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Supplementary Material

Appendix 1 - Defoliation and tree health – Related definitions.

Defoliation is an unspecific indicator, integrating the intrinsic genetic constitution of trees and site effects (soil fertility, climatic features, structure, and composition of the forest stand), and can be considered indicative of the equilibrium of a tree in its own environment, representing the result of accumulated impacts of stressful environmental conditions. External fluctuating pressures, such as abiotic and biotic factors, can cause year-to-year variations of defoliation. In addition to defoliation, other parameters concerning damage symptoms on different parts of the tree (leaves, branches, trunk) are assessed. The term "*tree condition*", therefore, refers to the overall appearance of a tree, encompassing defoliation and damage symptoms. Concurrently the term "*tree health*", as defined by Innes (1993), refers to the incidence of both abiotic and biotic factors affecting trees within a forest. The vitality of a tree concerns "the capacity to assimilate carbon, to resist stress, to adapt to changing environmental conditions and to reproduce" (Brang et al., 1998). The concept of "*tree vitality*" has been reviewed by Dobbertin (2005), who concluded that physiological indicators may best reflect the reaction of trees to environmental stressors. Unfortunately, many such indicators are difficult to measure in the field.

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Appendix 2 - The ICP Forests programme.

In the context of the efforts to monitor the impacts of atmospheric pollutants and acidic depositions on forests, a comprehensive program for the assessment of the conditions of forests was launched in Europe in 1985 (ICP Forests - International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests) (UN-ECE International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, https://unece.org/environmental-policy/air/forests) under the Convention on Long-Range Transboundary Air Pollution (CLRTAP, now: Air convention) and the European Union Scheme on the Protection of Forests Against Atmospheric Pollution.

Now, the objectives of the ICP Forests programme are widened. According to the 2016-2023 strategy (https://www.icp-forests.org/pdf/strategy2016-2023.pdf) "The mission of ICP Forests is to carry out multifunctional long-term monitoring of forests within the UNECE region and beyond and provide scientific knowledge on the effects of air pollution, climate change and other stressors on forest ecosystems". The ICP Forests programme consists of a pan-European network of permanent monitoring plots, where extensive (Level I) and intensive (Level II) surveys have been carried out since the 1980s. The extensive survey comprises about 6.000 plots (16 x 16 Km grid across Europe), where the conditions of trees are assessed every year according to a standardized methodology (Eichhorn et al., 2020); the intensive survey comprises about 800 plots, where cause-effect relationships are investigated (for details and protocols see www.icp-forests.net). The activities carried out on Level II plots include tree crown conditions assessment, ground vegetation, tree growth, phenology, atmospheric depositions, soil circulating solution, meteorology, ozone visible symptoms. In both surveys, the most relevant indicator to assess the vitality/physiological status of trees has been "defoliation", defined in the ICP Forests Manual for the visual assessment of crown condition and damaging agents, as needle or leaf loss in the crown as compared to a reference tree (Eichhorn et al., 2020). Defoliation is an unspecific indicator, integrating the intrinsic genetic constitution of trees and site effects (soil fertility, climatic features, structure, and composition of the forest stand). In the physiological sense, defoliation is a regulative mechanism used by trees to adapt to environmental or stand conditions which can be considered indicative of the plastic equilibrium of a tree in its own environment. External factors, such as abiotic and biotic stresses, can cause year-to-year variations of defoliation that, in turn, can have consequences on the physiological functioning of trees.

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Fig. S1 - Distribution of the permanent monitoring plots (ICP Forests network in Italy). The composition of the plots is reported (green plots: Conifers; brown plots: Broadleaves; blue plots: Mixed)

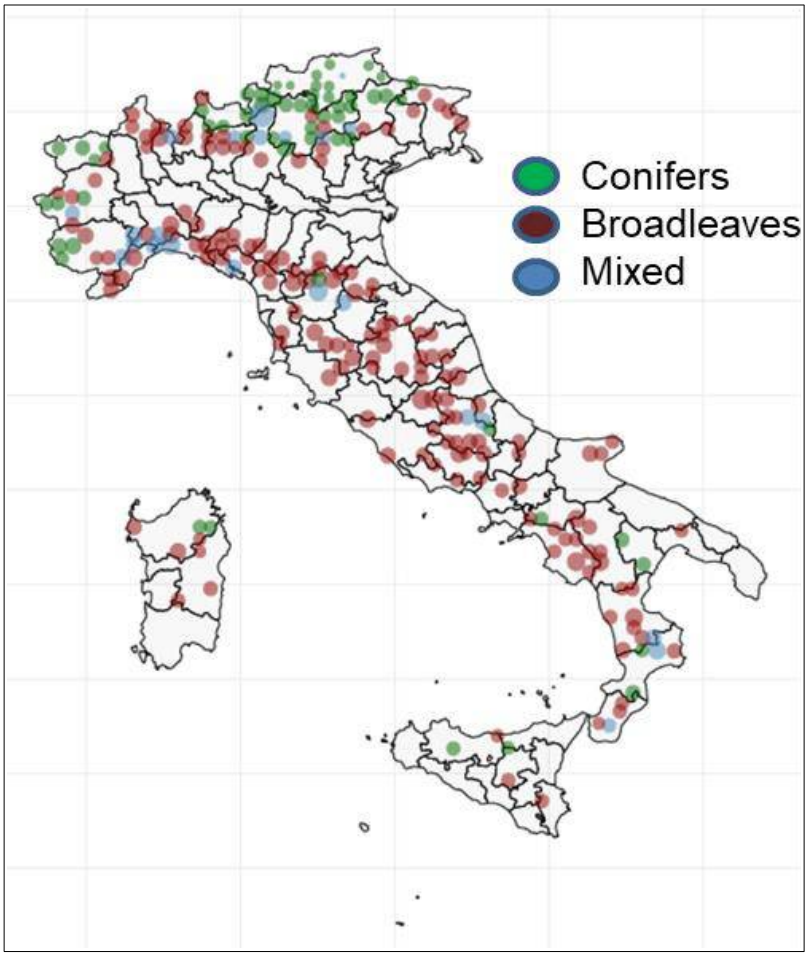

Fig. S2 - Trends of annual cumulated precipitations, mean temperatures and relative humidity (RH) at national level. Data re-elaborated from SNPA (2023). Values are indicated as anomalies (in percent) with respect to the mean of the 30-year period 1991-2020. Trends are significant ($p<0.001$) for Temperature and RH, and not significant for Precipitation (Mann-Kendall Trend Test).

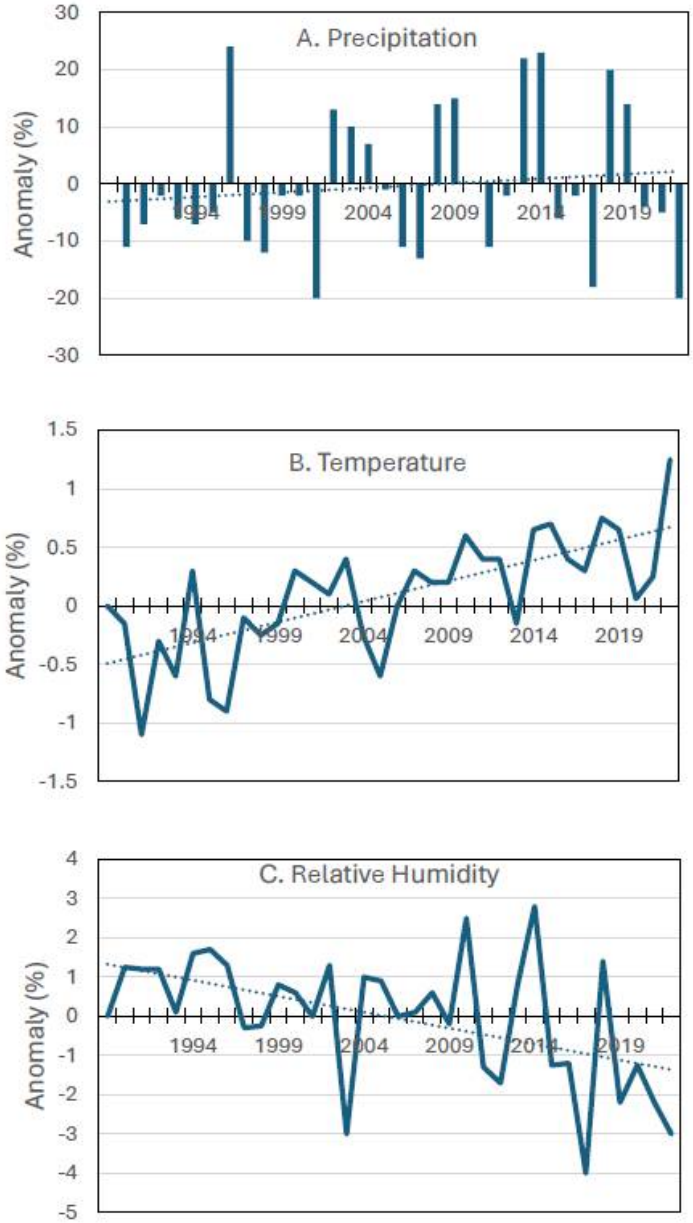

Fig. S3 - Levels and trends of defoliation of *Fagus sylvatica* in the Alpine (270 trees) and Temperate-Mediterranean (870 trees) bio-climatic regions.