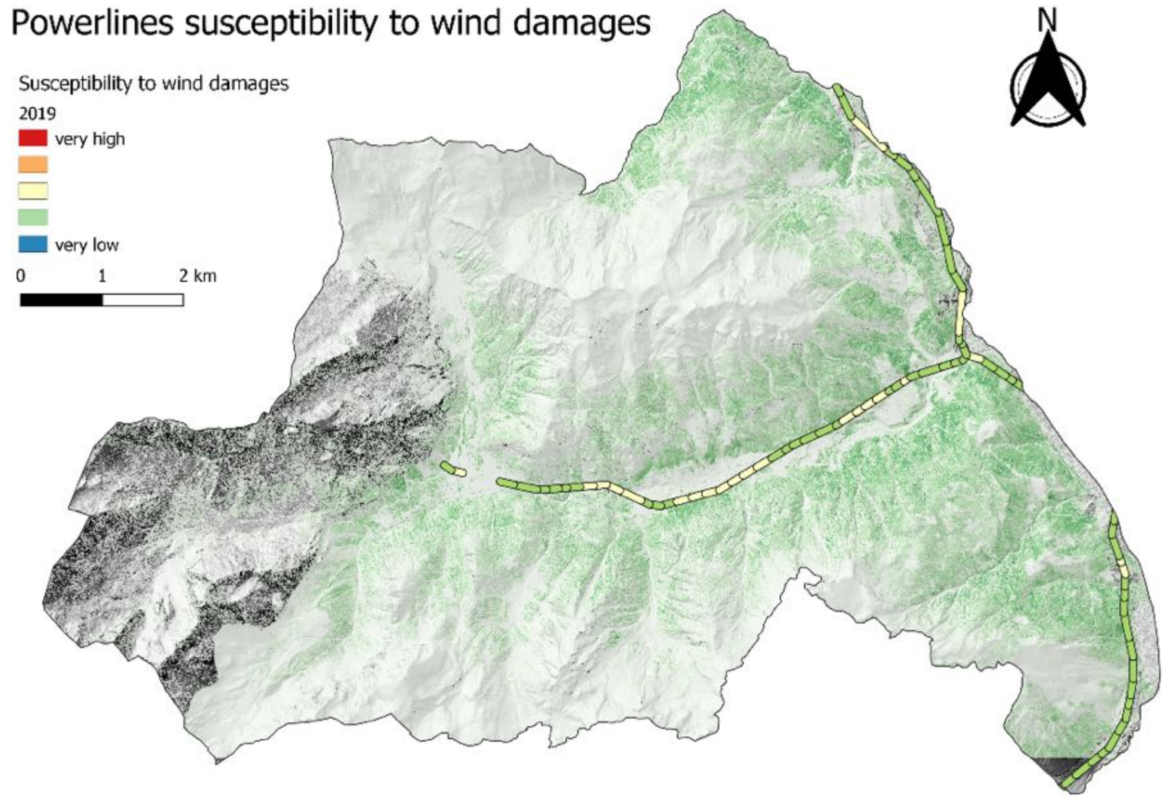

Figure 18. Powerlines susceptibility to wind damages for Rocca Pietore municipality

3.4 Assessment of the human vulnerability during storm events

Starting from information on damages suffered by respondents, 24% of them were left without electricity, 3% without water and 8% have reported damages to their property. The 82% of respondents renounced to at least one activity they usually do on Monday. Figure 19 reports the percentage of respondents that renounced to different activities they usually practice. The most frequently renounced activities are hobbies (58%), practicing sports (49%), meeting with friends and relatives (47%) and going to study (44%). The least frequently renounced activities are staying at home and going to work (23% in both cases). To investigate the determinants of the decision of renouncing to activities, a set of binary logit models was estimated (Table 3). Being with parents increased the likelihood of deciding to renounce going to study and grocery shopping. Being with children decreased the probability of renouncing to staying at home and increased that of renouncing grocery shopping. Partaking in activities useful to limit damages to own properties (i.e. removing debris and removing water) had a positive effect on probability to renouncing going to work, grocery shopping, practicing hobbies and volunteering. Having suffered a power outage increased the likelihood of renouncing going to work, grocery shopping, visiting friends and/or relatives and practicing hobbies. People who received aid during the event were more likely to renounce visiting friends and/or relatives. People with past experience with hazards were less likely to stay at home. People living in areas with high landslides risk were more likely to renounce visiting friends and/or relatives and practicing sports and hobbies. Graduated people were less likely to renounce staying at home and going to study and more likely to renounce practicing sports. Younger respondents were more likely to renounce going to work, going to study, visiting friends and/or relatives and practicing sports. Individuals with high income were more likely to renounce going to study. Finally, women were more likely to renounce grocery shopping, visiting friends and/or relatives and volunteering.

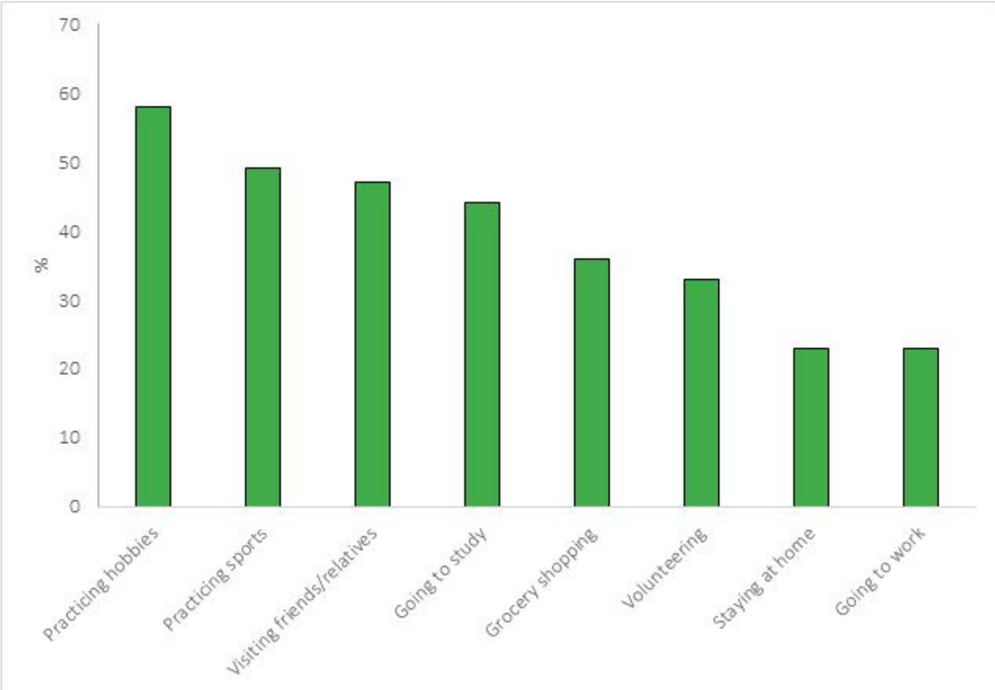

Figure 19. Percentage of respondents that renounced to activities (on total of respondents who usually practice the activity)

Table 3. Determinants of respondents' decision to renounce to activities (binary logit)

	Staying at home	Going to work	Going to study	Grocery shopping	Visiting friends/relatives	Practicing sports	Practicing hobbies	Volunteering
Intercept	-2.18	-1.99	0.06	-2.12	-1.53	-1.80	-3.02	
Being with parents			1.14	0.44				
Being with children	-1.09			0.44				
Removed debris		0.86						0.41
Removed water		0.83		0.71			0.57	0.56
Power outage		1.08		0.75	0.58		0.44	
Having received aid					0.77			
Past experience with hazards	0.39							
Living in landslides risk area					0.63	0.71	0.99	
Having a degree	-0.53		-0.65			0.41		
Age		-0.02	-0.09		-0.02	-0.02		
High income			1.02					
Woman				0.55	0.93			0.54

Note: only coefficients statistically significant at 95% level reported

Moving to communication, 32% of respondents reported having received some form of alert during or before the event. Figure 20 reports the reach of the alerts per province. Belluno is the province with the highest percentage of respondents who received an alert (64%), followed by Trento (45%). At the opposite, only 17% of respondents living in the Padova province received alerts, 15% in Verona and 12% in Vicenza.

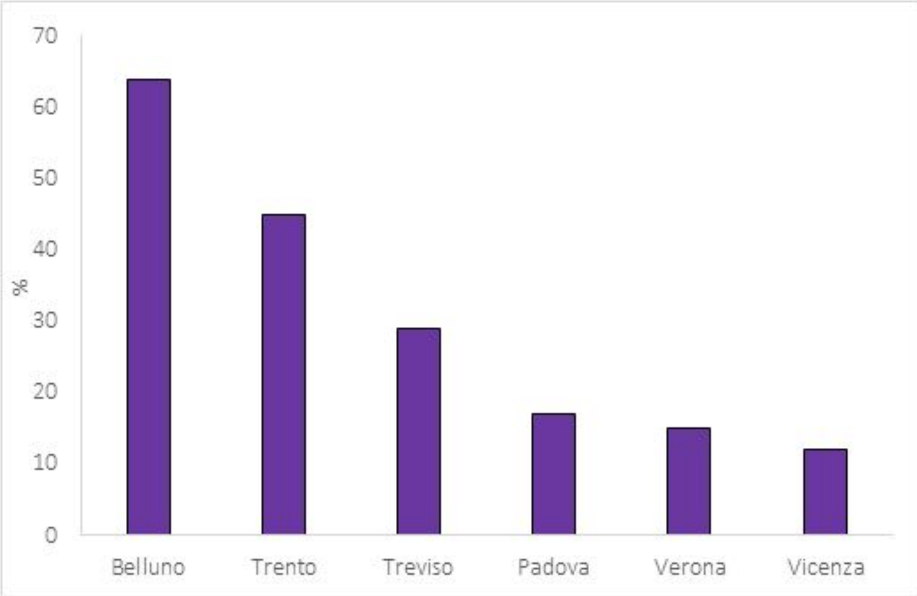

Figure 20. Alerts reach per province

Concerning the effects of the alerts, Figure 21 shows how people who received alerts were more likely to renounce to all activities, with the exception of staying at home (difference not statistically significant). People who received alerts were also more likely to engage in activities useful to limit damages, namely removing debris (19.7% vs 6.5%), removing waters (22.0 vs 10.0%), helping other people (14.7% vs 5.4%), securing objects at risk (44.6% vs 17.5%) and building temporary barriers (15.3% vs 4.8%).

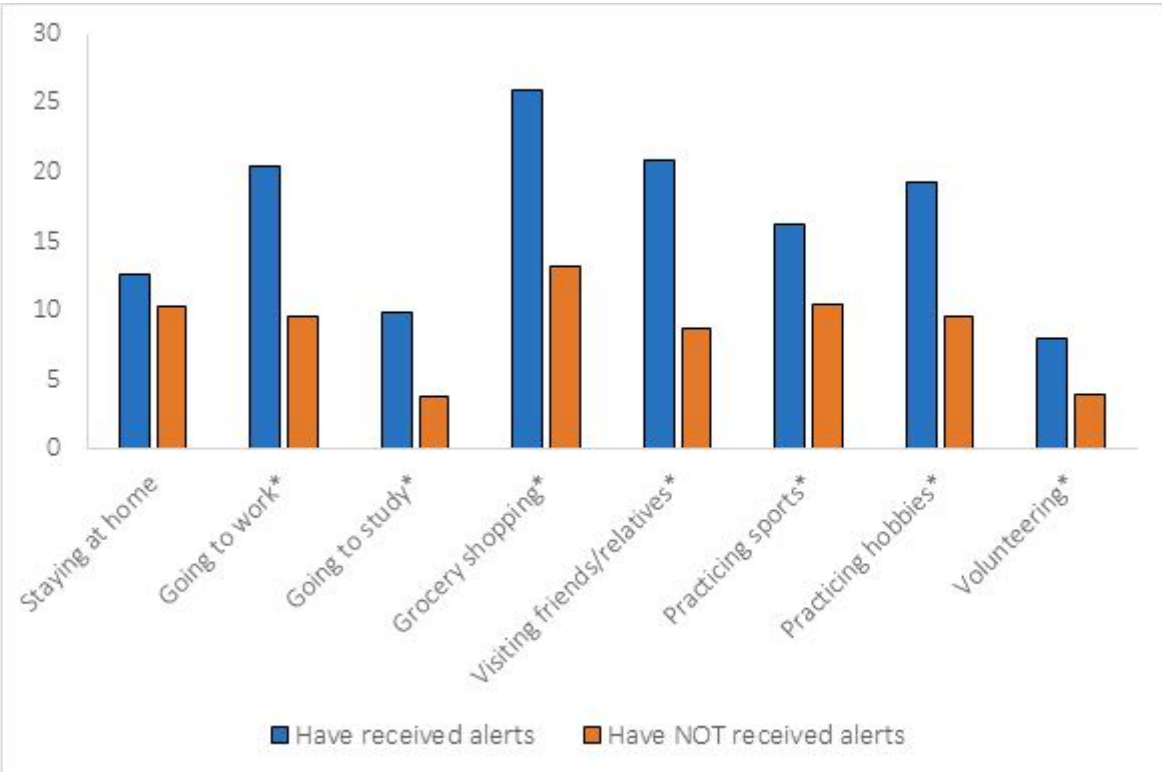

Figure 21. Respondents who renounced to activities per having received alerts

Note: * denotes a difference statistically significant at 95% level (Pearson's CHI squared test)

Table 4. Respondents who engaged in protection activities per having received alerts

	Have received alert	Have NOT received alert
Removing debris	19.7%	6.5%
Removing water	22.0%	10.0%
Helping other people	14.7%	5.4%
Securing objects at risk	44.6%	17.5%
Building temporary barriers	15.3%	4.8%

Note: all differences are statistically significant at 95% level (Pearson's CHI squared test)

4 Connections with other projects

The activities realised in the WP3, both in the field and in the models and outputs implementation have been very useful for starting and corroborating collaboration with other projects. Actually some projects have built on the first experiences and results coming from the VAIA FRONT projet. Specifically concerning WP3, the main connection was with the VaiaLand project (https://storymaps.arcgis.com/stories/805a52d1c18a4b4a8e44a30c153d5f39), a project that aims to evaluate landslide risk after the storm Vaia. It was possible to collaborate regarding rockfall dynamics and field surveys (Figure X), and interconnections with shallow landslides and soil slip in order to extend the susceptibility of FES to wind damages also in a mid-term interval (the phenomenon are starting normally after 3-5 years from the windthrow). The advances in knowledge reached in the WP3 on wind susceptibility of trees with the improved calibrated model, allowed the implementation of the forest module of the RESILIENCE project (http://resilience.stat.unipd.it/). The results and guidelines coming from the post-Vaia regeneration manipulation experiment have been include in the LIFE VAIA

The start-up role of the VAIA FRONT project was successfully obtained in the WP3.

5 WP3 outputs

All the papers, posters, and presentations had the VAIA FRONT project explicit reference in the text (acknowledgement or funding section) or the logo clearly visible (on the title slide for the ppt presentations). The list might not be exhaustive.

Papers

Costa M., Marchi N., Bettella F., Bolzon P., Berger F., Lingua E. (2021). Biological legacies and rockfall: the protective effect of a windthrown forest. FORESTS 2021, 12,1141. https://doi.org/10.3390/f12091141

Piragnolo M, Pirotti F, Zanrosso C, Lingua E, Grigolato S, 2021. Responding to Large-Scale Forest Damage in an Alpine Environment with Remote Sensing, Machine Learning, and Web-GIS. REMOTE SENSING, 13(8), 1541.

Marangon D, Marchi N, Lingua E, 2022. Windthrown elements: a key point improving microsite amelioration and browsing protection to transplanted seedlings. FOREST ECOLOGY AND MANAGEMENT, 508, 120050.
Marchi L, Costa M, Grigolato S, Lingua E, sub. (June2022). Overturning resistance of large diameter Norway spruce (*Picea abies* (L.) Karst) on sloped conditions. FOREST ECOLOGY AND MANAGEMENT, *Under review*

Book chapters

Lingua E, Marchi N, Bettella F, Costa M, Pirotti F, Piras M, Garbarino M, Morresi, D, Marzano R, 2021.Natural Disturbances and Protection Forests: At the Cutting Edge of Remote Sensing Technologies for the Rapid Assessment of Protective Effects against Rockfall. In Protective forests as Ecosystem-based solution for Disaster Risk Reduction (ECO-DRR),pp. 1-13.

Posters

Lingua E, Pirotti F, Grigolato S, Cavalli R, D'Agostino V, Motta R, Meloni F, Garbarino M, Marzano R, 2020. The Vaia storm in North Eastern Italy: facing an unprecedented disturbance in mountain forests of the Southern Alps. 9th IUFRO Wind and Trees Conference 2020, 24-28 February 2020, Rotorua, NZ.

Marangon D, Pilotti M, Zancanaro F, Costa M, Lingua E, 2021. Is deadwood helping regeneration? Natural regeneration dynamics in a stand replacing windthrow area., EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14348, https://doi.org/10.5194/egusphere-egu21-14348

Costa M, Marchi N, Trevisan I, Marangon D, Lingua E, 2021. Natural disturbances and protective effect: the role of biological legacies in protection forests. EGU General Assembly 2021, online, 19–30 April 2021. https://doi.org/10.5194/egusphere-egu21-12625

Costa M, Faes L, Marchi L, Lingua E, 2021. Evaluating the impact of natural disturbances on protection forests: a multi approach analysis. 5th International Conference on Soil, Bio- and Eco-Engineering SBEE, Bern, 21-25 June 2021.

Oral presentation at International conferences

Lingua E, Pirotti F, Grigolato S, Cavalli R, D'Agostino V, Motta R, Meloni F, Garbarino M, Marzano R, 2020. The Vaia storm in North Eastern Italy: facing an unprecedented disturbance in mountain forests of the Southern Alps. 9th IUFRO Wind and Trees Conference 2020, 24-28 February 2020, Rotorua, NZ.

Marangon D, Pilotti M, Zancanaro F, Costa M, Lingua E, 2021. Is deadwood helping regeneration? Natural regeneration dynamics in a stand replacing windthrown area., EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-14348, https://doi.org/10.5194/egusphere-egu21-14348

Costa M, Marchi N, Trevisan I, Marangon D, Lingua E, 2021. Natural disturbances and protective effect: the role of biological legacies in protection forests. EGU General Assembly 2021, online, 19–30 April 2021, EGU21-12625, https://doi.org/10.5194/egusphere-egu21-12625

Lingua E, Marchi N, Bettella F, Costa M, Pirotti F, Piras M, Garbarino M, Morresi D, Marzano R, Berger F, 2021. Natural disturbances and protection forests: at the cutting edge of remote sensing technologies for a rapid assessment of a stand protective function. EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-13223, https://doi.org/10.5194/egusphere-egu21-13223

Costa M, Faes L, Marchi L, Lingua E, 2021. Evaluating the impact of natural disturbances on protection forests: a multi approach analysis. 5th International Conference on Soil, Bio- and Eco-Engineering SBEE, Bern, 21-25 June 2021.

Thiene M, Franceschinis C, Borga M, Scolobig A, 2021. Adaptive behaviours and risk awareness during catastrophic events: the case of the Vaia storm in North-Eastern Italy. EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-6221, https://doi.org/10.5194/egusphere-egu21-6221

Marangon D, Betetto C, Lingua E, 2022. Short-term regeneration dynamics after windstorm: the study case of Vaia storm. EGU General Assembly 2022, Vienna, 23–27 May 2022, EGU22-9514, EGU22-9561, https://doi.org/10.5194/egusphere-egu22-9561

Costa M, Marchi L, Locatelli T, Lingua E, 2022. Trees susceptibility to wind damages: the effect of slope. EGU General Assembly 2022, Vienna, 23–27 May 2022, EGU22-9514, https://doi.org/10.5194/egusphere-egu22-9514

Workshops, seminars and webinars

Lingua E, Marchi N, Costa M, Marangon D, Taccaliti F, Betetto C, Bolzon P, 2020. Priorità di ripristino e dinamiche di ricostituzione post-Vaia. FIERA & FESTIVAL DELLE FORESTE. 11-13 Settembre 2020. Longarone (BL).

Lingua E, Grigolato S, Marchi N, Marchi L, Costa M, Marangon D, Taccaliti F, Betetto C, Bolzon P, Cavalli R, 2020. La foresta di Malgonera Un laboratorio a cielo aperto per lo studio delle dinamiche legate a VAIA. FIERA & FESTIVAL DELLE FORESTE. 11-13 Settembre 2020. Longarone (BL).

Marangon D, 2021. “Restoration ecology. Dinamiche di rinnovazione post-disturbo ed interazioni con le biological legacies”. Webinar presso l'Università degli Studi di Torino, 20/05/2021.

Lingua E, 2021. “Schianti da vento. La tempesta Vaia”. Seminar at the University of Torino, 09/12/2021

Marangon D, 2022. “Restoration ecology. Dinamiche di rinnovazione post-disturbo ed interazioni con le biological legacies”. Seminar presso l'Università degli Studi di Torino, 19/05/2022.

Costa M, Marangon D, Faes L, Lingua E, 2021. Modalità di gestione post disturbo: mantenimento della funzione di protezione e ripristino dei popolamenti forestali. Seminario presso l’Università di Padova. 16/11/2021

Costa M, 2020. Schianti e foreste di protezione. Webinar a cura dell’Università di Padova, 02/07/2020

Costa M., 2022. Wind and trees: the storm “Vaia” in Italy. Seminario presso la sede INRAE (Institut national de la recherche agronomique) di Cestas (Francia), a cura dell’Institut Européen De La Forêt Cultivée. 01/04/2022