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Table of contents

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39 (2), 2015: 62-69

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Review paper

Multi-species and multifunctional smallholder tree farming systems in Southeast Asia: timber, NTFPs, plus environmental benefits

James M Roshetko[1*], Manuel Bertomeu[2]

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Abstract - The rapid increase in human population, and the corresponding worldwide enhancement of social and economical conditions, are exerting a considerable pressure to convert forests to other uses. Moreover, these phenomena raise the demand for food, fuel, wood fibers and other non-wood products, contributing to a further boost of the production pressure in the surviving forests. Simultaneously, these forests are expected to provide a diverse array of environmental services. Furthermore, smallholder forestry systems are prominent components of 'trees outside the forest' in Southeast Asia and they are primarily 'planted' systems that rehabilitate or reforest marginal lands, in order to produce tree products and services. As they traditionally are a means of producing goods for home consumption, they have become significant suppliers of products for local, national and international markets. The aim of this paper is to demonstrate that smallholder forestry systems are a viable management system which is significantly contributing to global environmental goals and local economic objectives. This paper reviews global and Asian trends of human population growth, deforestation, and demand for forest and tree products. The origin, the diversity, the adaptable management and the importance of smallholder tree-based systems are here discussed and significant details are provided on the role of smallholder tree-based systems in the mitigation of deforestation, which could be obtained by expanding regional forest resources; in supplying alternative sources of forest products and environmental benefits; and in making significant contributions to local livelihoods for rural communities.

Keywords - Smallholder, tree-farming, livelihood enhancement, timber, NTFPs, environmental benefits.

Introduction

The global human population reached 7 billion in October 2011, only 12 years after having reached 6 billion, and having doubled since 1968 (Worldometers 2011). With an annual growth rate of 75 million, the population is projected to be over 9 billion by 2050 (United Nations 2015). This rapid human population growth, and a corresponding increase in the wealth of some nations, are exerting a significant pressure capable of converting forests to agricultural, industrial, and residential uses. This also increases the demand for food, fuel, wood and non-wood products, intensifying the pressure on the surviving forest systems. Simultaneously, these forest systems are expected to provide a diverse array of environmental services. For this reason, the United Nations Millennium Development Goals are calling for a more considerable per capita wealth growth which might lead to the eradication of extreme poverty and hunger, while ensuring environmental sustainability (United Nations 2012).

Agroforestry is a dynamic, ecologically based, natural resources management system which, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains the production of goods for the increased social, economic and environmental needs of land users at all levels (Mead 2004). These systems are increasingly recognized as important opportunities for smallholder livelihoods, with neutral-to-positive environmental impacts, and they have received significant research attention over the last two decades (Leakey et al. 2012).

'Agroforestation' refers to the establishment of smallholder agroforestry systems and implies land rehabilitation through the establishment of tree-farming systems and intensification of land management (Roshetko et al. 2007a). Farmers develop and manage such systems by nurturing trees on their farms, pasture lands and homesteads. These tree-farming systems are efficient agricultural and natural resources production systems. As a prominent component of 'trees outside the forest', smallholder tree-farming systems are primarily 'planted' systems that rehabilitate or reforest marginal farmlands where agricultural crop production is no longer biophysically or economically viable.

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[1] World Agroforestry Centre (ICRAF) Southeast Asia Regional Program, Bogor, West Java, Indonesia
[2] University of Extremadura, UEX, Plasencia, Cáceres, Spain
[*] corresponding author: J.Roshetko@cgiar.org

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These systems can also be used to reclaim degraded lands. Smallholder systems could be more productive and profitable if the common policy barriers that limited their development were removed (van Noordwijk et al. 2008).

This paper emphasizes the contribution of smallholder tree-farming systems to environmental sustainability and local livelihoods. It first reviews the trends of regional deforestation and human population growth both globally and in Asia, with an emphasis on South and Southeast Asia. Subsequently, common tree-farming systems are described and their potential to produce forest/tree products and environmental benefits are finally discussed. A particular emphasis is placed on the potential of smallholder tree-based systems to reduce the pressure on the remaining natural forests, to expand regional forest resources, to produce forest/tree products and environmental benefits as well as to make major contributions to local livelihoods for rural communities.

Forest loss, environmental degradation and loss of forest services

The rate of global forest loss in the 20 years between 1990 and 2010 was alarming: For the period 1990-2000, the global annual deforestation rate was 16 million hectares; for 2000-2010, it was 13 million hectares. In addition, this alarming rate likely underreports the damage sustained by the global forest resource, as forest degradation is not included.

Forest cover was reduced to slightly more than 4 billion hectares (30% of the global land area) and the two countries with the largest loss of forest area, over the 20 years period, were Brazil and Indonesia, which respectively lost 2.8 million and 1.2 million hectare/year, representing 0.5% and 1.1% of the annual loss of their forest area (FAO 2010). These changes primarily represent the loss of tropical forests to other land uses: conversion from diverse tropical ecosystems to annual agricultural systems, monoculture tree plantations and cleared (but left not used) landscapes.

Fortunately, the rate of forest loss in both countries and across the globe has declined, but the rate is still far from being sustainable. The rate of deforestation is somewhat offset by planting and natural forest regeneration. The total net change in global forest area was a decline of 8.3 million hectare/year in 1990-2000 and of 5.2 million hectare/year in 2000-2010, the difference with the above deforestation figures being between the areas planted or naturally regenerated (FAO 2011). Efforts to plant new forests and trees have gained momentum as the planted forests represent 7% of total global resources, with an increase of 5 million hectares in the first 10 years of the millennium (FAO 2010).

In Asia, the deforestation-afforestation trend has been mixed. On the basis of FAO data for the 1990-2000 period, the Asia-Pacific region lost forest cover at a rate of 700,000 hectare/year. However, in the subsequent 10 years the trend reversed, with the regional forest cover increasing by 1.4 million hectare/year (FAO 2011, FAO 2010). The reversal in regional deforestation was largely due to the successful tree planting programs in China, India, Vietnam and Thailand. In the 20 years under consideration, China amazingly planted 35.2 million hectares of forests, India 4.5 million, Vietnam 2.5 million and Thailand 1.3 million. Sub-regional and national performance varied significantly. East and South Asia both showed gains in forest cover, while Southeast Asia and the Pacific continued to lose forest cover (Table 1). In Indonesia, the rate of forest lost has greatly declined, but annual forest loss remained still high (100,000 hectares of primary forests and 30,000 hectares of planted forests).

Besides helping to reverse the loss of forest cover, planted forests are an important and efficient source of wood and non-wood products. In 2000, forest plantations accounted for approximately 5% of global forest cover, with industrial forest plantations accounting for only 3% but supplying 35% of global roundwood (FAO 2000). By reducing production pressure, planted forests may have a tempering effect on the rate of natural forest loss.

Established for diverse reasons, tree plantations have generally limited species diversity and they have frequently been monocultures of exotic species. Such systems are much inferior to natural forests in supporting most of the main ecosystem services: biodiversity and habitat conservation, genetic conservation, ecological resilience, water and soil conservation, and carbon storage. Additionally, in many cases, forest plantations are a main cause of natural forest conversion and loss, thus being a direct cause of natural forest growth, biodiversity and carbon stock loss. Hence, forest plantations are a paradox: they are an important and efficient source of wood and non-wood products but are also a main cause of the forest conversion and of the loss of environmental services provided by these natural systems.

Population growth, economic development and demand for forest products

While the forest base will decrease, human populations and economic development will grow, increasing the demand for, and the consumption of, forest and wood products throughout Asia and the

Table 1 - Forest areas in Asia and the Pacific, 1990-2010 (FAO 2011).

	Area (,000 ha)			Annual change (,000 ha)		Annual change %	
Sub-region[1]	**1990**	**2000**	**2010**	**1990-2000**	**2000-2010**	**1990-2000**	**2000-2010**
East Asia	209,108	226,815	254,626	1762	2781	0.81	1.16
South Asia	78,163	78,098	80,039	-7	221	-0.01	0.28
SE Asia	247,260	223,045	214,063	-2422	-898	-1.03	-0.41
Pacific	198,744	198,381	191,384	-36	-700	-0.02	-0.36
Asia-Pacific	733,364	726,339	740,383	-703	1404	-0.10	0.19
World	4,168,399	4,085,063	4,032,905	-8334	-5216	-0.20	-0.13

[1] **East Asia:** China, North Korea, Japan, Mongolia, South Korea
South Asia: Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
SE (Southeast) Asia: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Vietnam
Pacific: American Samoa, Australia, Cook Islands, Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru,, New Caledonia, New Zealand, Niue, Norfolk Island, Northern Marina Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna Islands.

rest of the world. In 1995, South and Southeast Asia were home to, respectively, 1,109 million (23% of the world's population) and 437 million (9%) (ADB 2004). By 2010, the human populations of the regions had grown to 1,598 million and 593 million, respectively, with their proportional share of the global population remaining steady (United Nations 2010).

Current annual population growth rates for individual countries in South and Southeast Asia ranged between 0.7% in Thailand and Myanmar; 1.8% in Pakistan, Nepal, Bhutan and Brunei; 2.1% in Timor-Leste; and 3.5% in Singapore (United Nations 2010). Gross national income (GNI) per capita in the regions in 2005 varied from US $270 in Nepal through US $430 in Cambodia and Laos to US $2,720 in Thailand and US $4,970 in Malaysia. Increases in GNI per capita between 2000 and 2005 varied from 17% in Nepal and Bhutan to 35% in Thailand, 62% in India and Vietnam, and 125% in Indonesia (ADB 2006). The gross domestic products (GDP) of most South and Southeast Asian countries have grown at annual rates of about 5-8% between 2010 and 2012 (CIA 2012). At such growth rates, the size of the middle classes in Asia's developing economies (excluding Japan) would double or triple in the first decade of the new millennium, numbering 0.8 to 1 billion people and forming a middle-class market equal to or surpassing that of the US and Europe combined (Chipeta et al. 1998). Population growth and expansion of middle classes with greater disposable incomes will increase the consumption of forest products, which, in turn, will be reflected in the expanded global trade of these products.

The demand for all forest products is significant and is projected to increase, from the regional to the international level. For instance, the global demand for industrial roundwood is expected to increase to 2,165 and 2,436 million m^3 by 2020 and 2030, respectively, these representing increases of 29% and 49% over global production in 2005. During the same time, Asia-Pacific demand for industrial roundwood will increase by 58% and 78%, respectively, but production will not keep pace with demand (FAO 2009). This projection emphasizes the urgent need to expand the regional forest base, a process that should include afforestation, reforestation, and smallholder agroforestry systems (Roshetko et al. 2008).

Smallholder tree-farming systems: origin, multiple goods and environmental benefits in Southeast Asia

In this paper, the term 'smallholder tree-farming systems' is interchangeable with 'smallholder agroforestry systems'. Depending on local needs or opportunities, smallholder systems may focus on tree crops, agricultural crops, livestock or a combination of the three. These various systems will differ greatly in size, species components, tree density, tree longevity, and management intensity.

Smallholder tree-farming systems may originate from natural forests that have been altered in composition or structure by local people, tree-based systems established on agricultural or fallowed land, or a combination of both. There are examples of forest degradation being deflected by the establishment of smallholder tree-farming systems which avoid the more serious stages of environmental degradation. In these situations, good markets for non-wood products, such as fruits, resins and latex, have allowed a transition of substantial areas of Southeast Asian forests into 'agroforests', i.e. a land use that combines 'planted trees' with forest flora and fauna, with either retained or naturally regenerated vegetation (de Jong et al. 2001, Michon and de Foresta 1990, 1995). Similarly, by the production of wood and non-wood products on farms, smallholder agroforestry systems have been identified as a means of reducing pressure on and conserving natural forests (de Foresta et al. 2003, Scherr and McNeely 2008, Strandby-Andersen et al. 2008). Farmers in Sumatra cultivating agroforestry systems relied less on wood supplies harvested from natural forests than those without agroforestry systems (Murniati et al. 2001). Dawson et al. (2013) comment on agroforestry's role in the conservation of tropical tree diversity through use.

In deforested regions, a shortage of local forest resources is often the catalyst of spontaneous expansion of smallholder agroforestry systems (Santos-Martín et al. 2012). This type of farmer-led, spontaneous, smallholder tree-farm development has been documented in Sri Lanka (Gunasena 1999), Philippines (Garrity and Agustin 1995, Schuren and Snelder 2008), Kenya (Scherr 1995) and Indonesia (Michon and Bompard 1987). In addition, proximity to urban centers creates high demand for timber, fruit and other forest products and stimulates spontaneous smallholder agroforestry. This is especially true for areas far from the extractive forest frontier and/or with farms large enough to support tree crops, in addition to seasonal cash crops. In other situations, the temporary migration of young people to cities results in the extensification of land use with tree farming evolving as a lower labour input alternative to annual crops (Bertomeu 2006). Thus, smallholder tree planting has led to land rehabilitation (Pulhin et al. 2006) and regional forest transition by restoring tree cover (Mather and Needle 1998).

Smallholder farmer tree-planting systems are generally successful on their own terms. Smallholders commonly have limited time, labour and financial resources. Planting trees represent a conscious investment chosen among other available options. Farmers generally restrict plantings to the number of trees that can be maintained and integrate tree-growing with agricultural crops and animal husbandry activities. The management practices undertaken to ensure good food crop yields, cultivation, weed control and fertilization, and tree pruning, also benefit trees (Bertomeu et al. 2011). The available land, labor and other resources are allocated according to the farmer's objectives. Because landholdings are small, farmers can select the farm niches most appropriate for tree production. The combination of limited resources, small individual plantings, and intimate familiarity with the planting site result in high species diversity, tree survival and good growth rates. Smallholder tree-growing activities benefit from intensive management over limited areas and vested self-interest: the desire of the farmer to profit from their investment of time and resources (Roshetko et al. 2008).

As opposed to forest plantations and other public-planted forests, smallholder tree-farming systems provide an array of tree and forest products and environmental benefits, including support of local livelihoods. Smallholder timber systems are frequently used to grow assets for emergencies or specific cash needs (Roshetko and Westley 1994, Bertomeu 2004, Perdana et al. 2012). Under these conditions, smallholder farmers look at tree farming as a means of diversifying their production, reducing risk, and building assets to enhance family incomes and security (Roshetko et al. 2007b, Schuren and Snelder 2008). Besides supporting family livelihoods, smallholder agroforestry systems also make a significant contribution to national economies and global trade. In the Philippines and Indonesia smallholder-produced timber has become an important source of raw material for the local industry and the international markets (Bertomeu 2004, Tukan et al. 2004, Bertomeu, 2008, Roshetko et al. 2013). Products from smallholder systems in Indonesia include rattan, forest honey, sandalwood, gaharu, damar, benzoin, cinnamon, cloves, nutmeg, candlenut, rubber, cacao, coffee, oil palm and tea (Dove 2004, de Foresta et al. 2003, Garcia Fernandez 2004, Rohadi et al. 2003, Sunderlin et al. 2000, DGEC 2012). The five major global tree commodities are oil palm, coffee, rubber, cacao and tea, with an export value of roughly US $80 billion in 2009 (Dawson et al. 2014). Indonesia is a major producer of all the five commodities. In 2011, smallholders in Indonesia produced most of the coffee and cacao, 80% of the rubber, 39% of the oil palm, and 26% of the tea (Table 2).

Smallholders' agroforestry also provide many environmental benefits, including soil fertility replenishment, water catchment protection, biodiversity conservation, genetic conservation, reforestation, carbon storage, besides the reduction of pressure on natural forests (Garrity 2004, Roshetko et al. 2007a, Idol et al. 2011, Dawson et al. 2013). In societies where the majority of people live in urban areas, concerns over the accelerating loss of open and green space are becoming prominent. This is a quality-of-life issue to many and increases the recognition of agroforestry systems value to provide ecological functions also.

The main purpose of diversified productions and the complementary achievement of private and public environmental benefits, attribute dynamic, productive, risk-averse values to agroforestry systems. Additionally, but less recognized, agroforestry systems demonstrate a valuable potential in both

Table 2 - Smallholder production of oil palm, coffee, rubber, cacao and tea in Indonesia, 2011 (DGEC 2012).

	Smallholder area (,000 ha)	% of total area	Smallholder production	% of total production (,000 ton)
Oil palm	3,315	42	7,774	39
Coffee	1,255	96	679	96
Rubber	2,935	85	2,104	80
Cacao	1,641	94	828	92
Tea	56	46	40	26

mitigation and adaptation to climate change. On a per area basis, tree-rich, smallholding systems store a significant amount of carbon. Multi-storey agroforests and tree gardens 60 years-old or more can store up to 350 Mg ha^{-1}; home-gardens and smallholders' timber systems around 40 years-old can store up to 280-300 Mg ha^{-1}. The amount of carbon stored by specific systems will depend on biophysical conditions and tree density. However, the amounts of carbon stored in smallholders' agroforestry systems are similar to those in some secondary forests over similar time periods and greatly exceed the carbon stored in the low-biomass systems - such as fallow agricultural land and *Imperata* grasslands - that smallholders' systems often replace (Roshetko et al. 2002).

Other factors bearing on carbon stock are the species composition and management practices, specifically, the time trees are being mantained in a system. For carbon storage it may be beneficial to limit the number of low-biomass species - such as coconuts (*Cocos nucifera*) and bananas (*Musa x paradisica*) - and the amount of timber harvested. These options have to be balanced with farmers' goals for their own livelihood and land management. To farmers, carbon is even less tangible than other environmental benefits, such as watershed protection or biodiversity conservation. First, farmers' agroforestry systems must be socially and economically viable because then they are less likely to be converted to other, lower carbon, land uses. Carbon payments to farmers would promote transparency and increase farmers' understanding of the services the agroforestry systems provide. Any income received for carbon should be treated as an additional return for services already provided by such systems. This approach would help protect smallholders from project or market failure (Roshetko et al. 2007a).

Smallholders can also play a key role in protecting, through use, plant and tree diversity. Although smallholder tree-based systems are less diverse than native forest, agroforestry landscapes of the tropics usually contain dozens or even hundreds of tree species (Idol et al. 2011, Dawson et al. 2013). In complex agroforests, farmers may retain remnants from natural forests because of the products they provide or for religious, cultural or aesthetic reasons. The high tree species richness found in these agroforests suggests a strong role for smallholders to conserve plants and trees in farmland (i.e., circa situm conservation) (Dawson et al. 2013).

In deforested landscapes, smallholder tree planting can increase tree diversity and density, using indigenous or exotic planting materials produced either on-farm or in commercial tree nurseries (Ordoñez et al. 2014). Farmer-led reforestation may initiate forest transition, accelerating the restoration of degraded lands and resulting in higher biodiversity value (van Weerd and Snelder 2008, Idol et al. 2011). Compared to large-scale forest plantations, smallholder systems contain a much greater number of plant and animal species (Michon and de Foresta 1995, Murdiyarso et al. 2002). This diversity can provide ecological resilience and contribute to the recovery and maintenance of beneficial ecological functions. Smallholder tree-based systems, similar to plantations, are 'working forests' and they can help relieve some of the pressure to harvest native forests (although their presence as such is not a sufficient condition for the protection of old-growth forests (Angelsen and Kaimowitz, 2001, Tomich et al. 2002). For instance, in watersheds, linked systems of upland and riparian tree-based buffer systems, designed with regard to other landscape practices and features, can optimize soil and water conservation (van Noordwijk et al. 1998), along with other economic and social services.

Conclusions

Smallholders with diverse, risk-averse farms that include a significant tree component, have been producing a range of tree-commodities and could be efficient producers of other tree-commodities in the future. As described above, their tree-farming systems have high potential to yield both wood and non-wood products and play a key role in the recovery of degraded lands. Smallholder tree-farming systems have the potential to be one component of a general poverty alleviation strategy for agrarian-based, poor rural communities (Roshetko et al. 2007a, Snelder 2008). Although the social potential of tree-farming systems has not been fully exploited and the extent to which these systems can alleviate poverty and enhance food security is poorly documented, the importance and potential of the systems will continue to rise, especially with the continued development of market economies and rural infrastructure (Roshetko et al 2002). The importance of smallholder systems first as a source of forest and tree products and secondly as provider of environmental benefits will only increase as global forest resources continue to shrink and human populations expand (Roshetko 2013).

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Review paper

Genetic resources and forestry in the Mediterranean region in relation to global change

Fulvio Ducci[1*]

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Abstract - The purpose of this review is to examine a few aspects of global change effects on forest genetic resources and their interaction. Genetic resources can provide many opportunities for the development of adaptive forest management in the Mediterranean region. At the same time, forestry and its various disciplines can offer manifold chances to develop methods and techniques for the *in situ* and *ex situ* protection, as well as for the correct management of species and populations at risk because of climate change. Among these aspects, the studies on the Marker Assisted Selection are particularly taken into consideration, as well as the phenotypic plasticity and the different types of assisted migration. A special emphasis is given to genetic resources growing at marginal peripheral populations, which need to be safeguarded as possible containers of adaptive diversity. They are subjected, in fact, to an extreme climatic stress more than others.

Keywords - Forest genetic resources, forest reproductive materials, genetics, adaptation, assisted migration, marginal peripheral populations, Mediterranean area, global change, silviculture.

Introduction

This paper aims to examine some key interactions between environmental factors and the management of forest genetic resources (FGR) in a context of rapid global changes.

The Mediterranean region is surely one of the major genetic hotspots for natural resources, closely interacting with human populations and cultures (Cavalli-Sforza 1991, Cavalli-Sforza et al. 1994) and it needs special care from both the scientific community and the policy makers and the public opinion.

Combining genetic, breeding and FGR management experiences, the Author provides some examples and considerations in order to draw attention to the complexity of managing Forest Genetic Resources in the context of the already evident changes occurring in the Mediterranean region.

Climate factors and Forest Trees

Over million years of evolution, trees have developed different behaviors in order to optimize their adaptive traits. Adaptation occurs at different levels and following ways (Larcher 2003).

- *Modulative adaptation*, it is important in sites where wide abrupt fluctuations of ecological factors occur (i.e. the circadian rhythms, as the opening and closing of stomata and chloroplast movements in relation to the minor or major light intensity fall here);

- *Modificative adaptation*, it takes place during morphogenesis in response to the environment and it is generally irreversible. The formation of light-leaves and shade-leaves in many species (e.g. silver fir) is one example. It could be regarded as a synonym of phenotypic plasticity;

- *Evolutionary adaptation*, it is fixed in the genotype according to habitat characteristics, preference of the species or its temperament. The distinction between shade-tolerant and light-demanding trees is an example, as well as between xero-tollerant or mesophyte trees or those adapted or not to acid soils.

Light, temperature and water availability are ultimately the main climatic factors interacting with forest trees, those that can significantly affect tree life and ecosystems where they live, with regard to the changes taking place.

Photosynthesis is the first adaptation process that biological forms invented to store energy

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[1] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy
[*] fulvio.ducci@entecra.it

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from the sun. This biological process has radically changed Earth's environment, triggering ecological processes and enabling the evolution, which is nothing but the search for species of the right position to take advantage of a trickle flow of energy flowing through the ecosystem (Larcher 2003).

Among the different ecological factors, temperature is one of the most important and can significantly address species distribution. In Mediterranean contexts, temperature, on the ground, up to 70°C. at Aleppo pinewoods in southern Italy were usually measured (Magini 1955).

Clear evidence exists of the adaptive meaning of temperatures influencing the photosynthetic function in trees, in relation to habitats (Taylor et al. 2012). Seedlings collected along an elevation gradient, from 730 to 1460 m above the sea level, showed a photosynthetic optimum temperature reduced to about 4.3° C per 500 m in altitude. These values are closely related to the negative elevation gradient of the measured air temperature that equals to ± 3.9 C per 500 m on average.

Under these conditions, the pressure of natural selection towards a greater photosynthetic rate is very heavy.

A plant is under water stress when the water requirement necessary for transpiration exceeds the amount provided by the roots. The trees react by increasing their own stomatal resistance, i.e. by closing stomata and reducing the CO^2 and water flow.

Climate modifications expected in the future

Since 1980s, global change has started to show its evidence and has been acknowledged as seriously affecting all of Earth ecosystems. Under this framework, forests, biodiversity and genetic resources are under threat, as well as people depending on goods and services (WMO 2007).

Diversity is the main tool for fragmenting risks in the Biosphere and also forest diversity contains adaptive traits which can be useful for the adaptation of species to the changing environment and for supplying the variation to be used in silvicultural activities to develop adaption and mitigation strategies of management.

The effects of global changes, with special regard to climate parameters can endanger forest tree populations because of the persistent and intense modification of patterns within main climatic factors (i.e. intensity, seasonal and geographical distribution).

Water availability, together with air temperature, will change seasonal patterns too rapidly and trees may not be able to adapt to the changes. The repeated drought stress over several years and its cumulative effects can at times be quantified only when the damage is already nearly definitive.

The Mediterranean region, already subjected to highly variable climate regimes, is more and more characterized by unpredictability and by an increasing frequency of extreme events. In this area, the effects of global change and especially of climate are likely to be even more sensitive. It therefore raises the need to manage and preserve the Mediterranean forest tree resources because differentiated and characterized by the presence of adaptive traits possibly useful to develop strategies for adaptation (Ducci et al. 2011 in Besacier et al. 2011, Ducci 2014).

The historical occurrence of many civilizations that significantly influenced the life of ecosystems and their genetic resources is a typical attribute of the Mediterranean region. People have been using and taking advantage of this biodiversity for millennia. Although it resulted in the rise of original habitats and human-designed landscape structures, in fact, the interaction between humans and biodiversity has sometimes led to the decline and disappearance of species and populations (Blondel and Aronson 1999).

Nowadays, climate change effects pose other formidable challenges to biodiversity in this region. Most valuable forest ecosystems and species in the Mediterranean region experienced and survived the most recent post-glaciation climate warming thank to the presence of mountain ranges where suitable ecological conditions were found at different altitudes. But the changes since last glacial periods were not so rapid as the changes predicted today. At least five cold periods have been recorded in Europe over the last 8000 years; their duration was between 100 and 300 years on average and they influenced both the life standard of civilizations and the diffusion-extension and type of forest ecosystems (Pinna 1977).

More recently, the IPCC (Intergovernmental Panel on the Climate Change 2001, 2012) predicted an average temperature increment over the next 50 years in Europe of 2 ÷ 4°C, according to the different regions. This change means the upward shifting of climatic and ecological areas in the mountains. For a number of reasons however, this “escape” will not always be sufficient to solve the problem. In fact, the on-going climate modification and its effects will be more complex than we can imagine and many factors will change the patterns and the related feedbacks and interactions.

Changes in the main patterns

The actual changes in climate seem to be very rapid as compared to past alternate warming, gla-

Table 1 - Scenarios for minimum temperature changes estimated according to different scenarios and in different regions of Italy (courtesy of Perini, Salvati et al. 2007). *Legenda*: IS: Initial Situation; S0: lower intensity scenario; S1: averaged intensity scenario; S2: higher intensity scenario.

Minimum temperatures (°C.)

Geografic Region (Italy)	Winter				Spring				Summer				Autumn			
	IS	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*
Nord	2.4	1.1	1.7	1.1	3.8	3.7	3.7	4.6	12.1	12.1	12.4	13.1	5.8	5.7	5.9	6.1
Central	2.3	3.5	3.4	3.8	6.8	6.7	6.9	7.5	15.3	15.3	15.7	16.3	9.8	9.7	10.0	10.4
South	5.7	7.0	7.0	7.2	9.4	9.4	9.5	9.9	18.2	18.2	18.5	19.2	13.0	12.9	13.2	13.5
Sicily	7.8	9.2	9.3	9.5	10.6	10.6	10.5	11.1	19.3	19.2	19.7	20.2	15.2	15.0	15.5	15.8
Sardinia	6.4	7.6	7.7	7.6	9.2	9.2	9.3	9.7	17.7	17.6	18.1	18.5	13.3	13.1	13.5	13.7

cial and micro-glacial periods. But the occurrence of climate change is not new and climate warming started earlier than admitted by media and popular press. Such change was recorded by climatologists since the second half of the XIX century.

At the end of 1800, many glaciers were lost or widely reduced in area on the Alps and other mountain ranges. In 1935, the sea mean temperature, at higher latitudes, increased of 1 to 3.5°C (Pinna 1977). Many similar forecasts and scenarios are recorded in the literature on this topic. Concerning Italy, for instance, Perini and Salvati (2007) produced some scenarios with major details. In particular, three different cases (different intensities of change) were considered by the authors, named respectively *S0* (ΔT (°C): 0.1 Tm 13.0° C.), *S1* (ΔT (°C): 0.2 Tm 13.4° C.) and *S2* (ΔT (°C): 0.8 Tm 14.0° C.) over the reference period 1960 - 1990). Climatic patterns change mainly with latitude, but also they vary according to orographic variation, local morphology and distance from the sea.

The *mean annual temperature* change is actually forecasted to increase from 13°C to 13.4 and 14.8°C respectively, with a maximum increment of 0.8° C.

This perspective of the authors is relatively moderate as compared with current ICCP scenarios (2012).

Minimum temperatures will probably change with different patterns and intensities in different geographical areas of Italy; the South of Italy and the larger Mediterranean islands will be especially affected (Table 1).

The changed patterns are even more pronounced when *maximum temperatures* are considered (Table 2).

Predicted change in *rainfall amount* would be also significantly heavy. About 60% of the annual precipitation could be lost in some areas, especially in winter and spring. The autumn rainfall would predictably be more stable, but both intensity and concentration of precipitation could become a problem due to the increased occurrence of floods. Their *geographical distribution* would also predictably change and, according to the most optimistic scenario (S0), Sicily and Sardinia would reduce total rainfall amounts between 17 and 21%, whilst reductions would amount to about 5% - 9% in the continental regions of Italy.

If both of the two worst scenarios (S1 and S2) are taken into account, the decrease of precipitation would predictably be 20% in northern, 17% in central Italy, 25-26% in the South and Sardinia, and 12% in Sicily (Table 3). An increasing drought towards a 200 kilometres higher latitude would affect Italian central regions.

Main traits of forest genetic resources under climate driving forces

According to Thompson (2005), the climate changes in the Mediterranean region, the most recent ones being occurred during the Quaternary (Huntley and Birks 1983), together with the salinity crisis in late the Messinian Tertiary, have driven the shaping of diversity among and within Mediterranean species.

Together with Balkans and the Iberian Peninsula, the Mediterranean region is indeed considered among the major and complex refuge zones in the Pleistocene. As a result, plant diversity is relatively high in this area (Hampe and Petit 2005, Fady and Conord 2010).

Table 2 - Scenarios for maximum temperature changes in different regions of Italy and in different seasons (courtesy of Perini, Salvati et al. 2007). *Legenda*: IS: Initial Situation; S0: lower intensity scenario; S1: averaged intensity scenario; S2: higher intensity scenario.

Maximum temperatures (°C.)

Geografic Region (Italy)	Winter				Spring				Summer				Autumn			
	IS	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*
Nord	4.6	5.3	5.3	5.8	13.2	13.0	13.5	14.8	22.8	228.8	23.1	24.0	14.5	14.2	14.5	14.6
Central	10.0	11.1	11.2	11.6	16.8	16.6	17.1	18.0	27.1	27.1	27.4	28.4	19.3	19.0	19.4	19.7
South	12.7	14.0	14.2	14.5	18.2	18.1	18.4	19.2	28.3	28.1	28.7	29.7	21.4	21.1	21.7	22.1
Sicily	14.6	15.9	16.0	16.3	18.9	18.8	19.2	20.0	28.8	28.5	29.3	30.0	23.0	22.7	23.2	23.7
Sardinia	13.8	15.0	15.1	15.3	18.5	18.2	18.9	19.8	28.7	28.5	29.2	30.2	22.1	21.8	22.4	22.8

Table 3 - Scenarios for rainfall changes in different regions of Italy in different seasons (courtesy of Perini, Salvati et al. 2007). *Legenda*: IS: Initial Situation; S0: lower intensity scenario; S1: averaged intensity scenario; S2: higher intensity scenario.

Precipitation (mm)

Geografic Region (Italy)	Winter				Spring				Summer				Autumn			
	IS	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*	*IS*	*S0*	*S1*	*S2*
Nord	220	221	152	179	264	250	220	184	263	242	238	204	282	262	212	267
Central	278	270	236	239	199	178	161	163	140	122	120	96	282	277	238	269
South	286	255	241	237	166	148	152	119	78	73	65	47	248	231	226	203
Sicily	223	203	226	247	132	109	113	88	34	21	19	26	186	177	202	191
Sardinia	241	180	198	190	126	124	90	92	34	24	21	19	201	146	177	169

As above mentioned, the Mediterranean region is one of the world's biodiversity hotspots for its outstandingly high plant species richness and endemism (Médail and Diadema 2009). In this area, the presence of genetically valuable populations of forest species belonging to central and northern ranges will be seriously affected and, in a few cases, endangered. These populations are in most cases characterized by high levels of differentiation and are frequently typically marginal.

It is thus likely that forest genetic resources originated in the southern latitudes of Europe have often developed their major traits under difficult environments and survived well under unsuitable ecological conditions because of unusual adaptive traits. They are valuable sources of variation for expanding as well as retreating forests under the climate pressure and for developing adaptive management, silviculture and mitigation initiatives.

The changing climatic patterns may have significant influences on the adaptive traits of species, and any rapid change can cause disequilibrium in growth, physiology and reproductive systems.

In Mediterranean climate areas, forest species adapted their living cycles to the rainfall time; autumn and winter represent for most of them the growing period and provide the best conditions for seed germination.

Besides, most of trees, especially those growing in temperate areas in mountain sites and belonging to mature ecosystems, such as many hardwoods, can activate their annual cycles only strictly following the seasonal climatic change. Thus, growth and reproductive steps can occur only in suitable conditions and/or when adverse conditions can be mitigated or avoided.

As above mentioned, the isotherms will probably shift very rapidly because of the increasing average temperatures. With regard to the ability of tree populations to migrate under the influence of isotherm shifts, Màtyàs (2007) proposed a scenario where mean temperature would increase by about 2°C in 35 years, an estimate more cautious than the Italian evaluations. According to his standpoint, in Europe the south thermal gradient would shift towards the north at the speed of 3 km/year and of 11.5 m in elevation (Màtyàs 2007).

In northern America, the shift is estimated 6-15 km/year in the plains and, in any case, the estimated speed would exceed the potential migration rate of most of forest trees (Aitken et al. 2008).

This change is very rapid, as most of the species have migration rates which can vary between 100 and 400 m/year in the plains (Màtyàs, personal communication), according to seed weight, reproductive system, habitat, ground morphology and other ecological and biological factors at local level. Iverson et al. (2004) estimated this rate at 100 - 200 m/year for northern America.

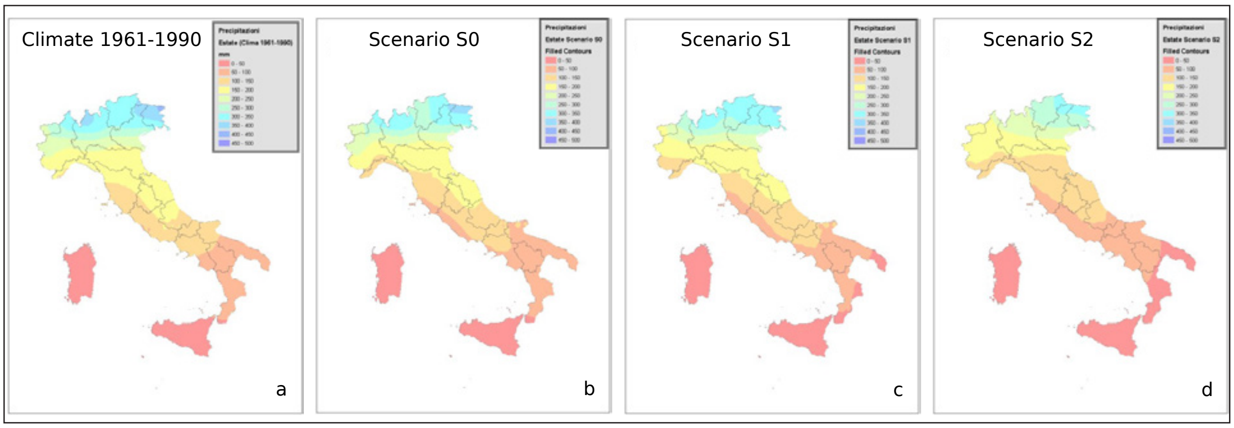


Figure 1 - Maps showing the peculiar situation of decreased summer mean rainfalls in most of central and southern Italy which will be only partially offset by the presence of the Apennines. a) 1961-1990; b) IPCC lower intensity scenario S0; c) IPCC lower average scenario S1; d) IPCC higher intensiry scenario S2.

With special regard to the southern European and the Mediterranean area, the mountain area is widespread and could probably contribute to mitigate changes with the elevation and aspect effects. There, tree species have to migrate upward following the shift of their environmental envelope and niche to survive. Migration towards mountain tops is made more difficult because of gravity. Moreover, mountains are not always so wide and high enough to allow the migration of an adequate gene pool to sufficiently high elevations.

Possible FGR responses to climate change

Tree species and their ecosystems in the Mediterranean region are adapted to several climatic constraints, such as summer drought, late spring frost and severe winter frost, depending on site.

Even the lower range of climate change scenarios predicts a worsening of these conditions, with increases in mean temperature and lengthening of summer drought (Màtyàs 2007, Màtyàs et al. 2009) and frequency/intensity of extreme events (IPCC 2007).

Already in 1937, De Philippis proposed an effective and realistic scheme of relationships between the main climatic and edaphic characteristics of the Mediterranean region and the corresponding change of main forest ecosystems (Fig. 2). In this work, the Author defined the limits of the Mediterranean area and the vegetation type replacing the holm oak forest as the mature forest ecosystem, highlighting, moreover, the possible main trends according to changing patterns.

According to the State of Mediterranean Forests 2013 (Besacier et al. 2013, COFO-FAO 2014), Forest Genetic Resources (FGRs) may respond in various ways to environmental change, including migration to track the geographical shift of areas providing suitable environmental conditions (Parmesan and Yohe 2003):

1. acclimation through phenotypic plasticity (i.e. the change in functional traits expressed by an individual in response to environment change across its lifetime; Chevin et al. 2010);
2. evolutionary adaptation (i.e. a change in gene frequency from one generation to the next resulting in a change in fitness; Kawecki and Ebert 2004);
3. changes in the forest community (van der Putten et al. 2010).

It is often accounted that migration was the dominant factor in shaping genetic diversity during the Pleistocene (Petit et al. 2003). However, despite past glacial and post-glacial migrations of many taxa (inferred from fossil pollen records and genetic data), which suggest a robust capacity for range shifts, today the migration potential of several species is considered insufficient to keep pace with the projected rapid future climatic change (Loarie et al. 2009).

Evolutionary adaptation can also be very rapid: major shifts have been demonstrated over only a few generations, such as increased drought resistance and growth in *Cedrus atlantica* (Lefèvre 2004) and epigenetic-based shifts in bud break phenology in *Picea abies* (Yakovlev et al. 2012). There are examples in the Mediterranean region of local adaptation in trees (although they are mostly phenological), especially from ‘common gardens’ and ex situ experiments (Savolainen et al. 2007, Vitasse et al. 2009). Phenotypic plasticity has been demonstrated to be an efficient response mechanism to change (e.g. *Cedrus atlantica* in Fallour-Rubio et al. 2009).

In nature, migration is an important way to re-establish populations in suitable conditions (Pitelka et al. 1997). The possibility to migrate or find local refuges exists principally in the northern and eastern sides of the Mediterranean region; migration would be a problem, however, for forest tree species in the southern part of the Mediterranean area, where the only chance of natural migration is towards the mountain top.

Another important limiting factor is drought. In general, it would affect the southern border of natural tree species ranges and its effects would probably be more tangible in the Mediterranean region than elsewhere in central and northern Europe. This region is characterized by several traits which make it an important hotspot of adaptive variation:
1. it is the xeric southern limit of many northern and continental European tree species (mostly in the northern side of the Mediterranean sea);
2. there are typical Mediterranean species of conifers and hardwoods, adapted to the Mediterranean climate;
3. there are also Mediterranean temperate forests, which are very sensitive to change;
4. there are remnants of former climatic changes (colder periods), found in refuges on the mountains (mostly on the southern side of the Mediterranean).

Concerning the above categories, the following short predictions can be formulated according to Pitelka (1997):

case 1) *the southern populations of northern species*, in many cases fragmented and isolated would be reduced progressively in size

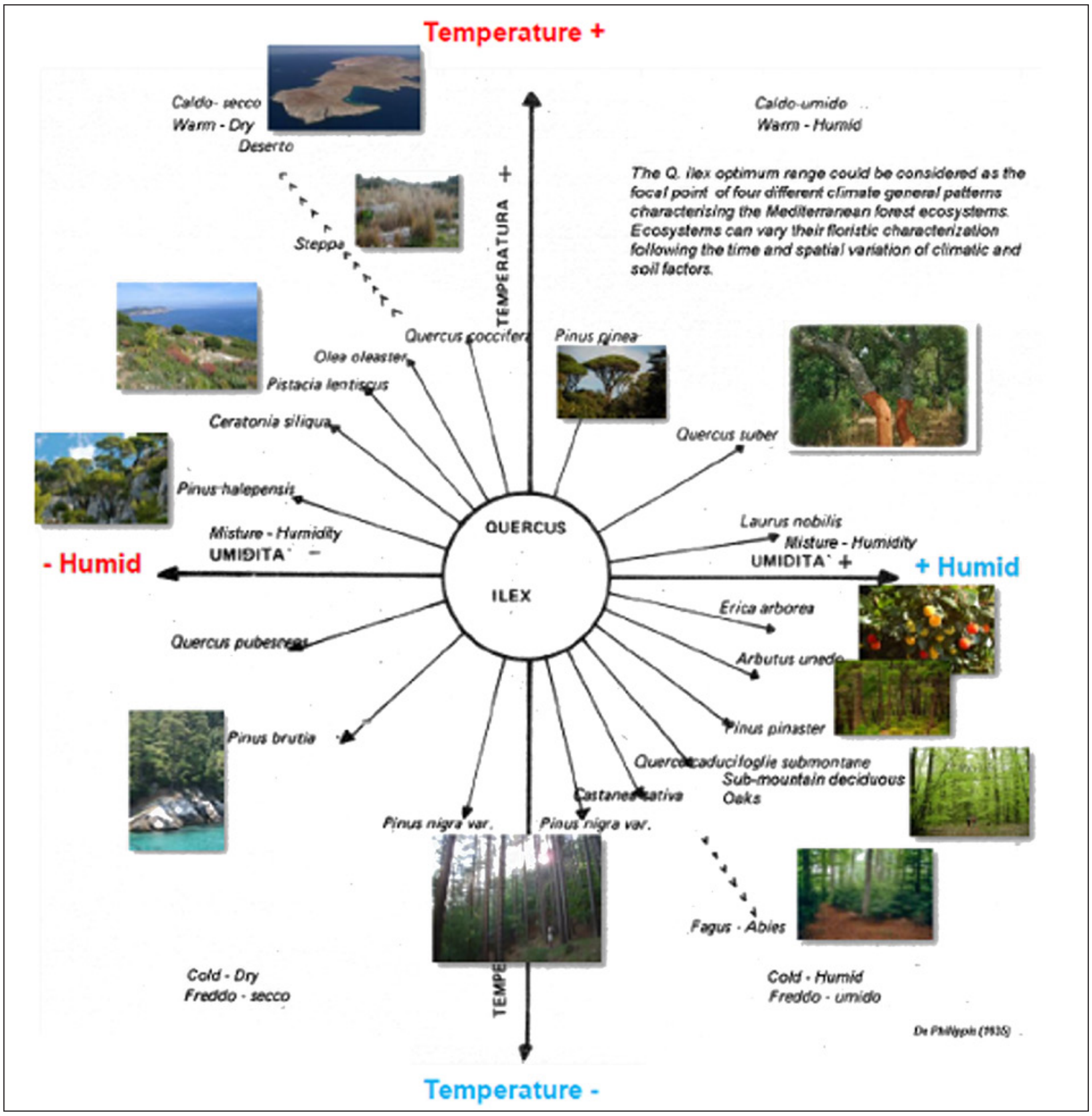


Figure 2 - Studying holm oak and cork oak (*Quercus ilex* and *Quercus suber*) in Mediterranean arboreal vegetation, Pavari highlighted the climatic and edaphic parameters influencing the distribution of these two species, then defined their needs and drew attention to the consequences of heavy and prolonged human action on their distribution (De Philippis 1937 in Pavari 1959, modified).

and eroded and, somewhere, populations would disappear. Indeed, the isotherm shift towards north would probably leaves smaller populations growing at higher elevations. These would remain isolated and genetically eroded. In the case, these populations were differentiated for adaptive traits and their disappearing will determine the loss of important amounts of genetic information. In any case, this information would be really endangered.

case 2) *the Mediterranean forests and ecosystems* (i.e. Mediterranean Pines, evergreen oaks and shrubs communities) could be initially the less endangered during the first steps of climate change. Most of them are

The marginal population of Pinus nigra v. Villetta Barrea in central-southern Italy (M. Marchi and A. Teani - CREA SEL).

characterized by extended and/or continuous populations and, in principle, this species should be more adaptable to drought. Despite this, even the toughest forest trees in the Mediterranean climate, need a minimum amount of water availability to survive. Their resources could be probably endangered in the same way of point (1) due to the progressive drying of climate, to weather extremes and also to related causes (i.e. forest fires and migration of human activities as agriculture and grazing).

case 3) *the deciduous trees forests of hardwoods or pines and other conifers* covering the mountain sites at average elevations. Their water and temperature requirements make them really sensitive to the changes expected in the Mediterranean region. Adaptation and migration towards higher elevations should be consequently implemented using natural (silviculture) and artificial methods. The search of local suitable condition spots for survival would be a good strategy.

case 4) *several relict populations as Cedars and Mediterranean firs and others*, grow in isolated and endangered populations at the higher elevations of all the Mediterranean contour. Most of them are small and/or under genetic erosion since long time. Climate change would probably put them in the first category of priorities for common action for their rescue.

Throughout the Mediterranean region, the selection pressure caused by drought has been always significant over the past millennia and its effects will probably increase with the ongoing climate change. In some areas, however, tree species have reached an equilibrium and/or found microclimates able to supply a refuge for them. The progressive further effects of drought will be probably initially seen in the decline of tree species in many areas and by mortality related to weather extremes. A recent evidence is the outcome of prolonged summer droughts of 2003, 2007, 2010 and 2011.

The prolonged drought decade since the 1980s, resulted in recurrent and frequent pullulations of pests and diseases for many species. Symptoms were initially mistaken as primary causes of mortality, whilst the former stress was probably the predisposing factor.

Temperature, drought and day length, are the most pronounced driving factors for phenological processes (eco-dormancy) in northern areas, and temperature is, among them, the most important and variable factor (Richardson et al. 1974, Linvill 1990). Temperatures can thus be seen as the limiting factor for the northern borders of the natural range of forest species in the area. Dormancy is an important function for tree phenology and for seed germination, related to temperature effect.

Dormancy. which is also related to phenology and seed germination (Walck et al. 2011) can be seriously influenced in many areas. Actually, changes in the "*Chilling Units*" (CU) amount can lead to disequilibrium in phenology for growth, flowering and seed germination, which are crucially important for a successful natural regeneration (Fig. 3). As an example, damages due to late spring frost occurrence are increasing in frequency (Hodkinson et al. 2011).

Each species, or *taxon*, requires a specific average number of CU to activate physiological processes and to break endo-dormancy.

The absence of early lower temperature signals in autumn concluding hardening and too early warmish weeks at the end of winter and in early spring can induce breaking of dormancy too early in many species. In such cases, these species will be not able to avoid damage by late frosts.

Genetic adaptation

Species were so far generally successful to adapt to climate changes (Eriksson et al. 1993).

The mechanisms used to confront such changes have proven effective in a long series of earlier climatic events and changes, even in relatively recent times. Earlier evolution did not account however the most dangerous environmental factor (i.e. humankind and its explosive (and polluting) demographic and industrial development).

Until now, trees have reacted relatively well to the change, and it is commonly thought that genetic variation is still enough to supply materials for the

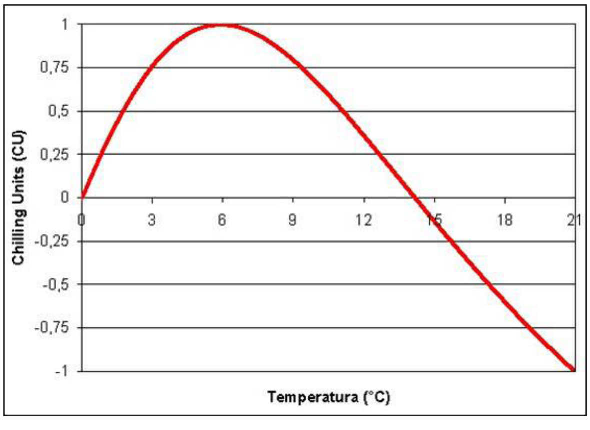


Figure 3 - Average effect of temperature (°C) on the Chilling Units (CU) requirements (Richardson et al. 1974). A CU is the time unit (1 hour) at moderately low temperature (5°C or less according to methods).

adaptation of the populations and to sustain their dynamics (Eriksson 1996 and 1998, Hamrick 2004).

Moreover, even phenotypic plasticity (Schlichting 1986, Pigliucci 2001) and long life cycles of forest trees can support natural regeneration over the decades, in spite of environmental fluctuations. Micro-environmental variability can play an important role in the process of conserving variability and in some cases microclimate refuges can be maintained. Adaptation is estimated to be relatively rapid: 2 o 3 generations can be sufficient for a forest tree population to modify its adaptive patterns.

However, as above mentioned, the speed of environmental change is increasing and there is a general fear that tree species and populations may not be able to adapt rapidly enough.

In the Mediterranean Region, a genetic hotspot region (Fady 2005), forest tree populations are in general small and genetically eroded; they are also generally isolated, and gene flows and gene exchanges between them are often limited.

Most species are distributed by meta-populations, which probably exchanged genes in past times, when the climate allowed their expansion. Nowadays, human activities, at least in Europe, have often interrupted the chance of gene flows definitively, and probably for longer times than similar interruptions in natural conditions.

Thus, in addition to natural factors which may influence the response of trees to environmental change, *social* and *civilization aspects* should be considered as factors which play a role in the spontaneous migration of forest species in places where agricultural areas, industrial trees, roads and human settlements establish insuperable barriers.

In the past, a lot of genetic information was used by forest populations and tree species to adapt to environmental change; the present, rapid climatic changes may exceed the tolerance limits of many species. We have to expect a dramatic loss of variation for populations in the Mediterranean area and, in some cases, we should expect an extinction of the species or part of them, especially in the most extreme conditions of their natural range.

Together with a genetic response, a wide part of the interest of the research community is focused on the assessment of the *quantitative response to change.* In fact, knowing rapidly and experimentally those responses is fundamental to support decision making and the actions aimed at conserving variation.

Conditions deserving special attention are both frequency and intensity of extreme events (frost, drought, high temperatures etc). These extreme events are important factors for the selection within populations and species. It is well known that species response to natural selection is not monolithic, as variation in responses to change can be clearly observed for many species (as many comparative provenance and progeny or clonal tests have widely shown).

Two main complex characteristics are used by forest tree species to be adapted.

Resistance/Tolerance and *Phenotypic plasticity* are the two faces of adaptation and are the basic traits which can be used to study the effects of changes on forest tree populations and their response:

- *Tolerance:* it is the ability of a genotype to preserve its fitness under the pressure of a damage factor. It is genetically settled and fixed by the evolutionary force; it allows each species to occupy a given ecological niche in a given habitat.
- *Phenotypic plasticity:* it is the asymmetric response of genotypes to extreme events. It can be defined as the property of a given genotype to produce different phenotypes in response to distinct environmental conditions.

Both of these properties are presently considered as a key for adaptation to climatic changes.

Among them the role played by evolution in shaping phenotypic plasticity remains still poorly understood (Pigliucci 2005). This property of many phenotypic traits can be used by organisms to start adaptation, which can become the first step of an evolutive process, producing fixation and then divergence and differentiation among populations.

Chambel et al. (2005) discussed this concept as a tool to understand the adaptive processes in forest species.

In a recent review Healy and Schulte (2015) supported the idea that the variety of patterns observed in the gene expression evolution in some species could evidence that a set of traits can occur in organisms, and that each of them can respond to environmental variation through phenotypic plasticity and genetic divergence in different ways. This aspect can influence genetic divergence between species and populations and finally their adaptive potential.

In this field, Santos-del-Blanco et al. (2013) heightened this concept by studying 52 Mediterranean pine populations. They found that pines can represent a model to learn about the adaptive value of allocation to reproduction vs. vegetative growth. That happens thanks to their higher differentiation among-population, from the adaptive point of view, and their ability to cope with environmentally dry and harsh contexts.

Their results followed theoretical predictions and support the idea that phenotypic plasticity for reproduction can be considered as adaptive under stressful environments. Phenotypic plasticity, together with natural selection on reproductive traits, can therefore play a relevant role in the future adaptation of forest tree species in an increasing selective context as in the Mediterranean area. Aranda et al. (2010) and Climent et al. (2009a, 2011, 2013) findings contributed to confirm these concepts as for Mediterranean and Asian pines. This is also important in introduced species adaptation, even in cases where genetic variability seems to be low after their introduction. For instance, Fady et al. (2003) reported about *Juglans regia*, a tree introduced in western Europe by different human migration waves (Pollegioni et al. 2014) and characterized by low genetic variation. They found that, for adaptation, the selection pressure operated by human uses is still high and bud break ranking is significantly correlated with its European *provenances*. As a practical consequence, southern European early bud break plant materials should not be planted under most middle European conditions. Moreover, as in these areas late spring frost can be expected, damages on the apical buds caused by frost are closely correlated to architectural traits (and thus wood quality).

A debate is still ongoing about the real ability of species to adapt in view of so rapid changes, but, pragmatically, strategies and possibly common actions plans have to be established in case they will be in danger of genetic impoverishment or extinction.

Whilst related information on adaptive characteristics of boreal species has gradually been collected over the past years, the lack of knowledge about the Mediterranean species in this regard is still wide. As above mentioned, other influences and pressures due to global change effects as pests and diseases, can affect tree and plant species.

On the sidelines of this work, primarily focused on adaptation to the physical factors of the environment, it is necessary to refer shortly to the complexity of ecosystems hit by the changes. Global change is actually increasing the biodiversity patterns in Europe and in other regions because of the rapid migration of new pathogenic or invasive organisms.

Over their long life-span, forest trees have to develop not only a demographic interaction with individuals of their own and other species, but also with biotic factors migrated or introduced in their natural range, as pathogens, parasites etc. Several case can be recorded where trees have to cope with many new problems.

Many palm species, for instance, are heavily endangered by the attacks of *Rhyncophorus ferrugineus* (*Coleoptera*) in the Region (Gomez and Ferry 1998) .

Recently, the economy of Stone Pine (*Pinus pinea* L.) coastal pinewoods has been seriously damaged by fungal pathogens, among them *Diplodia pinea* (Waterman 1943) and the western conifer seed bug *Leptoglossus occidentalis* (Tescari 2001), which have contributed to important losses of stone pine nuts.

Again, most of the chestnut (*Castanea* spp.) production in Europe is severely affected by *Dryocosmus kuriphilus* (Yasumatsu 1951) gall wasp known as chestnut gall wasp, Oriental chestnut gall wasp or Asian chestnut gall wasp. This pest is native to China and it is rapidly spreading to other world regions where competitors are lacking (Graziolin and Santi 2008).

Challenges for management and policy making

Climate change could have implications for the forest ecosystem services needed for human wellbeing, such as water cycling, carbon sequestration and the production of numerous wood and non-wood products (Millennium Ecosystem Assessment 2005).

FGRs also face other challenges: Sala et al. (2000), for example, showed that land-use change and biological invasions remain key drivers of biodiversity change in Mediterranean biomes.

Nevertheless, all forest management decisions should now take climate change into consideration, but how to take the uncertainty associated with climate change into account in management plans is a formidable challenge.

In a region with the attributes of the Mediterranean, where fragmentation is high because of geomorphology and the history of human activities is long, it is unlikely that the migration of plant species and forest types will be fully able to reduce the impacts of climate change on forests. Even where migration is possible, societies may be unwilling to accept massive forest dieback in some areas and the subsequent natural selection of more suitable genotypes, and may demand intervention.

Societies may also be unwilling to accept a substantial reduction in the productivity of high-yield forests as a consequence of phenotypic plasticity.

Some of the challenges that forest managers will face in developing strategies under the uncertainties of climate change are listed below. For each challenge, research can already provide management options.

Possible actions to be undertaken

Assuming that climatic change is ongoing and that its gravity is increasing, the possibility to undertake initiatives for the mitigation of climate change effects and the conservation of forest genetic resources (FGRs) in the Mediterranean region, should be considered.

In agreement with Sala et al. (2000), integrated efforts by climatologists, ecologists, social scientists, and policy makers will be required to get realistic scenarios of future changes in the Earth system, especially the Mediterranean.

These scenarios should be based on quantitative analyses and have to consider studies of the interactions among factors to which local biodiversity is most sensitive in each biome.

The knowledge of the expected effects on biodiversity will help to develop management practices according to the biological, social, and economic characteristics of the area where you are working on.

Choice of priorities

Research initiatives should be prioritized in order to save time and resources.

A first useful approach to apply priorities might be based on a list of *tree species which are presently considered to be seriously endangered.*

A method for prioritizing actions could be based on choosing *model species able to represent different climatic situations or altitude ranges.*

A third way could be based on choosing *model species which represent a number of genera.*

Màtyàs (2007) reported on a valuable comparison carried out among forest tree populations, according to their main characteristics and the structure of populations, and the corresponding urgency levels for action to be undertaken; see Table 4 below.

Mediterranean pines, evergreen oaks and other tree species belonging to Mediterranean habitats may be initially less endangered than central - northern temperate habitat species, actually they are generally better adapted to drought.

However, with the progressive drying of climate, the increase in weather extremes and related events such as forest fires, and shifts in human activities such as agriculture and grazing (particularly in the southern Mediterranean region), also the habitats in this area will come under increasing pressure.

Isolated populations of many mountain Mediterranean species (e.g. *Alnus cordata*, *Pinus nigra* v. *laricio* and *P. heldreichii*, Cedars and Mediterranean firs) growing at their ecological or geographical margins will be endangered. Most of these populations are small and scattered and have been affected by genetic erosion in the past.

Table 4 - Comparison between species/population structures and their urgency requirements (Màtyàs 2007, modified).

A. Species/population structures requiring **low urgency** for initiatives	B. Species/population structures requiring **high urgency** for initiatives
1. Continuous distribution	1. Fragmented or isolated distribution
2. High density	2. Small or scattered
3. Naturally regenerated	3. Artificially regenerated
4. Effective gene flows	4. Limited replenishment of the gene pool
5. Spontaneously spreading	5. Low dispersal capacity
6. Extensive, zonal habitats	6. Extreme sites as habitat or small size
7. Reproduction unaffected	7. Disturbances in flowering and seeding

Other isolated populations of widely distributed central and northern European species should receive special attention. This may be the case in southern areas of natural ranges in the Mediterranean area. Here, isolated populations growing on southern aspects of mountain sites could not have space to migrate in altitude to follow future climatic isotherm shifts. All these populations are likely to be already seriously suffering the effects of the present climate change, and they cannot migrate as a response to such pressure.

In some case, these populations are accounted and classified as Marginal Peripheral populations, also known as MaPs (Yeh and Layton 1979, Hampe and Petit 2005, Eckert et al. 2008).

Furthermore, it is to be considered that particular attention and therefore priority should be given to species or populations which are isolated and growing under extreme conditions. Very often, these species and populations, important for specific uses or endemic, are really endangered.

In these populations, the gene flow is generally reduced, as well as the ecosystem below a critical mass, and there are problems related to the low dispersal capacity and the genetic erosion.

This is the typical situation where the habitat has been severely reduced and even small additional disturbances can compromise the survival of the population. Consistent examples are *Cedrus libani*, *Abies nebrodensis*, *Cupressus dupreziana* and a number of other spp.

In situ *conservation*

Foresters should be aware that conserving and managing the genetic variability of forest trees *in situ*, following a dynamic approach, is the basis for selection and for developing adaptive management. It is also important to perpetuate the ecosystem functions and services as well as to ensure more resilience to the ecosystem.

In situ, conservationists and improvers can interact in order to select adaptable basic materials within Marginal populations, allowing the production of adapted offspring. Thus, the reaction of basic materials can be tested *in situ*, being exposed to the temporal and spatial variation of micro-environmental conditions. It is evident that *in situ* selection should be carried out mostly on highly heritable adaptive traits, mainly eco-physiological (drought and frost resistance/tolerance) and phenological.

McKown et al. (2014) studied this topic on *Populus trichocarpa* where they found that environmental gradients can shape both the phenotypic adaptive trait variation and the genetic structure.

Gene flow, genetic drift, selection, recombination, and the reproductive system characteristics are factors that act in determining the genetic structure of a population, but the value of the genetic resources of a stand is also strictly determined by the way foresters manage them.

In general, silviculturists do not seem to be aware of these concepts and they also do not seem to be used to account the genetic value of each single tree in the forest and their possible contribution to the structure of the species population they belong to.

Individual trees, through the variation of their fitness and by means of sexual interactions, determine the genetic structure of a population and, together with mutations, they produce variation and are the basis of the evolutive processes, adaptation included.

In silviculture and forest management, as for the *in situ* management of valuable populations, the knowledge of the spatial genetic structure of forests should be a common and shared approach.

A first simple model of structure in a stand is the subdivision of a population in sub-populations or *demes*. According to this model, if a plant population is dense enough, it is likely that pollen and seeds are dispersed not far from the trees that produce them (Sagnard et al. 2011), regardless of the type of dispersion. In this way, the exchange of genes in a population is very slow between groups of trees which are more distant and relatively quicker and easier within these and the entire population can be accounted for a number of sub-populations.

Because of their small size and isolation, isolated demes can differentiate themselves from others due to genetic drift. If their structure is stable for several generations, within demes you may have a certain degree of consanguinity between neighboring trees.

Gene flow between demes counteracts the effect of differentiation. The structuring pattern increases with number of generations and gradually, during that population is consolidating, until a balance between drift and gene flow is reached.

Managers and silviculturists should take in account the genetic structure of populations, as above described, in order to preserve genetic variation and they should therefore have in mind the need to have a good knowledge of the genetic structure and the spatial distribution of the genetic information of the forest they are managing (Lindner et al. 2011, Bolte et al. 2015). This would be necessary to preserve biodiversity and sustainability, as well as to maintain the availability of the selected materials to be used as a source for planting programmes.

As an example, an explorative study (Ducci et al. 2004) showed that in *Quercus cerris* coppices with standards, most of the genetic variation can be found in the left untouched or cut, depending on the practice in progress purpose, dominated stumps. Therefore, new forms of coppice management should be tested in order to preserve an amount of dominated or apparently not useful stumps as a stock of the genetic information belonging to the local gene pool.

Two cases regarding pedunculate oak (*Quercus robur*) and silver fir marginal populations (*Abies alba*) in the Po Valley and in central Italy, respectively, are reported in boxes A and B.

Silviculturists should account the right way to preserve this variation which was in the quoted case study neutral but, at the same time, an indicator of the genetic structure of the populations of concern.

A - A case-study.
The* in situ *management of marginal pedunculate oak populations in the Po Valley.

Most Italian populations of pedunculate oak, fractionated and usually not extended, are made up of a mature layer, consisting of a few trees per unit area and a nearly total absence of regeneration established.

The consistency of the mature layer decreases progressively, due to the natural ageing of individuals or to heavy meteo events, these leading to the collapse of mature trees. Not being available a continuous monitoring over time of the genetic structure, one can only assume the occurrence of an ongoing process of progressive genetic erosion. This aspect may help to explain the very low observed heterozygosity (*Ho*), despite the good potential expressed by high values of expected heterozygosity (*He*) and the high rate of inbreeding.

To address the population to a higher dynamic equilibrium is therefore necessary to carry out silvicultural operations which promote natural regeneration and, more generally, the dynamics of populations. It is necessary to try to encourage the mixing within the population as much as possible, both through improved pollen exchanges between trees and with the active management promoting the occurrence of dissemination and regeneration establishment (internal transfer of seeds and seedlings).

This pro-active practice will influence the following generations, increasing the levels of diversity and interchanges between related groups (demes made by families of siblings or half-siblings), especially within and among peripheral strips of the population, affected by intense genetic erosion.

A well-suited example is given by the small and isolated oak population of Capriano del Colle in the province of Brescia, Po Valley, already described by Ducci (2007).

In relatively recent times gene flows in both pedunculate and sessile oak populations growing in the Po Valley (northern Italy) were interrupted. The main changes occurred during the Renaissance age, when wood exploitation and the use of soil for agriculture had a dramatic rise following the population increase and the diffusion of settlements. Later, the industrial and urban development (XIX and XX century) made the original widespread oak forest covering the plains which were progressively reduced to small-sized, isolated remnants.

The forest of Capriano del Colle is small but relatively large as compared to the forest cover in this area of the Po valley. It has quite a favorable genetic potential useful to restore a dynamic population, now subjected to a high risk of genetic erosion, because of its state of maturity and for the absence of a natural regeneration already established.

Its genetic structure is articulated and clearly identifiable on the ground by clusters (Fig. 4) and characterized by a variation core surrounded by peripheral areas of lower variability. The low mobility of seeds, the ground morphology and the micro-environmental conditions drive the distribution of genetic clusters, following the shape of a small river valley. The site is also characterized by a relatively dry climate as compared to other populations and this may have influenced the genetic parameters, favoring, for instance, certain genotypes rather than others, and negatively affecting the viability of seed and the regeneration establishment in some years.

This attribute should be taken into account in planning any collection activities of reproductive materials.

Seed collections should be performed from trees located in different patches of the population, together with the silvicultural management needed to start population dynamics again and to provide, by targeted practices, sufficient brightness for the development and success of seedlings cohorts under the mature canopy trees. That should be done mainly within the variation core, in order to collect seedlings to be planted in clear areas and in the peripheral population, with lower genetic richness.

Seedlings originated from different areas of the forest, will improve the within population gene flows in the future generations and increase levels of diversity in the most peripheral and genetically eroded population. That will help to preserve the gene pool dynamism, as well as to reduce the likelihood of random rare alleles loss.

As for the *in situ* conservation of forest tree species aimed at **mitigating the effects of climate change**, there is no reliable scientific information available for the Mediterranean area. Many studies have been carried out on the genetics of forest tree populations and on quantitative productive traits in multi-site comparative trials. Such quantitative traits can be considered as indirect indicators for adaptability, but no specific research has been systematically carried out on the effects of climate change.

It is time to start studies on the role of the *in situ* conservation, including analyses on silviculture and tending effects on the genetic structure and therefore on management sustainability.

Konnert and Hosious (2010) discussed on these topics showing the importance of genetic aspects for developing a sustainable forest practice both for silviculture targeted to natural regeneration and for implementing artificial regeneration.

Special attention should be given to mixtures of tree species, and to the control of microclimate, through canopy cover and crown density regulation, to reduce susceptibility to drought.

The central area containing the variation core of the forest of Capriano del Colle (BS).

A peripheral strip of the oak population in Capriano del Colle (BS).

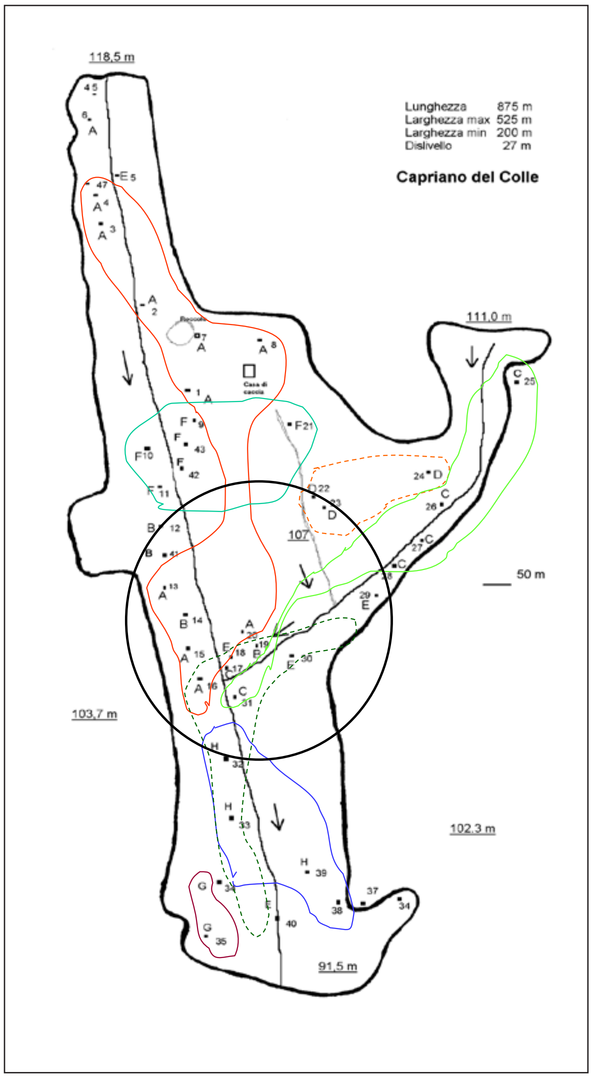


Figure 4 - Distribution of the genetic clusters at the Capriano del Colle (Bs) forest. The central core of genetic variation is circled (Ducci 2007).

Tree spacing and tree density can be managed to control light and then susceptibility to drought. Managers can also change the composition of species diversity to reduce the vulnerability of forests to disturbances as fire, drought, wind, insects or pathogens and find out and choose tree specific compositions better suited to a changed climatic regime.

Changes in tree density will also affect genetic diversity within species (Sagnard et al. 2011). Applying a not extensive silviculture, based on small management areas, will produce patchy alternatives where natural selection occurs. This can also allow managers to maintain the same tree species composition.

Monitoring *in situ*: genetic diversity and adaptability

Diversity is essential for the adaptation of tree populations and monitoring the genetic dynamics of trees is fundamental for developing long-term strategies.

Namkoong et al. (1996, 2002) and Eriksson et al. (1993, 1996, 1998) proposed different methods for monitoring the impact of forest management on genetic diversity by using genetic and demographic indicators to evaluate the efficiency of management actions which drive genetic processes, such as genetic drift, migration and selection, useful to maintain the existing levels of genetic diversity.

The concept of monitoring can be applied at several stages and in different fields of forestry, from the management of forest reproductive materials to plantations and natural populations.

B - The case of Abies alba MaP populations in central Italy (after the LIFE project RESILFOR)

In the framework of the Life Nature project entitled "Resilfor - Restoring Silver-fir Forest" (Miozzo et al. 2014) a few permanent plots were established to monitor changes in stand structures and also adaptive and genetic characteristics. These plots were established in northern Apennines, forest of La Verna (Arezzo) and in the forests of Mount Amiata, an ancient volcano (Southwestern Tuscany).

1) **Forest of La Verna** (community of Chiusi della Verna, Arezzo, Italy)

- Plot A: Lat. 43°42'30,22N, Long. 11°55'54.34"E, 1 ha, aspect NO, alt. 1166 m;
- Plot B: Lat. 43°42'31.80"N, Long. 11°56'01.42"E , 1 ha, aspect NE, alt. 1188 m.

2) **Natural reserve of Pigelleto** (community of Piancastagnaio, Siena, Italy):

- Plot A: Lat. 42°48'17.30"N, Long. 11°38'46.69"E, 1 ha, aspect NE , alt. 780 m [very low elevation as for the Mediterranean area];

Forest structure

The silver fir in the Apennines is undergoing a slow and steady contraction of its range, in favor of broadleaf trees (mainly beech).

Going into detail about each area, the forest of La Verna is substantially made up of fir - beech even-aged forest, with the sporadic presence of other species.

At Pigelleto, vice versa, chestnut first, along with elm, ash and hornbeam are commonly associated in the chestnut phytoclimatic belt.

The structure of fir populations, included in the permanent monitoring plots, revealed a tendency to form an even-aged groups, even if very irregular structure, probably resulting from not well-planned cuts of the past (Pigelleto), or influenced by natural disasters (storms) such as those occurred in La Verna.

Genetic structure

Genetic data, and especially data of the regeneration, fully confirm these features.

The populations still contain relatively high levels of genetic variability useful to support the evolutionary dynamics for future and new challenges. The analysis, both within and among adult/mature layers and on natural regeneration, showed good levels of panmittic balance in the different demographic classes. A trend to homozygosity is relatively usual within forest species especially those where self-pollination is frequent.

The clustered spatial distribution of diversity on the plot, at the ground level, showed to be lightly structured. This feature confirms what has been observed in small populations of other species such as *Abies nebrodensis* in Sicily and pedunculate oak (*Quercus robur*) in the Po Valley (Ducci et al. 1999, Ducci 2007, see box A): diversity is highest at the center of the population, where genetic clusters tend to overlap. This distribution can be driven by forces such as gravity or direction of local winds, which disperse the seeds in the direction of the slope or in the more sheltered inner valleys.

At La Verna and at Pigelleto, the number of genotypic clusters decreases towards the margins of the populations, while outward the number of individual genotypes increases and clusters are fewer.

In the case of small populations, this phenomenon can be generated by genetic erosion at the edges, as well as determined by local ecological factors.

In the case of larger populations, the same occurrence may depend on trees spreading pollen and seeds in the tested plot area from more distant parts or unknown *demes* of the forest, not covered by the analysis and topographically more distant.

Concerning the natural regeneration pattern, the mixture determined by wind dispersion of seeds and pollen is high. This is confirmed by the spatial overlapping of clusters and by the high variability.

Adaptation

To better characterize the populations from the adaptive and plasticity potentials viewpoint, the phenological-cambial activity has been monitored. This technology is very precise and data reliability is high.

High intra-population variability were highlighted, with respect to the earliness and tardiness (dates of the beginning and end of the vegetative phase) of firs. Some fir trees were able to grow until December under warmer conditions, while others have growth periods much shorter. There are a few trees which are highly sensitive to the availability of summer rains, constantly producing false rings, while others are very regular.

A high plasticity of the species was also observed. The phenotypic plasticity is defined as the ability of a genotype. In this case, the species (i.e. the relationship between the Tyrrhenian fir populations) change the phenotypic behavior, in relation to different environmental factors. In fact, the firs of La Verna and Pigelleto revealed to be enough "plastic" to cope with many different environmental conditions. The phenological monitoring allowed to observe both the plasticity at the spatial scale (the two sites), and at the time scale (the years of monitoring) and to observe the behavior of silver in two environments as diverse as La Verna (cold, relatively dry and internal) and Pigelleto (much more temperate and with a longer growing season).

At Pigelleto, the warmer weather until late December in 2011, resulted in phenological cambial stages, typical of spring and summer time.

The results clearly showed how fir copes with different environmental conditions. Its variation in adaptation and plasticity at an individual and population level will be a source of diversity, useful to preserve the species in these areas and to develop adaptive silvicultural strategies.

Guiding principles for managing these populations

It is fundamental that genetic monitoring has been repeated for several years to pick up different reactions in relation to different climatic and biological seasons and trends.

While plots should be managed with the highest standards of ‘close to nature’ silviculture, or at least continuing to proceed as made so far [given the function of monitoring areas], on the other hand, it is basic to manage in reducing the influence of beech where this species tends to be invasive. Anyway, this has to be carried out in a controlled way, by maintaining edge micro climate ’ocean like’ conditions, because this marginal/cline conditions provide protection to fir offspring in the early stages of development.

Silviculturists have to manage the overripe layers of tree population, isolating adult trees vigorous enough to produce and bear fruiting.

The quantitative assessments of molecular genetic variation at either the neutral or the adaptive level can be therefore used.

Advances are being made in genomics and with bio-statistical tools to improve the efficiency and cost-effectiveness of genetic monitoring and the inference on demographic relationships within populations obtained good results (Schwartz et al. 2006, Chybicki and Burczyk 2010).

Recent advances in forest trees were made about association studies between single nucleotide polymorphism (SNP) and adaptive traits (Holliday et al. 2010, Eckert et al. 2009).

The importance of preserving marginal and/or peripheral populations (MaP)

As above introduced, *Marginal Populations*

(MaP) and the genetic information they contain are especially vulnerable.

With this definition, the populations growing at the edges of the natural range of forest species are determined. Margins can be identified at both lower and higher latitudes and similar situations can be generated by other factors, in relation to the elevation effects on temperature and water availability.

Even those populations having a margin context determined by an environmental factor may be marginal, regardless of location, it includes those produced by human influences at the local level.

It is meaningful that in southern areas of many tree species range, most of the present genetic variation is concentrated at the rear edge populations, concentrated in three main hot spots, respectively located in the Iberian peninsula, in Italy and in the Balkans. That is a clear heritage of the Pleistocene glacial refuges.

Marginal populations, which generally survive in less favorable environmental contexts, are typically isolated (geographically separated) from the central continuous range and can be small and at risk of extinction.

Among them, we can identify:

1) populations of the geographic edge (*leading edge* and *rear edge*) that may also coincide with the marginal ecological requirements of the species,

2) marginal populations, from an ecological viewpoint, living in the central range of species but in ecologically marginal conditions as compared with the species requirements,

3) populations growing at the altitudinal margins.

The pioneer populations in the *leading edge*, migrating along the shifting of climate zones, leave behind the central population (*core population*) in its optimum. They are followed, in turn, by progressively more and more rarefied populations which remain isolated from the central core (*rear edge*, or marginal populations).

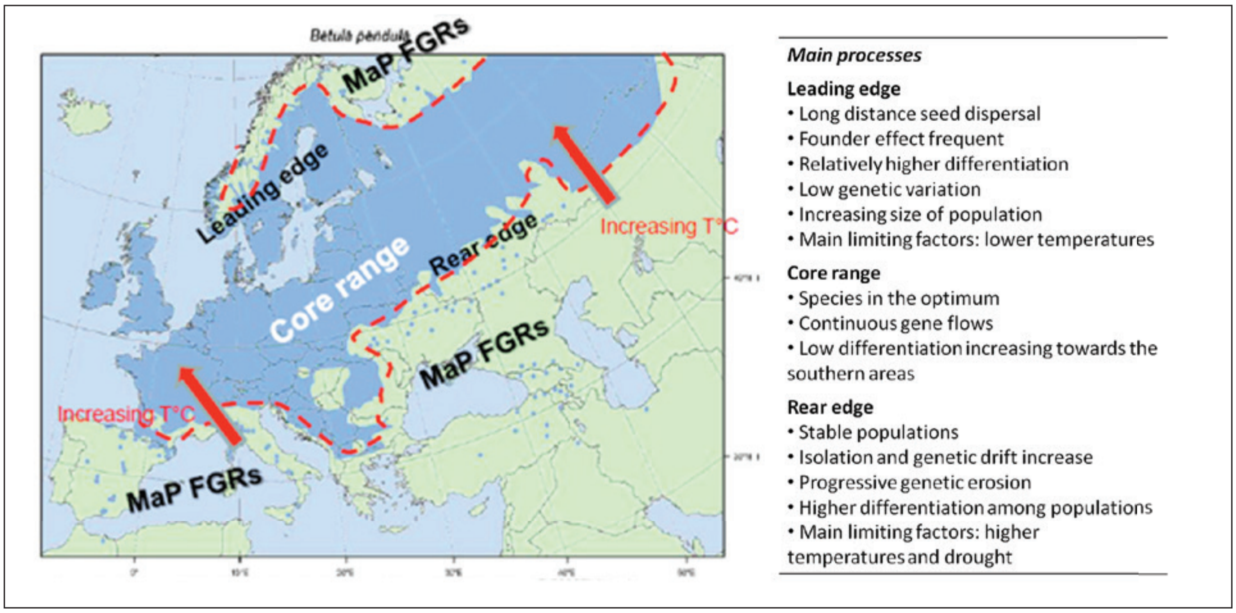
The MaP populations, growing at the geographical edges, may be divergent from the genetic viewpoint due to the joint effect of genetic drift and natural selection, but they can also fill the role of containers of genetic diversity among species due to the outcomes of the spatial-temporal environmental variation at the edges and to the consequent dynamics being induced (Hampe and Petit 2005).

The *leading edge* populations can be characterized by dispersion over long distances and probably the founder effect occurrence is frequent. The *rear edge* populations can be subject to extinction whilst the natural range can undergo latitudinal displacement (*trailing edge*) and sometimes leave small populations surviving in relatively suitable environmental conditions, but with reduced extension (*stable edge*).

The same occurrence takes place when the upland forest populations are being accounted. Here, leading or rear fronts can be detected within the limits of high and lower altitude (Ettinger et al. 2011, Batllori et al. 2012).

According to climatic oscillations, the fronts were reversed several times in past ages, and probably, at each time, populations have shuffled or swapped their genetic information.

The importance of these marginal populations resides in the fact that they may contain adaptive traits of special interest for the species because of



Main processes

Leading edge

- Long distance seed dispersal
- Founder effect frequent
- Relatively higher differentiation
- Low genetic variation
- Increasing size of population
- Main limiting factors: lower temperatures

Core range

- Species in the optimum
- Continuous gene flows
- Low differentiation increasing towards the southern areas

Rear edge

- Stable populations
- Isolation and genetic drift increase
- Progressive genetic erosion
- Higher differentiation among populations
- Main limiting factors: higher temperatures and drought

Figure 5 - Variation of different genetic parameters of the species in relation to the stucture of their range and according to the type of edge in advancement or withdrawal (Ducci 2015, after Hampe and Petit 2005).

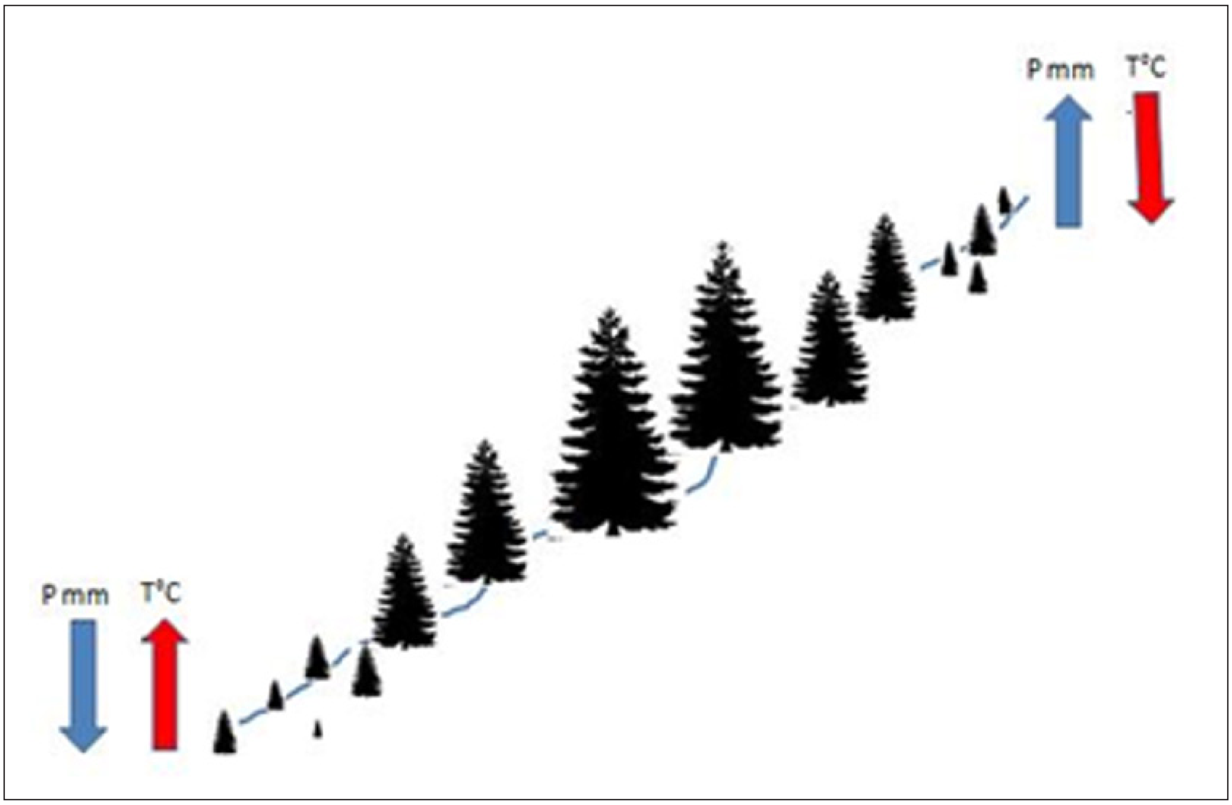


Figure 6 - Representation of the optimum and of upper and lower margins in the sense of the altitude (Ducci 2015, elaborated after Ettinger et al. 2011).

more marked and variable evolutionary factors at margin areas.

Limiting factors or otherwise factors able of exerting selective pressures, typical of southern marginal areas or low altitude, are related to the effects of high temperatures and aridity.

In northern and higher-altitude areas, the main driving factors are connected to lower temperatures.

While, for boreal species, especially in the northern districts of their distribution areas, the information on the genetic structure of populations is wide, for those having southern and Mediterranean range it is still inadequate.

Ex situ *conservation*

Without scientific experimental information on adaptive indicators, it is difficult to manage genetic resources and strategies for their conservation. For this purpose, it is extremely important to profit from the existence of several *ex situ* experimental networks and collections established in the Mediterranean area.

IUFRO, FAO *Silva Mediterranea* and other important international networks established, in the past, wide international multi-site tests; these concerned mainly conifers (4 genera and some 20 species) and *Quercus suber*. This genetic stock, just recently inventoried in the framework of *Silva Mediterranea* (Pichot 2011, in Besacier et al. 2011) and European projects as TreeBreedex and Trees-4Future, will be a sound base on which future actions may be developed.

Traits to be accounted for the future activities will reflect the present trends in forest and tree breeding research, as such research has proved to be efficient (formerly *Silva Mediterranea* itself, IUFRO, EUFORGEN networks, EU TREEBREEDEX, Tree4Future etc.).

Adaptive characters and *phenotypic plasticity* have to be initially investigated as simply phenotypic quantitative traits; in the following steps, the genetic aspects of these traits should also be investigated as a basis for breeding, improvement and conservation, and for genetic mapping (i.e. QTLs, QTNs, SNPs association techniques etc.). The relationship between variation in complex traits and molecular diversity of genes can be studied following a genomic approach, but the identification of genes responsible for variation remains a slow and time-consuming process, especially in long-lived organisms such as forest trees (Vendramin and Morgante 2005).

New strategies have to be identified, tested and adopted according to a common agreement, to reduce the negative impacts of climate change on tree species and populations and the loss of the genetic information they represent. Moreover, the basic concept to be taken into consideration is that *ex situ* conservation should target, where and when possible, dynamic traits.

Reproductive materials and legislation

Ex situ conservation can be carried out all levels: regional, national and international. The possibility for entering international agreements for safeguarding national genetic resources in another country should be reviewed and better developed. This concept is not new. International field trials and common field experiments can be, partially, considered as forms of conservation abroad of genetic resources.

In the case of the Mediterranean region, seriously endangered and valuable forest tree populations or species should be identified and conserved with the support of the international community.

Efforts should be shared among countries and framed within the networks created to host genetic materials in suitable environments and managing them according to common plans. This point is very important and it should stimulate cooperation.

Conceivably, laws and regulations on management *in situ*, nursery systems and trade in forest reproductive materials, should be modified and integrated into the overall forest management, thus contributing to the mitigation of negative climate change effects.

Furthermore, in relation to the above statements, the Revision of *seed zones* and *provenance regions delineation* should be considered, and the present concepts about relatively static Provenance regions systems should be modified following a more dynamic vision, while also the rapid modifications of climate and phytoecological parameters should be taken into account (Ying and Yanchuk 2006).

Almost universally, forest reproductive materials (FRMs) are used in forest plantation projects according to guidelines written under the assumption that local soil and climatic conditions will remain stable. The organization for Economic Co-operation and Development (OECD) is the main reference for FRM certification and standardization in the Mediterranean region, but the European Directive 1999/105/CE also provides general criteria and guidelines for FRM trade within the EU. According to most climate models, climatic conditions in the region will not remain stable in the next decades and there is need to revise the rules on the delineation of the provenance of the species and the transfer of seeds and other reproductive materials (Konnert et al. 2015).

Under this framework, the recent Survey of World Forest Genetic Resources (2014) with the contribution of FAO *Silva Mediterranea* for Forest Genetic Resources in the Mediterranean region should be accounted. Already in the 90's, Topak (1997) inventoried the FRMs used for reforestation in 17 FAO *Silva Mediterranea* countries adopting the OECD standards.

Moreover, the FAO *Silva Mediterranea* database lists national and international forest tree common gardens[1] in the Mediterranean region. Such basic information is essential for rethinking seed zone delineation and provenance selection in the face of climate change.

The recent establishment of the Nagoya Protocol (2014), focused on the Access to Genetic Resources and Equitable Sharing of Benefits arising from their use. This international instrument adopted by the Conference of Parties to the CBD (Convention on Biological Biodiversity) at its X Meeting held in October 2010 in Nagoya, Japan, was opened for signature on Feb. 2, 2011.

The aim of the Protocol is the fair and equitable sharing of benefits arising from the utilization of genetic resources, including the appropriate access to genetic resources and appropriate transfer of relevant technologies, taking into account all rights to those resources and those technologies and appropriate funding thereby contributing to the conservation of biological diversity and to the sustainable use of its components.

The Protocol contains provisions ruling both the access to genetic resources and the equitable sharing of benefits arising from the use of them. A user who wants to access a genetic resource of another country (e.g. a medicinal plant for studying the active ingredient, or to produce a medication) must follow the provided procedure in the country access, providing that resource.

In addition, a contract must be drawn up providing for the equitable sharing of benefits, between user and provider, arising from the use of the resource in question (e.g. profits, technology, knowledge, and so on). Genetic resources are often associated with the traditional knowledge of indigenous and local communities. Therefore some provisions of the Protocol rule the access to such knowledge and the equitable sharing of benefits procured by their application.

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[1] 'Common garden': field test in which many individuals (clones, families, populations) of a given plant species sampled from an identified geographic area are grown in a common environment, making it possible to infer genetic information from the observation of phenotypic differences. These networks were early known as "multisite comparative trials".

Assisted migration

The above mentioned legislative tools can help to develop actions aimed at preserving really endangered genetic resources, when no other possibilities can be considered for their rescue. Assisted Migration is an option still to be studied more in depth.

Examples of artificial migrations or translocation in forest trees are spread in Europe since long time. We can mention agriculture crop species as well as fruit crop trees following mankind in his migrations.

Among forest trees, several historical case studies can be found in areas where ancient civilizations passed and left signs of successful translocations. Some of them are millennial. Genetic evidences of the translocation of walnut along the Silk Road were found by Pollegioni et al. (2014), but we can also record widespread examples as chestnut in western Europe mountain ranges, cypress introduced in Tuscany by Etruscans and Greeks, *Pinus pinea* spread by Phoenician and Greeks in all the Mediterranean, and more recently Greek fir, Black pine and finally Douglas fir as one of the most important and successful recent intercontinental translocations.

Despite trees are used to migrate in response to changing climate eras, the present climate projections show the real impossibility of forest tree species to migrate so rapidly. In most cases, probably species will be able to find out adaptation within their gene pools.

Aitken et al. (2011) discussed this topic concerning boreal populations trees. These populations are characterized by adaptive variation patterns and - as above said - they show moderate to heavy clines in phenology and growth along temperature gradients. These adaptive traits appear to be the result of small effects of many genes, and may facilitate rapid local adaptation despite the high gene flow in the northwestern American area. On this way, the gene flow with alleles linked to adaptive traits to warmer climate conditions may promote adaptation and migration at the leading edge, while populations at the rear will likely face extirpation.

In the opinion of the Authors *'widespread species with large populations and high fecundity are likely to persist and adapt, but will likely suffer adaptation lag for a few generations. As all tree species will be suffering lags, interspecific competition may weaken, facilitating persistence under suboptimal conditions'.*

Species with small populations, fragmented ranges, low fecundity, or suffering declines due to introduced insects or diseases should be candidates for facilitated migration.

So, the idea that most of the widespread species own resources and variation are sufficient conditions for adaptation to climate changes is widely diffused. But, in some cases, the natural tools will not be enough to preserve species and populations and human actions would be probably oriented towards the adoption of Assisted migration methods. In this case, transfer guidelines have to be developed rapidly, possibly based on experimental results or already existing cases.

Assisted migration, implies some human interventions to help a species to migrate. This basic concept can be also extended to single endangered populations. Several variants/synonyms can be found in literature of this definition *as assisted population migration*, *translocation*, *reinforcement*, *assisted population/range expansion*, *assisted long-distance migration* (Ste-Marie et al. 2011). As a very complex development of these variants, Seddon (2010) introduced the concept of migration of groups of species defined as *community construction.*

In the present experiences on assisted migration, a prudential "mimic" approach is generally used. Indeed, Authors highlight the increasing risks of unforeseen influences and consequences when very wide migration distances are being considered (Vitt et al. 20110). For this reason, the within range relocation is mainly diffused.

Anyway, in some extreme cases, a more determined approach should be considered. In Europe and especially in southern areas, an early human activity has left examples of forest tree species relocated and, in a few cases, this presence is reported since several hundred years (i.e. Cypress, Stone pine, Aleppo pine, Chestnut, Firs, Cedars). This artificial old population could be taken into account to test the possible consequences of the long geographic and ecological distances of the past translocations, even from the genetic structure and adaptive viewpoint.

Another basic topic concerns the trade of forest reproductive materials. The present rules concerning forest reproductive materials do not take care of the procedures related to future climate conditions and the associated risks (Williams and Dumrose 2013).

Several techniques, as Assisted gene flow (AGF) between populations and Assisted migration, can help to mitigate any maladaptation due to the climate change effects (Aitken and Whitlock 2013). Several initiatives were undertaken in Canada, where species have access to wide free lands where they can carry out migration strategies.

On the contrary, in Europe situations related to a fragmented landscape are more frequently diffused. In this landscape also the range of many species is fragmented and a huge number of species and populations may be unable to migrate to suitable habitats and get locally extinct.

McLachlan et al. (2007) proposed several examples, comments and considerations about this topic, on how relevant policy analysis and decisions about the opportunity to adopt this approach and at what intensity have to be undertaken.

The authors posed some important and basic questions about the developing of informed policies on Assisted Migration strategies. The first is aimed to identify the demographic trait that should trigger the implementation of assisted migration; a second one is aimed to know how many or which species or other taxa should be prioritized as candidates for translocation, and eventually to know how to manage populations in order to minimize adverse ecological effects.

Human land use may also create an impediment to gene flow among populations. In situations where trees are prevented from migration, human intervention may be necessary to prevent extinction. This action, can take the form of "assisted migration" or "managed relocation", a set of frequently considered controversial techniques useful to ensure the maintenance of (forest tree) populations in a changing global environment through the intentional creation of populations beyond the boundaries of their current presence (Ducci 2011).

The tendency to consider the opportunity to give rise to assisted migration in these cases already exists. As we have seen in the context of the risks for the species and forest populations induced by climate change, migration is an important strategy. Species will be successful in their perpetuation purpose only if able to move and adapt in environments and places where historically they did not previously exist.

In addition to the geographical barriers and the limits imposed by the areal distribution of ecological factors, the effect of human activities on the landscape fragmentation has been the crucial additional factor over the last centuries. It took place with the clearing of the large forest cover and of natural areas.

Nowadays, we have to face an almost permanent discontinuation of possible migration routes which could be useful to establish and/or restore the gene flow by tracking the motion of local climate. This interruption is mainly due to human settlements and agriculture.

In these cases, therefore, there is the need to provide forms of assisted migration, which aims to implement the physical transfer of populations, which are especially recognized for their adaptive or biological value, in areas outside of their natural range.

The main purpose of assisted migration is to preserve the genetic information contained in the original gene pool and restart the evolutionary dynamics along with these demographic - structural patterns as well as to recreate an *ex situ* secondary ecosystem, where they can start dynamics again.

Several definitions of Assisted migration can be found in the literature regarding this topic. Vitt et al. (2009) and S.te Marie et al. (2011) used different key words and definitions to define the concepts of Assisted migration, Assisted colonization, Managed relocation.

A few examples can be cited about species or population translocations: concerning *Pinus albicaulis*, McLane and Aitken (2012) reported their ongoing experiments in Northwestern America to test a model for establishing translocations. Furthermore, in Canada, Gray et al. (2011), tested assisted migration methods on *Populus tremuloides* populations. According to their experimental findings, model projections for this area seem restricted to a short 20-years planning horizon for prescribing seed movement in reforestation programs.

They also found that a safe and realistic climate change adaptation strategy has to be based on a holistic approach to obtain information. Some uncertainty is associated with recommendations for assisted migration, due to the rapid evolution of scenarios.

About Europe, we can cite the experimental case study of *Abies nebrodensis*, the Sicilian fir.

Various inventories and numerous research trials (Morandini 1969, Morandini 1986, Morandini et al. 1994, Virgilio et al. 2000) have shown that this species, although reduced to a small-sized population almost totally unable of originating a viable and dynamic regeneration *in situ*, still contains sufficient variability to enable a rescue attempt (Vendramin 1997, Ducci et al. 1999). This fir was chosen as a model to develop and then to implement an experimental program of assisted migration. Within this program, the residual individuals were transferred in the northern Apennines, in the form of grafted trees, at the beginning of the '90s (Ducci 2011). Two seed orchards were created with these grafts and the obtained seeds made possible to produce siblings that, year after year, are being transplanted into two areas away from any source of pollen contamination. Thus, they will form the first generation in the new environment.

Each of the two areas (Ducci 2014), respecting the climatic requirements of the species, has similar physical environmental characteristics. They are differentiated only with regard to the former vegetation cover, it being in the first case an ancient mixed chestnut and sporadic beech forest with hornbeam, yew and holly. In the second area, an abandoned field ground surrounded by the forest, former conditions ranged from semi-forest cover to full light conditions.

The purpose is to trigger more driving forces, give rise to different dynamics and allow more genetic characteristics to be preserved and to become clear.

In Sicily, Raimondo and Schicchi (2005) carried out a similar programme, both at local and regional level, in the framework of a LIFE Natura project, dedicated to *Abies nebrodensis in situ* and *ex situ* conservation, between 2001 and 2005.

Assisted migration has far-reaching consequences, far beyond the technical problems of physical translocation, all the manifold dimensions of community ecology, conservation and socio-economy being concerned (Richardson et al. 2009). These would need to be addressed also by forest managers and policymakers.

Garzon and Fernandez (2015) tested tools and scenarios for evaluating the sensitivity of target sites and identifying potential sources not yet developed. They used the Spanish and French National Forest Inventories to design scenarios for AM on *Pinus halepensis* Miller and *Pinus pinaster* Aiton, following a projection to 2050. Results suggest that volume and mortality trends are not always correlated with seed sources and targets, that projected provenances mortality do not always follow a southern to northern pattern and that refugia may be useful for compensating for the effects of climate change only in a subset of provenances.

Conclusions

Several indicators confirm that the Mediterranean region is being strongly affected by the climate change.

Over the last decades, temperatures have increased along with the frequency of deep and prolonged drought episodes, while rainfalls reduced by up to 20 % in the Italian peninsula as well as in other regions of the Mediterranean.

By 2100, temperatures are expected to increase from 2°C to 4°C on average, while precipitations could decrease from 4% to 30% and might interact with the already typical vulnerability of Mediterranean countries related to the general environmental degradation which is due to the relatively diffused high human pressure.

These direct and indirect effects of the global change may lead to huge human, social and economic losses.

Concerning forest resources, especially the genetic ones, the observed and predicted effects of climate change, specifically the increased extreme events, bring new threats forth and risk exacerbating the existing pressures, the environmental degradation and the vulnerability of Mediterranean ecosystems, particularly the valuable genetic resources contained within.

Together with climate change effects, several cohorts of natural hazards such as pests, diseases and also the increased frequency and intensity of forest fires, are endangering our resources.

Major, sometimes irreversible, changes are affecting the most vulnerable forest ecosystems where marginal populations of mesic species are growing and have probably developed some valuable adaptive traits (e.g. the rear edges).

The main challenge is thus connected to the opposition to the climate change acceleration, which makes difficult also any adaptation strategy. Only a scientific approach conveying a more in-depth knowledge would be useful to rethink and prepare any kind of strategy. This means that part of the already existing possibly useful data must be reorganized and, again, inferred under a new vision and updated approaches. This requires time and the tools must be adapted to the new needs, and there must be the production of new climatic and phytoclimatic models. Details in mapping have to be improved using smaller scales as well as new software is required for the inference of models and traits related to genomics in adaptation.

The present concept tools (including, modeling, silviculture, nursery legislation, policies etc.) and research networks are still based on a '*static*' or too long-term vision of the environment, whilst a major and rapid dynamism is nowadays perceived (Kerr and Dobrowski 2013).

The generally diffused current low level of silvicultural management of our forests constitutes a real danger for the maintenance of these specific populations, which need to be carefully managed *in situ* with proper and well-focused adaptive cultivation techniques, aimed at preserving their diversity and demographic structure, as well.

Strategies for the management of Mediterranean mountain forests should carefully take into account the issues to strengthen their natural resilience and to equally distribute resources. In this context, urgent initiatives are strongly required to mitigate the impact of climate change on our Mediterranean forest ecosystems and other woodlands.

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Research paper

Climate change impact on a mixed lowland oak stand in Serbia

Dejan Stojanović[1*]; Tom Levanič[2]; Bratislav Matović[1]; Andres Bravo-Oviedo[3]

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Abstract - Climatic changes and bad environmental conditions may lead to forests vitality loss and even mortality. This is the reason why increased sanitary felling operations were performed in mixed oak forests in northern Serbia in 2013 in order to solve the severe dieback which affected some Pedunculate oak (*Quercus robur* L.) and Turkey oak (*Quercus cerris* L.) stands, after the very dry years 2011 and 2012. Dendrochronological techniques were applied to both these oak species collected in a stand, to examine the impact of temperature, precipitation and ground water level on forest growth and investigate the potential causes of the dieback. Differences in tree-ring patterns between surviving and dead trees were not significant according to t-value (from 5.68 to 14.20) and *Gleichläufigkeit* coefficient (from 76% to 82%), this meaning no distinctive responses of the two ecologically different oak species. As for radial increment, pedunculate and Turkey oak trees showed a similar response to environmental variables in this mixed stand. The Simple Pearson's correlation analysis, which was conducted, showed that among three basic environmental variables (the mean monthly air temperature, the monthly sum of precipitation and the mean monthly water level, proxy of ground water level), the water level of Danube river in May and the temperature in April were statistically related to the growth of the four tree groups: (i) pedunculate oak vital, (ii) pedunculate oak dead, (iii) Turkey oak vital and (iv) Turkey oak dead trees, for the period 1961-2010 ($p<0.05$, $n=60$). Similar phenomena had already been observed in the Sava River basin for the growth of pure pedunculate oak forests. The long-term decline of the Danube River water level may be related to climate variations and to the changes of water management, river bed, as well as land-use. Together with the increase of temperature, this decline of the water level, and its potential unavailability in the soil, represents a serious challenge for the mixed oak forests silviculture in the Danube basin.

Keywords - *Quercus cerris*, *Quercus robur*, dendroecology, Danube, dieback.

Introduction

The causes of forests decline are complex and uncertain, as the issue involves different abiotic and biotic factors which are predisposing, inciting and contributing to the decline itself (Manion 1991). Some projections indicate that the global land area that is experiencing heat waves may double by 2020, and quadruple by 2040. This may impact on a wide variety of tree processes such as photosynthesis, leaf area development, stomatal conductance, and transpiration among others (Teskey et al. 2014). Drought-induced forest decline may affect carbon, energy and water balance, with an adverse effect on ecosystem services (Martinez-Vilalta et al. 2012). In fact, many cases of drought-induced forest decline in the European continental climate zone have been already reported (Spathelf et al. 2014).

During the last decades, oak decline and mortality were frequently recorded in lowlands of Serbia. There were several hypotheses about the causes of oak dieback (Stojanović et al. 2013): (i) construction of protective embankment along rivers, which prevented occasional flooding in forests which had been flooded in the past; (ii) inappropriate forest management measures; (iii) change of climatic factors; (iv) attacks of pests and diseases.

Medarević et al. (2009) first reviewed the occurrence of oak mortality in this area stating that economic benefits were reduced from 64% to 95% of what expected due to this problem.

Furthermore, Bauer et al. (2013) provided some useful details regarding sanitary felling on permanent plots.

Stojanović et al. (2013), using dendro-ecological methods, rejected the hypothesis about the negative impact of protective embankments along the Sava River as the main cause of pedunculate oak decline and dieback in the Srem region. Effectively other scientists like Matić (1989) had already argued that intensive thinning operations may lead to oak mortality and Vajda (1948) had recognized the change of climatic trends as the potential cause of occasional oak diebacks in the region.

Application of dendrochronology in the research

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[1] Institute of Lowland Forestry and Environment, University of Novi Sad, Antona Cehova 13d, Novi Sad, Serbia
[2] Slovenian Forestry Institute, Vecna pot 2, Ljubljana, Slovenia
[3] Forest Research Center - National Institute of Agricultural and Food Research and Technology & Sustainable Forest Management Research Institute University of Valladolid-INIA, Madrid, Spain
[*] corresponding author: dejan.stojanovic@uns.ac.rs

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on forest decline is not actually a new approach (Cook et al. 1987), also for oak species outside Europe (Dwyer et al. 1995). For instance, Levanič et al. (2011) investigated pedunculate oak mortality in Slovenia using advanced dendrochronological methods.

Moreover, Stojanović et al. (2014a) recognized the significance of Danube water level for the growth of oak forests, with preliminary results, later extended in this study. Stojanović et al. (2014b) found the same linear trend in the Sava River water level and in the tree-ring widths and provided projections of the Sava future dynamics.

Finally, Stojanović et al. (2015) investigated the statistical relationships between the growth of pedunculate oak stands, the Sava water level, the temperature and the precipitation. Water level in the nearby river, as a proxy of ground water table depth, appeared to be positively correlated with tree growth, while air temperature was negatively correlated.

The aim of this study is to consider more in depth both the drivers of growth (temperature, precipitation and water level) and decline of the observed mixed pedunculate-Turkey oak stand, as well as to analyse the patterns among different tree groups: (i) pedunculate oak vital, (ii) pedunculate oak dead, (iii) Turkey oak vital and (iv) Turkey oak dead trees.

The novelty of this research is in the evaluation of mixed Turkey-pedunculate oak stand, in the parallel analysis of living and dead trees, as well as in the evaluation of Danube River impact to the forest. Besides the evaluated parameters, it may be that air pollution, paired with climate change, played a role in the decline of these forests (Bytnerowicz et al. 2007), but long-term time-series of air pollutants are not available in the area. Our hypotheses were to find out close relationships between environmental factors and growth; distinctive response between Turkey and Pedunculate oak, as well as the difference among living and dead trees.

Materials and Methods

The samples were taken in the late 2013 and early 2014 from a mature stand experiencing severe dieback (Branjevina 08i, Forest Management Unit "Sombor", 45° 28' N, 19° 10' E). Its distance from the Danube River is about 5 km. Such stands in Serbia are managed according to the shelterwood system, with several thinnings and the establishment of a new generation at the end of the cycle. 10 dead and 10 vital trees of pedunculate oak (*Quercus robur* L.) and Turkey oak (*Quercus cerris* L.) were selected. The latter species was dominant because of the larger number of trees.

The stand was arranged according to a single tree mixture. Ecological condition within the stand can be considered uniform. The age of the trees was 120 years, according to forestry plans. Cross-sections were taken at 1/5 height (between 5 and 7 m), because it is assumed that this part of the trunk has the most balanced growth due to water and sugars flow. The samples were dried, cut and polished with sandpaper. They were first scanned in high resolution using the ATRICS system (Levanič 2007) and then the tree-ring width was measured using WinDENDRO.

The chronologies were cross-dated and synchronized with the PAST-5™ dendrochronological software, using both visual on-screen comparisons and statistical parameters (t-value after Baillie and Pilcher (tBP), Baillie and Pilcher 1973, and Gleichläufigkeit coefficient (GLK%), Eckstein and Bauch 1969).

Individual tree-ring widths (TRW) were standardized using ARSTAN for Windows (Cook and Holmes 1999) to remove age-related trends (Cook 1985) and averaged into four tree-ring chronologies, representing each one of the studied groups. ARSTAN was also used for the calculation of all the basic statistical parameters of the tree-ring widths.

BootRes package (Zang 2010) allowed the calculation of the bootstrapped Simple Pearson's correlation between environmental factors (water level of the Danube River, air temperature and precipitation) and TRW residuals for the period 1961-2010. We analysed the months of the year prior to ring formation up to the end of the growing season in the year of ring formation (displayed on the x-axis marked as small letters and capital letters, respectively). Significant correlations ($p<0.05$, $n=60$ years) were displayed with darker colour.

R package berryFunction was used to construct climate diagrams, according to Walter and Lieth (Boessenkool 2015). The mean monthly climate data and Danube water level data were obtained from the Hydro-meteorological Service of the Republic of Serbia for the station Sombor (45° 46' N, 19° 09' E) and the measuring point Bezdan (45° 50' N, 18° 51' E), respectively.

Results

The differences between the chronologies of the surviving and the dead trees and the tree species were not significant in dendrochronological terms (Tab. 1). All the four analysed groups showed a declining trend over the past decades (Fig. 1).

With respect to the tree-ring widths, pedunculate and Turkey oak trees, in this mixed stand, showed a similar growth pattern. According to tree-rings, 7

Table 1 - Statistical parameters among the four groups of oaks. Values of GLK coefficient >75.00% and t_{BP} >4.00 mean that the pairs of chronologies are similar.

	Pedunculate oak - live	Pedunculate oak - dead	Turkey oak - live	Turkey oak - dead
Pedunculate oak - live	x	81.60	78.20	76.00
Pedunculate oak - dead	10.50	x	79.10	78.60
Turkey oak - live	9.27	10.90	x	82.00
Turkey oak - dead	5.68	12.80	14.20	x

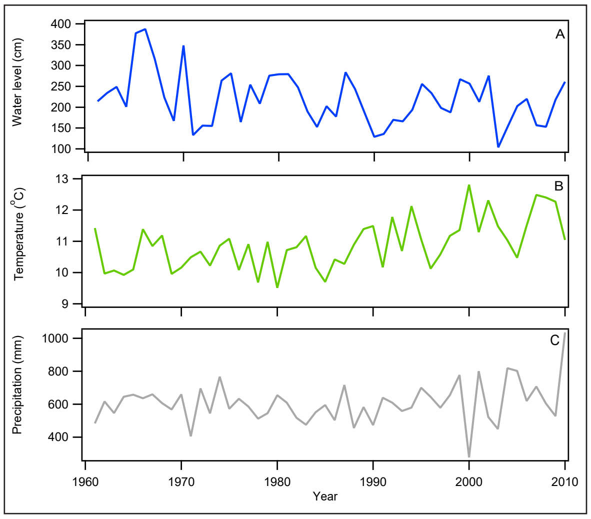

Figure 2 - Time-series of (A) mean annual Danube water level (Bezdan station), (B) mean annual temperature (Sombor station) and (C) annual sum of precipitation (Sombor station) for the period 1961-2010.

out of 10 Turkey oaks, that experienced mortality, died in 2012, while just 2 out of 10 pedunculate oaks died the same year and all the others in 2013.

Time-series and climate diagrams, according to Walter and Lieth, show the increasing air temperature trend, the decreasing water level trend and the change of precipitation regime (more intensive extreme events) in the period 1991-2010, as compared with the reference period 1961-1990 (Fig. 2, 3 and 4).

The mean annual air temperature in the period 1991-2010 increased by 0.8 °C, while the annual amount of precipitation dropped by 55 mm in 20 years. Besides the change in climate statistics, we also observed seasonal changes in the temporal distribution and in the amount of precipitation, with a heavy decrease in winter and early spring. This might lead to a decreased water accumulation in the soil and an increased drought stress in the trees, especially at the peak of the growing period.

An in-depth analysis of the water level data of Danube River shows that, beside a decrease of more than 50 cm in the height of water level in the summer months (June, July and August) there is also a shift in the peak of the highest water level from summer months (1961-1990) to spring months (1991-2010).

A correlation analysis between the tree-ring indices and the three environmental variables, i.e. air temperature, precipitation and water level of Dan-

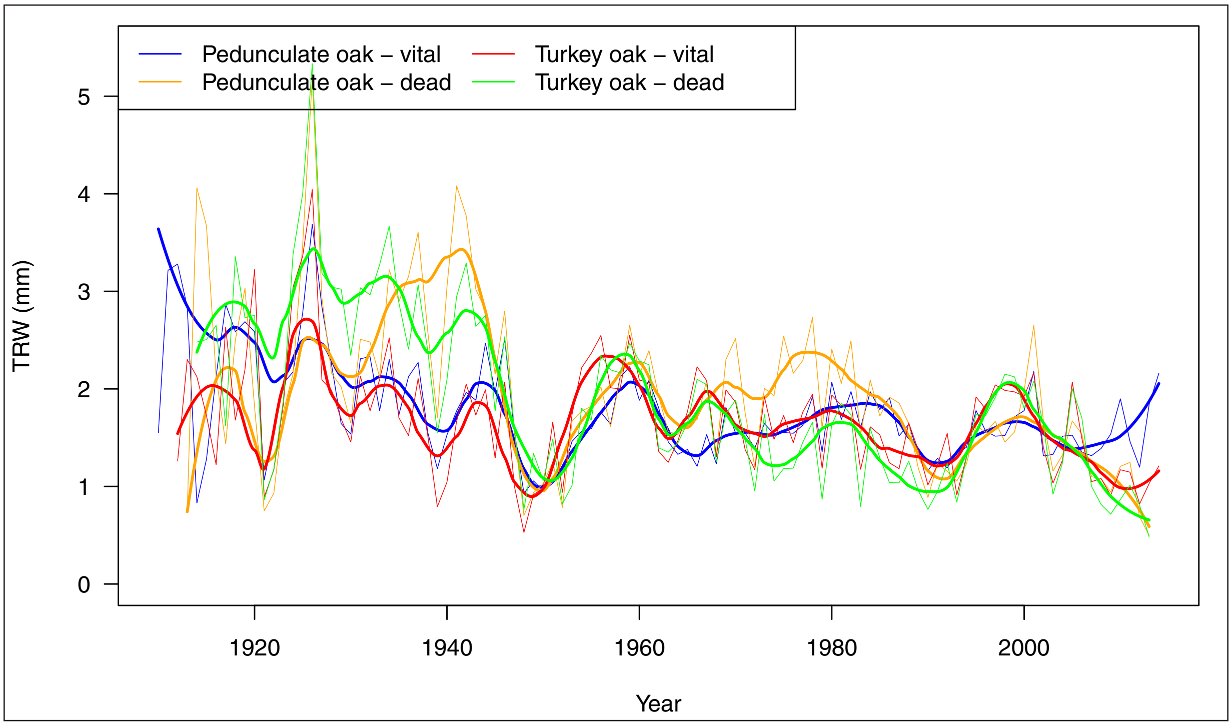

Figure 1 - Mean tree-ring width chronologies (thin lines) of the four tree groups (pedunculate and Turkey oak, vital and dead trees) at the Branjevina stand. Spline curves (thick lines) describe the low frequency growth trend. Each tree-ring width chronology is based on 10 trees.

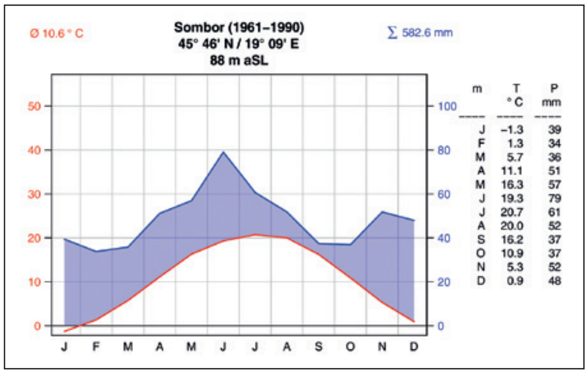

Figure 3 - Climate diagram at the Sombor station for the period 1961-1990.

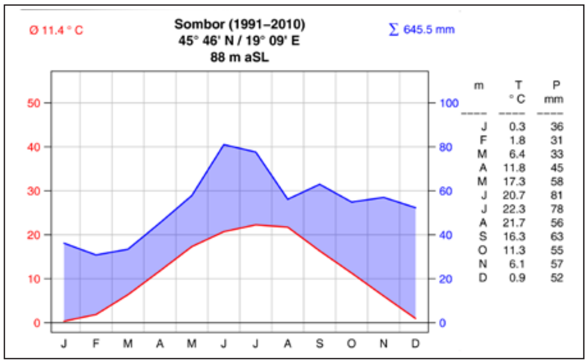

Figure 4 - Climate diagram at the Sombor station for the period 1991-2010.

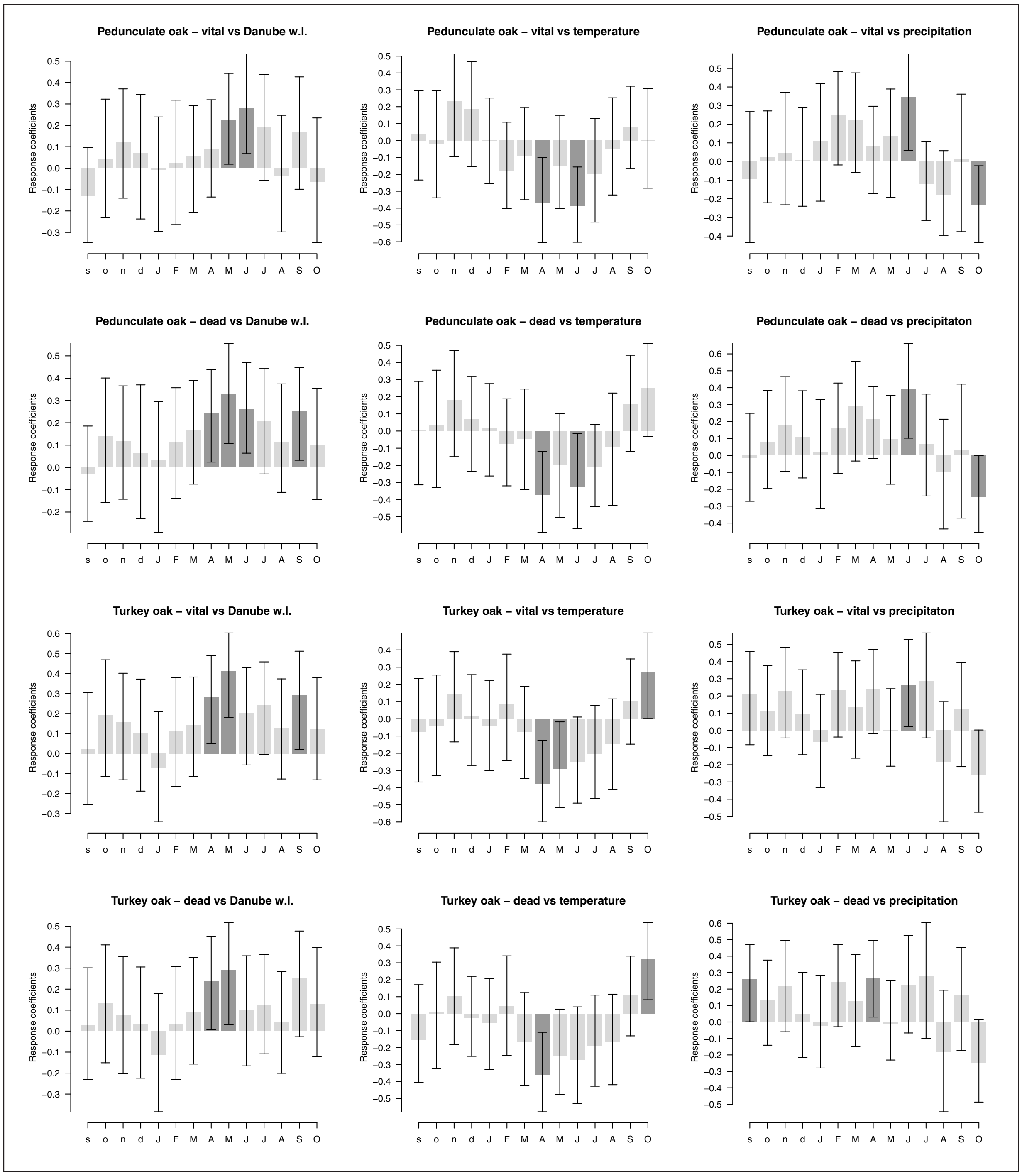

Figure 5 - Bootstrapped Pearson's correlation between tree-ring width residuals and Danube water level (left), air temperature (middle) and precipitation (right) at the Sombor station in the period 1961-2010 for the four groups of trees (top-bottom): (i) pedunculate oak vital, (ii) pedunculate oak dead, (iii) Turkey oak vital and (iv) Turkey oak dead. Months marked by small letters are from the year prior to the growth and capital letters represents the year of the growth. Dark colour represents significant correlation at $p<0.05$ (n=60).

ube River for the period 1961-2010, showed that the water level in May (as a proxy of the ground water level) and the air temperature in April were significantly correlated for all the four tree groups (Fig. 5). The precipitation in June correlated significantly with the growth of pedunculate oak tree groups for the observed period.

Discussion

The results confirm the hypothesis of a relationship between the growth of mixed oak forests and specific environmental variables (the water level in May and the temperature in April for pedunculate and Turkey oak). The observed change (decrease of water level, increase of air temperature and change of precipitation regime, Fig. 2) took place along with the increased mortality in oak forests.

A few other studies support the findings of this research. For instance, Stojanović et al. (2014c) focused on pedunculate oak as one of the most potentially endangered tree species in Serbia, according to different climate change scenarios and the use of ecological niche modelling. Since the extremely dry years 2011 and 2012, about 7% of the growing stock in a compartment of 400 ha was cut in sanitary felling operations (more than 10,000 m^3 of wood) in 2013, in the wider area concerned with this research (Public Enterprise *Vojvodinašume* - Serbia).

A similar phenomenon regarding the impact of environmental variables on tree growth was recently observed in the Sava River basin. Stojanović et al. (2015) found that the Sava River water level and the air temperature in April, May, June, July and August played a key role in the growth of pedunculate oak in the lowlands. A new finding was that the relationship between tree-ring growth and water level has smoothly weakened during the last decades, according to a running correlation analysis, whilst the one between growth and precipitation became more evident, which led to the conclusion that the water level of Sava river, and consequently the ground water level, became so low that roots could not reach the ground water anymore and the trees needed to rely only on precipitation.

The similar growing patterns of pedunculate and Turkey oak, within the investigated mixed stand (Table 1), draw attention to the non-distinctive response of two ecologically different species, this leading to reject the former hypothesis. The phenomenon may be explained by the functional redundancy (Rosenfeld 2002), i.e. the observational evidence that a few species perform similar roles in communities and ecosystems, with the implication that they may be substituted without compromising the ecosystem processes (Lawton and Brown 1993). The full mixture of the two oak species may also explain their common growth response. The analysis of C and O isotopes will, in case, further contribute to the understanding of physiological traits within the investigated tree species and tree groupings.

The long-term decline of Danube River water level may be related to multiple factors: the climate change, the water management, the river bed and/or land-use (Stojanović et al. 2014a). Teskey et al. (2014) pointed out that the drought stress followed by heat waves can lead to an increased tree mortality. With regards to this statement, the increase of air temperature and the change of precipitation regime should be accounted in future studies, where, in particular, the change in precipitation regime means namely less rain during the winter months and a decrease of the overall amount of precipitation (Fig. 2 and 3).

Here, the Danube water level was used as the proxy of ground water table. According to Stojanović et al. (2015), the Sava River water level was highly correlated with the ground water table throughout a sixty-year period. The correlation was above 0.7 with a two-month lag. Since the Danube and the Sava River are both flowing through lowlands and the oak forests are similar with respect to their distance from the rivers and management practice, we assumed that similar ecological impacts exist.

These are the variables to be accounted in the context of future forest management: the observed trend in the Danube River water level drawdown, the air temperature increase, the precipitation regime change, as well as the growth decline of mixed oak forests.

Conclusions

- The recorded differences in tree-growth patterns between pedunculate oak and Turkey oak, both for living and dying trees, were not statistically significant in dendrochronological terms in the analysed context, in opposition to own ecological requirements, according to general forestry knowledge.
- The correlation analysis showed that, according to three basic environmental variables (i.e. the mean monthly temperature, the mean amount of precipitation and the mean monthly water level), the Danube river water level in May (as a proxy of ground water level) and the air temperature in April were statistically related to the growth of all the four studied tree groups over the period 1961-2010.

Acknowledgements

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Research paper

Stand structure and influence of climate on growth trends of a Marginal forest population of *Pinus nigra* spp. *nigra*

Maurizio Marchi[1], Cristiano Castaldi[1*], Paolo Merlini[1], Susanna Nocentini[2], Fulvio Ducci[1]

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Abstract - The Black pine of Villetta Barrea (*Pinus nigra* ssp. *nigra* var *italica*) is a variety of the *nigra* subspecies. It is naturally distributed only in the Abruzzo Region, near the village of Villetta Barrea, with a rear-edge Marginal Population. A dendrochronological sampling of the population was implemented with the aim of studying its stand structure and the most probable interactions between growth trends and climate. Mensurational data were used to characterize the stand and, furthermore, the general correlation function (CF) and the moving correlation function (MCF), with a 30 years window, were used to assess the interrelation between the growth of the tree rings and the climate.The results indicated that the past forest management, mainly carried out with thinnings from below and selective cuttings, influenced the current structure of the forest (mean diameter) but no differences in growth trends were detected within the population. The survey on Villetta Barrea Black pine showed a positive and statistically significant correlation between the ring-width and the average temperatures of the months of December (before the ring formation - t-1), February and March; but it also showed a negative correlation with the temperatures of July, September and October of the current year (t). Moreover, the analysis with moving correlation functions suggested that, in the last decades, the population has negatively reacted to very few climate factors and, in particular, to the changes in temperatures (both minimum and maximum temperatures). This is especially true for the shifts occurred in September, the year of the ring formation.

Keywords - *Pinus nigra* ssp. *nigra* var. *italica,* Villetta Barrea, Marginal Forest Population, Abruzzo, tree-rings.

Introduction

Tree-rings analysis is becoming a common technique used for analysing forest resources, with particular regard to the marginal forest populations (Hampe and Petit 2005). It can help in: (i) investigating past endogenous and exogenous dynamics; (ii) detecting correlations between species and climate and finding pointer years (Spiecker 2002, Gallucci and Urbinati 2009); and, finally, (iii) forecasting species adaptation potential to the Global Change effects (Linares and Tiscar 2010, Amodei et al. 2012, Mazza et al. 2013). Furthermore, it is also a useful tool for the management of forest resources, because climate change may have different impacts on different forest ecosystems.

The expected changes in tree-growth might influence the competitive relationships between species, genetic pools and the geographic distribution of forest species (Lindner 2000). Following climate change effects, it is likely that forest species will migrate or will have to adapt to new environmental conditions (Parmesan 1996, Parmesan 2006).

In such a framework, and to make a better use of existing potentials and/or minimize the negative impacts of climate change on forests, conservation strategies should be developed principally in the southern Mediterranean area. A large number of “rear-edge Marginal populations” (Hampe and Petit 2005) is actually located here because the area was a glacial refugium (Petit et al. 2003, Afzal-Rafii and Dodd 2007).

In particular, the European Black pine (*Pinus nigra* J.F. Arnold 1785) can be considered a collective and Tertiary-relict species which was already present during the Pliocene, in sites where it occurs at present (Vidakovic 1974). It continued to spread during the Quaternary age (Gellini and Grossoni 2003) and, due to its wide and very discontinuous distribution, genetic and phenotypic variability is very high among populations (Isajev et al. 2004). Botanists have described at least fifteen subspecies in the course of time (Fenaroli and Gambi 1976), but today there is a general agreement on the division into six subspecies (Quézel and Médail 2003), ranging from Spain to Turkey. In spite of this, many isolated populations have been recognized, due to the fragmented range of the Black pine across Europe.

The Black pine of Villetta Barrea (*Pinus nigra* ssp. *nigra* var. *italica*) belongs to the nigra subspe-

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[1] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy
[2] University of Florence, Department of Agricultural, Food and Forestry Systems, Firenze, Italy
[*] corresponding author: cristiano.castaldi@entecra.it

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cies and is native of the Abruzzo Region (Central Italy), near the small town of Villetta Barrea (41.7768 N, 13.9374 E). The species is currently distributed on the two opposite sides of the Sangro valley, on approximately 400 hectares, and is partly included in an integral reserve in the Camosciara area (Abruzzo National Park).

In order to study the relationships between growth, climate and forest management of the Villetta Barrea Black pine, we investigated the only official seed stand for the *italica* variety of *nigra* subspecies existing in Italy and in Europe (code number “ABR04” of the Regional Register of the Basic Material of Abruzzo), which is also the only managed part of this Marginal Forest Population (MaP). Mensurational data were used to determine the stand structure in relation to the site attributes and the past management, while the tree ring series were analysed to determine the influence of climate on growth trends.

Materials and methods

Study area and silvicultural history

The seed stand covers an area of about 105 hectares which is characterized by a typical Mediterranean climate (Fig. 1). It is mainly a pure-pine stand, variously mixed with beech stools, mostly in the more humid zones and at the higher elevations. The last management plan of the Municipality of Villetta Barrea (valid for the period 2002-2011), divided the seed stand into five compartments (see Tab. 1).

Many documents were found in the repository of the forest administration of Villetta Barrea and reported in the last management plan (Chapter 5 of the approved document). Even if very few documents described the past silvicultural treatment, the main practice of the past was a sort of selective felling. It is mentioned that the oldest cutting dates back to the early 1600, when the Black pine was used principally for buildings and infrastructures. A sort of selective logging was often conducted across the whole area, until the first decades of the twentieth century.

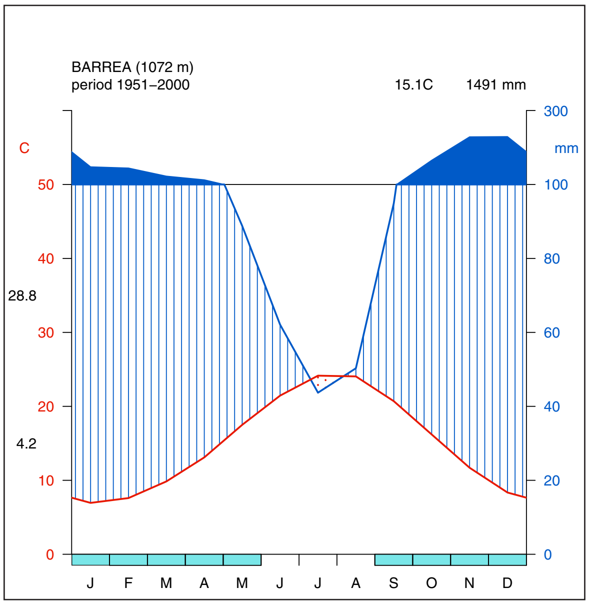

Figure 1 - Walter & Lieth diagram for the location of Barrea, the nearest meteorological station to Villetta Barrea.

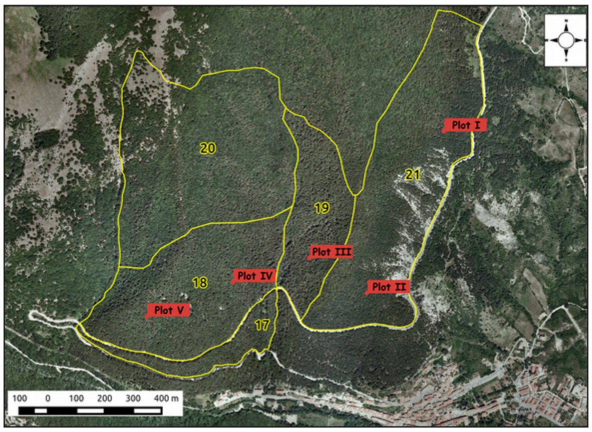

Figure 2 - Spatial distribution of survey plots (red points and labels) and forest compartments (yellow lines and numbers) across the investigated area.

Many economic transactions were registered by the forest administration, reporting the amount of the sold trees, the purchaser and the price. A few trees were also felled for the internal use of the community of Villetta Barrea.

Since 1924, the National Forest Service (office of Villetta Barrea) promoted a change, from this type of selective felling, towards an even-aged silvicultural approach which was aimed at giving more light to the soil; this condition being believed to better maintain the black pine in pure stands. Nevertheless, this practice was never really applied and pine stands have been slowly abandoned.

Survey of mensurational parameters

Five circular plots with 20 metres radius were placed in the study area to describe stand variability (Fig. 2). Plot position was initially chosen following a random but stratified criterion (one plot per compartment). However, after a first field survey, two compartments were excluded from the analysis: (a) the unit 17, because too small and without any substantial structural difference from unit 18 (Tab. 1); (b) the unit 20, mainly dominated by beech coppice black pine, being present only with isolated trees or small groups.

Consequently, 2 of the 5 plots were re-assigned to the two larger compartments (18 and 21). The position of each plot was recorded using GPS and all the sampled trees were numbered, making the plots permanent for any further analysis or survey.

In each plot, we measured the diameter at breast height (DBH) of all trees and the total height on a

Table 1 - Main characteristics of the analysed compartments and survey plots.

Compartment	Area	Elevation	Slope	Aspect	Plot
17	5.13 ha	1080 m	40%	S	-
18	22.63 ha	1175 m	50%	SE	IV ; V
19	11.64 ha	1200 m	50%	W	III
20	33.74 ha	1470 m	60%	SE	-
21	31.86 ha	1200 m	65%	SE	I ; II

representative sample of 10-15 trees (25% of total number). Also the trees volume of each species was calculated with the ForIT package (Puletti et al. 2014) of R Cran software (R Core team 2014), i.e. the implementation of the biomass and volume models worked out by Gasparini and Tabacchi (2011) and Tabacchi et al. (2011) for the 2nd Italian National Forest Inventory (INFC 2005).

A non-parametric ANOVA on DBH was performed to assess the differences between plots. Each plot was considered as a different treatment, while differences among the plots in slope and aspect were included into the error variance.

Dendrochronological sampling

The dendrochronological samples were collected following the “Principle of aggregate tree-rings” (Cook 1987) this being the more largely used in dendrochronology. The principle states that any individual tree-growth series can be "decomposed" into an aggregate of environmental factors, both "endogenous" and "exogenous", affecting the pattern of tree-growth over time. The terms "endogenous" and "exogenous" are used to differentiate forest disturbances developed by the trees themselves (endogenous), from disturbances arising from processes independent from the forest (exogenous). For instance, the gap-phase is an endogenous stand dynamics process, whilst an insect attack or a thinning implementation are exogenous processes.

The aggregate series in a fixed moment “ t ” can be expressed with the formula [1]:

$$R_t = A_t + C_t + D1_t + D2_t + E_t$$

where:

- R_t is the observed ring-width series;
- A_t is the age-size related trend in ring-width;
- C_t is the climatically-related environmental signal;
- $D1_t$ is the disturbance pulse caused by a local endogenous disturbance;
- $D2_t$ is the disturbance pulse caused by a stand-wide exogenous disturbance;
- E_t is the largely unexplained year-to-year variability not related to the other signals.

A_t, C_t, and E_t are assumed to be continuously present in R_t, while $D1_t$ and $D2_t$ may or may not be present depending on a disturbance occurred at a considered time or not. When the aim is to study the relationships between growth (R_t) and climate (C_t), the other factors should be minimized and, consequently, a correct sampling of the trees is very important.

Following the structure of the formula, a data collection and a subsequent pre-analysis on the seed stand of Villetta Barrea were made to minimize the effects of A, D1 and D2 and maximise C. After the forest mensuration survey, 5-7 cores at each plot (depending on the abundance of suited trees) were extracted with a 5-mm diameter increment borer, at breast height, from healthy, dominant and straight trees, to maximize the effect of “C”. Each series was then prepared in the lab on a wooden support, measured with LINTAB6® and cross-dated to minimize or eliminate any probable error due to missing rings or reading mistakes. Afterwards, each tree-ring series was standardized separately with a double detrending procedure. The negative exponential curve was used to remove the trend due to the tree circumference increasing with age (A), whereas low-frequency variance and other disturbances (D1 and D2) were removed using a spline function (Cook 1981) with a 50% frequency response (cut-off) of 10 years to emphasize higher inter-annual frequency climatic variance (Cook 1981, Biondi and Visani 1993, Amodei et al. 2012).

Before any classical climatic correlation analysis, and in order to complete the information derived from ANOVA on DBH, both not-standardized and standardized tree ring series were also used, in a second ANOVA, to asses differences between plots (for the common growing period only). The analysis was performed to check dissimilarities and to verify if the plots were grouped in the same way as DBHs .

The influence of climate on tree-ring growth was investigated using the mean correlation function (CF) and the moving correlation functions (MCF) based on Pearson’s correlation coefficients (Fritts 1976). CF and MCF are based on the same assumptions but they use different principles and time-periods. While CF takes into account the whole growing period of trees, MCF uses a smaller interval of time repeated for the whole period (generally 20-30-40-50 years, depending on the available data, species sensitivity and case-study). In this case, a 30-year window was used to avoid biases which could be induced by extreme events and to retain the influence of mid-frequency climate variations. Each moving window analyzes a cycle of 30 years, going forward from year to year. In both cases (CF and MCF) monthly climate variables (maximum, minimum temperatures and monthly precipitation) were sequenced from October of the previous year

Table 2 - Mean mensurational values of survey plots.

PLOT (Comp.)	M_dbh (cm)	CV_dbh	M_ht (m)	Tr/ha (m²)	G/ha_P (m³)	Vol/ha_P (m²)	G/ha_B	Age
I (21)	24.5	42%	13.9	1138	46.6	321.0	1.3	124-179
II (21)	26.4	56%	14.3	923	50.6	372.5	0.2	104-145
III (19)	22.8	64%	11.8	1082	39.6	259.7	0.7	143-184
IV (18)	28.0	35%	19.5	1178	60.2	574.5	0.8	80-99
V (18)	28.3	41%	16.52	724	45.7	266.0	2.0	104-118

M_dbh = mean diameter at breast height; CV_dbh = coefficient of DBH variation; M_ht = mean height; Tr/ha = number of trees ha^{-1}; G/ha_P = Basal area of Pinus ha^{-1}; Vol/ha_P = Volume of Pinus ha^{-1}; G/ha_B= Basal area of Broadleaves ha^{-1}

(t-1) to September of the year of growth (t) and the results of the correlation functions were tested for significance using the 95% percentile range method after a bootstrap process with 1,000 replications.

The *dplR* package (Bunn et al. 2014) and the *bootRes* package (Zang and Biondi 2012) of R cran software were used for the tree ring series management and the computation of the climatic correlation.

Climatic data

Data from a weather station located in the Barrea village (41,7570 N; 13,9919 E approx. 1,000 metres a.s.l.) were initially made available. Data series were anyway discontinuous, especially regarding rainfall. To get through the problem, a complete dataset was derived from ClimateEU database (http://www.ualberta.ca/~ahamann/data/climateeu.html), an unpublished software for the interpolation of climate data from PRISM database (Daly et al. 2008). It was applied for monthly precipitations and temperatures from 1901 to 2009. ClimateEU data were compared with local data calculating the fitness of ClimateEU tested with a regression method. In addition, Mann-Kendall non-parametric test was applied to assess the presence of climatic trends, possibly influencing the analysis (Brunetti et al. 2006).

Results

Mensurational data were collected during the growing season 2012 and are summarized in Tab. 2, Fig. 3 and 4. Mean DBH ranged between 22.8 cm (plot III) and 28.3 cm (plot V) whilst maximum tree height varied from 23 m (plot IV) to 16.1 m (plot III). The highest values of tree mean height (19.5 m), number of trees (1,178 ha^{-1}), basal area per hectare (60.2 m^2 ha^{-1}) and volume (574.5 m^3 ha^{-1}) were measured in plot IV. Plot III had the lowest mean tree height (11.8 m), basal area (39.6 m^2 ha^{-1}) and volume (259.7 m^3 ha^{-1}) and the highest variation of DBHs (64%). In addition, plots III and IV were characterized by the oldest and the youngest dominant trees, respectively. Height curves are compared in Fig. 3. Plots I, II and III were shaped similarly as for slope but with different values. In general, the stand structure revealed to be very variable chiefly for mean tree height and standing volumes.

The ANOVA on DBH confirmed the high variability and, as expected, grouped plots exactly according to compartments (Tab. 3 and Fig. 4).

The dendrochronological sampling was implemented in the following year (2013) before the start of the growing season. The main statistics on tree rings series, plot chronologies and mean stand chronology are reported In Tab. 4. The age of dominant trees ranges between 80 and 184 years with a mean annual increment between 0.627 mm (Plot IV Tree 1 - P4T1) and 1,967 mm (Plot V Tree 1 - P5T1). Sensitivity was generally low whereas the first order autocorrelation was quite high, it emphasizing the high inter-annual correlation between tree-ring widths. Calculating first-order autocorrelation coefficients on standardized indices, the absolute values ranged between 0.11 and 0.22. That means that only a small amount of the low-frequency year-to-year variation was not corrected with the standardization procedure.

Similarly to DBH ANOVA, the analysis on raw tree rings series on the common growth period (1933-2012) too, showed statistically significant differences among plots. Plots were however grouped differently following the age of sampled trees (Tab. 5 and Fig. 5). As expected, ANOVA on detrended (i.e. standardized) chronologies did not show the same differences (Fig. 6).

Before the searching of climatic correlations, ClimateEU data were carefully checked and compared to local data for the common time-period available (1955-2010). Regressions were always highly significant with a very high adj-R2 for temperature, but not for precipitation due to many missing values (mainly for storage errors) in the Barrea's database. At all

Table 3 - Results of Kruskal-Wallis Rank Sum Test and relative post-hoc test (Wilcoxon Rank Sum and Signed Rank Tests).

Statistical Mean DBH	Plot (compartment)	Group
26.43	IV (18)	A
26.28	V (18)	A
23.03	II (21)	B
22.63	I (21)	B
19.19	III (19)	C

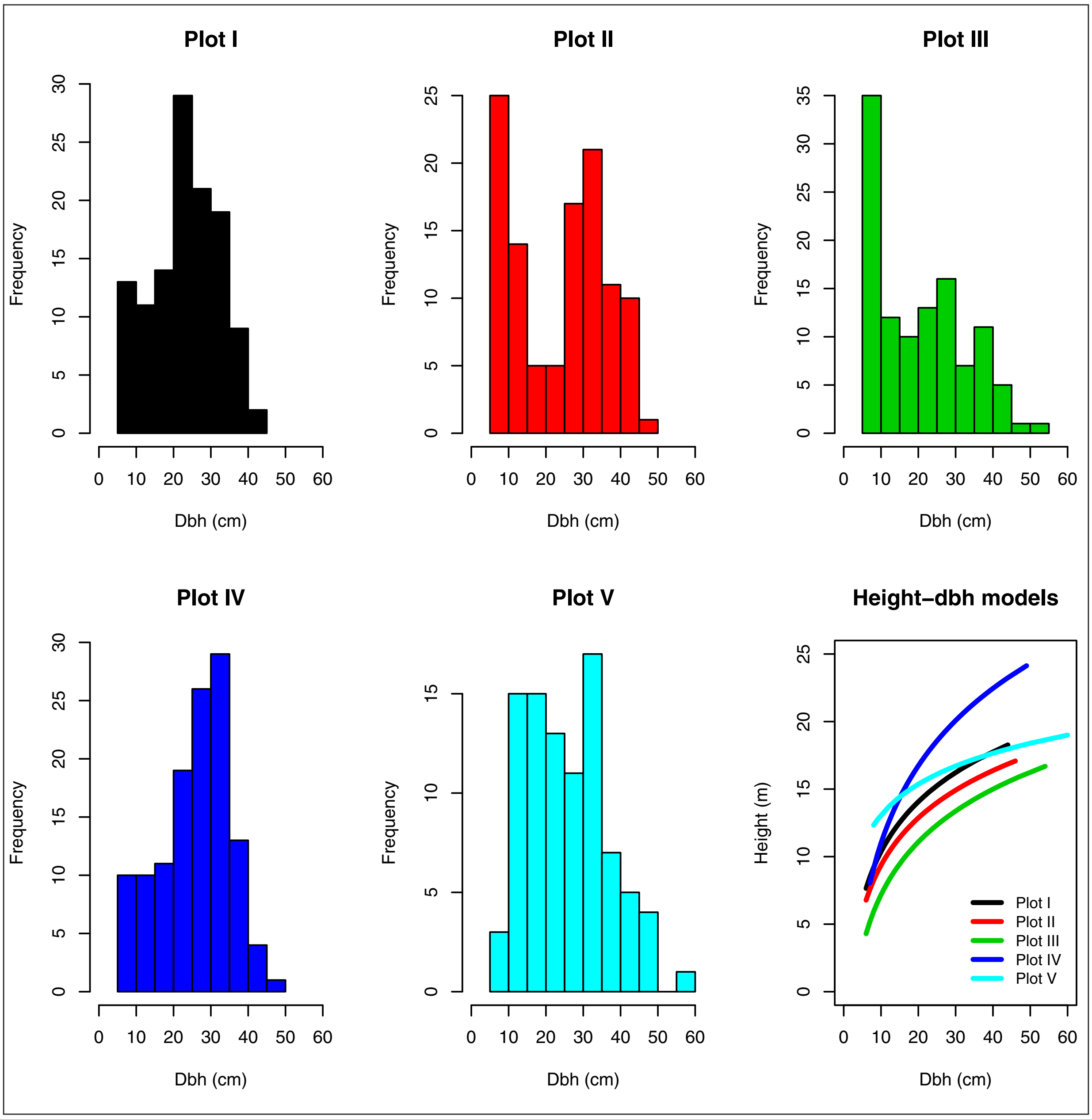

Figure 3 - Histograms of dbh values in each plot and comparison between the height-dbh models.

cases, however, the slope of functions showed a very high p-level, that means both the ClimateEU's and the Barrea's trends were statistically comparable (Tab. 6).

The Mann-Kendall test assessed the absence of climate trends, even if a growing linear trend in annual maximum and minimum temperatures was observed (Fig. 7) with +0.009°C/year for minimum and +0.004°C/year for maximum temperatures. Particular trends were detected only over the periods 1900-1940, 1941-1975 and 1976-2010. Over the first period, minimum temperatures, compared with maximum temperatures, were detected as growing more rapidly (+0.015°C/year vs. +0.006°C/year). Within the central period, minimum t. remained quite stable whilst maximum t. had a sensible decrease until 1960, reaching the same values of the early 1900. Over the third period, temperature continued to rise with close mean values (+0.029°C/year for minimum temperatures and +0.026°C/year for maximum t.). The same periods and trends were analysed for the precipitation amount. Very low adjusted-R2 (0.07-0.04) were detected, demonstrating lack of statistical relationships. Nevertheless, a general decrease between 1901 and 2010, even if relatively low (approx. -1.02 mm/year), was quite clear (Fig. 8, third plot with green line).

Correlations between species' growth and climate were then detected with CF and MCF, these showing different trends and results. With CF a significant and positive correlation was found with the minimum temperatures (Fig. 8) of the previous month of December, and the months of February and March of the same year, whilst a negative cor-

Table 4 - Main statistics of tree rings series.

Series	First	Last	Years	M	SD	SK	S1	S2	G	AR	ARS
M-P1	1834	2012	179	1.080	0.847	2.287	0.123	0.127	0.287	0.926	0.142
M-P2	1868	2012	145	1.137	1.493	1.163	0.156	0.157	0.359	0.899	0.100
M-P3	1829	2012	184	1.036	0.679	2.692	0.147	0.151	0.279	0.925	0.067
M-P4	1914	2012	99	1.745	0.785	0.698	0.165	0.162	0.249	0.872	0.060
M-P5	1895	2012	118	1.984	1.62	1.916	0.156	0.157	0.402	0.852	0.078
chrono	**1829**	**2012**	**184**	**1.578**	**0.823**	**1.165**	**0.141**	**0.146**	**0.278**	**0.873**	**0.081**

M = mean increment (mm); SD = standar deviation; SK = Skewness; S1 & S2 = sensitivity of first and second order; G = Gini coefficient; AR = Autocorrelation; ARS = Autocorrelation after standardization.

relation was found with the minimum temperatures of July and September of the current year. The maximum temperatures (Fig. 9) of the same winter months were correlated in the same way (positive), whilst a negative correlation was detected only for May within the same growing season. Concerning precipitation, the growth was significantly and negatively correlated only with the events of the previous December (Fig. 10). The analysis with MCF (Fig. 11) highlighted many periods in which we had a significant relationship between radial growth and climate. Whilst some of them were roughly stable with time, others appeared unstable throughout the period. The main correlations with temperatures were generally confirmed, even if not continuously, across the whole time-series. The minimum temperatures of August and September were negatively correlated over different decades. More evident and continuous correlations were detected with the minimum temperatures of February and March but only until 1950. Furthermore, only the minimum temperatures of March were significant, but only between 1975 and 1982. Other positive correlations were present and more continuous in the considered period and concerned maximum temperatures of the same months. As for the last decades of the concerned period, significant correlations were found only during October (minimum), December and September (maximum). In relation to the rainfall amount, very low and fragmented events were detected, especially in the last period (1973-2010) and regarding May and June of the growing season (t).

Discussion

The seed stand of the MaP is a pure Black pine forest where broadleaves are quite sporadic and relatively more present where local conditions (such as ditches or cooler exposures) allowed them to be more competitive. In general, the vertical structure of stands showed two well-recognizable levels with Black pine as dominant species. Beech and ash were particularly present as stools following the selective cutting operated in the past and the animal browsing. In many areas, above all where beech was unable to compete, such as where we

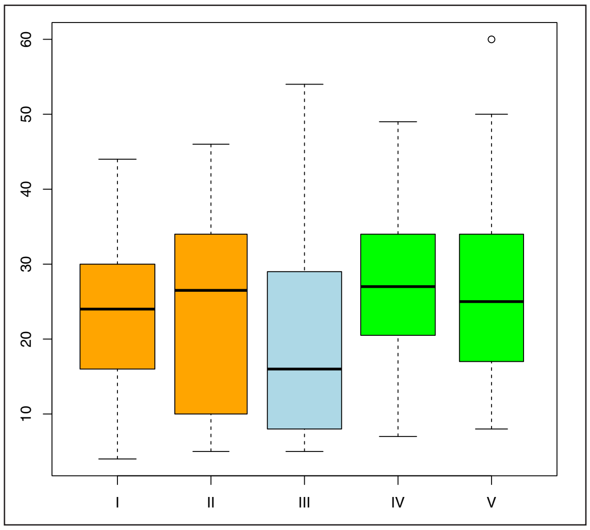

Figure 4 - Boxplot of DBH values.

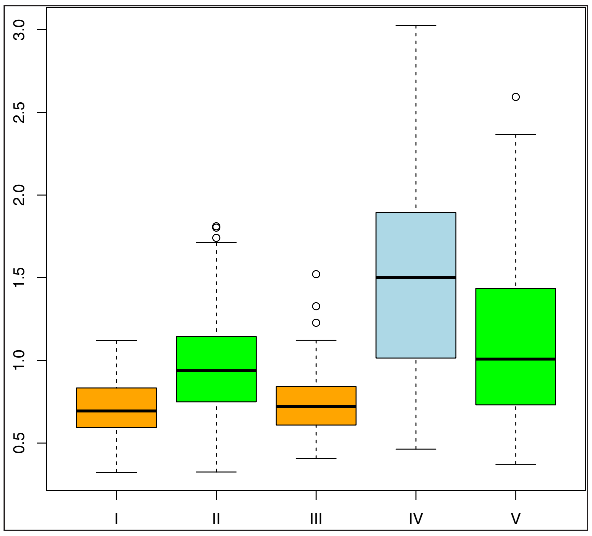

Figure 5 - Boxplot of ringwidths of raw chronologies.

Table 5 - Results of Kruskal-Wallis Rank Sum Test and relative post-hoc test (Wilcoxon Rank Sum and Signed Rank Tests) on raw chronologies on the common growth period.

Statistical Mean ringwidth	Plot (compartment)	Group
1.515 mm	IV (18)	A
1.137 mm	V (18)	B
0.973 mm	II (21)	B
0.744 mm	III (19)	C
0.710 mm	I (21)	C

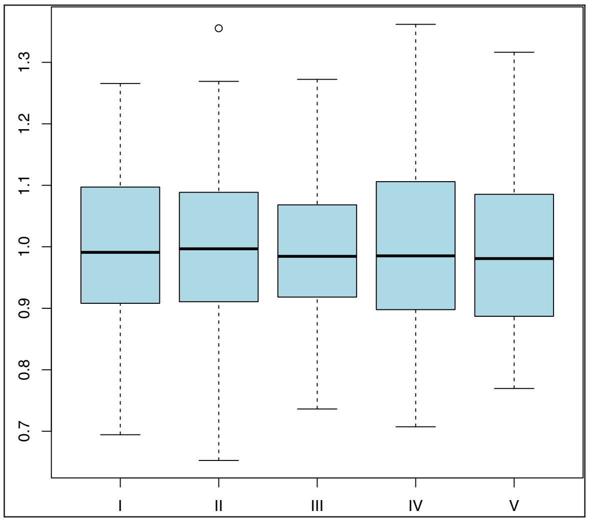

Figure 6 - Boxplot of ringwidths of detrended chronologies.

have southern exposures or shallow soils, Black pine occupied both levels.

Stand data collected in 2012 did not show any significant difference between the present time and the situation before the approval of the last management plan. In fact, any practices' implementation was reported by the management administration during the years 2001-2011 and no traces of tree felling were detected on the ground. ANOVA on DBH showed that forest structure was influenced by forest management, but also that mean radial increment was mainly influenced by stand age, site quality and ecological dynamics. According to our results, three different stand structures could be identified as follows:

- Even-aged adult stands (compartment 18 - plots IV and V): pine stands in these plots can be considered as even-aged with trees from medium to large size- and small DBH variation. The standing volume was chiefly related to the high number of medium-sized trees, and ranged from 259 m3 ha-1 to 574 m3 ha-1. The maximum age of dominant trees varied between 80 and 120 years, small-sized trees were sporadic and mainly young broadleaves. Maximum tree height was 21 m.
- Even-aged stands with old trees (compartment 21 - plots I and II): These plots can be considered as even-aged; the plot II had a high number of small-sized trees with DBH lower than 15 cm, probably due to a natural regeneration process. Standing volumes were quite similar, around 350 m3 ha-1 but the age of the bigger trees was very variable, ranging from 104 to 179 years.
- Uneven-aged stands with very old trees (compartment 19 - plot III): mean DBH and tree height

Table 6 - Results of regressions analysis based on the linear formula y = mx + q. Significance of parameters are reported with the following legend: p<0.1 (.), p<0.05 (*), p<0.01 (**), p<0.001 (***).

Variable	Adj R²	Intercept (q)	Slope (m)
Minimum annual temperature	0.927	-0.655***	0.918***
Maximum annual temperature	0.977	2.617***	0.955***
Total annual precipitation	0.369	15.705**	1.143***

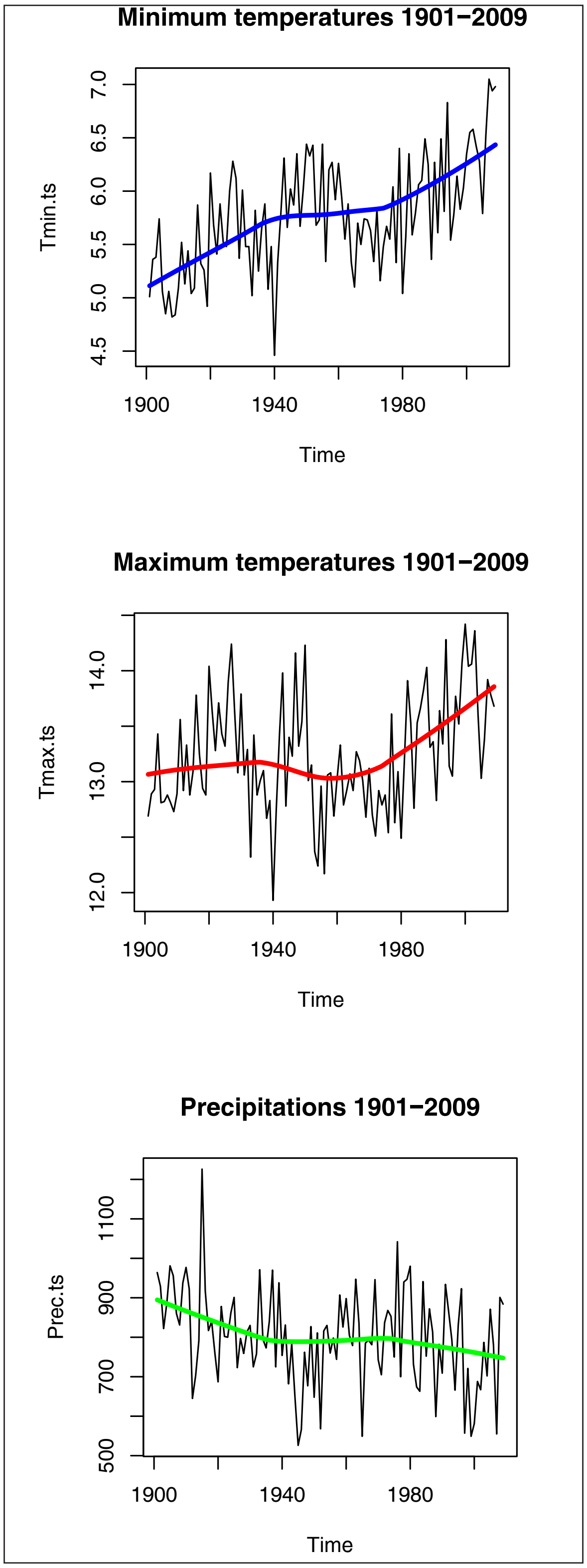

Figure 7 - Trends of minimum (blue line) and maximum (red line) annual temperatures and annual precipitations (green line) from 1901 to 2009 in Villetta Barrea (ClimateEU data).

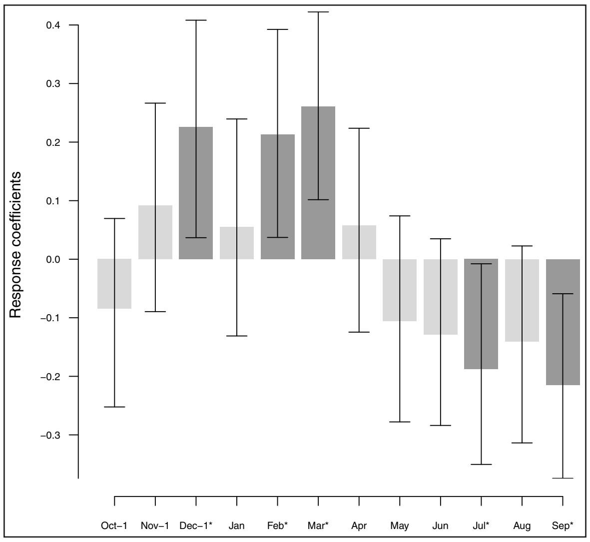

Figure 8 - Correlation function for Minimum temperatures.

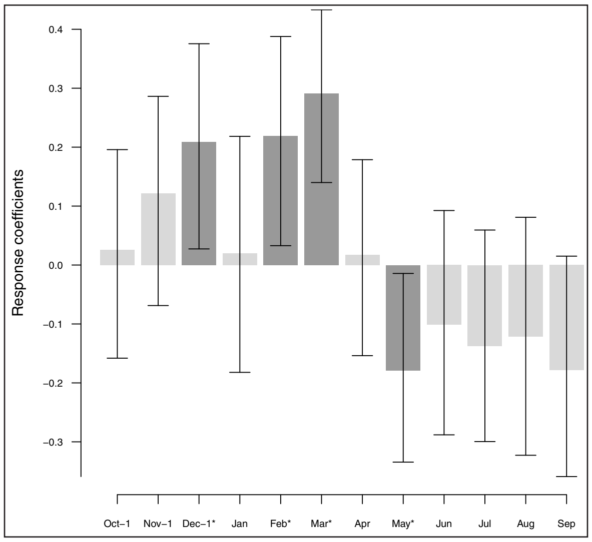

Figure 9 - Correlation function for Maximum temperatures.

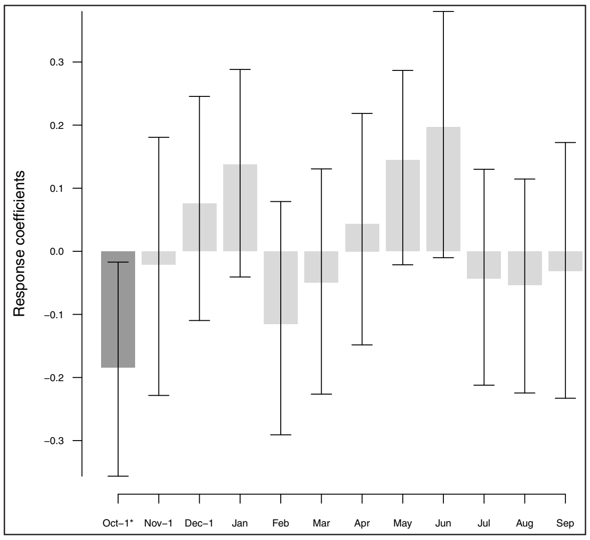

Figure 10 - Correlation function for Precipitations.

were the smallest surveyed over the whole area. Tree density was very high, surely due to the high number of small-sized trees, and the coefficient of variation of DBH was high too, this indicating a very variable vertical structure. Standing volumes were the lowest measured, around 250 m3 ha-1. This stand could be considered as uneven-aged, where Black pine has established a natural regeneration dynamics. In this area the oldest (dominant) trees are aged from 143 to 184 years.

Climate influenced in the same way the growing trends, despite differences in age and size of trees. Dendrochronological analyses demonstrated that, despite a different mean increment in each of the sampled areas, mainly related to tree age, trees reacted in a similar way.

As reported in many other studies on Black pine spp., sensitivity to high summer temperatures was confirmed (Génova and Fernández 1999, Martin-Benito et al. 2010, Amodei et al. 2012). On the other hand, no continuous and recent correlation with the precipitation amount effect was detected, this probably depending on two main factors: the autecology of the Black pine of Villetta Barrea and the local soil structure. Black pine of Villetta Barrea is a bit more tolerant to drought stresses than other *Pinus nigra* subspecies (Gellini and Grossoni 2003). In addition, soil and local ecological conditions can increase or reduce water availability during different seasons as well as the amount of snow in winter.

It has been demonstrated that growth response and climate must be analysed in accordance to soil substrate characteristics and that pines on quartzite bedrock are much more sensitive to the precipitation amount than similar populations on dolomite and calcareous bedrocks (Génova and Martinez-Morillas 2002). In calcareous soils, the effect of the chemical alteration of the bedrock may offer to pine roots the opportunity to explore deeper levels (Amodei et al. 2012).

A positive correlation between radial growth and late-winter temperatures (February and March) in CF results was also reported by Linares and Tiscar (2010) on Salzmann pine in southern Spain. In this situation, trees may open buds earlier and, consequently, increase the length of the growing season. This is very likely to occur in Villetta Barrea, where water availability does not appear to be a problem. Results from MCF analysis pointed out few months with very unstable correlation and the lack of statistical significance over the last decades. The months detected as main driving forces with CF, proved to be relevant only for past events such as the temperatures of February and March. The endemic population of Villetta Barrea seemed to be less sensitive than a few planted stands analysed by Piermattei et al. (2014).

Some factors, not relevant with CF, turned out to be important with the MCF analysis and especially

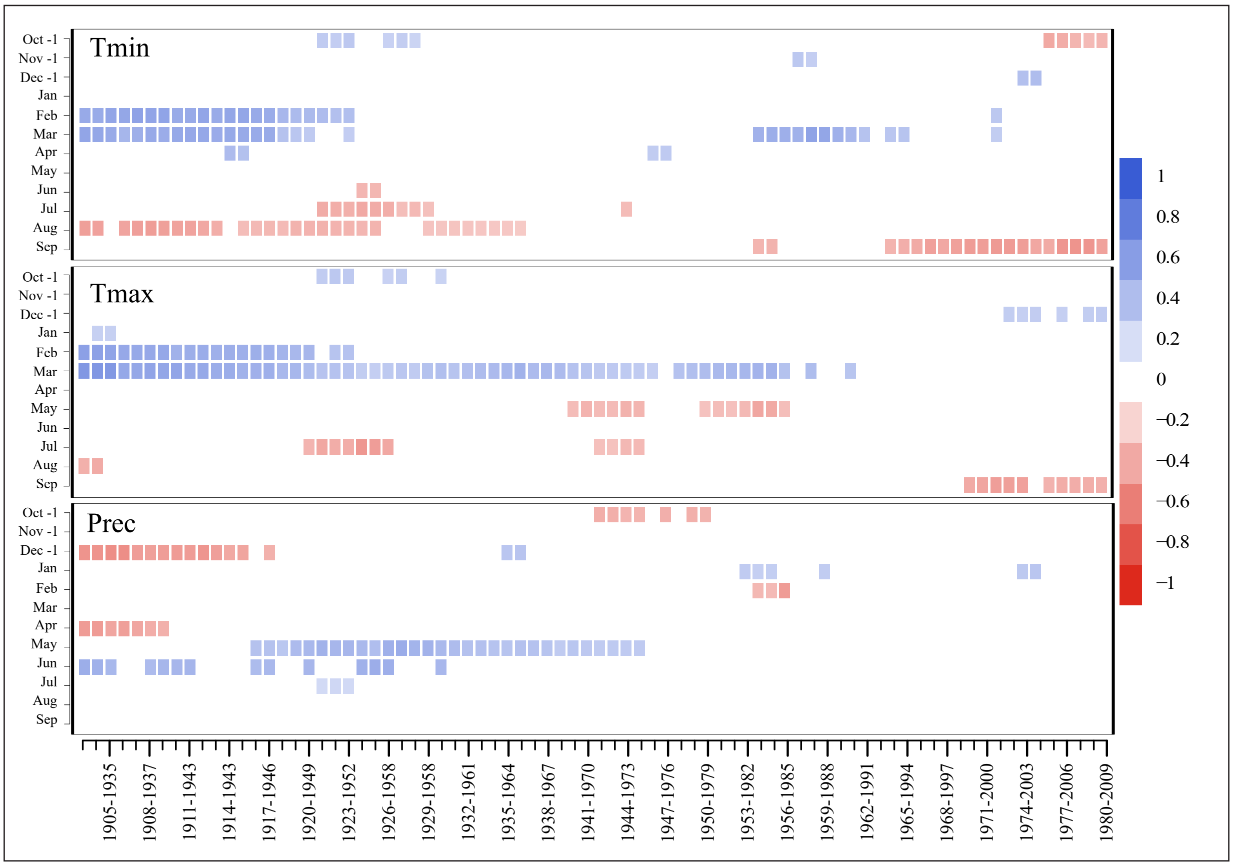

Figure11 - Result of the analysis with moving correlation function from period 1901-1930 (the first on on the left side) to 1980-2009 (the last on on the right side). Only significant correlations (p-value > 0.05) are reported.

concerning the last decades, such as the minimum temperatures of the previous October. In addition, also the shifted response from August to September was detected. In fact, the minimum temperature of August was statistically significant only in the past decades as long as the late '60s, whilst the same variable in September becomes relevant over the last decades. In this case the connection is probably linked to the cold stress that is likely to occur in late September at high elevation. High temperatures in late summer months can induce a longer growing season which can suddenly stop when an extreme event occurs. In this case, the moving windows approach of MCF appeared as a very good tool to address the study of forest species adaptability to climate change.

Definitively, the temperatures of September demonstrated to be the main driving force for the growth of Black pine of Villetta Barrea in the MaP and, in any case, the genetic provenance must also be accounted as a possible driver for variability.

Conclusions

Tree-ring analysis showed that the relationship between radial growth and climate was not affected by different stand structures and tree ages. The influence of climate factors is currently no longer active and the species is probably adapting to a new-established, changing environment. This will probably play a key role in the future and it is an issue to be duly taken into account in the management planning.

Many other questions and issues must be developed to cover all the possible analyses connected to marginal forest populations and to the management of forest genetic resources in view of the expected Global Change. For instance, the available information about tree species genetics and local adaptation progress must be carefully accounted.

The comparison between the population of Villetta Barrea and other populations and subspecies (mainly *nigra* and *laricio*) was useful to assess whether the one examined here is a case of genetic adaptation or an example of phenotypic plasticity and further similar surveys should be encouraged.

Acknowledgements

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Research paper

Cultivation techniques in a 34 years old farming oak (*Quercus robur* L.) plantation in the Arno valley (Tuscany)

Serena Ravagni[1*], Claudio Bidini[1], Elisa Bianchetto[2], Angelo Vitone[3], Francesco Pelleri[1]

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Abstract - This report aims to provide a description of the cultivation techniques adopted at the oldest oak pure plantation (age 34) established within the environmental restoration plan of soil dumps at the Santa Barbara ENEL Company opencast mine in Cavriglia (AR). The goals of the initial plan, following which the plantation was carried out, were to (i) verify the possibility of restoring the soil dump by using tree farming plantations and produce a range of valuable timber assortments; (ii) test the growth potential of the oak species in a pure plantation. The plantation, carried out with a stem density of 1,111 trees per hectare, was managed by targeted practices (pruning up to the stem height of 4-5 m and then undertaking four thinnings). A geometric-selective thinning was applied first and, later, periodical thinning from above was implemented, releasing, as a result, about 70 crop trees per hectare. In the meanwhile, it was possible to monitor the growth parameters concerning dbh, tree height and crown diameter. The stem quality and the presence of epicormic branches were evaluated in 2013 and the relationship between the presence of epicormic branches and tree characteristics were also analyzed. The wood production was compared with other European plantations, especially from France. Today, 34 years after the plantation got started, the site is an interesting case-study of tree farming as it plays a consistent role within the environmental restoration of the area. The applied management system allowed to reach a noticeable wood production level and also valuable timber assortments for industrial use. Crop trees (70 per hectare) reached a mean dbh of 38.1 cm, the height of 22.3 m at the age of 34.

Keywords - English oak, thinning, valuable timber, tree farming, plantation.

Introduction

English oak (*Quercus robur* L.) is a quite widespread species in Europe, with geographical distribution from the Atlantic coast of France and northern Portugal up to the Urals and the Caucasus, and from Britain and southern Scandinavia up to northern Greece, the Italian peninsula and the Pyrenees. In Italy, it is present in almost all the regions, especially in the North and mainly in the plains. English oak needs a constant and continuous level of water availability in the soil, proving to be susceptible to drought. In dry years, in fact, the more sized trees, may easily show typical phenomena of desiccation, in the upper canopy.

English oak prefers soils with shallow and stable groundwater, tolerating periodic flooding of the root system up to 2-3 months. Such behavior is made easier by the rather shallow roots, this allowing bearing the lack of oxygen in the soil, but making them less suited to preventing drought occurrence. The species is therefore naturally located at the base of slopes and at valley bottoms (Frattegiani 1996, Lemaire 2010, Mori et al. 2007, Sevrin 1997).

English oak is a very light-demanding species and it can be considered a pioneer tree, because of its ability to colonize open spaces and abandoned fields. Being so light-demanding, it requires a dynamic silvicultural approach with frequent thinnings, ensuring an adequate crown development and a regular diameter growth, in order to get the best growth performance (Lemaire 2010).

In Europe, English oak is cultivated for valuable timber production. At this purpose, many experimental trials have been set up to define suited management criteria and get valuable timber production in a shorter time-span than according to customary management system (Nebout 2006). All these trials are characterized by an initial phase (qualifying period) where the tree stand is maintained at high stem density to favor the natural pruning. This phase is necessary to get straight stems without branches. The best crop trees are then selected and frequent thinnings from above are carried out all around them

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[1] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Forestry Research Centre (CREA-SEL), Arezzo, Italy
[2] Consiglio per la Ricerca e la sperimentazione in Agricoltura e l'analisi dell'economia agraria, Centro per l' Agrobiologia e la Pedologia (CREA-ABP), Firenze, Italy
[3] Dottorando, Dipartimento di Bio-scienze e Territorio (DiBT), Università degli Studi del Molise
[*] corresponding author: serena.ravagni@gmail.com

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(thinning phase) to get the free growth of crown and, at the same time, maintain the diameter growth of selected trees high and costant.

Experiences about this issue can be found in Britain since the 1950s with dense oak plantations aged 20 (Jobling and Pearce 1977, Kerr 1996). At the moment, similar management criteria are being applied in Central Europe (Lemaire 2010, Perin and Claessens 2009, Nebout 2006) and we also have, in Italy, a few cases aimed at getting valuable, large-sized stems in a shorter time, as compared with traditional management (Corazzesi et al. 2010).

Furthermore, while in central and northern Europe we have a good general ecological, genetic, eco-physiological, technological, silvicultural and operational knowledge concerning valuable oaks, in the Mediterranean area this background is limited and, moreover, the biological response of these oak species is not well-known. In spite of this, the residual oak stands in southern Europe are extremely important as a relict source of genetic variability (Aa.Vv. 1999, Ducci 2007).

In Italy, English oak is particularly widespread in the lowlands and also in the alluvial plain of the Arno valley. Its presence has been greatly reduced since Middle Ages, following the diffusion of human settlements and the population increase, which was due to the progressive deforestation in favor of the agricultural practice. In addition, the widespread coppicing system did not support the species because of its lower sprouting ability compared with the other tree species associated in mixed forests.

Since the 1950s, the progressive re-diffusion of secondary forests, due to the abandonment of agriculture and pasture activity in the mountains and hilly marginal areas, has been noticeable, whilst more recently a growing attention towards the protection of lowland forests and the establishment of new forests has been developed. Since the 1980s, new plantations have been carried out in the Po valley (Pividori et al. 2015) under the financial support of both Regional governments and the European Union (set-aside, EEC Regulation 2080/92 and Rural Development Plans).

The widespread cultivation of English oak is linked to its timber value, workability and aesthetical features. Moreover, since a few decades, the market of valuable broadleaved trees acknowledges increasing prices to high quality trunks for veneers and furniture. In this latter case the market requires straight and healthy, cylindrical trunks, free of knots, with a larger than 50 cm diameter and a regular growth course, i.e. the awaited goals to be pursued when cultivating valuable tree species.

Since the late 1970s, in the Valdarno Aretino, over 240 hectares of plantations for timber production were carried out in a close cooperation between the Forestry Research Institute (now CREA-SEL) and ENEL Co., according to the Plan of environmental restoration of the wide landfill mining, stocking the thermal power station of Santa Barbara (AR).

English oak was the most used tree species in these reforestation activity. The reasons for this are twofold: on the one hand, English oak was chosen because of its own feature of pioneer species suited to the barren soil of the mining area, on the other hand, to test the opportunity to use the species, poorly known in Italy, in tree farming plantation for valuable timber production (Buresti 1984).

The plantation here analyzed and others carried out in the Santa Barbara district, resulted to be an important training for the experimental activity in tree farming. The significance of this site lies, therefore, in testing new pruning techniques and different thinning trials in addition to verifying the oak potential in the concerned area. The outputs of this experience were later applied at other Italian sites. Given the lack of specific models and information about planting and management for similar growth environments, the applied criteria described in this paper should be considered and evaluated as a fully experimental trial. This paper does not intend therefore to propose a model, but to report methods and results achieved so far.

The early goals may be summarized as follows: (i) restoration of an environment heavily modified, ensuring, first of all, the ground cover and then the recovery of biological activity in the soil, which was greatly reduced, if not absent, at the time of planting; (ii) checking the cultivation of English oak at this site and defining management techniques suited to produce valuable timber in a life-span of 40-50 years with the traits required by industrial processing.

Materials and methods

Study site

The area is characterized by an average annual rainfall of 927 mm and an average temperature of 13° C, with a dry period in July. The soil, at the time of planting, had very special characteristics, resulting from the accumulation of inert layers; soil texture was silty-clay, with a sub-acid pH and a balanced amount of the main nutrients (N, P, K), but also with a reduced presence of calcium (Buresti 1984).

Plantation design

The pure plantation was established in November 1979 in an area of 2,700 m^2, according to a square design with a spacing of 3 m and with a density of 1,111 trees per hectare. 1 year old oak seedlings were used, choosing a provenance which was close to the site (the forest of Renacci). Extensive deep ploughing and hoeing all around the seedlings were implemented for two years after planting, to reduce weeds and shrubs competition. Pruning was carried out up to the height of 5-6 meters over the following years. Annual dbh inventory was carried out since 2000. Total height, tree crown insertion and dbh of dominant trees were periodically measured.

Thinning

The plantation underwent four thinning operations. The first thinning was carried out at the age of 13 (winter 1992) according to a mixed geometric-selective design. Tree crowns began to touch one another and it was necessary to intervene to prevent the occurrence of competition for light, which would negatively affect their diametrical growth.

Given the young age of the plantation and its still evident homogeneity, a geometric thinning was applied with rare exceptions. 50% of the trees were felled, following alternate diagonal rows; the selective criterion was applied only in few cases to preserve good-shaped trees (Buresti et al. 1993).

A second thinning was performed in 1996 with a selective criterion, still removing about the 50% of the trees. At this time, the worst and less vital phenotypes were felled, and also a relatively even distribution of the trees on the ground was maintained. Four years after the first thinning, tree crowns were already in contact but no significant reductions in diametrical growth were recorded. The surveys showed the progress of individual differentiation regarding tree vitality and stem shape and this is the reason why a selective design was applied for the second thinning (Buresti et al. 2000).


View of the plot at the age of 24 years following the third thinning.

Following the French and Belgian experiences (Sevrin 1997, Baar at al. 2005, Baar 2010, De Potter et al. 2012), the third thinning did not concern the whole plantation, but a few crop trees: 70 superior phenotypes per hectare were chosen and a thinning from above was performed around them.

According to Lemaire (2010), a regular and sustained diametric growth of the crop trees is provided by wide and well-lighted crowns, with green branches for at least half of total stem height.

Three main criteria were followed for selecting the crop trees:


View of the plot at the age of 34 years following the fourth thinning.

Final crop tree. Age 34 years.

1. Average distance between the trees of about 12 meters;
2. Preference for the most vital and dominant trees;
3. Preference for the trees with the following stem qualities: straightness, knots absence, lack of injuries or pathogens.

Following the selection of crop trees, further thinnings were carried out in 2003 and in 2013, surrounding competitors were progressively felled to increase the space available for the crown development. About 40% of the trees were removed in 2003, and about 33% in 2013.

At each thinning operation, the stem volume of the felled trees was measured analyzing the stem sections, up to the top diameter of 5 cm, in order to build up a local volume function of the English oak plantations in the Arno valley (Marchi et al., forthcoming).

Epicormic branches

One year after the last thinning, a survey of the epicormic branches distribution was conducted to record their presence, their age and distribution along the stems. The data were analyzed according to the Pearson's χ^2 test. The aim of the analysis was to identify the possible relationship between the presence of epicormic branches, the tree position within the plantation (edge tree, inner tree) and the Dch/H (crown diameter to total tree height ratio).

Results and discussion

Mensurational parameters

The analysis of dbh and the total tree height datasets was focused on the crop trees, i.e. on trees concerned since the third thinning. Fig. 1 and 2 show the regular and sustained increase both of dbh and tree height, their values being on average 38.1 cm and 22.3 m, respectively, at the age of 34.

The analysis of the dbh current level (c.a.i.) of the crop trees (Fig. 3) highlights its decrease since 2001 (age 22), which was triggered because of the starting competition for the light. To avoid this effect and the loss of crown reaction, a further thinning was recommended. The thinning, carried out in 2003, at the age of 24, had beneficial effects, i.e. it gave rise to the positive trees reaction to the major light availability and we had the recovery of c.a.i. to value higher than 1 cm.

Dbh c.a.i. kept rather stable and sustained up to 2010, with a heavy reduction in the very dry year 2007 (age 28). Since 2010, the reduction of dbh c.a.i. would have required a timely thinning, which was carried out only in 2013, when a collapse of average dbh c.a.i. up to 0.5 cm yr^{1} took place.

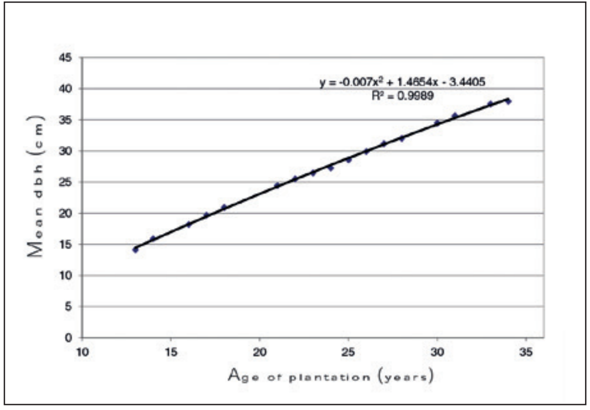

Figure 1 - Crop trees: trend of mean dbh.

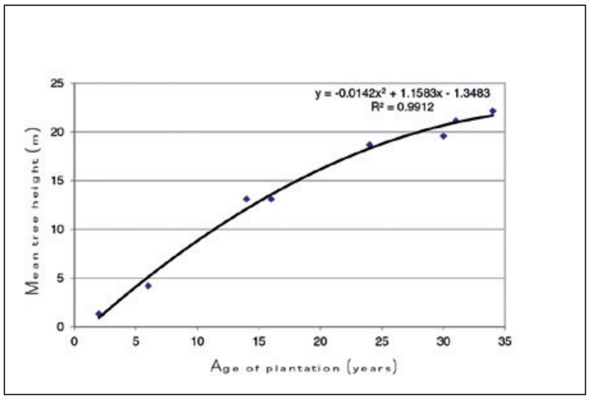

Figure 2 - Crop trees: trend of mean height.

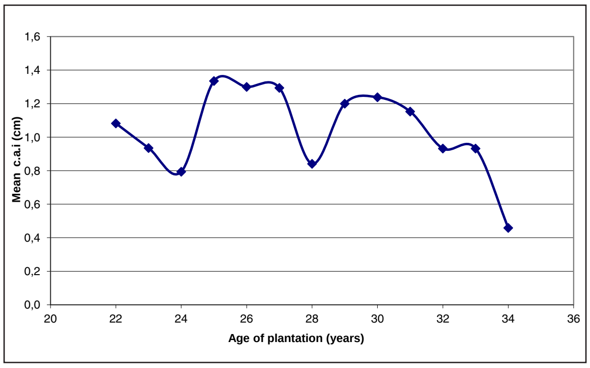

Figure 3 - Crop trees: dbh c.a.i. trend.

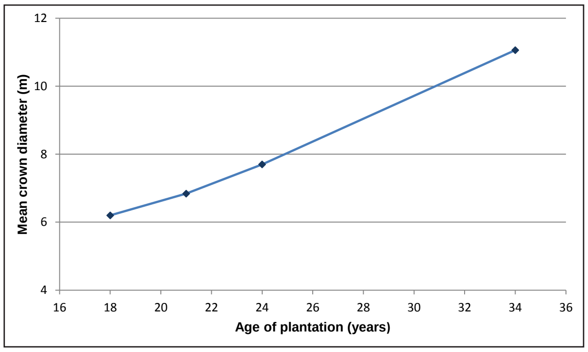

Figure 4 - Crop trees: crown diameter trend.

If we take into account the pattern of crop trees' crown diameter increase (Fig. 4), there is evidence of the regular growth, without any remarkable change over time.

In a few European papers some mensurational parameters related to common oak stands (in free-

Table 1- Variation of mensurational parameters with plantation age.

Year	plant. age	n. trees ($n\ ha^{-1}$)	mean dbh (cm)	tree height (m)	tree volume ($m^3\ ha^{-1}$)	removal ($m^3\ ha^{-1}$)	canopy cover (%)
1993 pre-thin.	14	1,111	12.5	11.0	73.06		/
1993 post-thin.	14	588	14.2	10.9	40.17	32.89	/
1996 pre-thin.	18	588	17.2	12.4	84.63		/
1996 post-thin.	18	281	20.0	/	43.74	40.89	63%
2003 pre-thin.	24	277	25.6	17.8	113.88		79%
2003 post-thin.	24	164	27.9	/	73.90	39.98	57.6%
2013 pre-thin.	34	157	36.9	22.2	146.04		84.7%
2013 post-thin.	34	105	37.7	22.3	101.82	44.22	72.5%

growing and unthinned) are being compared. These parameters are defined as "shape parameters" and provide an indication of English oak growth pattern (Lemaire 2010, Perin et al. 2009, Jobling et al. 1977).

A synthetic competition index, applied to determine the competition level as a function of the crown width, is given by crown diameter to total height ratio (Dch/H). The right balance is achieved with values varying between 50% and 60%.

At the Santa Barbara plantation, Dch/H values between 40% and 60% were measured, i.e. very close to the optimal readings highlighted by the French trials. Even the index height of crown insertion to total height ratio (Hi/H) provides optimal figures, lower than 40% and typical of trees with deep crowns.

Accounting for stem volume felled at the different thinning times reported in Tab. 1 and Fig. 5, its value was fairly constant at each intervention, with a total removal of 158 m^3 per hectare. Total mass reaches 260 $m^3\ ha^{-1}$.

Epicormic branches

Data analysis say that, at the present time, the 33% of trees do not host any sort of epicormic branches. The 57% of the stem sprouts are one year old and produced after the last thinning (2013). The 53% of one year sprouts were present on two trees. These are not located at the plantation edge and do not show a low Dch/H relationship. In the case, the genetic component is probably prevailing and plays an basic role in the phenomenon (Servin 1997, Attocchi 2013a). The χ^2 analysis highlighted that trees with Dch/H values lower than 0.5 showed an increased frequency of sprouts. This index is considered reliable to evaluate the tendency to the emission of epicormic branches. Dch/H value in the range 50-60% highlights crowns wide and deep enough to be less prone to new epicormic branches production in English oak (Lemaire 2010).

Pruning, and especially thinning play an important role in the management of oak plantations as a stimulus to the production of new epicormic shoots (Attocchi 2013a). From medium to low tree density plantations, pruning is necessary to get valuable timber productions whilst, in the most dense plantings, natural pruning is usually prevailing and it is integrated only when necessary (Spiecker 1991, Weaver and Spiecker 1993, Attocchi 2013b). The risk of newly-established epicormic shoots may be reduced by early and progressive pruning, carried out only around final crop trees. At each pruning time, the lower branches have to be removed only to get a clean bole free of branches up to 50% of total stem height. At this type of plantation a clean bole of 5-6 m (25-30% of final height) may be considered an awaited goal. Where possible, a basic role is to preserve the dominated layer and favor, in this way, both natural or artificial establishment of an understory (which is characterized by shade-tolerant species, able to reduce the direct enlightenment of the stems). Recently in a few European countries, mixed plantation are being preferred, intercropping oaks or other valuable broadleaved species with nurse trees (alders, hornbeams, limes, etc.) and shrubs like (hazel, elder, etc) (Hochbichler 1993, Buresti et al. 2006).

Stem quality

Following the last thinning, stems of selected trees were individually classified on the basis of the stem quality at the end of the crop cycle (Nosenzo et al. 2008). The 41% of the crop trees had a first stem, 2.5 m long, attributable to Class A, i.e. suitable for the more profitable uses, such as veneer. The 47% had a first stem attributable to Class B, suitable

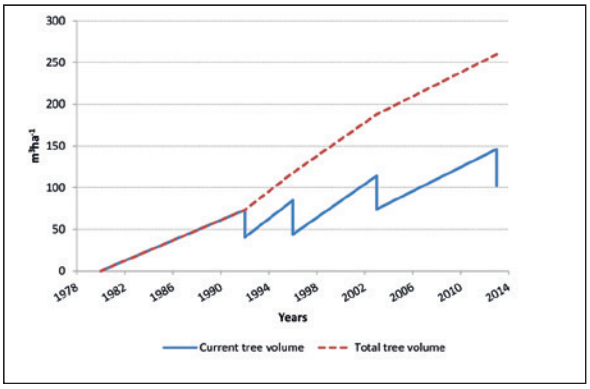

Figure 5 - Current and total tree volume trends.

for fine saw timber, while the 12% had a first part attributable to class C, i.e. to standard saw timber.

Conclusions

The soil condition at the time of plantation was extremely poor: no vegetation cover in any form or organic layer were present. The current well-established tree farming plantation fully satisfies the manifold goals of environmental recovery expected by the owner, ENEL Co., on the landfill grounds, i.e. stabilize the soil; limit the erosive action of running water on bare soil; form again an organic layer; restore the biological growth medium and the landscape. At the time of the implementation, and according to the already achieved experience, the chances of a successful establishment of the plantation were really uncertain, in terms of both tree species choice (design, pure or mixture) and physical environment of introduction.

Under this perspective, the trial may be considered as a fully experimental implementation. 34 years later, not only the goal of mining area restoration, but also the results in terms of trees' growth performance have been reached. The limited practices implemented in the soil after the plantation, confirm the ability of English oak to act as a pioneer species and to colonize difficult and poor soils, provided that a good water availability is being ensured.

Dbh c.a.i. varying from 0.8 to 1.2 cm is a quite good performance both in terms of growth and of growth-steadiness along the full time-span up to 2011. The sharp reduction occurred over the last two years is basically linked to the delay of the fourth thinning operation and to the particularly unfavorable rainfall pattern in 2011 and 2012. At the age of 34, crop trees have achieved an average diameter of 38.1 cm and an average height value of 22.3 m; these performances are fully comparable with those of the French forests - first site-class (Lemaire 2010). The total wood production at the site is about 260 m^3ha^{-1}, where the standing volume is about two-thirds of the intermediate yield at the age of 34. This ratio being an own attribute of this type of tree farming.

Due attention has to be paid over the cultivation-span to crowns cover fulfilment, given their prolonged compression causes the death of long-shaded lower branches, the consequence being the loss of trees' ability to react further to thinning occurrence and the reduction in diameter growth.

The rule to keep deep enough crowns in the plantation management has to be underlined, as well as to get and maintain Dch/H values above or close to 0.50. This rule has probably also limited the sprouting of epicormic branches along the stem which often occurs as a result of delayed thinning, producing a reduction of wood quality.

Even if today a few design features of the original plantation could be improved further to current experience, the case-study may be considered a relevant trial for two reasons. The first relates to the potential of English oak which, if properly managed, can ensure interesting results in terms of wood production on relatively short rotations. The second highlights the importance, for the plantation design, of giving each crop tree a suitable space for crown development (Buresti et al. 2006, Buresti Lattes and Mori 2009, Buresti Lattes and Mori 2012). It is fundamental to increase this individual available space over time, as a function of the progressive expansion of the crowns. This is, actually, the only way to ensure the active photosynthetic area, capable of maintaining constant and high radial stem increment.

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