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Beech Forests
Joint Natural Heritage of Europe
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Bioclimatology, growth processes, longevity and structural attributes in an Italian network of old-growth beech forests spreading from the Alps to the Apennines

GIANLUCA PIOVESAN, ALFREDO ALESSANDRINI, FRANCO BIONDI, ALFREDO DI FILIPPO, BARTOLOMEO SCHIRONE and EMANUELE ZIACO

The network of managed and old-growth beech forests in Italy

Beech forests are among the most common forest communities in Italy, from the Alps to the Apennines including Sicily, the southernmost limit for the species, which is absent only in Sardinia (PIGNATTI 1998). Total cover is 1,035,103 ha, of which 428,155 ha are high forests, 477,225 ha coppice stands, and 129,722 ha undefined or not classified (INFC, 2005). Beech forests represent the final stage of montane sub-Atlantic vegetation associated with oceanic conditions, and given its sensitivity to environmental changes and wide diffusion, beech is very suitable for monitoring purposes. During the last 10-20 years different tree-ring networks have been developed in beech forests of the Italian peninsula (BIONDI 1993; BIONDI & VISANI 1996; NOLA 1997; PIOVESAN & SCHIRONE 2000; PIOVESAN et al. 2005b; DI FILIPPO et al. 2007). In 2002 a national network mainly centred on beech was established to describe the bioclimatology of Italian beech (SCHIRONE et al. 2003; PIOVESAN et al. 2005a). Recently this network has been enlarged with support from the Scientific Research Program of National Relevance 2007AZFFAK PRIN project (“Climate change and forests – Dendroecological and ecophysiological responses, productivity and carbon balance on the Italian network of old-growth beech forests”), reaching more than 40 beech stands sampled along a wide latitudinal (from 37° 52’ to 46° 34’ N) and altitudinal (200 – 1850 m a.s.l.) gradient. The aim of the network is to provide dendroecological indicators of natural conditions for Italian beech forests, to understand the main disturbance agents responsible for forest development, to investigate the impacts of climate changes on beech growth and productivity, and finally to comprehend patterns and processes of old-growth beech forests in comparison with managed stands.

Despite the long lasting history of human utilization that modified for millennia the Italian landscape, still nowadays it is possible to find patches of old-growth forests in some remote montane areas both in the Alps and the Apennines (PIOVESAN et al. 2010). An old-growth forest is a forest ecosystem whose structural features are influenced by the presence of old trees and it is characterized by a high degree of naturalness (SPIES 2004). Old-growth structures in temperate deciduous forests can be recognized when mortality of dominant trees in the canopy is no longer driven by density-dependent processes, but start to be linked to natural events (e.g. windthrows, glaze storms), which create gaps for the establishment of new cohorts (DI FILIPPO et al. 2005). Over-exploitation of forest resources has provoked the substitution of former temperate deciduous forests with secondary simplified formations or monospecific stands all around Europe, and only few patches of forest have escaped logging (LIIRA et al. 2007). At present old-growth remnants are forest ecosystems with high ecological value (FRANKLIN & SPIES 1991; FRELICH & REICH 2003) as they represent the most complex plant community in European landscapes. Such stands usually host very old trees, which may reach the maximum potential longevity for the species (PIOVESAN et al. 2005b). Nevertheless the age of single individuals is not sufficient to detect the presence of stands with old-growth features, and this approach may appear too restrictive and overly linked to an anthropocentric vision of nature (FRELICH & REICH 2003). At the same time structural indicators alone (basal area, volume, deadwood amounts) are not able to define the naturalness of a stand, because bio-ecological properties typical of natural forests, such as the presence of large-sized senescent and dying trees or the disturbance regimes that shape the canopy structure and its dynamics, need to be characterized as well (NAGEL et al. 2007). In this respect structural indicators (GOFF & WEST 1975; KEDDY & DRUMMOND 1996; GREENBERG et al. 1997; EMBORG et al. 2000; NILSSON et al. 2002; CHRISTENSEN et al. 2005; DEBELJAK 2006) and dendroecological reconstructions of forest dynamics and age structures (PIOVESAN et al. 2005b; NAGEL et al. 2007; FIRM et al. 2009; FRAVER et al. 2009) might be merged to investigate features and processes typical of primeval stands that are not adequately represented in managed forests (GILG 2004) but substantially contribute to define the “old-growthness” of a stand (SPIES & FRANKLIN 1988).

Several different reasons led to the conservation of old-growth forest stands in the Italian landscape, and, the following types defined by FRELICH (2002) are found:
a) **primary old-growth forests**; these are either forests that escaped logging mainly because of site inaccessibility or small stands growing in marginal stations (e.g. remote valleys, steep slopes) within broader forested areas. This is the case of the old-growth forest of Valle Cervara and of other high-mountain forest remnants in the Abruzzi region and elsewhere throughout the Italian peninsula. Structures and dynamics of primary old-growth forests are influenced exclusively by natural processes, while human impacts are essentially absent, as testified by bibliographic and paleoecological records;

b) **secondary old-growth forests**; these are stands that escaped logging for different reasons. In the Alps they were mostly preserved to ensure protection of villages from landslides or avalanches (DI FILIPPO et al. 2007). Cattle grazing and deadwood harvesting were common in these forests, called “boschi banditi”, which presently include a number of old, large trees, especially in Central Italy (e.g. the beechwood of Sant' Antonio in the Majella National Park). In some cases old practices, such as tree pruning to obtain fodder for livestock or for fuel wood, still influence the shape of several individuals, testifying the past human impact on pollard trees, whose conservation could require resuming these practices. Other stands were left untouched to preserve springs that provided precious fresh water to rural villages and activities (e.g. grazing), particularly in calcareous mountain areas. An example of such stands is represented by the Fonte Regna site (PIOVESAN et al. 1995), a patch of mixed forest composed by large beech and holm oaks (*Quercus ilex* L.), completely enclosed by a stone wall which has marked the border of the restricted area for many centuries. Further examples of secondary old-growth forests are represented by stands once included in aristocratic hunting reserves (PONTAILLER et al. 1997; VON OHEIMB et al. 2005) like the high-mountain stand of Coppo del Principe in Central Italy or by stands that were excluded from silvicultural practices to preserve recreational, historical and cultural values, like the beechwood of Monte Cimino (LO MONACO 1983). A final type of secondary old-growth stands consists of forest areas included inside natural reserves in recent decades (mostly starting in the 1970s), and then left to develop naturally. These stands, especially when growing in the most fertile hilly sites (e.g. the beech forest of Monte Venere) have experienced a surprisingly fast structural diversification.

**Bioclimatology and longevity of beech**

A network of tree-ring site chronologies including six different species sampled at various elevations throughout Italy was used to investigate the spatial organization of tree populations according to the climatic factors that control their growth variability (Fig. 1). After a process of statistical amplification of the climatic signal (by age trend removal, averaging and prewhitening), a bio climatic classification of the chronologies according to their dominant climatic signal was obtained by a Hierarchical Cluster Analysis (HCA) (PIOVESAN et al., 2005a; DI FILIPPO et al. 2007). Chronologies were grouped according to their latitudinal and altitudinal position (Fig. 1), which exerted a stronger influence than genetic features in sites at the altitudinal limit of the species range, especially within the beech network – the most widespread one. As an example, the uppermost oak population (COTQUCE, living at 900 m a.s.l. on the Apennines) was linked to mountain beech chronologies instead of other oak records. The climatic signal analysis revealed the separation between two biomes, the Mediterranean and the Alpine one (PIOVESAN et al. 2005a; DI FILIPPO et al. 2007), whose spatial boundary was a function of summer drought control on growth (PIOVESAN et al. 2005a). Within each biome, altitude is the main factor controlling the climate signal, as it determines mean temperature regime as well as growing season onset and duration. In both the Alps and the Apennines Fagus sylvatica populations were arranged by the HCA in three altitudinal bioclimatic belts: low-elevation, mountain and high-mountain beech stands. While summer drought was the dominant climatic factor across all elevations in Central Italy (PIOVESAN et al. 2005a), the Alpine stands were controlled mainly by thermal limitations (DI FILIPPO et al. 2007; Fig. 2). In the Mediterranean biome we observed a shortening of the drought period (from May-August to July-August) with increasing altitude, and an increasing need for warmth in early spring. On the Eastern Alps the influence of drought remains limited to low-elevation stands, while at high elevation warmer temperature favors growth.
Beech forests of the southern European mountains

Beech forests of the southern European mountains

Fig. 2. Elevation range covered by altitudinal bioclimatic zones of beech on the eastern Alps and the Central Apennines, showing beech lifespan (years in parentheses), and the main climatic factors limiting beech growth within each zone. In the case of low-elevation forest (above all in the Alps) the very low longevity is due to the absence in the landscape of primary old-growth forest.

Our bioclimatic classification allowed for framing the climate-change impact on forests considering the spatial organization of the main growth-limiting climate factors. For example, average Basal Area Increment (BAI, an indicator of tree productivity) showed diverging trends for different biomes and altitudinal zones (Fig. 3). Beech in the Apennines lost productivity across the entire elevation gradient following an increase in summer drought (PIOVESAN et al. 2008). This decline in tree productivity began during the 60s-70s and, especially in low-elevation and mountain stands, accounted on average for 20-30% of BAI. In the eastern Alps we instead observed increasing productivity especially in mountain and high-mountain areas, possibly in connection with global change (e.g an improved thermal regime) (Fig. 3).

Analysis of height-DBH curves developed along an altitudinal gradient (high-mountain, mountain and low-elevation beech stands) shows how elevation influences forest growth dynamics (Fig. 4). Forest statuses significantly decreased with increasing elevation that means a decreasing net primary production. Generally high elevation sites presented less fertile soils and climate disturbed (e.g. wind) sites, while at lower elevations beech can grow only in the most fertile sites. Heights greater than 40 m are common on volcanic soils of Central Italy, e.g. in the mountain stand of Monte Cimino, where the highest (~50 m) beech trees in Italy are found.

Our dendroecological investigations uncovered a number of multi-century old trees, with the oldest ones found in high-mountain areas of central Italy (Fig. 5). An inverse relationship emerged between growth rates and elevation (data not shown), while a direct one between maximum age and elevation was found (Fig. 2), which implies the existence of a non-linear inverse correlation between mean growth rates and longevity. For this reason high-mountain beech trees in both Alpine and Apennine sites have a longer life span compared to middle- and low-elevations stands, even if older individuals often are not characterized by large dimensions, since they are subjected to worse site conditions (e.g. high-mountain environments, close to the tree-line). Other studies have showed how reduced growth rates and dimensions commonly associated with extreme environments allow tree species to reach greater longevity in marginal sites (PENUELAS 2005). Observed longevity at a site may significantly differ from the species’ maximum potential longevity because of multiple factors, most of them directly related to elevation (e.g. temperature, summer drought, spring frosts, wind exposure). In Italy the oldest beech stands are found at the uppermost limit of vegetation, as in the case of the
Valle Cervara (maximum age 510 years) and Coppo del Morto (maximum age 530 years), two primary old-growth forests of Central Italy growing around 1700-1800 m a.s.l.; the high-mountain natural forest of Coppo del Principe reaches a maximum age of 376 years. On the Alps the oldest stand is the high-mountain beech forest of Lateis (380 years, 1450 m a.s.l.) and other old stands are the mountain stands of Timau (348 years) and Trelli (323 years) (PIOVESAN et al. 2010). Mountain beech forests in Central Italy are younger (206 and 179 years in Monte Cimino and Fonte Regna, respectively) while low-elevation sites show considerably lower ages (e.g. 150 years, Monte Venere, with sporadic individuals reaching 200 years, as in Monte Fogliano). Furthermore at lower elevations, e.g. on hilly areas of Central and North-eastern Italy, sustained growth rates speed up canopy accession of dominant trees, making them more exposed to natural events or prone to be damaged by wood pathogens; the structural cycle of such forests is thereby accelerated (faster turnover in respect to mountain sites) and their maximum potential longevity strongly reduced.

**Fig. 3.** Average Basal Area Increment (BAI) per altitudinal zone in the Alps and the Apennines. Curves are 50-yr cubic smoothing splines.
Primary and secondary old-growth forests in Italy: evidences from three case studies

In the Italian network of beech forests, after structural and dendroecological analyses, we identified 5 old-growth forests in the Alps and 8 in Central and Southern Italy (especially Valle Cervara and Coppo del Morto) that represent significant examples of beech forest in the Mediterranean region (PIOVESAN et al. 2005b). Valle Cervara escaped logging because of its high elevations, while the remaining old-growth stands are represented by secondary formations in mountain areas. Highly natural formations could be found at lower elevations (Venere, Oriolo and Gargano), but these stands were intensively exploited until a few decades ago, and after the end of silvicultural practices they have showed a sudden reactivation of natural processes (e.g. opening of gaps in the canopy following the death of dominant large trees). With regard to structural indicators, Italian old-growth beech forests have high basal area (29 – 52 m² ha⁻¹) and volume (319 – 990 m³ ha⁻¹), comparable to values commonly reported in the literature (KEDDY & DRUMMOND 1996; PIOVESAN et al. 2005b). On the other hand, deadwood amounts are generally low when compared to other natural beech stands of Europe (CHRISTENSEN et al. 2005): high-mountain old-growth stands of Central Italy (Valle Cervara, Coppo del Morto and Coppo del Principe) have the most deadwood, ranging from 65 to 91 m³ ha⁻¹. It is extremely interesting to notice that in these stands the ratio between deadwood and total volume (live plus dead volume) remains almost constant (~11.5%), and that also the density of large snags (DBH>70 cm) is about the same (5 large snags ha⁻¹ in Valle Cervara and Coppo del Morto; 6 in Coppo del Principe). Large snags, together with large live trees with cavities, are called “wildlife trees” (KEDDY & DRUMMOND 1996), and represent fundamental structural and functional components of forest ecosystem since they provide micro-habitats for many species of mammals, birds and arthropods, dramatically increasing forest biodiversity (WINTER & MÖLLER 2008). In the Italian beech network, density of large snags might be the best parameter to distinguish old-growth forests at the most advanced level of structural evolution from secondary stands. In fact, large dead trees are usually absent in the secondary old-growth stands, except in a couple of sites where they are underrepresented (1 and 2 large snags ha⁻¹ at Monte Cimino and Gargano, respectively). Secondary old-growth beech stands are still impacted by deadwood harvesting, which is a common practice in rural communities, making deadwood values a less than optimal structural indicator in this region.

Fig. 4. Height-DBH relationships for beech from different bioclimatic altitudinal belts in the Alps and the Apennines.
Diameter distributions of Italian beech forests vary from “rotated sigmoid” (GOFF & WEST 1975) in primary old-growth stands and some of the oldest secondary stands, to bimodal or gaussian in the less natural to managed stands. Diameter distribution is a key structural feature to describe natural forests and interpret their growth history (EMBORG et al. 2000). Recent findings suggest a rotated sigmoid curve for describing tree-size distribution in old-growth forests (ZHANG et al. 2001; WESTPHAL et al. 2006). The rotated sigmoid is characterized by a steep decrease in tree density in the smallest and largest diameter classes, and a plateau in the middle diameter classes, which is particularly evident when displayed on semi-logarithmic axes (JANOWIAK et al. 2008). Rotated-sigmoid distributions have been related to U-shaped mortality trends found in mature and old-growth stands, in which higher mortality rates affect both the smallest individuals, as a con-
sequence of self-thinning (COOMES et al. 2003), and the largest ones, because of natural disturbances
(LORIMER et al. 2001). Bimodal distributions, representative of most secondary stands, are typical of the
“demographic transition” stage (FRELICH 2002), as such forests become more uneven-aged overall, but nu-
merous patches are still in the optimal phase (EMBORG et al. 2000).

Case study #1 Basal stands: fast structural restoring
The Central Italy forest of Monte Venere is a low-elevation stand, growing from 550 to 850 m a.s.l. on fertile
and deep volcanic soils. Pure beech stands stretch over 171 ha, included in a wider forested area of 234 ha,
which is part of the Lake Vico Natural Reserve. The Reserve was established in 1982, but silvicultural prac-
tices inside the beech forest had ended in 1973 because of the Latium Regional Law 43/73, that classified the
beechwood of Monte Venere among forests of “environmental and public importance”. Mountain top stands
currently display the highest degree of natural recovering: in this area 8 permanent plots were re-sampled in
2006 (ZIACO 2006), ten years after the previous monitoring campaign (PIOVESAN 1997), to quantify the
structural development of a stand left to its natural evolution. Over this 10-year sampling interval, principal
structural indicators maintained features attributable to even-aged forests: diameter distribution was gaus-
sian-shaped, a single cohort was clearly evident, and regeneration was rare; deadwood amount was scarce (in
part because of past harvesting) and maximum tree age (150 years) was considerably lower than the maxi-
mum life-span for the species. On the other hand, stands are evolving toward an uneven-aged structure, as
testified by the sloping epsometric curve found in 2006 compared to 1996 (Fig.6a). Thanks to soil fertility,
growth rates were very high, with 1996-2006 annual increments of 0.32 m² ha⁻¹ yr⁻¹ for basal area and 11 m³
ha⁻¹ yr⁻¹ for volume (Fig. 6c). Density of large trees (DBH >60 cm) increased from 18 to 27% of total, ac-
counting for 57% of total wood volume in 2006 vs 46% in 1996 (Fig. 6b). New canopy gaps are widespread
among the stands, even if dead trees have no remarkable sizes since mortality is still driven by density-
dependent processes, and the highest mortality rates are experienced by small- or middle-sized trees. Conse-
quently canopy gaps are too small to allow beech regeneration to become established, as they are closed by
branches of adjacent trees. A substantial increase in forest naturalness will occur when larger individuals will
be removed from the canopy by natural disturbances, and the gaps will reach larger dimensions, thus opening
enough space for the establishment of new cohorts, while at the same time increasing the amount of dead-
wood in the stand.

Fig.6. Structural evolution of the low-elevation site of Monte Venere: A) comparisons between DBH-height curves in
1996 and in 2006; B) relative frequencies of stems (bars) in four DBH classes and relative volume (points) contributed
by each class in 1996 and in 2006; C) total volume n 1996 and in 2006 and 1996-2006 yearly increment by DBH class.

Case study #2 Mountain stands: influence of soil types
Soil types may define growth and structural features of beech stands located in the same elevation range. As
an example, the sites of Monte Cimino and Fonte Regna are mountain secondary old-growth beech forests
located in Central Italy, growing at the same altitude (~ 1000 m a.s.l.), the former on volcanic soils, the latter
on calcareous soils. Monte Cimino is mostly a beech forest, impacted for a long time by grazing; during the
19th century, under the pressure of local communities, silvicultural activity was stopped to emphasize the
social-aesthetic value of the forest. After 1949, year of the last timber logging (LO MONACO 1983), no other
interventions occurred, and today the forest is in the demographic transition stage (FRELICH 2002), passing
from a single-layer canopy to a multi-cohort structure. In the forest of Fonte Regna there is an interesting
coexistence between woody species of evergreen (Quercus ilex) and deciduous habit (Fagus sylvatica and
Acer obtusatum). Preservation of the beech forest of Fonte Regna was historically linked to the presence of a
spring that provided freshwater to the contiguous town of Roccantica (PIOVESAN et al. 1995). Grazing is still nowadays a disturbance factor, especially in the lower parts of the forests, and, analogously to Monte Cimino, it is possible to find unnatural individual canopies caused by the practice of tree topping.

Most structural indicators exceed reference values for old-growth stands: basal area is 48 m² ha⁻¹ at Monte Cimino and 42 m² ha⁻¹ at Fonte Regna; volume is 707 m³ ha⁻¹ at Monte Cimino and 540 m³ ha⁻¹ at Fonte Regna. Deadwood is very low at Monte Cimino (19 m³ ha⁻¹), because logs are frequently harvested by local people, while at Fonte Regna deadwood is much more abundant (42 m³ ha⁻¹) and, contrarily to what happens in natural forests, snags (24 m³ ha⁻¹) contribute more than coarse woody debris (18 m³ ha⁻¹). Diameter distributions are approaching rotated-sigmoid curves, but are still more similar to bimodal distributions, typical of stands in the transition stage toward uneven-aged structures. Density of large trees (DBH>70 cm) is abundant at both sites (54 and 21 stems ha⁻¹ respectively at Monte Cimino and Fonte Regna), confirming a history of low-impact forest management. The effects of different soil types are shown by the comparison between DBH-height curves for the two stands: greater heights reached in the beechwood of Monte Cimino are clearly evident (Fig. 7); stand stature, a valid indicator of site fertility, is 46 m in Monte Cimino, 32 m in Fonte Regna. Soils in the volcanic district of Monti Cimini are generally fertile and often more than 1 m deep, while at Fonte Regna fertility is limited by the presence of rocky soils, a calcareous substrate, and steep slopes (50-60%). Soil fertility in the beechwood of Monte Cimino further increases in impluvium areas, where organic matter accumulates and individuals may reach heights of more than 50 m, representing some of the tallest trees in Italy. Analogous differences in soil fertility between mountain beech forests can be found by comparing other volcanic sites (Monte Venere, stature 41 m; Monte Fogliano, 39 m; Oriolo, 39 m) with calcareous ones (Morino, stature 35 m; Collelongo, 28 m).

Case study #3 High-mountain stands: pattern and processes in old-growth stands including the oldest beech trees

The oldest beech stands in Italy are found at very high elevations, often at the altitudinal limit for the species. A typical example of primary old-growth forest is Valle Cervara, which ranges in elevation from 1200 to 1850 m a.s.l., and is located in Central Italy, in the northwest corner of the Abruzzi, Lazio and Molise National Park (PNALM). The valley ("Valle") is amphitheatre-shaped and east-west oriented, and its upper part escaped logging because of both difficult access and a protection role. In the 1950s the stand was saved from a massive logging campaign by the joint work of botanist Loreto Grande and the Forest Service, so that presently, because of its naturalistic importance, the valley is ascribed to the integral reserve zone of the PNALM. The stand includes patches of both primary (about 25 ha) and secondary old-growth forest (PIOVESAN et al. 2005b), the latter representing areas that are recovering from the last logging after World War II. Another example of primary old-growth beechwood, but in the eastern Alps, is Lateis, which grows from 1370 to 1530 m a.s.l., and was historically preserved from logging to be maintained as “protection forest” for the small village of Lateis. Generally in the eastern Alps old-growth structures are found in stands situated above small towns where topography is strongly sloping (often reaching 100%); for this reason they have been publicly owned since the 16th century, when they belonged to the Republic of Venice (PAIERO et al. 1975).

The beechwoods of Valle Cervara and Lateis are the oldest known ones respectively in the Apennines and the Alps. Dendrocological analyses showed mean age of the five oldest trees in Valle Cervara to be 425 years, while in Lateis the five oldest trees had a mean age of 371 years. Maximum age reached in Valle Cervara was 510 years: this was the oldest beech tree in the northern hemisphere (PIOVESAN et al. 2005b), until the recent discovery of an older individual in the PNALM at the Coppo del Morto site (530 years); maximum age found at Lateis was considerably lower (380 years). Structural analyses revealed various similarities between the two stands, both growing on calcareous soils. Basal area was 41 m² ha⁻¹ at Valle Cervara and 40 m² ha⁻¹ at Lateis; volume was 497 m³ ha⁻¹ at Valle Cervara and 533 m³ ha⁻¹ at Lateis (PIOVESAN et al. 2010). Diameter distribution at both sites (Fig. 8) could be represented, after log transformation, by a rotated-sigmoid curve (GOFF & WEST 1975), thus confirming the recurrence of such distribution in old-growth stands (ZHANG et al. 2001). On the other hand important structural indicators can substantially differ between the Alps and the Apennines. Deadwood amount was considerably lower at Lateis (18 m³ ha⁻¹, or 3.3% of total aboveground volume, which includes both live and dead volume), compared to Valle Cervara (65 m³ ha⁻¹; 11.6% of total volume). Even in the Alpine protection forests, deadwood, especially logs, were harvested in the past, and in most cases this practice still continues, making this indicator less accurate. Density
of large live trees (DBH>70 cm) is high at Valle Cervara (17 stem ha⁻¹), while these are almost absent at Lateis (1 stem ha⁻¹); similarly, large snags (standing dead trees with DBH>70 cm) are well represented at Valle Cervara (5 stems ha⁻¹) while completely absent at Lateis.

**Fig. 7.** A) DBH-height curves of two mountain beech forests of the Apennines: the volcanic site of Monte Cimino (black line) and the calcareous site of Fonte Regna (gray line); B) relative frequencies (bars) and diameter distributions (after log transformation) for Monte Cimino (black line) and Fonte Regna (gray line).
Disturbance chronologies produced for these stands by the boundary line release criteria (BLACK & ABRAMS 2003) uncovered a dominance of low-severity disturbances scattered in several decades from 1700 to 1999. These findings underline the importance of gap dynamics in maintaining beech forests, more than stand-replacing events, which instead would synchronize recruitment rates and canopy accessions (PIOVESAN et al. 2005b). Beech is well adapted to a small gap disturbance regime thanks to its physiological and morphological plasticity (CANHAM 1988). The presence of peaks in disturbance events, such as those of the 1760s, 1820s and 1880s at Valle Cervara, does not exclude a role for periodic intermediate severity events (e.g. windstorms), which could contribute to the creation of multiple tree gaps (NAGEL et al. 2007). Growth patterns of the oldest individuals confirm the adaptation of beech trees to gap dynamics (Fig. 9): these chronologies, even 500 years old, show very low increments for several decades (periods of suppression) and one or more disturbances (multi-gap episodes), marked in tree-ring widths as ecological releases (PIOVESAN et al. 2010). In some cases gradual, instead of abrupt, growth releases can be observed, revealing the presence of low-severity, progressive disturbance events releasing the crown of surviving trees.

**Fig. 8.** Diameter distributions of the Apennine stand of Valle Cervara and the Alpine stand of Lateis (left); rotated-sigmoid curves obtained after log transformation of diametric distributions (right).
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Fig. 9. Ring-width series and disturbance events for the three oldest trees at Valle Cervara (left) and Lateis (right), detected according to the boundary line release criteria (Mod_rel = moderate releases; Maj_rel = major releases).
Effects of bioclimatology on structures, dynamics and processes linked to altitude and disturbance regimes

Bioclimatic context regulates ecosystem processes such as stand productivity, disturbance regime, realized longevity, and turnover rates, hence can be used to predict the recovery rate of natural structural attributes in secondary forests. Moreover, it can be used to build a framework to understand and project climate change impacts on natural forests, e.g. with regard to productivity or mortality.

Secondary old-growth stands left to natural evolution should acquire more natural conditions, showing an increase in windthrows, gap openings, and structural diversification. In the case of secondary beech forests, their complete re-naturalization may require hundreds of years depending on a number of factors (e.g. site fertility, stand structure). Given that a most challenging goal for modern silviculture is to try to speed up such recovery processes, it is critical to select effective structural indicators to measure "naturalness". For instance, large amounts of deadwood found in secondary old-growth stands may represent the consequence of a massive shift toward the decay stage of large patches of forest, thus representing only a transitory process toward more natural, dynamically balanced structures. In this cases such large amounts of deadwood will be reached again in the future only if severe disturbances occur (e.g. windstorms). The need to contextualize structural indicators with bioclimatic units emerged early in our forest network analysis.

Climate influences growth processes and mortality, thus determining the potential longevity and structural features of tree species, particularly those like beech with large latitudinal and elevational distribution. We argue that standardizing old-growth structural (e.g. large trees; volume and basal area; deadwood) and functional descriptors (longevity, forest turnover) by bioclimatic zones (e.g. ecoregions and altitudinal belts) as well as soil features (calcaceous vs volcanic) provides a more accurate tool for modern management purposes. For instance large biomass stocks may be reached in a few decades in the most fertile low-elevation sites, while re-naturalization of high-mountain stands proceeds through slower dynamics and longer time frames. At present we are able to characterize old-growth steady-state dynamics only for high-mountain beech stands, which are characterized by high structural diversity and remarkable temporal stability.

Networking in old-growth forests conservation: from education to biomonitoring

Forest networks are key tools to increase knowledge, monitoring, and management of forest ecosystems, especially the most threatened, old-growth ones. Because of their ecological richness and uniqueness, old-growth forests represent a challenge for silvicultural and conservational studies, but public opinion requires using the best possible science for preserving or restoring old-growths, which mostly have intrinsic, intangible value (PETERKEN 1996). For this reason the recognition of primeval beech forest in the Carpathians as World Heritage Sites by UNESCO represents a milestone for beech conservation. The nomination of the “Ancient Beech Forests of Germany” as extension to the World Natural Heritage “Primeval Beech Forests of the Carpathians” is another important step, but to preserve all biological diversity we should expand our perspective to include other areas as well (e.g. Mediterranean region).

At the same time there is the need to develop a small- to large-scale program of environmental education about natural forests, old-growth features, their ecological and biological importance, the “obscure” services they provide to human communities, to explain why it is so important to preserve old-growth forest remnants (JENSEN & MIDDLETON 1990). Recently we established an educational nature-trail inside the beechwood of Monte Cimino, with the double aim of promoting a shared comprehension of the old-growth forest (from scientific information to public opinion) and to increase tourist awareness of this ecosystem. Thereby we promoted various meetings with local schools, and finally produced a short book that was distributed to local people (ALESSANDRINI et al., 2008).

Old-growth forest research should now focus on extending study scales from local to continental. In the case of beech forests, comparisons between different regions and countries will allow researchers to outline a description of the different structural dynamics acting on such ecosystems according to
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bioclimatic/phytogeographical units (e.g. BOHN et al. 2000/2004), to plan effective conservation strategies not only to preserve existing patches of old-growth, but also to increase the extension of natural forests through the restoration of old-growth attributes (e.g. deadwood, fine-grained structures) and the creation of new forests reserves (KNAPP et al. 2008), especially in those situations where climate change impacts are particularly significant (e.g. PIOVESAN et al. 2008). Dendroecological networks could be used to monitor tree responses to climatic variability, and consequently to implement valid strategies to mitigate impacts. For this reason a research project at continental scale (since old-growth beech forests are present in many European countries) focused on biotic components of old-growth beech forests (e.g. from tree-rings to bryophytes and lichens, from mammals to soil arthropods) could represent a unique example of a large-scale monitoring program to understand the impact of climate change on forests and to preserve landscape biodiversity.

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Impressions of Italian beech forests

Left. Historical picture of the high-mountain protection old-growth beech stand of Lateis (top), presently (bottom) the oldest found in the Alps (maximum age 380 years).

Right. High-mountain forest environments in Central Apennines (top: Valle Cervara; bottom: Coppo del Principi).

Two examples of mountain beech forest of Central Apennines: the secondary old-growth stand of Monte Cimino (maximum age 205 years, left), growing on fertile volcanic soils, and Fonte Regna in Sabina (maximum age 179 years, right), a mixed stand of beech and the evergreen holly oak (*Quercus ilex* L.)
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Left. The low-elevation forest of Foresta Umbra (Gargano, Southern Italy). This secondary old-growth stand is located inside the “Parcel Pavari”, after the name of Italian forester Aldo Pavari who included this stand in a network of forest parcels left to natural evolution at the beginning of the 1950s.

Right. The high-mountain old-growth beech stand of Coppo del Principe (maximum age 376 years), inside the Abruzzi, Lazio and Molise National Park.

The mountain secondary old-growth stand of Gracco (Eastern Alps).

Pollard trees in the secondary old-growth stand of Timau (Eastern Alps).
Top. Spring flowering of *Corydalis cava* in the beech forest of Monte Cimino.
Bottom. Coexistence of deciduous beech with evergreen holly oak in the mountain site of Fonte Regna.