The following supplement accompanies the article

Climate change response of vegetation across climatic zones in Italy

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Table S1. List of keywords used for the literature search

Italy; warming; vegetation
Italy; warming; plant
Italy; drought; vegetation
Italy; drought; plant
Italy; additional rain; vegetation
Italy; additional rain; plant
Italy; increased rain; vegetation
Italy; increased rain; plant
Italy; snow cover; vegetation
Italy; snow cover; plant
Italy; water addition; vegetation
Italy; water addition; plant
Italy; frost; vegetation
Italy; frost; plant
Italy; cooling; vegetation
Italy; cooling; plant
Italy; extreme event; vegetation
Italy; extreme event; plant
Italy; climate change; vegetation
Italy; climate change; plant
Italy; glacier foreland; plant
Italy; glacier forefield; plant

Table S2. List of experimental research projects with indications of climatic zone (A: alpine; T: temperate; S: sub-Mediterranean; M: Mediterranean), species or system, treatments (D: drought; W: warming; R: water addition; N: fertilization; S: snow cover; F: frost; M: management regimes; I: species interactions), methods, measurements and main results.

Climatic zone	Species/System	Treatment	Methods	Response variables	Results	Literature
A	Sub-Alpine dwarf-shrub heath	R, N	Water collection and distribution. 16 plots (1 m x 1 m), 5 years of treatment.	Species cover; species richness; ANPP	ANPP increased with fertilization but was unaffected by irrigation. In the drier community species richness was raised by irrigation.	Brancaleoni et al. 2007
A	Sub-Alpine dwarf-shrub heath	S	Snow addition/removal; thermo-reflecting sheet. 9 plots (1.5 m x 1.5 m), 3 years of snow cover manipulation.	Growth; CO2 exchange; flower production; tissue chemistry	The structure and species dominance patterns didn't change significantly in response to reduced snowcover. Spring frost caused a reduction in growth and flower production.	Gerdol et al. 2013
A	Snow-bed	W	Open-top chambers (basal width: 90 cm x 127 cm); space-for-time substitution. 20 permanent plots randomly located in an area of 2 ha	Decomposition	Litter decay not affected by warmer summer temperatures but reduced by advanced snowmelt. Plant traits exerted the major control over litter decomposition. Long-term effects of climate warming, resulting from shifts in litter quality due to changes in the abundance of plant functional types, will likely have a stronger impact on plant litter decomposition than short-term variations in microclimatic features.	Carbognani et al. . 2014a;
A	Snow-bed	W	Open-top chambers (basal width: 90 cm x 127 cm); space-for-time substitution and laboratory simulations. 20 permanent plots randomly located in an area of 2 ha	Flowering and germination phenology; seeds longevity.	Seeds produced by plants exposed to warmer temperatures were significantly longer lived and resistant to heat than those from plants at natural conditions. Plants developed under warmer climates produced seeds with changed germination responses to temperature and/or cold stratification, but the extent of these changes across species could be driven by seed dormancy traits. Noticeable plastic response of flowering to changing micro-climatic conditions, both for snowbed specialized and alpine generalist species. At the annual scale, the timing of snow-melt seems to play a major role, while at the growing-season time-scale the temperature was the most common trigger of the blooming period.	Bernareggi et al. 2015, 2016; Carbognani et al. 2016.
A	Snow-bed	S	Snow removal; experimental plots of 2.5 m x 1.5 m)	Flowering phenology	Advanced snowmelt resulted in early flowering and a longer prefloration period.	Petraglia et al. 2014

Climatic zone	Species/System	Treatment	Methods	Response variables	Results	Literature
A	Glacier foreland species	W	Temperature and light-controlled incubators. Seeds collected from 8 species	Seed germination phenology	Early snowmelt in spring caused the main ecological factors enhancing the recruitment success, but spring germination may increase the exposition to freezing episodes. Early-emerging seedlings could be more resistant to summer drought and winter extremes.	Mondoni et al. 2012; 2015
A	Alpine species	W, D	Laboratory simulation of seasonal temperature treatments. 53 species, at least 700 seeds per species.	Seed germination phenology	Heat waves resulted in a significant increase of spring germination in 30% of the species and elicited autumn germination in 50%. When heat waves were combined with drought, seed germination decreased in all species. In the future, heat waves will affect the germination phenology of alpine plants, by shifting the emergence time from spring to autumn and by increasing the proportion of emerged seedlings.	Orsenigo et al. 2015
A	*Sphagnum capillifolium*	W, N	*Sphagnum* samples collected from 1 site. Growth chamber; nighttime warming and nutrient supply of N and P.	Net photosynthesis, leaf N, growth.	N and P appeared to limit growth in *Sphagnum capillifolium* at optimal temperature. Climate warming is expected to increase growth rates of *Sphagnum* but the consequence on the ecosystem carbon balance cannot be predicted.	Gerdol et al. 1998
T	*Fagus sylvatica*	D	Controlled environment chambers. 42 seedlings per treatment.	Net photosynthesis; leaf conductance	Water stress on *Fagus sylvatica* seedlings caused significant declines in net photosynthesis and leaf conductance in shade-grown and control individuals.	Tognetti et al. 1994
T	*Pinus sylvestris*	D	Seedlings from 10 provenances; greenhouse	Seedlings and buds development; shoot and root lenght	Provenances differed in all measured growth traits (but not in root traits). Central and East Europe provenances are more sensitive to drought with respect to south and west Europe provenances.	Taeger et al. 2013
T, S	*Fagus sylvatica*	D	Controlled environment chambers. 60 seedlings from two origins (xeric and mesic sites)	Xylem water potential, leaf relative water content, net photosynthesis, chlorophyll content	With the onset of water stress, values of water potential, leaf relative water content, net photosynthesis and leaf chlorophyll concentration decreased. The *Fagus sylvatica* seedling population from Sicily (xeric site) showed a delay in effects of imposed drought with respect to the population from Tuscany (mesic site). Total, shoot, stem and root dry weight tended to be higher in seedlings from Tuscany even though both populations had similar photosynthetic rates.	Tognetti et al. 1995

Climatic zone	Species/System	Treatment	Methods	Response variables	Results	Literature
T, S	*Arrhenatherum elatius, Festuca pratensis, Holcus lanatus*	D, W	Fixed rain-out shelters. Seeds collected in different countries (for Italy: 3 sites)	Biomass; tissue die-back	Ecotypes and drought manipulation had significant impacts on biomass production and tissue die-back. The warming treatment yielded a less significant response. The northern ecotypes generally did not perform significantly worse than the presumably better-adapted southern ecotypes.	Beierkuhnlein et al. 2011
S	*Quercus pubescens*	D, W	Fixed rain-out shelters; Infrared lamps. Seeds collected in different countries (for Italy: 1 site)	Survival, Growth traits, leaf palatability	In *Quercus pubescens* saplings: provenance difference in survival and maintainance of the apex under extreme drought. Bud bank characteristics showed no general differences among provenances but responded to warming manipulations. In Italian individuals, warming caused an increase of the apical budbank. Drought and warming did not affect the palatability of leaves.	Wellstein & Cianfaglione 2014; Backhaus et al. 2014
S	*Quercus pubescens*	D, W	Open-top chambers with retractable roofs. Seeds collected from 5-10 mature trees in several stands (only 1 in Italy).	Shoot height, stem diameter, root length; whole-tree leaf area; response of N metabolites	In *Quercus pubescens* saplings: shoot height growth reduced by drought and stimulated by air warming; stem diameter growth reduced by drought and to a much lesser extent by air warming; root length growth slightly reduced by air warming but unresponsive to drought. Evidence of provenance specific growth responses of oak saplings to drought and air warming.	Arend et al. 2011; Hu et al. 2013
S	*Alnus cordata*	D	Controlled environment pots. 2-years-old seedlings from 5 Italian provenances.	Leaf area; transpiration, stomatal conductance; xylem water potential	*Alnus cordata* seedlings under drought treatment showed a reduction in the xylem water potential, stomatal conductance, transpiration and net photosynthesis. Recovery of physiological parameters after rewatering. Different responses to drought according to the provenance.	Borghetti et al. 1989
S	*Pinus nigra*	D, W	Juveniles from different provenances (2 Italian sites) exposed to different conditions.	Cold hardiness of foliage; height, shoot quantity, needle phenology	Simulated summer drought and warming can surprisingly increase cold hardiness, with the sub-Mediterranean provenances exhibiting the highest cold hardiness increase. Provenances differed in absolute growth and survival rates, but not in terms of shoot quantity and, surprisingly, sensitivity to drought and warming.	Kreyling et al. 2012; Thiel et al. 2012
S	*Fagus sylvatica*	F	Climate chambers; young plants (9-years-old) from 16 provenances (9 Italian sites, 4 in central and 5 in southern Italy).	Resistance to frost; phenology (time of buds opening)	Provenances from South Italy have proven to be the most sensitive to frost. There was a difference in opening of buds between beech provenances from southern Italy and those from Central Europe in the amount of seven days.	Višnjić & Dohrenbusch 2004

Climatic zone	Species/System	Treatment	Methods	Response variables	Results	Literature
S	*Pinus halepensis*	D	Six-month-old seedlings from 2 provenances exposed to drought.	Water potential, net photosynthesis and stomatal conductance	Water potential, net photosynthesis and stomatal conductance decreased during drought in both provenances (Italy and Greece). Upon rewatering, photosynthesis did not fully recover in Italian seedlings, while all other parameters recovered to control levels in both provenances.	Michelozzi et al. 2011
S	Sub-Mediterranean montane grasslands	D, R	Fixed rain-out shelters. 2 grasslands (mesic and xeric). 5 plots (1 m x 1 m) for each treatment.	ANPP	The response of ANPP to rainfall manipulation is influenced by early season precipitation. A significant increase of the ANPP due to experimental increase in summer rainfall appeared in the year with wet spring, but only in the mesic north-facing slope. This response was driven by the increased productivity of perennial forbs.	Chelli et al. 2016
S, M	*Pinus halepensis* and *Pinus laricio* plantations	D	Transparent polyethylene sheet above the soil. 2 even-aged stands: 1 with *P. halepensis* (6 plots, 170 mq each); 1 with *P. laricio* (6 plots, 10 mq each.	Physiological parameters; tree growth; water relations	Needle and shoot elongation and stem radial growth were considerably reduced in droughted trees. In *Pinus halepensis*: decrease of predawn water potential; transpiration strongly reduced by stomatal closure. In *Pinus laricio* drought did not result in tree mortality or foliage dieback; stand transpiration was strongly reduced by drought treatment over the summer, but not during winter.	Borghetti et al. 1998, 2005; Cinnirella et al. 2002
M	Mediterranean shrubland	D, W	Moveable rain-out shelters. 6 sites (1 in Italy). 3 replicates (plots of 20 mq) per treatment.	Species cover, ANPP, litterfall, shoots growth, phenology, leaf functioning, soil CO2 emission	Reduction of cover, shoot elongation and ANPP for *Cistus monspeliensis* after drought treatment; increase in leaf N and P concentrations in the drought treatment in *Cistus monspeliensis* as well as an anticipated decrease in stomatal conductance with respect to the control have been registered. Drought also caused anticipated leaf shedding. No relevant effects of warming. The annual CO2 emissions were not significantly affected by the treatments	De Dato et al. 2006; Peñuelas et al. 2007; Estiarte et al. 2008; Prieto et al. 2009; De Dato et al. 2010; De Dato et al. 2013; Kroel-Dulay et al. 2015.
M	Mediterranean woodland	D, R	Partial rain exclusion using suspended pipes; periodic summer irrigation. 2 plots (8 m x 12 m) replicated three times according to treatments.	Growth; LAI; gas exchange; leaf pigment content; leaf litter	Longlasting effect caused by drought: down-regulation of stomatal conductance and photosynthesis, accumulation of photo-protective pigments, reduction in shoot growth, leaf area index and increase in shoot-bearing flowers. Enhanced soil moisture during summer months highly stimulated annual stem primary production, litter fall, soil respiration and net annual plant-derived C input to soil.	Ripullone et al. 2009; Cotrufo et al. 2011

Climatic zone	Species/System	Treatment	Methods	Response variables	Results	Literature
M	*Pinus halepensis*	D	Controlled environment chambers. 2-years-old seedlings from 6 Italian provenances.	Leaf conductance, hydraulic conductance, tissue water potential and xylem embolism	Drought-stressed *Pinus halepensis* seedlings had lower mean leaf conductance, transpiration rates and hydraulic conductance than well-watered seedlings. Drought-stressed seedlings of provenances from more xeric habitats had greater leaf conductance, transpiration rates and hydraulic conductances than drought-stressed seedlings of provenances from more mesic habitats. Seedlings from xeric provenances have greater resistance to desiccation.	Tognetti et al. 1997
M	*Quercus ilex*	D, W	Sowing of acorns (from 3 different Italian sites) in a botanical garden. Dessiccation experiment on seedlings.	Shoot elongation; leaf growth, morphology and anatomy; leaf water status; gas exchange; phenotypic plasticity	Morphological and anatomical leaf traits differed between the provenances with higher leaf mass area, total leaf thickness in the driest provenance giving to the seedlings a higher water use efficiency, relative water content at predawn and photosynthetic rates than the other provenances in warm air temperature conditions. The smaller leaf area of the seedlings from the northernmost limit of *Q. Ilex* in Italy seemed to have a higher photosynthetic capacity in cold air temperature conditions than the others.	Gratani et al. 2003; Pesoli et al. 2003
M	*Pinus halepensis*	D, W	Seeds from 5 provenances (1 in Italy) sowed in experimental plots with different ambient climatic conditions.	Eco-physiological parameters representing tree physiology, hydraulics, phenology, photosynthesis	Differential responses to variations in ambient climatic conditions were observed in three key traits: (i) growing season length decreased with drying in all provenances; (ii) water use efficiency increased with drying, but to a different extent in different provenances; (iii) xylem native embolism was stable across climates, but varied markedly among different provenances.	Klein et al. 2013
M	*Tamarix africana*	R	Six genotypes collected in southern Italy. Growth chambers with 3 irrigation treatments (control, flooding with fresh water, flooding with salty water).	Stomatal conductance, xylem anatomy.	Fresh-water level reduction negatively affected stomatal conductance. Furthermore decreases in mean xylem vessel area, assimilation rates and stomatal conductance were also observed compared to the control, indicating both an osmotic stress and a toxic effect of NaCl on leaf gas exchange. Water level variation under both saline and non saline conditions could affect the survival of *Tamarix* spp.	Abou Jaoudè et al. 2012

Table S3. List of observational research projects with indications of climatic zone (A: alpine; T: temperate; S: sub-Mediterranean; M: Mediterranean), species or system, gradients (D: drought; W: warming; R: water addition; N: increase in soil nutrient; S: snow cover; F: frost; M: management regimes; I: species interactions), methods, measurements and main results.

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
A	From the treeline to Alpine/Sub-nival vegetation	W	"Gloria" protocol. Re-sampling after 5 and 7 years on 3 target regions, 4 summits each.	Species richness, species frequency on 1 m^2 plots around the summit	Increased species richness on all four summits, with the greatest gains recorded on the two highest summits. Species' frequencies were also increased. A thermophilization trend was demonstrated. Upward migration of the forest boundary. Species that disappeared from the four summits are from different altitudinal ranges; however, nival and subnivalalpine species remained. One endemic species disappeared from the highest summit.	Erschbamer et al. 2009, 2011; Gottfried et al. 2012; Pauli et al. 2012
A	Alpine vegetation of the central Apennines	W	"Gloria" protocol. Sampling on 4 summits and 1 glacial circle	Species richness and abundance	70% of species do not reach the highest summit and only 11% of the overall flora is shared by all of the summits examined. Floristic-quantitative and climatic analyses highlight a great species richness and vegetation cover in eastward aspects. The East-facing slopes will be the first to be affected by the coming of subalpine species from below, whereas northward exposures will be the most conservative.	Stanisci et al. 2005; Gottfried et al. 2012; Pauli et al. 2012
A	Alpine vegetation of SW Alps and central Apennines	W	Gloria protocol, re-visitation after 10 years. A total of 7 summits and 112 permanent plots.	Species richness and vegetation structure	Moderate decrease in regional endemic flora. Expansion of graminoids and small woody plants, more suitable to face climate warming in Italian summits. Expansion of thermophilic species.	Stanisci et al. 2016
A	Alpine vegetation of the central Apennines	W, N	Revisitation after 42 years (1972-2014). Phytosociological relevés.	Species richness and abundance; functional groups.	Over the last 42 years, clear floristic changes and significant ecological and structural variations occurred. A significant increase in thermophilic and mesonitrophilic plant species has been observed, as well as an increment in the frequencies of hemicryptophytes.	Evangelista et al. 2016
A	Alpine to nival vegetation	W	Comparison of historical records (1954–1958) with results from recent surveys (2003–2005).	Presence of all vascular plant species and their maximum altitude	Increased species richness. For 52 species, median migration rate of 23,9m per decade. Species with more pronounced altitudinal shifts possess lighter diaspores. The strongest increase in species richness was found between 2800m and 3100m in relation to an estimated shift of the permafrost limit by +240 m during the last 50 years.	Parolo & Rossi 2008

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
A	Alpine vegetation	W	Comparison of 30 (not all in Italy, info not available) old records (1895 to 1953) with new samplings (1992-1993).	Species richness and abundance	Increased species richness for 21 summits (70%); stagnation or light decrease in 9 summits (30%). Confirmation of upward species migration. Migration strongly depends on morphology (high rates at summits with little erosion and solid, structured ridges) and partially on the presence of migration corridors.	Pauli et al. 1996
A	Alpine to nival vegetation	W	Comparison of an old (1953) phytosociological map with new surveys (2003)	Species richness, vegetation cover and upward migration	The snow depth recorded decreased and the length of the snow season shortened as well. Climate warming induced permafrost degradation. The vegetation changes between 1953 and 2003 showed a general pattern of increase in coverage and species richness. Upward displacement of shrublands to 2500 m, while the widespread persistent species showed a surprising downward shift. Regression of wetland vegetation.	Cannone et al. 2007; Cannone & Pignatti 2014
A	Snow-beds	S	21 stands according to extremes of the snowmelt gradient (9 in late snow-free stands; 12 in early snow-free stands)	Vascular species richness, vascular species and bryophytes frequency, Net Primary production	An historical average difference of 2.4 weeks in the release from snow cover did not affect either density or production of the dominant species. In contrast, vascular species richness was limited by length of growing season, and some vascular species showed differences in density and NPP between late and early snow-free stands. Total NPP of vascular species was markedly higher in the early snow-free stands. In this extreme habitat, species richness, density and production were very responsive to variation in the snow cover period.	Carbognani et al. 2012
A	Alpine species	W, S	Ten and five years datasets respectively for Abeli et al. (2012a) and Abeli et al. (2012b). Selection of six plants of conservation interest (4 species in Abeli et al. 2012a; 2 species in Abeli et al. 2012b)	N. of flowering stems and n. of inflorescences per flowering stem. Biomass only for 2 species.	Inflorescence production of all the studied species (*Carex foetida, Leucanthemopsis alpina, Senecio incanus, Silene suecica, Alopecurus alpinus, Vicia cusnae*) was significantly affected by variation in the mean temperature of June/July. In particular, *Alopecurus alpinus* and *Vicia cusnae* were significantly affected by the heat wave of 2003 However, species response to temperature was contrasting: some being negatively and others being positively affected. The response of inflorescence production to snow cover duration was not consistent across species. Vegetative growth of *Alopecurus alpinus* and *Vicia cusnae* was not affected by warming.	Abeli et al. 2012a; Abeli et al. 2012b

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
A	Alpine bog	D, W	Transects in 20 bogs after the heat wave of 2003	Sphagnum survival in the following year	Increased mortality of peat mosses forming high hummocks. At habitat scale, the distribution of desiccated peat mosses was restricted to the hummock face receiving the greatest amount of solar irradiation. At regional scale, the study identified a climatic threshold: when mean monthly P: T dropped below 6.5 (mm: °C) during May–September 2003, there was an irreversible desiccation of peat mosses. Absence of any sign of recovery after 4 years.	Bragazza 2008
A	Alpine bog	W	Natural heat wave (2003) during a fertilization experiment	Species presence and cover; Net ecosystem CO2 exchange; Growth and decomposition rate	Complex patterns of short- and mid-term changes in the relative cover of vascular species and mosses in relation to the heat wave and the fertilization. Net ecosystem CO2 exchange unaffected by fertilization but strongly influenced by the heat wave and water table depth.	Brancaleoni & Gerdol 2014; Gerdol et al. 2008a; Gerdol et al. 2007
A	Snow-beds	W	Re-survey of 11 plots after 6 years.	Richness, co-occurrence, composition, and abundance	Increase in vascular species richness and abundance. Shifting of species co-occurrence toward higher species segregation. Change in the proportion of snowbed and non-snowbed plants. All the changes demonstrated that the community was not in a stable equilibrium with the current climate.	Carbognani et al. 2014 b
A	*Pinus mugo* in the sub-Alpine belt	W, D	2 sites, 3 study areas per site along an altitudinal gradient	Ring widths	*Pinus mugo* growth is affected by spring temperature and summer precipitation. Essentially three months played a key role in Pinus mugo growth: April, May (beginning of the growing season) and October (end of the growing season).	Palombo et al. 2014
A	Alpine bog	D, R	10 year-study on 50 plots	Plant cover	Complex population dynamics at the micro-habitat scale. Population dynamics of bryophytes appeared primarily affected by precipitation, which can temporarily alter competitive equilibria among species. Vascular plants were also affected by moisture conditions, but in this case, a major role was played by the autogenic growth of the mire surface through peat accumulation. Long-term field investigations are claimed.	Bragazza 2006
A	Glacier foreland	W	Chronosequence of successional categories	CSR strategy for 45 species	Functional shift from broadly ruderal pioneers towards stress-tolerants in late succession. Till deposited at the retreating glacier terminus provides a substrate that can support faster growing species (with high foliar N contents), but is only tenable to those that can avoid physical disturbance via rapid phenological development (i.e. ruderals). Stress-tolerance and lower N contents in late succession suggest selection for efficient nutrient use.	Caccianiga et al. 2006

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
A	Glacier foreland	W	23 sampling plots	Glacier monitoring and species cover	Vegetation started to colonize surfaces deglaciated for only one year, with a rate at least four times greater than that reported in the literature. The first colonizers are early-successional, scree slopes, and perennial clonal species with high phenotypic plasticity rather than pioneer and snowbed species. Such impressive acceleration coincided with only slight local summer warning (approximately +0.5°C) and a poorly documented local decrease in the snow cover depth and duration.	Cannone et al. 2008
A	Glacier foreland	W	160 years old soil due to the quick glacier melting in the last 80 years	Rhizobacterial communities of 12 plant species	In a successional chronosequence resulting from a continuous glacier retreat pioneer vegetation which colonize early transitional successional stages, select species-specific rhizosphere microbial communities able to promote plant growth in these oligotrophic conditions.	Ciccazzo et al. 2014, 2016
T	*Fagus sylvatica*	D, F	Selection of dominant and co-dominant trees in 2 sites	Basal area increment	For the two sites considered, average annual BAI variability was mostly related to drought stress during the current summer at the lower elevation site, while May temperature (late frosts) was a more important signal at the higher elevation site. The main climatic signal in common between the two sites was linked to drought during the growing season in the year before wood formation	Piovesan et al. 2008
T	Sub-alpine forest	W, M	Altitudinal gradient along 2 slopes	Structural sampling (DBH, Height), increment cores, basal area.	Growth rates of mature *Pinus cembra* and *Larix decidua* increased. Widespread rise in forest- and tree lines. However it was difficult to infer cause/effect relationships from this site: the simultaneous occurrence of grazing reduction and the beginning of the climatic warming during the late 1800s complicated the interpretation of changes.	Motta & Nola 2001
T	*Larix decidua, Picea abies, Pinus cembra*	W, D	2 trees per species; weekly measurements from May to October.	Xylem water potential and transpiration.	Regardless of species, a very high stomatal sensitivity to vapour pressure deficit was recorded. *L. decidua* maintained relatively high transpiration rates even during moderate water deficit periods due to its water uptake capacity and deep root system, while *P. abies* and *P. cembra* showed a water saving behaviour. Climate change could favour *L. decidua.*	Anfodillo et al. 1998
T	*Fagus sylvatica*	D	CONECOFOR network. Sampling on five trees per stand	Leaf morphology and chemistry	Foliar responses to stress factors in 2 southern stands and 2 northern stands. In southern Italy, climate and stand-related factors exerted the greatest influence on leaf morphology and chemistry of beech trees, whereas in northern Italy, ozone pollution and nitrogen deposition played a greater role.	Bussotti et al. 2005
T	*Pinus nigra*	W, M	More than 600 trees mapped above the treeline in 4 sites	Structural parameters and tree-ring widths	The pine encroachment process appears synchronic and spatially diffused. Consistent tree-growth dynamics and the species adaptation to a warming climate are signals envisaging a possible treeline upward shift. Also the reduced livestock grazing over the last decades seemed to play a role.	Piermattei et al. 2012, 2014

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
T	Sub-alpine plantation	W, D	5 conifer species in 2 contrasting sites	Basal area increment, isotopic analysis, water use efficiency	Water use efficiency increased over the last 50yrs. Regardless of species, radial growth decreased under xeric conditions and was stable under mesic conditions. The temperature-induced drought stress has overridden the potential CO2 'fertilization' on tree growth. European larch and Norway spruce, growing close to their dry distribution limit at the xeric site, were found to be the most vulnerable species to soil water deficits: if summer become drier, tree growth may collapse likely inducing dieback and compromising the provision of ecosystem services.	Levesque et al. 2013, 2014
T, S	*Abies alba*	D	10 dominant or co-dominant trees per site	Basal area increment	Populations of Abies alba located outside the Mediterranean area (e.g. northern Italy) have shown a increase in growth over the last two decades, whereas most populations in southern Italy have displayed a marked decline in growth since the 1980s. The reduction in growth of many populations in southern Italy is related to an observed increase in aridity, whereas in more temperate areas warming is enhancing growth.	Gazol et al. 2015
T, S	*Abies alba, Fagus sylvatica*	D, R	Selection of 65 trees (33 for *F. sylvatica* and 32 for *A. alba*) in two study sites	Radial growth	Differential climate–growth responses according to species and site. Growth patterns were highly responsive to summer water stress or to climatic condition of the previous growing season. Summer precipitation allevatied drought stress. Changes in rainfall patterns could have significant impact on growth and species composition likely favoring more drought tolerant species (i.e. *Quercus* spp.)	Rita et al. 2014
S	Conifer plantations	D, W	Selection of dominant trees	Growth addressed by analysing tree-ring width and carbon and oxygen stable isotopes.	Significant differences in ecophysiological responses to climate variations between the native *A. alba* and the non native *P. abies*. *A. alba* was found to be more sensitive to changes in temperature and precipitation than *P. abies*. Early-spring precipitation was a major factor influencing the annual growth of *A. alba*, which although native, proved to be sensitive to drought. *P. abies*, on the other hand, showed a higher tolerance to summer drought stress.	Battipaglia et al. 2009
S	Mixed *Quercus* forest	D, I	One pure plot *Q. cerris*, one of *Q. petraea* and one mixed plot	Measurement of sap flux density and leaf carbon isotope composition, as a proxy for intrinsic water use efficiency	*Q. petraea* transpiration response to drought did not differ between pure and mixed plots. In contrast, *Q.cerris* transpiration was reduced mainly in mixed plots at the maximum of the drought. Higher intrinsic water use efficiency was observed for *Q. cerris* in the mixed plot supporting the higher water stress intensity in such plot for *Q. cerris*. Negative impact of *Q. petraea* on *Q. cerris* when these species compete for water resources.	Grossiord et al. 2014
S	*Quercus petraea*	D	Selection of 100 mature trees in 5 stands	Leaf morphology	Lower trait plasticity occur in the southermost stand (also the southermost part of the biogeographic range for the species) suggesting a) an effect of a genetic drift force and b) adaptation to drier stable conditions.	Bruschi et al. 2003a; Bruschi et al. 2003b

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
S	*Sesleria nitida, Lotus corniculatus, Astragalus sempervirens, Thymus longicaulis*	D, W	2 contrasting habitats (mesic vs xeric condition)	Whole plant, leaf, clonal and seed traits	Significant intraspecific differences in trait attributes between contrasting habitats indicate phenotypic adaptation to in situ environmental conditions. All the considered traits showed intermediate to high degree of intraspecific variability. Considering the differences in water availability and soil temperature (8 °C) between the habitats, the authors suggest that these species can be pre-adapted to the overall expected environmental changes.	Wellstein et al. 2013
S	Sub-Mediterranean grasslands	D, W	29 sites, 10 m x 10 m plots. Space-for-time substitution	Species abundance; whole plant, leaf, clonal, seed traits	From productive to harsh conditions, there was a shift from tolerance to avoidance strategies. The increase of temperature and water scarcity leads to the establishment of regeneration strategies that enable plants to cope with the unpredictability of changes in stress intensity and duration. Climate change will likely lead to a variation in dominance inside plant communities rather than a shift upwards of species ranges.	Tardella et al. 2016
M	*Quercus ilex*	D	2 forest stands in contrasting environmental conditions (mesic vs xeric)	Water potential and morpho-anatomical parameters	The annual trend of leaf water potential was strongly influenced by season and site. Leaves reached their definitive shape before the most severe drought, so that sclerophylly is not determined by summer conditions. Sclerophyllic leaves were able to maintain their internal moisture status also in the worst drought conditions. Surprisingly, starch reserves in twigs were lower at the mesic site, where greater photosynthetic activity is expected. Maybe, in such conditions, starch was utilized for growth, whereas in xeric conditions, its role was to provide osmolytes to cope with stress conditions.	Bussotti et al. 2002
M	*Pinus pinea*	W, D	Dominant and co-dominant trees. 2 cores per tree	Ring widths	The second half of the century was characterized by lower growth rates when compared with past growths, mainly due to the decrease in precipitation. Strong correlation between growth and winter precipitation. The influence of increasing temperature is not clear, but in dry years it may contribute to growth limitations.	Mazza & Manetti 2013
M	Mediterranean nitrofilous and ruderal alien species	W	Space-time dynamics of 7 species	Distribution areas	For all the species, rapid increases in the population numbers have been observed, along with a northward shift of their distribution areas. These changes correspond to the increase in average annual temperature.	Biondi et al. 2012
M	Coastal dunes and forests	W, D	21 sample sites	Vegetation and microclimatic monitoring	General tendency of all forest types to shift towards xerophile conditions. The woodland with major risk is the *Lauro-Carpinetum* which loses 18% of air humidity in a very short period (5 years). Dune vegetation showed homeostatic capacity in relationship with structural complexity increasing from pioneer communities.	Guidotti et al. 2010

Climatic zone	Species/System	Gradient	Methods	Response variables	Results	Literature
M	Coastal dunes	W	Phytosociological releves conducted in 1989-90 and 2010-12 in 6 Natura 2000 sites	Plant cover and proportion of functional groups	Only fore dune habitats showed significant differences in species cover between the two time periods, with higher plant cover in the more recent relevés and a significant increase in thermophilic species, probably caused by moderate increment in average yearly temperature.	Del Vecchio et al. 2015

LITERATURE CITED

Abeli T, Rossi G, Gentili R, Mondoni A, Cristofanelli P (2012a) Response of alpine plant flower production to temperature and snow cover fluctuation at the species range boundary. Plant Ecol 213:1–13

Abeli T, Rossi G, Gentili R, Gandini M, Mondoni A, Cristofanelli P (2012b) Effect of the extreme summer heat waves on isolated populations of two orophitic plants in the north Apennines (Italy). Nord J Bot 30:109–115

Abou Jaoudè R, De Dato G, De Angelis P (2012) Photosynthetic and wood anatomical responses of *Tamarix africana* Poiret to water level reduction after short-term fresh- and saline-water flooding. Ecol Res 27:857–866

Anfodillo T, Rento S, Carraro V, Furlanetto L, Urbinati C, Carrer M (1998) Tree water relations and climatic variations at the alpine timberline: seasonal changes of sap flux and xylem water potential in *Larix decidua* Miller, *Picea abies* (L.) Karst. and *Pinus cembra* L. Ann Sci For 55:159–172

Arend M, Kuster T, Gunthardt-Goerg MS, Dobbertin M (2011) Provenance-specific growth responses to drought and air warming in three European oak species (*Quercus robur, Q. petraea* and *Q. pubescens*). Tree Physiol 31:287–297

Backhaus S, Wiehl D, Beierkuhnlein C, Jentsch A, Wellstein C (2014) Warming and drought do not influence the palatability of *Quercus pubescens* Willd. leaves of four European provenances. Arthropod-Plant Interact 8:329–337

Battipaglia G, Saurer M, Cherubini P, Siegwolf RTW, Cotrufo MF (2009) Tree rings indicate different drought resistance of a native (*Abies alba* Mill.) and a nonnative (*Picea abies* (L.) Karst.) species co-occurring at a dry site in Southern Italy. For Ecol Manage 257:820–828

Beierkuhnlein C, Thiel D, Jentsch A, Willner E, Kreyling J (2011) Ecotypes of European grass species respond differently to warming and extreme drought. J Ecol 99:703–713

Bernareggi G, Carbognani M, Petraglia A, Mondoni A (2015) Climate warming could increase seed longevity of alpine snowbed plants. Alp Bot 125:69–78

Bernareggi G, Carbognani M, Mondoni A, Petraglia A (2016) Seed dormancy and germination changes of snowbed species under climate warming: the role of pre- and post-dispersal temperatures. Ann Bot (Lond) 118:529–539

Biondi E, Casavecchia S, Pesaresi S (2012) Nitrophilous and ruderal species as indicators of climate change. Case study from the Italian Adriatic coast. Plant Biosyst 146:134–142

Borghetti M, Cocco S, Lambardi M, Raddi S (1989) Response to water stress of Italian alder seedlings from diverse geographic origins. Can J For Res 19:1071–1076

Borghetti M, Cinnirella S, Magnani F, Saracino A (1998) Impact of long-term drought on xylem embolism and growth in *Pinus halepensis* Mill. Trees (Berl) 12:187–195

Borghetti M, Cinnirella S, Magnani F, Saracino A (2005) Effetti di carenze idriche prolungate su pinete mediterranee: insegnamenti da due esperimenti in Italia meridionale. Forest 2:31–36

Bragazza L (2006) A decade of plant species changes on a mire in the Italian Alps: vegetation-controlled or climate-driven mechanisms? Clim Change 77:415–429

Bragazza L (2008) A climatic threshold triggers the die-off of peat mosses during an extreme heat wave. Glob Change Biol 14: 2688−2695

Brancaleoni L, Gualmini M, Tomaselli M, Gerdol R (2007) Responses of subalpine dwarf-shrub heath to irrigation and fertilization. J Veg Sci 18:337–344

Brancaleoni L, Gerdol R (2014) Habitat-dependent interactive effects of a heatwave and experimental fertilization on the vegetation of an alpine mire. J Veg Sci 25: 427−438

Bruschi P, Grossoni P, Bussotti F (2003a) Within- and among-tree variation in leaf morphology of *Quercus petraea* (Matt.) Liebl. Natural populations. Trees (Berl) 17:164–172

Bruschi P, Vendramin GG, Bussotti F, Grossoni P (2003b) Morphological and molecular diversity among italian populations of *Quercus petraea* (Fagaceae). Ann Bot (Lond) 91:707–716

Bussotti F, Bettini D, Grossoni P, Mansuino S, Nibbi R, Soda C, Tani C (2002) Structural and functional traits of *Quercus ilex* in response to water availability. Environ Exp Bot 47:11–23

Bussotti F, Pancrazi M, Matteucci G, Gerosa G (2005) Leaf morphology and chemistry in *Fagus sylvatica* (beech) trees as affected by site factors and ozone: results from CONECOFOR permanent monitoring plots in Italy. Tree Physiol 25:211–219

Caccianiga M, Luzzaro A, Pierce S, Ceriani RM, Cerabolini B (2006) The functional basis of a primary succession resolved by CSR classification. Oikos 112:10–20

Cannone N, Pignatti S (2014) Ecological responses of plant species and communities to climate warming: upward shift or range filling processes? Clim Change 123:201–214

Cannone N, Sgorbati S, Guglielmin M (2007) Unexpected impacts of climate change on alpine vegetation. Front Ecol Environ 5:360–364

Cannone N, Diolaiuti G, Guglielmin M, Smiraglia C (2008) Accelerating climate change impacts on alpine glacier forefield ecosystems in the European Alps. Ecol Appl 18:637–648

Carbognani M, Petraglia A, Tomaselli M (2012) Influence of snowmelt time on species richness, density and production in a late snowbed community. Acta Oecol 43:113–120

Carbognani M, Petraglia A, Tomaselli M (2014a) Warming effects and plant trait control on the early-decomposition in alpine snowbeds. Plant Soil 376:277–290

Carbognani M, Bernareggi G, Perucco F, Tomaselli M, Petraglia A (2016) Micro-climatic controls and warming effects on flowering time in alpine snowbeds. Oecologia 182:573–585

Chelli S, Canullo R, Campetella G, Schmitt AO, Bartha S, Cervellini M, Wellstein C (2016) The response of sub-Mediterranean grasslands to rainfall variation is influenced by early season precipitation. Appl Veg Sci 19:611–619

Ciccazzo S, Esposito A, Rolli E, Zerbe S, Daffonchio D, Brusetti L (2014) Different pioneer plant species select specific rhizosphere bacterial communities in a high mountain environment. Springerplus 3:391

Ciccazzo S, Esposito A, Borruso L, Brusetti L (2016) Microbial communities and primary succession in high altitude mountain environments. Ann Microbiol 66:43–60

Cinnirella S, Magnani F, Saracino A, Borghetti M (2002) Response of a mature *Pinus laricio* plantation to a three-year restriction of water supply: structural and functional acclimatation to drought. Tree Physiol 22:21–30

Cotrufo MF, Alberti G, Inglima I, Marjanovic H and others (2011) Decreased summer drought affects plant productivity and soil carbon dynamics in a Mediterranean woodland. Biogeosciences 8:2729–2739

De Dato G, Pellizzaro G, Cesaraccio C, Sirca C and others (2006) Effects of warmer and drier climate conditions on plant composition and biomass production in a Mediterranean shrubland community. Forest 3:511–526

De Dato G, De Angelis P, Sirca C, Beier C (2010) Impact of drought and increasing temperatures on soil CO2 emissions in a Mediterranean shrubland (gariga). Plant Soil 327:153–166

De Dato G, Micali M, Abou Jaoudè R, Liberati D, De Angelis P (2013) Earlier summer drought affects leaf functioning of the Mediterranean species Cistus monspeliensis L. Environ Exp Bot 93:13–19

Del Vecchio S, Prisco I, Acosta ATR, Stanisci A (2015) Changes in plant species composition of coastal dune habitats over a 20-year period. AoB Plants 7:plv018

Erschbamer B, Kiebacher T, Mallaun M, Unterluggauer P (2009) Short-term signals of climate change along an altitudinal gradient in the South Alps. Plant Ecol 202:79–89

Erschbamer B, Unterluggauer P, Winkler E, Mallaun M (2011) Changes in plant species diversity revealed by long-term monitoring on mountain summits in the Dolomites (northern Italy). Preslia 83:387–401

Estiarte M, Peñuelas J, Sardans J, Emmett BA, and others (2008) Root-surface phosphatase activity in shrublands across a European gradient: Effects of warming. J Environ Biol 29:25–29

Evangelista A, Frate L, Carranza ML, Attorre F, Pelino G, Stanisci A (2016) Changes in composition, ecology and structure of highmountain vegetation: a re-visitation study over 42 years. AoB Plants 8:plw004

Gazol A, Camarero JJ, Gutierrez E, Popa I, and others (2015) Distinct effects of climate warming on populations of silver fir (*Abies alba*) across Europe. J Biogeogr 42:1150–1162

Gerdol R, Bonora A, Marchesini R, Gualandri R, Pancaldi S (1998) Growth response of *Sphagnum capillifolium* to nighttime temperature and nutrient level: mechanisms and implications for global change. Arct Alp Res 30:388–395

Gerdol R, Petraglia A, Bragazza L, Iacumin P, Brancaleoni L (2007) Nitrogen deposition interacts with climate in affecting production and decomposition rates in Sphagnum mosses. Glob Change Biol 13: 1810−1821

Gerdol R, Bragazza L, Brancaleoni L (2008a) Heatwave 2003: high summer temperature, rather than experimental fertilization, affects vegetation and CO2 exchange in an alpine bog. New Phytol 179: 142−154

Gerdol R, Siffi C, Iaucumin P, Gualmini M, Tomaselli M (2013) Advanced snowmelt affects vegetative growth and sexual reproduction of *Vaccinium myrtillus* in a sub-alpine heath. J Veg Sci 24:569–579

Gottfried M, Pauli H, Futschik A, Akhalkatsi M, and others (2012) Continent-wide response of mountain vegetation to climate change. Nat Clim Change 2:111–115

Gratani L, Meneghini M, Pesoli P, Crescente MF (2003) Structural and functional plasticity of *Quercus ilex* seedlings of different provenances in Italy. Trees (Berl) 17:515–521

Grossiord C, Gessler A, Granier A, Pollastrini M, Bussotti F, Bonal D (2014) Interspecific competition influences the response of oak transpiration to increasing drought stress in a mixed Mediterranean forest. For Ecol Manage 318:54–61

Guidotti S, Pignatti S, Testi A (2010) Microclimatic responses of plant communities to climatic changes: a study case in the mediterranean coastal vegetation near Rome. Ann Bot (Rome) 9112

Hu B, Simon J, Kuster TM, Arend M, Siegwolf R, Rennenberg H (2013) Nitrogen partitioning in oak leaves depends on species, provenance, climate conditions and soil type. Plant Biol 15:198–209

Klein T, Di Matteo G, Rotenberg E, Cohen S, Yakir D (2013) Differential ecophysiological response of a major Mediterranean pine species across a climatic gradient. Tree Physiol 33:26–36

Kreyling J, Wiesenberg GLB, Thiel D, Wohlfart C and others (2012) Cold hardiness of *Pinus nigra* Arnold as influenced by geographic origin, warming and extreme summer drought. Environ Exp Bot 78:99–108

Kroel-Dulay G, Ransijn J, Kappel Schmidt I, Beier C, and others (2015) Increased sensitivity to climate change in disturbed ecosystems. Nat Commun 6:6682

Levesque M, Saurer M, Siegwolf R, Eilmann B, Brang P, Bugmann H, Rigling A (2013) Drought response of five conifer species under contrasting water availability suggests high vulnerability of Norway spruce and European larch. Glob Change Biol 19:3184–3199

Levesque M, Siegwolf R, Saurer M, Eilmann B, Rigling A (2014) Increased water-use efficiency does not lead to enhanced tree growth under xeric and mesic conditions. New Phytol 203:94–109

Mazza G, Manetti MC (2013) Growth rate and climate responses of *Pinus pinea* L. in Italian coastal sands over the last century. Clim Change 121:713–725

Michelozzi M, Loreto F, Colom R, Rossi F, Calamassi R (2011) Drought responses in Aleppo pine seedlings from two wild provenances with different climatic features. Photosynthetica 49:564–572

Mondoni A, Rossi G, Orsenigo S, Probert RJ (2012) Climate warming could shift the timing of seed germination in alpine plants. Ann Bot (Lond) 110:155–164

Mondoni A, Pedrini S, Bernareggi G, Rossi G and others (2015) Climate warming could increase recruitment success in glacier foreland plants. Ann Bot (Lond) 116:907–916

Motta R, Nola P (2001) Growth trends and dynamics in sub-alpine forest stands in the Varaita Valley (Piedmont, Italy) and their relationships with human activities and global change. J Veg Sci 12:219–230

Orsenigo S, Abeli T, Rossi G, Bonasoni P, Pasquaretta C, Gandini M, Mondoni A (2015) Effects of autumn and spring heat waves on seed germination of high mountain plants. PLOS ONE 10:e0133626. doi:10.1371/journal.pone.0133626

Palombo C, Battipaglia G, Cherubini P, Chirici G and others (2014) Warming-related growth responses at the southern limit distribution of mountain pine (Pinus mugo Turra subsp. mugo). J Veg Sci 25: 571−583

Parolo G, Rossi G (2008) Upward migration of vascular plants following a climate warming trend in the Alps. Basic Appl Ecol 9:100–107

Pauli H, Gottfried M, Grabherr G (1996) Effects of climate change on mountain ecosystems – upward shifting of alpine plants. World Resour Rev 8:382–390

Pauli H, Gottfried M, Dullinger S, Abdaladze O, and others (2012) Recent plant diversity changes on Europe's mountain summits. Science 336:353–355

Peñuelas J, Prieto P, Beier C, Cesaraccio C, and others (2007) Response of plant species richness and primary productivity in shrublands along a north-south gradient in Europe to seven years of experimental warming and drought. Reductions in primary productivity in the heat and drought year of 2003. Glob Change Biol 13:2563–2581

Pesoli P, Gratani L, Larcher W (2003) Responses of *Quercus ilex* from different provenances to experimentally imposed water stress. Biol Plant 46:577–581

Petraglia A, Tomaselli M, Petit Bon M, Delnevo M, Chiari G, Carbognani M (2014) Responses of flowering phenology of snowbed plants to an experimentally imposed extreme advanced snowmelt. Plant Ecol 215:759–768

Piermattei A, Renzaglia F, Urbinati C (2012) Recent expansion of *Pinus nigra* Arn. above the timberline in the central Apennines, Italy. Ann Sci 69:509–517

Piermattei A, Garbarino M, Urbinati C (2014) Structural attributes, tree-ring growth and climate sensitivity of *Pinus nigra* Arn. at high altitude: common patterns of a possible treeline shift in the central Apennines (Italy). Dendrochronologia 32:210–219

Piovesan G, Biondi F, Di Filippo A, Alessandrini A, Maugeri M (2008) Drought-driven growth reduction in old beech (*Fagus sylvatica* L.) forests of the central Apennines, Italy. Glob Change Biol 14:1265–1281

Prieto P, Peñuelas J, Niinemets U, Ogaya R, and others (2009) Changes in the onset of spring growth in shrubland species response to experimental warming along a north-south gradient in Europe. Glob Ecol Biogeogr 18:473–484

Ripullone F, Borghetti M, Raddi S, Vicinelli E and others (2009) Physiological and structural changes in response to altered precipitation regimes in a Mediterranean macchia ecosystem. Trees (Berl) 23:823–834

Rita A, Gentilesca T, Ripullone F, Todaro L, Borghetti M (2014) Differential climate–growth relationships in *Abies alba* Mill. and *Fagus sylvatica* L. in Mediterranean mountain forests. Dendrochronologia 32:220–229

Stanisci A, Pelino G, Blasi C (2005) Vascular plant diversity and climate change in the alpine belt of the central Apennines (Italy). Biodivers Conserv 14: 1301−1318

Stanisci A, Frate L, Morra di Cella U, Pelino G, Petey M, Siniscalco C, Carranza ML (2016) Short-term signals of climate change in Italian summit vegetation: observations at two GLORIA sites. Plant Biosyst 150:227–235

Taeger S, Fussi B, Konnert M, Menzel A (2013) Large-scale genetic structure and drought-induced effects on European Scots pine (*Pinus sylvestris* L.) seedlings. Eur J For Res 132:481–496

Tardella FM, Piermarteri K, Malatesta L, Catorci A (2016) Environmental gradients and grassland trait variation: Insight into the effects of climate change. Acta Oecol 76:47–60

Thiel D, Nagy L, Beierkuhnlein C, Huber G, Jenstch A, Konnert M, Kreyling J (2012) Uniform drought and warming responses in *Pinus nigra* provenances despite specific overall performances. For Ecol Manage 270:200–208

Tognetti R, Michelozzi M, Borghetti M (1994) Response to light of shade-grown beech seedlings subjected to different watering regimes. Tree Physiol 14:751–758

Tognetti R, Johnson JD, Michelozzi M (1995) The response of European beech (*Fagus sylvatica* L.) seedlings from two italian populations to drought and recovery. Trees (Berl) 9:348–354

Tognetti R, Michelozzi M, Giovannelli A (1997) Geographical variation in water relations, hydraulic architecture and terpene composition of Aleppo pine seedlings from Italian provenances. Tree Physiol 17:241–250

Višnjić C, Dohrenbusch A (2004) Frostresistenz und Phänologie europäischer Buchenprovenienzen (*Fagus sylvatica* L.). Allg Forst Jagdztg 175:101–108

Wellstein C, Cianfaglione K (2014) Impact of extreme drought and warming on survival and growth characteristics of different provenances of juvenile *Quercus pubescens* Willd. Folia Geobot 49:31–47

Wellstein C, Chelli S, Campetella G, Bartha S, Galiè M, Spada F, Canullo R (2013) Intraspecific phenotypic variability of plant functional traits in contrasting mountain grasslands habitats. Biodivers Conserv 22:2353–2374