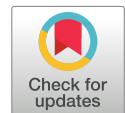


**International Journal of Environment and Geoinformatics****Research Article** **Open Access****Effects of forest age, structure and dominant species (spruce and Swiss stone pine) on water balance in the Tyrolean Alps**Polina Lemenkova<sup>1</sup>  <sup>1</sup> University of Bologna, Department of Biological, Geological and Environmental Sciences, Via Irnerio Bologna, Emilia-Romagna, Italy**Abstract**

Subalpine forests in the Alps are vulnerable ecosystems and valuable supplies of water for environment. Coniferous forests are sensitive to climate changes and human interventions. Although several water balance components have been assessed in earlier research, nothing is known about the frequency and impact of fog on the water balance. This article presents the results of the investigation carried out in subalpine coniferous forests of northern Italy. The aim is to determine the hydrological balance of the area and evaluate the significance of fog occurrence in forests dominated by spruce (*Picea abies*) and Swiss stone pines (*Pinus cembra*), as well as Scots pine (*Pinus sylvestris* L.) and European rowan (*Sorbus aucuparia*). Methods include water outflow, fog interception, and eddy covariance (EC) techniques for measuring evapotranspiration. The workflow included operation with tree transpiration sensors, phonecam pictures, throughfall and stemflow gauges, water discharge measurements, soil moisture sensors, and epiphyte quantification. These methods were used to monitor dense, old-growth coniferous forest (>200 years old trees) as well as young trees (< 30 years). The study has shown that fog plays a significant influence on the water balance of temperate, coniferous mountain forests. Besides, precipitation interception and evapotranspiration partitioning vary with forest age.

**Keywords**

environment • forest • coniferous • spruce • pine • Alps • water balance • hydrology



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## Introduction

Climate change and biodiversity loss have an intertwined nature and threaten the resilience of the Earth and its habitats (Ribeiro and Vasconcelos, 2025; Özel et al., 2025). Given Nature's essential role for planetary well-being, tackling these crises is the most urgent challenge of our time and it is crucial for meeting the UN sustainable goals. To foster transformative change of the economic, social and environmental systems, however, we need to increase our capacity to understand and predict the consequences of global change on ecosystems through modelling and data analysis. Thirty years after the introduction of the Habitats Directive, the NATURA 2000 network is the keystone of the EU's response to global change (Valeri & Capotorti, 2023). Besides, it is the core of the EU Biodiversity strategy for 2030 (Gietda-Pinas et al., 2025; Regelman et al., 2023). NATURA 2000 sites host large swaths of natural and semi-natural ecosystems, including precious coniferous forests of the northern Italy (Dobrowolska et al., 2017). Its contribution to global change cannot be underestimated. Coniferous ecosystems in Italian Alps store huge amount of carbon, are mostly net carbon sinks, and their positive contributions to climate change adaptation spill over outside the protected areas themselves by dampening the effect of hydrological events downstream (Gobbi et al., 2006; Prigioni, & Deflorian, 2005; Rolland et al., 2000).

Notwithstanding the importance of the Habitats Directive, its scope is skewed on conserving species and habitats, rather than modelling natural processes such as climate-environmental interactions. This static approach to environment and nature conservation is currently being challenged by the promoters of landscape restoration, self-sustaining ecosystems with fully occupied trophic levels that are nature-led across the landscapes (Peretti et al., 2025; Di Trapani et al., 2025). Since its development, the concept of landscape preservation and restoration acquired with high policy relevance to the UN environmental policies (Majlingova, 2025; Gonçalves et al., 2025; Spangenberg, 2023). While nature conservation promises to enhance biodiversity, ecological resilience and ecosystem service delivery, its long-term effects on biodiversity of Alps and climate benefits remain unquantified.

Italian mountain ranges in the Alps represent an ideal scenario for environmental modelling. Once densely populated, these areas became economically marginal and underwent the cessation of traditional agro-forestry activities, widespread land abandonment and profound habitat changes (Asam et al., 2018; Gasparini et al., 2025; Balistrocchi et al., 2021). The reasons are related to human social activities and climate change. After the inclusion in the NATURA 2000

network, many of the areas of the Italian Alps evolved with little human interventions, essentially undergoing a process of forest restoration (Agnoletti and Santoro, 2015). This led to challenges related to the changes in the natural landscapes, including precious habitats, and biodiversity of Italian Peninsula.

Understanding the impacts of climate effects on landscape functionality and environmental stability is challenging. However, it requires environmental climate monitoring and data modelling. So far, the existing literature presents scant, scarcely integrated and little research studied on this topic. Investigations between climate and vegetation responses are rare and insufficiently presented in the existing literature. Achieving the complete picture of the climate-environmental change in the Italian Alps requires integrating different datasets, techniques of modelling, expertise and investigation. Integrating meteorological monitoring (e.g., Eddy covariance measurements) with remote sensing, mapping and statistical data analysis (e.g., Python-based plotting) is beneficial for environmental analysis. Interpreting climate-environmental interactions in the boreal coniferous forests of the Italian Alps also requires researchers' perception and knowledge. Previous studies showed that integrated approach that combines qualitative and quantitative techniques of data analysis allows understanding the patterns and trends of climate-environmental changes (Biasi et al., 2015, 2024; Moresi et al., 2025), as well as triggers for these processes.

Boreal forests are the second biggest biome after tropical forests, covering over 12 M km<sup>2</sup> of land. Boreal forests are crucial to global hydrology and climatology because of their vastness, which allows them to control water and energy fluxes over a wide area (Li et al., 2025; Benetti et al., 2024; Stenberg et al., 2022). Besides, mountain regions are crucial water providers (Dinca et al. 2025, Klaučo et al. 2013; Lemenkova, 2022a; Farahnak et al., 2019). Given ongoing climate warming above the global average, coniferous mountainous forests are also largely impacted by these processes (Wei et al. 2025a; Hu et al. 2024; Klaučo et al. 2017). Boreal forests also play an important role in water balance and the global carbon cycle (Wei et al. 2025b). To illustrate this, boreal forests produce ca. 0.5 Pg of carbon annually and storing approximately one-third of the global terrestrial carbon which is crucial for the environmental sustainability on the global scale (Seedre et al. 2011; Li et al. 2024; Boisvenue et al. 2012). However, few studies have partitioned the water balance in boreal forests. In the existing studies, evapotranspiration (ET) and water balance has been shown to represent up to 85 % of incoming precipitation (P).



The gradients of meteorological and soil conditions along with topographic differences and geomorphic slope steepness influence the distribution of vegetation in boreal mountain regions. Previous studies investigated relationships between water content and soil to reveal behavior of particles at fine spatial scales (Haukenes et al. 2022; Lindh and Lemenkova, 2022). These studies demonstrated the responses of soil on water content and external environmental conditions. Thus, environmental processes and elements cause significant impact on the water balance in the Alpine regions. Forests with a dominating coniferous species cover the subalpine zone in the Italian Alps and other Central European mountains.

The growing global climate changes brings significant risks and challenges to environmental safety and the ecological stability of boreal forests in the Alps. Thus, increased radial growth is one of the negative effects of warmer temperatures on subalpine forests. The availability of sufficient water to offset the increased evapotranspiration is necessary for normal ecosystem functionality. At the same time, instability in meteorological parameters (precipitation, evapotranspiration, temperature) often cause land cover changes (Burton et al. 2006; Lemenkova, 2024c). Our awareness of environmental shifts requires modelling and analyzing the dynamics in boreal forests using parametrization of the climate and environmental factors that affect coniferous mountainous forests. For example, the value of the mountain forests can be illustrated by absorbing water via the canopy of forest stands that affect the water balance. Water is being returned to the atmosphere as vapor which maintains water cycle and necessary level of humidity required for ecosystem functioning.

The importance of water resources not only for mountains but also in other regions globally is discussed earlier in many relevant works. For example, drought and floods are mitigated by soil water and groundwater, as well as water content in leaves of trees. Water contained in wetlands and riverbank ecosystems protect from erosion and flooding the areas of wetlands and watershed of lagoons (Olğün Kiyak & Tari, 2024; Lemenkova, 2024a, 2024b). In the mountains, glaciers control water flows, where aquifers can serve as a buffer for storage during dry seasons. In Alpine ecosystems, water cycle ensures functioning of ecosystems. Furthermore, alpine trees improve infiltration and decrease runoff thus affecting geologic components of the landscapes (Couling et al. 2007).

Analysis of the components constituting mountain ecosystems, such as precipitation, infiltration, temperature, and water fluxes, require advance modelling approaches in both Alpine and subalpine areas. Available literature on Alpine ecosystems highlights numerous key issues related to climate

change and associated changes in vegetation, water balance (decreased runoff, melt of glaciers, etc.), including hazard risks (e.g., landslides in the mountains) that are critical for environmental risk assessment (Ghaderpour et al., 2024). Due to these factors, researchers on mountain landscapes are focused on identifying and quantifying these problems to reveal the shift in the mountainous vegetation, as well as hydrological and environmental parameters related to climate warming.

## Objectives and goals

The yearly water balance and all of its components of a subalpine forest in South Tyrol were estimated using dataset collected in 2019. Specifically, it aims at better understanding of the possible effects of fog, tree age, and the lichen abundance that relates to these factors on the water balance. Modelling using advanced methods is required to better analyses moisture availability in coniferous forests. Such methods include, for instance, modelling tools available in statistical packages of Python and R (Lemenkova, 2019a, 2019b). Using advanced tools for data processing ensures accurate data processing for information extraction which needs to be considered for climate change prediction. Besides, using data modelling and statistical analysis enables estimation of practical consequences for mountainous engineering that involves geological risks in the mountains (e.g., tunnel construction, evaluation of soil stability, etc. (Lindh and Lemenkova, 2023a, 2023b; Huayna et al. 2024). For instance, degradation of forest (Biasi et al., 2024) and changes in land use (Brunori et al., 2018) and deforestation can lead to environmental problems. This includes, for instance, soil erosion, landslides, rockfalls in the areas with steep slopes, increased/decreased water runoff or reduced water storage. In turn, the drying of springs and insufficient water have such consequences as biodiversity loss and extinction of rare species in the Alpine mountains.

It is challenging to determine directly from observations how forests affect the climate on a regional scale in Italy, and the attempts are reported (Blasi et al., 2014). An ecological influence, such as the impact of leaf emergence on springtime evapotranspiration and air temperature, can occasionally be found by careful analysis of climatic data. With this regard, to estimate fog water, the fog was derived from the comparison of the gross and net precipitation require advanced methods of data modelling (Chen, 2025; Lemenkova, 2025a, 2025b; Singh et al. 2023). Since there are still gaps in the understanding of water redistribution in forests and its consequences for land-use management, water policies, and the climate system, this paper contributes to a better understanding of links between

hydrological-climatic processes and ecosystem response in the South Tyrolean Alps, northern Italy.

## Study area

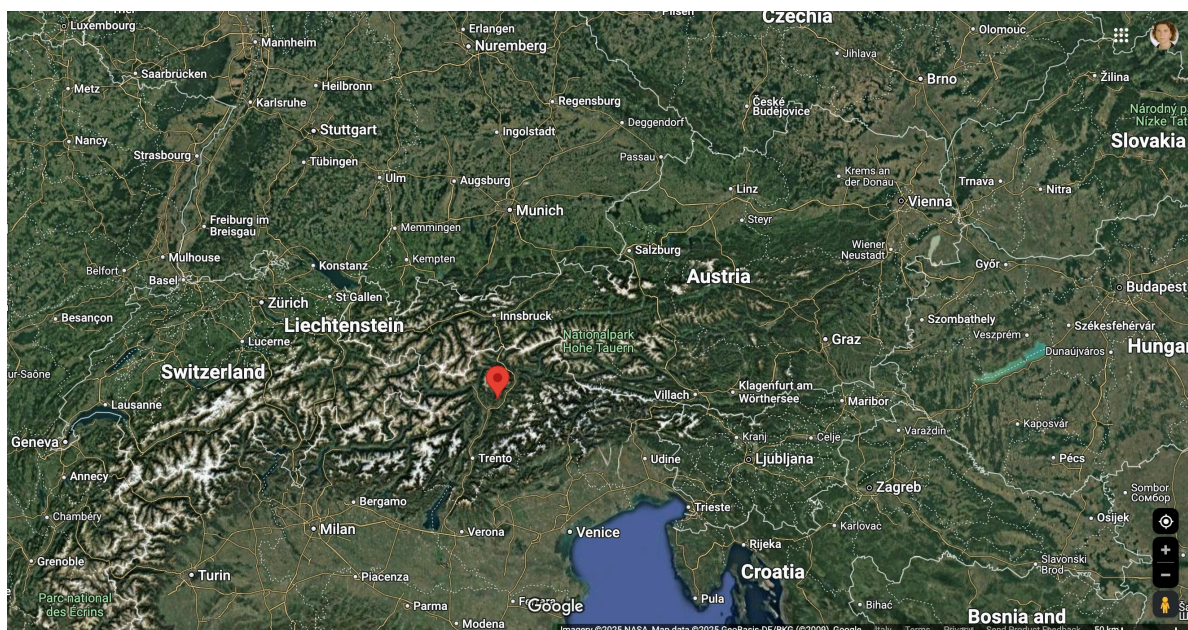
The experiment took place in the Italian Alps in South Tyrol (geographic coordinates: 46°35'11"E, 11°26'00"N, elevation: 1735 m a.s.l.), [Figure 1](#). ICOS, Lter and Fluxnet (Pastorello et al., 2020) are among the monitoring networks for which the website IT-Ren offers data. The catchment area is 0.44 square kilometers. The ArcGIS program (ESRI, Redlands, CA, USA) was used to measure the water basin on the local digital elevation model. The tree layer (diameter at breast height (DBH) >5 cm) consisted of 85% spruce (*Picea abies* (L)), 12% Swiss stone pine (*Pinus cembra* L.), and 3% European larch (*Larix europea* L.) trees. Scots pine (*Pinus sylvestris* L.) and European rowan (*Sorbus aucuparia*) individuals were also present sparsely. The dominant tree height was approximately 29 m. The understory consisted mainly of alpenrose (*Rhododendron ferrugineum* L.) and blueberry (*Vaccinium myrtillus* L.). Intervening grasslands were dominated by wavy hairgrass [*Deschampsia flexuosa* (L.) Trin.

## Materials and Methods

The influence of aged trees on water balance was evaluated by estimating different environmental parameters. These include water interception, epiphyte composition and temperature at different heights with an adjacent young canopy forest. Total evapotranspiration was measured using eddy covariance techniques and transpiration with sap flow sensors. The idea

of the eddy covariance is that it records the turbulent flux data and calculates the covariance of fluctuations in the vertical wind velocity and in the physical measured quantity. Then, these data were statistically analyzed using Python libraries (Lemenkova, 2019c). Additional measurements at the soil level were performed in an old (>200 years old) and young (< 30 years old) forest. In both stands, the soil moisture was measured. Finally, water discharge was measured at the catchment level of the watershed basin. We assessed the proportional contributions of the water components in the balance at the catchment level in order to estimate the water balance. Field experiments and eddy covariance flux towers offer local-scale information about forest-atmosphere interactions, and developments in remote sensing technology can help extrapolate this information to broader spatial scales.

Precipitation below the canopy as throughfall was measured with sixteen manual rain gauges, arranged in two groups of eight in the two main forest formations, the 200-year-old section and the 30-year-old section. These pluviometers, with a 10-cm diameter orifice, were arranged in rows with a 5-m distance between each pluviometer and data were recorded almost on a weekly basis. Additionally, six tipping bucket pluviometers arranged 5 m apart in two groups of three continuously recorded the below canopy precipitation at a 10-min resolution. To increase their collection representativeness, funnels with a diameter of 30 cm were placed above the orifice of each pluviometer. Throughfall



Source: Goole Earth Engine.

Figure 1. Aerial satellite-based map of the study area (the exact location is marked by the red pointer) within the watershed basin

measurement equipment (automated and manual gauges) put at soil level in both young and mature forests is shown in Figure 2.

Tree transpiration was estimated by measuring the sap flow of five spruce trees with a DBH ranging from 23 cm to 57 cm. The sap flow measurements of up to 10 trees going back to 2016 showed a representative behavior of these trees for their size classes. To minimize the errors due to incoming shortwave radiation, one sensor of the tissue heat balance sensor (Table 1) was installed at the north side of the trees. The measuring system provided sap flow rates integrated for the whole sapwood depth per unit trunk circumference ( $\text{kg h}^{-1} \text{cm}^{-1}$ ). We logged the measured values at 10-min intervals and then scaled them to the tree level by multiplying them with stem circumference (minus the bark and phloem thickness measured during sensor installation) and integrated them to 30-min and daily sums per tree ( $\text{L day}^{-1}$ ). When a sensor was installed for more than a year, we checked whether wound reaction and/or an accumulation of resin led to a decrease in sap flow by comparing the 95<sup>th</sup> percentile (P95) of 30-min sap flow rates for 2019 and the previous years. For the two smallest trees, we found a considerable decrease in the P95 sap flow and consequently corrected sap flow for 2019 by multiplying it with the ratio of P95 [(year of sensor installation)/P95(2019)]. Minor data gaps caused by power outages or temporary sensor malfunction were filled by using a linear correlation of the respective tree's sap flow with eddy

covariance evapotranspiration ( $R^2 = 0.57$  to  $0.66$  at a 30-min resolution).

Fog had a minor impact on annual and seasonal water budgets in temperate mountain forests, just like it does in tropical rain forests and subtropical cloud forests. However, in some weather situations, fog could have a discernible effect. Because older forests include epiphytic lichens, we also proposed that stands with older trees ( $\geq 200$  years) would have a larger interception capacity and lower throughfall rates than younger stands. In this regard, it is possible to develop positive feedback between evaporation fluxes and tree age using Python-based modelling techniques using libraries Matplotlib, NumPy and Pandas. To better understand fog occurrence, we compared the relevance of the measured meteorological conditions (relative humidity, temperature, radiation, wind speed and direction, ratio of diffuse to total global radiation and vapor pressure deficit) during periods with dry conditions (dry), fog (less than 1 km visibility) and rainfall.

Tree transpiration was calculated by dividing sap flow by the projected crown area of the respective tree, thereby converting units from kg per tree to mm. The projected crown area was estimated from the mean crown radius measured in the four cardinal directions. The average tree transpiration of the two smaller trees (DBH 23 cm and 32 cm, respectively) was used to represent the young stand, while the average of the three larger trees (DBH 43 cm, 50 cm, and 57 cm, respectively)



Figure 2. Measurement equipment (automated and manual gauges) put at soil level in both young and mature forests

was used to represent the old stand. All the selected trees were dominant. To estimate the canopy interception ( $I$ ), we used the water balance at canopy level on a daily scale during periods with rainfall-only and mixed precipitation,

$$I = Pr + Pm - Tf - St \quad (1)$$

where  $I$  is canopy water storage or interception (mm),  $Pr$  is rainfall (mm),  $Pm$  is mixed precipitation (rainfall during days with the presence of fog) (mm),  $Tf$  is throughfall (mm) and  $St$  is stemflow (mm). The accuracy of the equipment of the measured variables and the systematic error of  $I$  in Eq. 2 are shown in Table 1. Data gaps owing to logger failure were filled by linear correlation with working gauges, as the correlations between them were high ( $R^2 > 0.87$ ). The data for the manual gauges were missing for the last sampling interval and were added via a linear correlation with the results from the automatic gauges ( $R^2 > 0.77$ ).

Stemflow was measured at one tree each at the old and young stand. Water running downwards around the tree trunk was collected into a funnel and measured with a tipping bucket pluviometer (Table 1). The measured volume of stemflow was divided with the projected crown area of the trees to convert the data into mm. Missing values owing to logger failure were added via linear correlations with automatic throughfall measurements ( $R^2 = 0.81$  for the old forest and 0.55 for the young forest). Soil water content was measured continuously within the study site (Table 1) and the change of soil water content was calculated as the difference between the start and end of the measuring period and the hydrologic year, respectively. Water discharge at the catchment scale was measured using a combination of a water stage sensor and flow velocity measurements. The water stage sensor was placed at the lowest spot of the catchment, just above an artificial water basin (46°35'00"N, 11°26'02"E, 1,675 m a.s.l.) and continuously measured the height of the water table in the stream ( $S$  in cm). Discharge ( $DC$  in  $l\ s^{-1}$ ) was calculated as

$$DC = a \cdot S^b \quad (2)$$

where  $a$  and  $b$  are empirical parameters according to the salt method. Meteorological conditions for the days in 2019 that had rain, fog, and mixed precipitation were assessed using available datasets.

## Results and Discussion

Convective rainfall events were important throughout the warm summer, but the cold winters were quite dry, as evidenced by the average monthly precipitation, which was expressed as a monthly sum and the maximum daily sum. The results of the frequency of fog and precipitation across time demonstrated the following findings. Except for a drier June and October and November that were 1.5- and more than 3-

fold wetter than the average, respectively, the precipitation in the study area in 2019 was largely consistent with the 20-year average. The highest daily precipitation also showed these deviations. Our measuring season really ended by an extraordinary snowfall event that began on November 8 and caused a significant snow break, particularly in the young forest. Additionally, the first half of 2019 saw a significant departure in air temperature from the 20-year normal, with May being cold and February and June being warm.

Days with fog (defined as days with fog and days with mixed precipitation) may have accounted for 45% of overcast days in 2011 according to Wagner and Petitta (2015), if we take into account our data from 2019. The study site did not have direct access to long-term fog data. As a result, the information gleaned from the 2015 and 2019 webcam images (more information is in Table 2) is useful.

Overall, there were 296.5 hours of fog between January and August 2015, with 72 days of fog and 37 days of mixed precipitation (109 days; 30% of days were foggy and 15% had mixed precipitation). For the entire observed time in 2015 and 2019, as well as the common period observed in both years, there were days with dry weather, fog and precipitation (rain or snowfall), and mixed precipitation of fog and rain or snowfall, Table 1. Days with fog were common in 2019, although there weren't many days with only fog (which were common in 2015); instead, fog was frequently present on days with precipitation (which we categorized as days with mixed precipitation). During a monitoring period of 167 days (from late spring to autumn of 2019), there was 241 hours of fog during 9 days with fog (5%) and 45 days with mixed precipitation (27%).

**Table 1.** Meteorological parameters over the datasets in study periods

|                     | 2015 all        |      | 2015 common period |      | 2019 all          |      | 2019 common period |      |
|---------------------|-----------------|------|--------------------|------|-------------------|------|--------------------|------|
| measuring period    | 11. - 30.8.2015 |      | 25.5. - 30.8.2015  |      | 25.5. - 7.11.2019 |      | 25.5. - 30.8.2019  |      |
| time observed       | 9-17            |      | 9-17               |      | 0-24              |      | 0-24               |      |
|                     | days            | %    | days               | %    | days              | %    | days               | %    |
| dry                 | 123             | 50.6 | 40                 | 41.2 | 79                | 47.3 | 46                 | 47.4 |
| fog                 | 72              | 29.6 | 31                 | 32.0 | 9                 | 5.4  | 2                  | 2.1  |
| rain/snow           | 11              | 4.5  | 6                  | 6.2  | 34                | 20.4 | 31                 | 32.0 |
| mixed precipitation | 37              | 15.2 | 20                 | 20.6 | 45                | 26.9 | 18                 | 18.6 |
| total               | 243             | 100  | 97                 | 100  | 167               | 100  | 97                 | 100  |

The significance of days with both fog and rainfall (mixed precipitation) is shown by these findings. In 2011, measurements over 254 days showed 70% cloudy conditions in South Tyrol; however, no fog or mixed precipitation

data were obtained. The average monthly temperature (monthly average and average daily maxima and minima) and precipitation is shown in Figure 3 (monthly sum and maximum daily sum) for 2019 (thick line) as well as during 1999–2019. The residual of evapotranspiration (ET) obtained using eddy covariance for the entire forest less interception (I) and tree transpiration (T) quantified as sap flow was used to compute evapotranspiration of soil and understory (Esu). Deep percolation was not measured during the measuring period since  $ET + DC + dSWC$  exceeded total precipitation. However, discharge (DC) and change of soil moisture (dSWC) were measured throughout the entire forest.

Figure 4 illustrates water partitioning for the young and old forests. Python's Sankey plotting technique is used to create the figure of the parameters in the young forest (left) and in the old forest (right). The data demonstrate the 5-month measurement period spanning from 30.05 to 07.11. 2019. Based on fog data, total precipitation was divided into two categories: rainfall (P) and mixed precipitation (Mixed fog + P). The residual of the measured  $P + \text{mixed fog} + P - \text{throughfall (Tf)} - \text{stemflow (Sf)}$  was used to compute intercept (I). In the presented Sankey diagram, the visualization is used to represent the flow of quantities between different meteorological entities and states of biophysical tree responses. The input and output flows between these parameters are visually presented using Python-based plotting of the data. Hence, water partitioning for the young forest (left) and the old forest (right) for the 5 months measuring period from 2019-5-30 until 2019-11-07. Total precipitation was split into rainfall (P), mixed precipitation

(Mixed fog + P) according to fog observations. Interception (I) was calculated as the residual of measured  $P + \text{mixed fog} + P - \text{throughfall (Tf)} - \text{stemflow (Sf)}$ . Evapotranspiration of soil and understory (Esu) was calculated as the residual of evapotranspiration (ET) measured with eddy covariance for the whole forest minus interception (I) and tree transpiration (T) measured as sap flow. Discharge (DC) and change of soil moisture (dSWC) were also measured for the whole forest, deep percolation was not quantified for the measuring period as  $ET + DC + dSWC$  was greater than total precipitation.

Various measuring techniques were combined to quantify the frequency of fog episodes in a subalpine coniferous forest in the Italian Alps and evaluate the hydrological balance at basin and canopy scales. Within the measurement's error range, there was a 25 mm discrepancy in the amount of water output from evapotranspiration and water discharge, as well as the fluctuation in soil water content, and the amount of water input from rain and snow forms (excluding fog). As a result, the filamentous lichens were able to develop in the higher portion of the canopy, and the trees were able to retain a significant amount of leaf area. Because of these two characteristics, the crown, especially in mature coniferous forests, has a great ability to catch liquid precipitation, release just a tiny quantity of precipitation to the soil, and subsequently release runoff, preserving local ET while lowering sensible heat flux in the process. On the presented Sankey diagram, the lines width of the curved lines is proportional to the flow quantity of the environmental parameters. Such approach enables us to identify the largest flows between the meteorological variables and the responses of forest for old and young

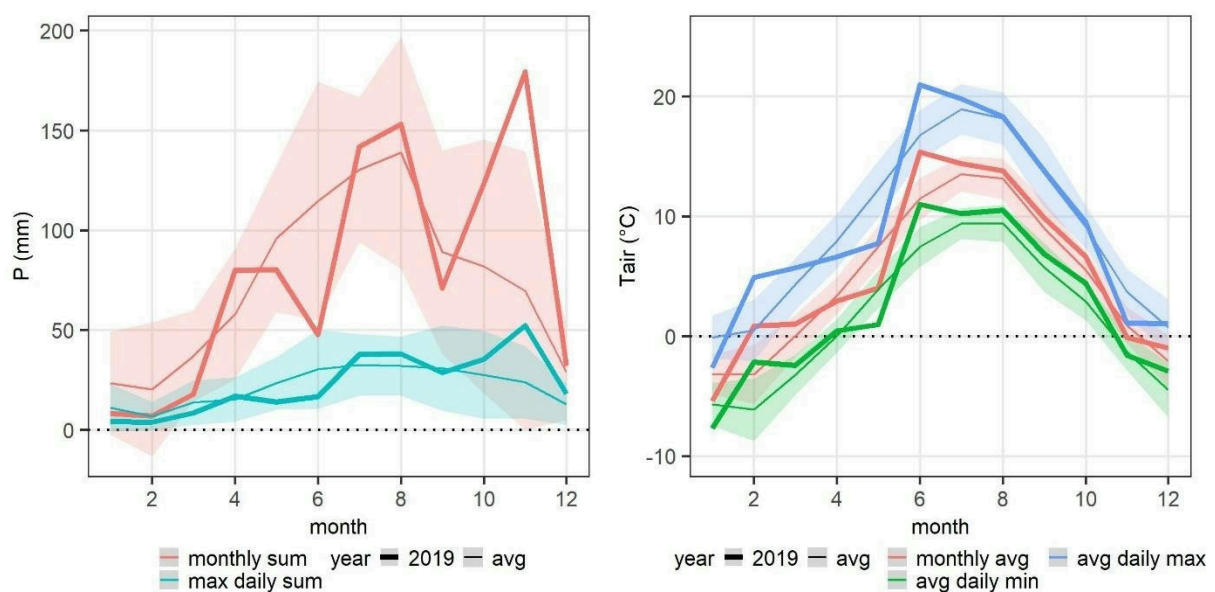


Figure 3. Statistical analysis of the environmental variables

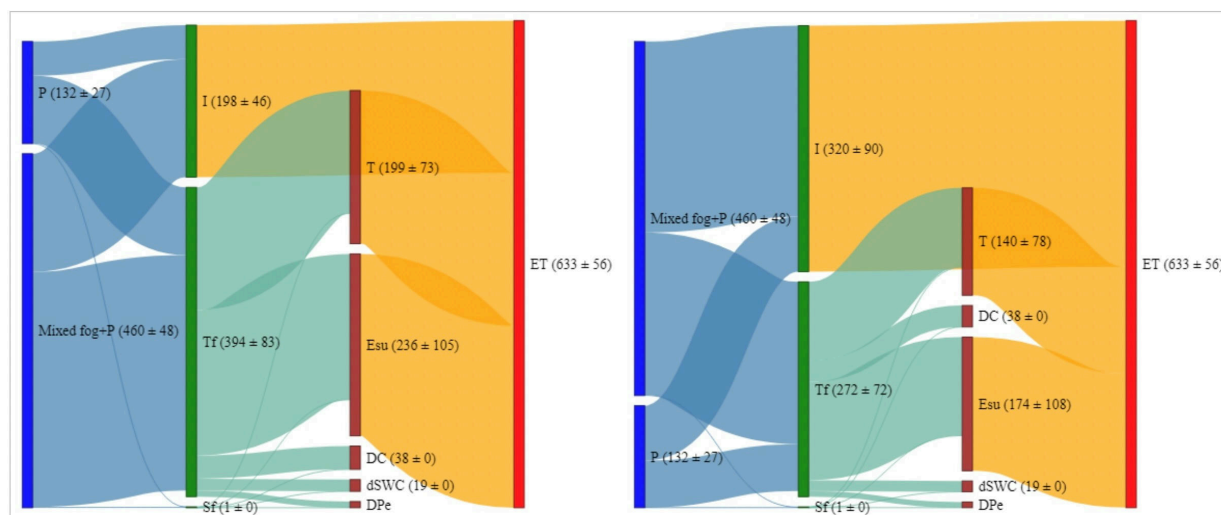


**Figure 4.** A sankey diagram which is a visualization to depict a flow from one meteorological parameter to values of another: precipitation (P), temperature (T), evapotranspiration (ET), fog and other parameters of the water balance and ecosystem. The parameters being connected are nodes of the system, while the connections are environmental links. The variables on Sankey diagram include the following parameters: Precipitation (P), evaporation plus soil evaporation (Esu), discharge (DC), change of soil moisture (dSWC), deep percolation (DPe), throughfall (Tf), stemflow (Sf), evapotranspiration (ET), and Interception (I).

stands. Moreover, Sankey diagram is useful for showing how hydrological resources move through a forest ecosystem, highlighting dominant paths and potential links between the quantitative variables.

The effects of climate change in the Italian Alps lead to the decrease of forest areas and habitat homogenization on regional scale. In contrast, the consequences may trigger the decrease in landscape diversity, land use practices, forest structural characteristics and biodiversity. For instance, previous reports inform that forest dynamics lead to natural disturbances, changes in forest cover and structure as well as patterns in landscape patches of the Alps (Paletto et al., 2013; Notaro and Paletto, 2011). On the one hand, climate changes such as increased temperature provide conditions for restoration of important ecosystems and historically significant landscapes, including release of advanced beech regeneration. On the other hand, it may also lead to gully erosion and terrace failure in mountain terraced landscapes (Dupire et al., 2015; Mauro, 2011; Camera et al., 2015). Nevertheless, by reducing the reliance of human communities on timber products, land cover changes driven by climate processes is now offering new opportunities for habitat restoration and biodiversity conservation in the Alps. Specifically, a temporary homogenization effect may occur after land abandonment in the Alps with consequences in terms of biodiversity, restoration and non-provisional ecosystem restoration.

## Conclusion

The overall outcome of this study is presented by data analysis using ecological statistics. The series of graphs are presented to demonstrate the trends and relationship mechanisms between the meteorological parameters, hydrology and biophysical responses in the forests of the Italian Alps. This study evaluated the effects of the relationship between climate changes and water balance (fog, evapotranspiration, and water vapor) in the coniferous forest areas. The specific results included the models which assessed how temporal climate changes (variations in temperature and precipitation) affected the water balance in old (>200 y.o.) and young (< 30 y.o.) forest stands. We revealed the positive effect of old forests, in comparison to young forests, because of the contribution to the higher humidity and distribution of lichens of the old stands. Besides, we investigated the indirect effects of climate-environmental relationships and water availability that influence coniferous plant biodiversity in the Italian Alps. We also highlighted the areas of maximum water balance change that were affected through insufficient water resources (lower precipitation and higher temperatures during summer periods). Besides, we performed the ecological statistical analysis and quantified the proportions of the meteorological parameters on temperature (T) and precipitation (P) and other variables for average daily and monthly periods.

Using Python-based modelling applied to the available dataset, we characterized multiple pressure drivers from climate variables that drive habitats and biodiversity change

in the studied area for the aim of nature conservation outlook. Finally, the applications of the presented study can be used to predict the impacts of climate change in the northern Italy according to the climate change scenarios specifically for mountainous areas. Hence, future studies can be continued with regard to the distribution of vegetation species, combining vegetation vulnerability and exposure to climate change in Europe and Mediterranean regions. In this way, this study has applicability to the environmental risk analysis and vegetation changes under the pressure of climate effects (water balance).

As a result, this study revealed that fog, when combined with rainfall on the same day, as mixed precipitation, increased throughfall, which in turn increased net precipitation (soil water recharge, in the absence of runoff), and evaporative conditions inside the canopy, even though fog has not been included in previous water balance studies. As a result, we can affirm that fog was crucial to the water balance during many days of mixed precipitation, sustaining a high relative humidity within the forest's dense coniferous crowns for a number of days. Given that the amount of water vapor in the atmosphere is now declining and that the positive feedback in the water cycle in terrestrial ecosystems may be disrupted in the future, old-growth vegetation is essential for regulating the climate in the Alpine area. This data supports recent research showing that natural trees can control higher temperatures in the Alps and subalpine ecosystems.

From an environmental point of view, this study supports new data showing that natural forests are essential for reducing heat extremes over vegetated terrestrial ecosystems. The significance of connection in the positive feedback between the presence of woods and chilly, humid weather is also attributed to fog and cloudiness. The ability of the intercepted water to function as a climate regulator at the local and mesoscale is climatologically significant, in addition to the physiological element of the plant's water use. By emitting 44.2 W m<sup>-2</sup> of latent heat instead of sensible heat, one millimeter of water at 20 °C lowers the temperature and increases the amount of water vapor in the atmosphere. Fog's primary function is to maintain this beneficial feedback in the water cycle by promoting the growth of lichens and thick vegetation and raising the amount of water vapor available.



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