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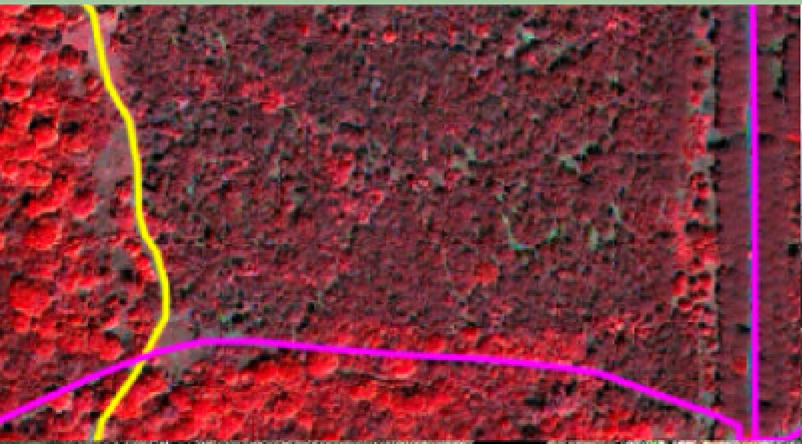




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Conference paper

Forestry research to support the transition towards a bio-based economy

Piermaria Corona[1*]

This special issue is dedicated to the celebration of the 92[nd] anniversary of the Forestry Research Centre of the Italian Agricultural Research Council. The Centre originated in 1922 as Royal Experimental Station of Silviculture, joined to the Chair of Silviculture of the Royal Institution for Upper Education in Forestry of Firenze (Italy). Aldo Pavari, eminent scientist and teacher at the University of Firenze, was the first director from 1922 up to his death in 1960. On the year 1967, the Experimental Station was reorganized as Experimental Institute for Silviculture with head offices in Arezzo and local branches in Firenze, Isernia and Cosenza. From 1972 to 1995 the position of director was held by Riccardo Morandini, who defined new goals and reformed both inner structure and research programme, renewing the experimental approach to forest sciences. Since 1999, the Experimental Institute for Silviculture has become the current Forestry Research Centre.

Forestry research is constantly revised as new questions arise or new techniques and tools become available. The vast expertise in this domain of Science builds upon the legacy of many years of experience, as shown e.g. just by the long history of the Annals of Silvicultural Research (Fabbio 2013). A well-grounded past is expedient to suitably understand the present and to creatively envision future scenarios.

In a world increasingly committed to reduce its carbon footprint, an emerging bio-based economy, in which renewable green resources such as forest biomass, rather than fossil fuels, are used to meet Society's needs for energy, chemicals and raw materials (e.g. Hannerz et al. 2014), is now becoming a reality. Both forestry research and innovation lay the foundations for a structural change from a fossil-based economy to a bio-based economy. This transition holds great potential for growth, and to significantly improve the quality of human life.

Under such a perspective, the aim of this special issue of the Annals of Silvicultural Research is to put together selected expertise and viewpoints of internationally renowned scientists in the field of forestry and bio-based economy to provide a multifaceted, updated reference of available forestry practices that contribute to the development of bio-economy, also considering their transferability to stakeholders.

Practical forestry has still many challenges ahead, the first one to increase wood yield while simultaneously minimizing input and environmental impacts. However, it can be argued that the very major challenge is of theoretical nature in itself. Managing the forest resources in a world characterized by extreme complexity and radical uncertainty requires a portfolio of approaches, including short-term and long-term strategies to support socio-ecological systems to adapt to changes in climate, environment, economy and society (Wagner et al. 2014).

Adaptive forest management learns from system reactions to support its resilience, by shifting from approaches based on forecasting (i.e. the classical anticipatory management idea, *sensu* Kay and Regier 2000) to approaches based on monitoring, considering that optimization models have low ability to effectively support the management of natural renewable resources under ever changing environmental and socio-economic contexts (Corona and Scotti 1998). This implies straddling from a strictly ruled hierarchical forest planning to a systemic view of forest management (Ciancio and Nocentini 1997 and 2008). In other words, the overall goal is not to maintain an optimal condition of the resource (a concept that becomes meaningless under ever changing environmental and socio-economic contexts) but to develop an optimal management capacity. This is accomplished by: (i) trying to maintain ecological resilience so that forest ecosystems are able to react to stresses (whilst forestry faces internal/external changes, the forester's role is to look for technical solutions for adapting without losing integrity); (ii) generating flexibility in institutions and stakeholders' expectations, to allow for the management to be adaptive when external conditions change; (iii) maintaining a flexible view

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of participation (multi-stakeholder participation results in better management planning, and suggests that participatory methods are an effective way of capturing the information and perspectives necessary to manage socio-ecological systems).

Policy processes towards a bio-based economy should seek to produce decisions that are "evidence-based". To this end, a key challenge is to introduce into forest research programs question-driven approaches able at identifying and assessing mechanisms that influence both the changes of socio-ecological systems (Corona et al. 2011) and their governance (Giessen and Buttoud 2014). Good question-setting must result in quantifiable objectives that offer unambiguous signposts for measuring progresses along the transition towards a bio-based economy and require a well-developed partnership among researchers, resource managers and policy-makers. Contextually, the use of scientific knowledge to support evidence-based decisions requires suitable communication of key findings: this special issue contributes to this end.

Acknowledgments

The celebration of the 92nd anniversary from the foundation of the Forestry Research Centre was kindly sponsored and supported by the International Union of Forest Research Organizations (IUFRO 2.02.13, 4.02.06, 9.05.01, 9.05.04), the Italian Agricultural Research Council (CRA) and the Italian Ministry for Agricultural, Food and Forest Policies (MIPAAF).

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Conference paper

Keynote speech for the opening of the renewed Forestry Research Centre headquarters

Orazio Ciancio[1*]

Coming back here at the Forestry Research Centre in Arezzo, where I have been working for a long time earlier as a researcher and afterwards as director of the working group on "Forest biology and protection", it is close to my heart clarifying two strictly related points. The first point concerns the story of this Centre. The second one The Italian Academy of Forest Sciences.

Maybe not everyone knows the most important stages of the establishment and development of these institutions. I believe therefore useful to highlight briefly the main aspects.

The Italian Forestry School was established in 1869 designated as "Royal Forest Institute of Vallombrosa". The first director was ADOLFO DI BERENGER (1815-1895) up to 1877. He was replaced by FRANCESCO PICCIOLI (1841-1910) in 1880. VITTORIO PERONA (1851-1917) was appointed as director in 1910. ALBERTO COTTA (1872-1962) assumed then this position up to 1913.

Following the Law 834/1912 (LUIGI LUZZATTI 1841-1927) concerning measures related to forestry education, the mentioned Royal Institute was moved to Firenze, designed as "Royal Institute for Upper Education in Forestry" and opened on January 1914.

ARRIGO SERPIERI (1877-1960), appointed as director of the Institute, included in the teaching and scientific regulations a chair of experimental research, assigned to ALDO PAVARI (1888-1960). In 1922, following the Law 742/1921, the chair was turned into in the Royal Experimental Station of Silviculture, then rearranged into Experimental Institute for Silviculture in 1967, today Forestry Research Centre of the Italian Agricultural Research Council.

ALDO PAVARI contributed significantly to the development of ecologically-based dendrology and silviculture. Studies of phyto-geography, ecology and forest genetics became the grounds of silviculture. From the scientific viewpoint, the "silviculture on ecological basis" operates the knowledge transfer from biological sciences to forestry.

Under this perspective, according to A. PAVARI, "[...] the different approaches and technical methods of silviculture will be able to get out of the circle of empiricism, albeit refined, only when they will be considered as consequences of specific environmentally determined conditions. Then, as well as the geography of forest botany, forestry too will be framed into ecology in a systematic way".

The innovation was to think of forestry as an art and an experimental science as well. On the one hand, cultivation techniques had to be the result of ad hoc experiments; on the other hand, it was stated that "[…] under similar climatic conditions, beyond regional boundaries and floristic composition, there are forests mutually comparable to which similar methods of cultivation can be applied".

The phyto-climatic classification of A. Pavari and its validation for the Italian region carried out by A. DE PHILIPPIS are considered two milestones. Generations of foresters have applied the principles of these in the reafforestation and forestry practice.

On the footsteps of A. Pavari, who provided the general approach, RICCARDO MORANDINI (1925-2011) and EZIO MAGINI (1917-2000) developed the sector of tree genetic improvement. Relevant examples concern studies and experimental trials on the certification of forest nurseries' production, on the establishment of tree seed orchards and on the development of the "National Book of seed stands". The studies of E. MAGINI were crucial for the understanding of extent and distribution of forest species' genetic variability and for the conservation of genetic resources in situ and ex situ.

"La sperimentazione di specie forestali esotiche in Italia" edited by A. PAVARI and A. DE PHILIPPIS is regarded "a model" by WRIGHT. These studies defined an era. They contributed the scientific and

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technical advancement and the development of what later became an autonomous discipline: the forest tree crop farming.

Technically, silviculture on ecological basis assumes a distributive arrangement and the shaping of large units of forest vegetation according to the ecological identity concept. PAVARI makes reference to ”[...] the identity of plant physiognomy of forest consortia located in ecologically similar conditions but differentiated by own floristic composition”, these matching with ”environmentally equivalent” forms taken as representative of similar ecological conditions. The physiognomic identity is characterized by ”[...] the determinative action of a limiting factor, upon which not only geographical and topographical forest species' and communities' distribution, but also criteria and operational techniques of forestry depend”.

Silviculture on ecological basis is essentially comparative forestry. If macro environmental factors, especially climate and soil, are known as well as specific requirements, silvicultural systems and methods applied to a given forest can be replicated, ceteris paribus, into an another forest with the same physiognomy, despite its composition. Species have to be employed in the ”right place”. Intermediate and regeneration cuttings' technique is related to species' requirements. If natural regeneration does not occur, a suited artificial regeneration technique will be employed.

The second issue concerns the establishment of the Italian Academy of Forest Sciences. This body, currently under the aegis of the Ministry of Heritage and Culture, was established on June 1951 by the efforts of a few Fathers of the Italian Republic, highest officers of the State Forest Corps and Italian masters of Forest Sciences at the time. A. PAVARI was among them.

The Minister of Agriculture and Forestry, AMINTORE FANFANI (1908-1999) was among the founding members and the founder of the Academy, “to provide scientific and technical support to public Agencies in charge of Law 991/1952 implementation”, also known as FANFANI Law. He designed villa "La Favorita", owned at that time by the Agency for State Forests, as the Academy headquarters.

The President of the Italian Republic LUIGI EINAUDI (1874-1961), honorary member of this Institution, declared the Academy a moral body by Presidential Decree 4586/1951 and attended the opening ceremony which took place at the Palazzo Vecchio in Firenze, at the presence of AMINTORE FANFANI, the Mayor GIORGIO LA PIRA (1904-1977), the Minister of Justice ADONE ZOLI (1871-1959) and other distinguished guests of the political, academic and forest sector.

LUIGI STURZO (1871-1959) was involved in the life of the Institution issuing in the Academy Journal “L'Italia Forestale e Montana” a few papers devoted to social and economic problems of Italian mountain environment.

The institutional tasks of the Academy are highlighted at the first article of its Statute: give impulse and vitality to the progress of forest sciences and to their enforcement to forestry and related environmental issues in order to foster the collective wellbeing. These tasks are being carried out through scientific research, conferences, workshops and publications.

The activities of the Academy are carried out under an international framework by means of highly valued studies and research excellence. The many and varied skills of the 433 Academicians, Italians and foreigners, allow the Institution to be a focal research body with respect to forestry and environmental sciences and, namely, to coordinate research projects involving Universities and Italian and European research Institutions.

Furthermore, the Academy supports the scientific communication of what can be named as the culture of the forest by means of journals, articles, monographs, events and managing its library.

By the Decree of Tuscany Region 1648/2013 the library has been declared “of Cultural Interest” according to ”the importance of its collections, specialized in the field of forest sciences and related environmental protection issues, subjects for which the Academy is a national and international reference centre”.

The commitment is high and aimed at providing the right significance to the scientific outcomes reached since the foundation, these having cultural and political implications at regional, national, European and global level. The goal is simple and ambitious as well: planning the future of the forest sector.

In the symbol of the Academy, next to an oak tree depicting the forest, there is the Petronius motto Serva me, servabo te (Take care of me, I will take care of you). In this topical motto - given the role played by forests for environmental protection, climate change mitigation, biodiversity conservation and life quality assurance - the need of forests' preservation to ensure the wellbeing of future generations is underlined.

I do think I am the last still operating researcher who took up his scientific career at the Royal Experimental Station of Silviculture in 1963. I am proud of this position. I had the opportunity to contribute in the development of forest experimentation for over 20 years. Large part of my fortunate career, before at the University of Tuscia and then at the University of Firenze, originated with this Institution, whose renewed headquarters are today opened.

Under the leadership of ALDO PAVARI, distinguished and unforgettable founder of the Experimental Station and undisputed master of forestry, the first generation of researchers implemented an innovative scientific contribution: ALESSANDRO DE PHILIPPIS (1908-2002), ERNESTO ALLEGRI (1904-1986), LUCIO SUSMEL (1914-2006), UMBERTO BAGNARESI (1927-2003), GERMANO GAMBI (1921-1992), RICCARDO MORANDINI (1925-2011). All the foresters, Italians and foreigners, must be grateful to all of them for the advancement of forest science and for their contribution to make research in our Country known outside.

Looking back, I do think I belong to the second generation of the School that marked the history of forestry in Italy, and in the world. Today, the third generation of scholars and researchers is here in close connection with the Experimental Station.

The former Director of the Centre Prof. FRANCESCO IOVINO is here today. I long worked with him in Calabria, and I wish to thank him for his great commitment driving him in all phases of his studies and research activities.

The current Director of CRA-SEL Prof. PIERMARIA CORONA too, belongs to this generation. I express him my best wishes for his research activity and innovative experimentation. And I would emphasize innovative. I am aware of his great abilities to have been working with him at the University of Firenze. He performed a distinguished scientific contribution in various forestry disciplines and I believe he will give a breakthrough to research within this Centre. This is an essential turning point to overcome current difficulties of the forestry sector.

I am sure the Centre will run through the basic path outlined by the first generation of researchers and will play again a significant role in the innovative course of forestry research.

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Conference paper

Forest biotechnology advances to support global bioeconomy

Antoine Harfouche[1*], Sacha Khoury[1], Francesco Fabbrini[1], Giuseppe Scarascia Mugnozza[1]

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Abstract - The world is shifting to an innovation economy and forest biotechnology can play a major role in the bio-economy by providing farmers, producers, and consumers with tools that can better advance this transition. First-generation or conventional biofuels are primarily produced from food crops and are therefore limited in their ability to meet challenges for petroleum-product substitution and climate change mitigation, and to overcome the food-versus-fuel dilemma. In the longer term, forest lignocellulosic biomass will provide a unique renewable resource for large-scale production of bioenergy, biofuels and bio-products. These second-generation or advanced biofuels and bio-products have also the potential to avoid many of the issues facing the first-generation biofuels, particularly the competition concerning land and water used for food production. To expand the range of natural biological resources the rapidly evolving tools of biotechnology can ameliorate the conversion process, lower the conversion costs and also enhance target yield of forest biomass feedstock and the product of interest. Therefore, linking forest biotechnology with industrial biotechnology presents a promising approach to convert woody lignocellulosic biomass into biofuels and bio-products. Major advances and applications of forest biotechnology that are being achieved to competitively position forest biomass feedstocks with corn and other food crops are outlined. Finally, recommendations for future work are discussed.

Keywords - Forest biotechnology, bio-economy, biofuels, bio-materials

Introduction

Bioeconomy encompasses all economic activities that are fueled by research and innovation in the biological sciences. It is a large and rapidly growing segment of the global economy that provides significant public benefit (OECD 2009). Also, it has emerged as a worldwide priority because of its tremendous potential for growth and the numerous societal and environmental benefits it offers. Bioeconomy can help to reduce the world dependence on fossil fuels, address key environmental challenges, transform manufacturing processes, and increase the productivity and scope of the agricultural and silvicultural sectors while creating new jobs and innovative industries.

Food, feed, energy, and industrial products demand will increase concomitantly with human population and climate change. This production therefore needs to be high enough and, at the same time, minimize or prevent harm to the environment. Yet, this balance cannot be achieved with current strategies. Moreover, food and energy crises have often occurred in the past. In recent years, the rapidly increasing demand for food (i.e., for human populations and livestock) along with biofuels has led to food price volatility (Battisti et al. 2009).

Based on recent findings, new avenues for forest breeding which take into account the integration of modern genetic and genomic techniques with conventional breeding will expedite forest tree improvement (Harfouche et al. 2012a and 2014). In this context, we argue that forest breeders and land owners have the opportunity to make use of modern biotechnologies in an innovative ecologically sound silviculture.

In addition, as we are advancing towards a global economy that is attempting to find ways to break its addiction to fossil fuels and develop an economy based on renewable biological materials and energy sources, forest biomass is being actively explored as a possible substitute in many parts of the world.

Forest trees constitute about 82% of the continental biomass (Roy et al. 2001) and harbor more than 50% of the terrestrial biodiversity (Neale and Kremer 2011). They also help to mitigate climate change, and provide a wide range of products that meet human needs, including wood, biomass, paper, fuel, and bio-materials (Harfouche et al. 2012a). However, forest tress grown in the field are usually exposed to environmental stress. Current and predicted climatic conditions, such as prolonged drought, increased soil and water salinity, and low-temperature episodes pose a serious danger to forest productivity, affecting tree growth and survival (Harfouche et al. 2014).

Conventional breeding has been successful at ameliorating several phenotypic characteristics that

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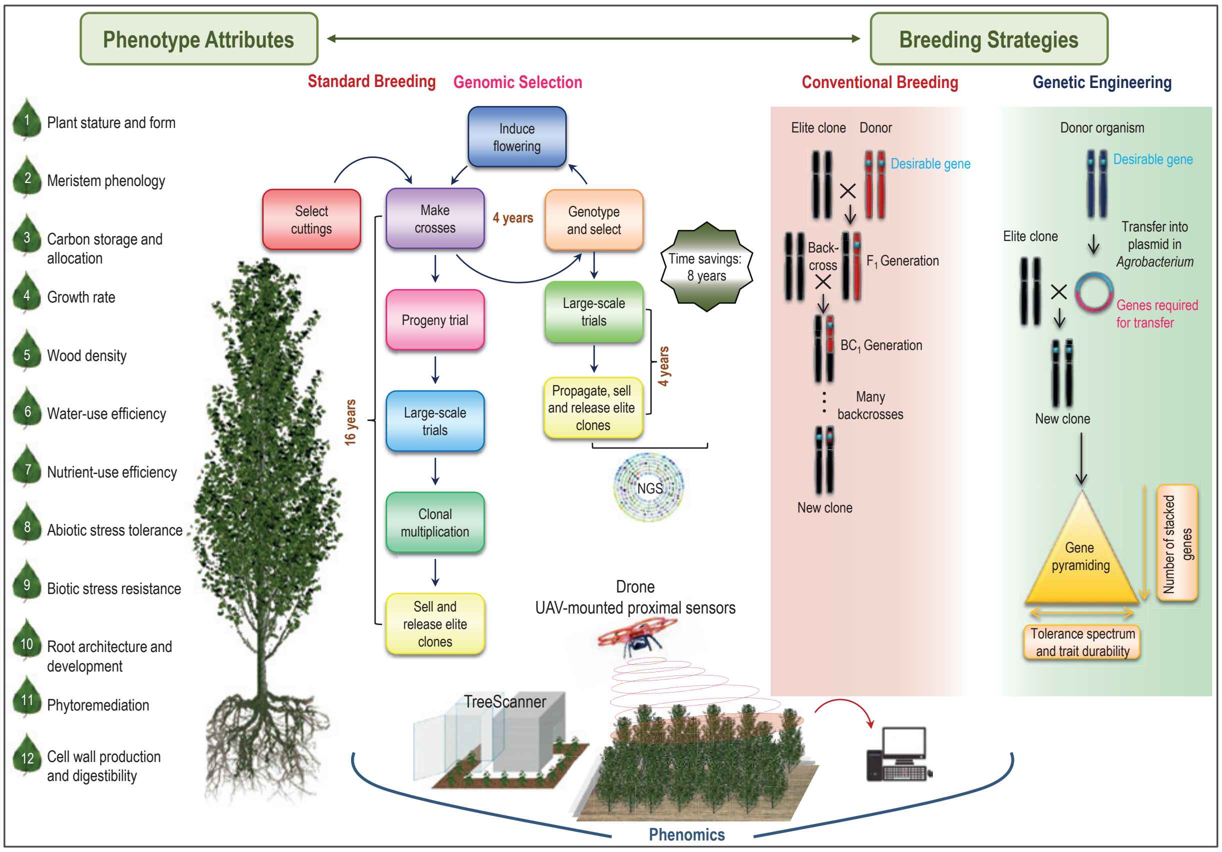

Figure 1 - A schematic representation of integrated forest breeding strategies in next generation genomics and phenomics era focusing on poplar as the tree model species for biofuel research. Incorporation of Next-Generation Sequencing (NGS) based multi-omics approaches with genetic engineering, Genomic Selection and phenomics can be used to speed up tree breeding and save time as compared with conventional breeding. These new varieties will maximize yield per acre with minimum inputs and exhibit value-added traits that enhance their use as biofuel and bio-based feedstocks.

impact tree growth, such as crown architecture and partial resistance to biotic stress. But, continued improvement of forest trees by traditional means is slow due to their long generation times and large genomes (Neale and Kremer 2011). Nevertheless, over the past two decades, genetic improvement opportunities have been broadened by genetic engineering targeting important traits in model forest-tree species (Harfouche et al. 2011). This stems from the urgent need to better understand how forest trees adapt to severe environmental conditions in order to develop new and improved varieties that are able to sustain productivity and meet future demands for commercial products. For example, the completion of a draft genome sequence of the poplar (*Populus trichocarpa* Torr. & Gray ex Brayshaw; Tuskan et al. 2006) has advanced forest tree genetics to unprecedented levels. Recent releases of the genome sequences of white spruce (*Picea glauca* (Moench) Voss; Birol et al. 2013), Norway spruce (*P. abies* L.; Nystedt et al. 2013) and Eucalyptus (*Eucalyptus grandis*; Myburg et al. 2014) and the anticipated release of the Pinus genome will undoubtedly lead to more rapid advances.

Despite the enormous promise of advanced forest biotechnology, it has yet to gain traction as a viable breeding alternative, mainly because of its exhaustive biosafety regulations and the divided public opinion over it. Besides, understanding the relationship between genotype and phenotype and dissecting complex polygenic traits in forest trees becomes a central goal in tree genetic improvement.

In addition, innovative technologies, such as genomic selection (GS) and next-generation Ecotilling (Harfouche et al. 2012a), are now proving to be important strategic approaches to improving our understanding of various processes in forest trees and the role of key genes associated with their regulation (Resende et al. 2012, Vanholme et al. 2013). Although there have been considerable advances in our understanding of lignin biosynthesis and monomer composition, most of the genetic engineering efforts have been restricted to poplars, and overcoming biomass recalcitrance due to novel engineering of lignin pathways in other forest trees is still in its infancy.

This article provides a summary of recent achievements in forest biotechnology with an overview on the integrative approach to accelerate the development of improved forest feedstocks for a sustainable bioeconomy (Fig. 1). Furthermore, it discusses new approaches and concepts (Fig. 2, 3 and 4) to advance the forest-based bio-economy and issues that should be considered when devel-

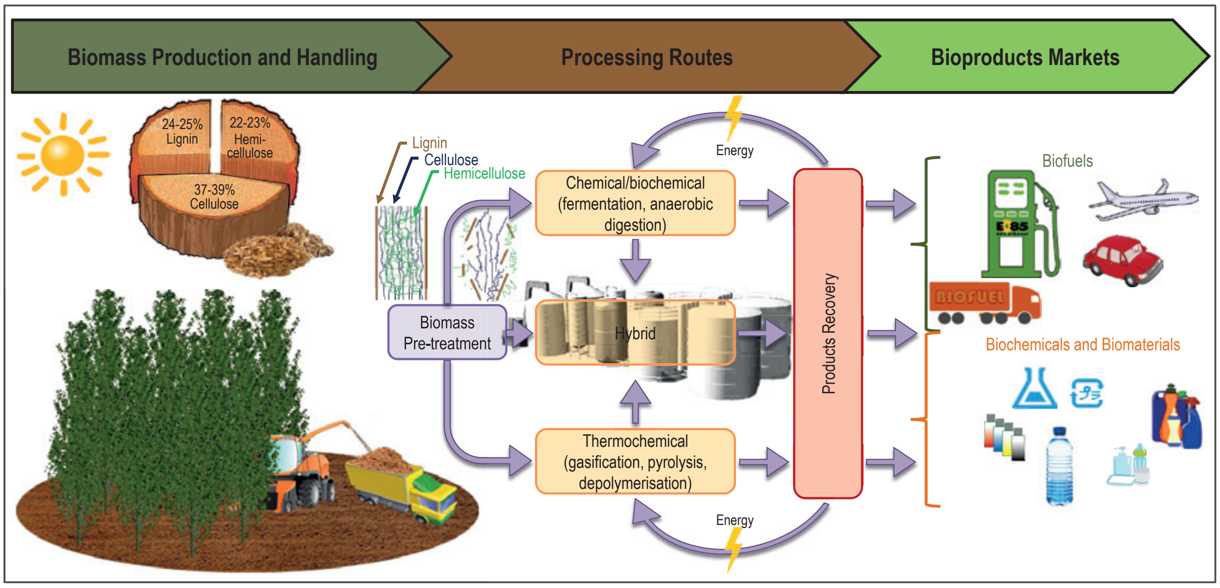

Figure 2 - The integrated biorefinery concept. Forest lignocellulosic biomass are ideal feedstocks that can be used to produce bioenergy, biofuels and bio-products, using thermochemical or biochemical conversion routes, or a combination of both.

oping and deploying biotech trees with improved attributes.

The emerging global bioeconomy

Bioeconomy involves the sustainable production of renewable biological resources and their conversion into food, feed, biofuels, bioenergy, and bio-products by harnessing the power of biotechnology, but at the same time preserving the environment and ecosystem services. In this article, bio-based production encompasses items produced from forest biomass feedstocks including biofuels, bioenergy and bio-products or bio-materials (largely bio-chemicals and bio-plastics) (Fig. 2).

Until recently, in most countries the focus has been to a great extent on first-generation biofuels production. However, second-generation biofuels and bio-materials offer exciting opportunities for future manufacturing to replace existing fossil-based materials with bio-based, therefore, contributing to greenhouse gas (GHG) emissions reductions. Yet, green credentials are not enough to justify their place in the market. Therefore, the technical, economic and social performances of these materials have to be considered (Philp and Pavanan 2013). In addition, bio-based production promises high-value jobs. Carus et al. (2011) have estimated that materials use of biomass can directly support 5-10 times more employment and 4-9 times the value-added compared with energy uses, principally due to longer, more complex supply chains for material use. Moreover, a report commissioned for The Blue Green Alliance estimated that shifting 20% of current plastics production into bio-plastics would create a net 104,000 jobs in the US economy (Heintz and Pollin 2011).

However, if a bioeconomy is to succeed in any country, it should rely on international cooperation and trade (Philp and Pavanan 2013). On the one hand, the drivers behind the development of bio-based production are global: climate change mitigation, energy security and independence, the attraction and creation of new jobs associated to rural regeneration. On the other hand, global food security is a grand challenge facing society, and there are ways in which energy and food production come into direct competition (Seidenberger et al. 2008).

Bioeconomy is becoming a reality in many parts of the world as it offers great opportunities and solutions to tackle major societal, environmental and economic challenges. A global bio-economy that is also based on agricultural and forest biomass is emerging in Europe, the United States and Canada that offers an avenue toward a more low-carbon green economy. Exploitation of non-food feedstocks such as forest biomass is gaining importance for this sustainable production.

The bioeconomy concept is currently flexible and it is interpreted differently in different countries and regions. While, many countries have already published national strategies and visions on the bio-economy (i.e., The Bio-economy to 2030: Designing a Policy Agenda by OECD, the National Bio-economy Blueprint in the United States, Innovating for Sustainable Growth: A Bio-economy for Europe, The Canadian Blueprint: Beyond Moose and Mountains) some have established organizations and networks to stimulate and develop it. Though, sustainability is recognized as important, the driving force behind the bioeconomy is the opportunity for economic growth and innovation.

The role of forest biotechnology in a sustainable bioeconomy future

The tools of biotechnology have the potential to produce a new generation of genetically improved bioenergy crops that are engineered to either produce high biomass yield and digestibility, or offer protection to bioenergy crops against environmental stresses, or a combination of all attributes (Fig. 1).

Lignocellulosic biofuels promise to resolve the most significant problems associated with existing first-generation biofuels. For example, Littlewood et al. (2014) have recently shown that bioethanol from poplar biomass feedstock is a commercially viable alternative to fossil fuel in the European Union. A techno-economic modeling to compare the price of bioethanol produced from short rotation coppice (SRC) poplar feedstocks under two leading processing technologies (dilute acid and liquid hot water), in five European countries (Sweden, France, Italy, Slovakia, and Spain) has been used. In a forward-looking scenario, genetically engineering poplar with a reduced lignin content showed potential to enhance the competitiveness of bioethanol with conventional fuel by reducing overall costs by approximately 41% in four out of the five countries modeled (Littlewood et al. 2014). Current research and development (R&D) also focus on evaluating poplar biomass production potential in a SRC. Such research is critical for investigating the performance of novel poplar genotypes deriving from standard breeding programs with potential for commercial biomass production over multiple coppice rotations. Results by Sabatti et al. (2014) showed that poplar biomass production differed significantly among rotations starting from 16 tons/ha/year in the first, peaking at 20 tons/ha/year in the second, and decreasing to 17 tons/ha/year in the third rotation. This will ultimately lead to a more efficient economic feasibility of utilizing tree woody biomass for biofuels and bio-materials.

Miscanthus can greatly reduce the land intensity of biofuel production. While only 4.5 dry tons of harvestable corn grain are extracted from each acre of corn grain, 13 dry tons of harvestable biomass of Miscanthus is produced per acre. Thirteen-hundred gallons of cellulosic ethanol can be produced per acre of Miscanthus biomass plantation. Only 450 gallons of corn-ethanol are yielded per acre of corn. In the United States, a hypothetical scenario to produce 35 billion gallons of bioethanol, using corn as a feedstock would demand one-quarter of all harvested cropland. However, using Miscanthus bioenergy crops would need less than one-tenth (Heaton et al. 2008).

Biotechnologically-improved bioenergy crops such as poplar can also be grown on marginal and drought-prone lands where major crops are less productive. This would permit to ease the competition on land and water resources to be used for food and feed. Recently, it has been shown that the constitutive overexpression of the wintersweet (*Chimonanthus praecox*) fatty acyl–acyl carrier protein thioesterase (CpFATB) in poplar activates an oxidative signal cascade and leads to drought tolerance in the transgenic plants. The genetically engineered poplar maintained significantly higher photosynthetic rates, suggesting that changes in fatty-acid composition and saturation levels may be involved in leaf tolerance to dehydration during drought stress (Zhang et al. 2013). Another important study reported that gene stacking by overexpressing multiple resistance genes enhanced tolerance to environmental stresses in transgenic poplar. The transgenic lines harboring effector genes: *vgb*, encoding aerobe *Vitreoscilla hemoglobin; SacB*, encoding a levansucrase that is involved in fructan biosynthesis in *Bacillus subtilis;* and *JERF36*, a tomato gene encoding jasmonate/ethylene-responsive factor protein exhibited higher growth than the controls, as demonstrated by greater height, basal diameter, and biomass than the corresponding non-transgenics. This improved growth could be primarily due to higher water-use efficiency and fructan levels, and better root architecture under drought and salinity stress (Su et al. 2011).

These selected recent advances in maximizing tree tolerance to drought stress will allow an important bioenergy crop to be bred so it will grow in less than ideal soils and climate. Together, these results demonstrate the potential of forest biotechnology for improving environmental stress tolerance and biomass processability in forest trees.

Equally important, GS is extremely appealing in forest trees due to the prospects of improving accuracy when selecting for traits with low heritability (e.g., biomass productivity and abiotic stress tolerance) and where long generation times and late-expressing, complex traits are involved (Grattapaglia and Resende 2010). However, successful application of GS in tree breeding programs aimed at developing trees that are tolerant to environmental stresses or to dissect quantitative trait variation will require comprehensive physiological information that rely on rigorous phenotyping. Therefore, high-throughput phenotyping of morpho-physiological traits will require the utilization of sophisticated, non-destructive imaging techniques in a multi-

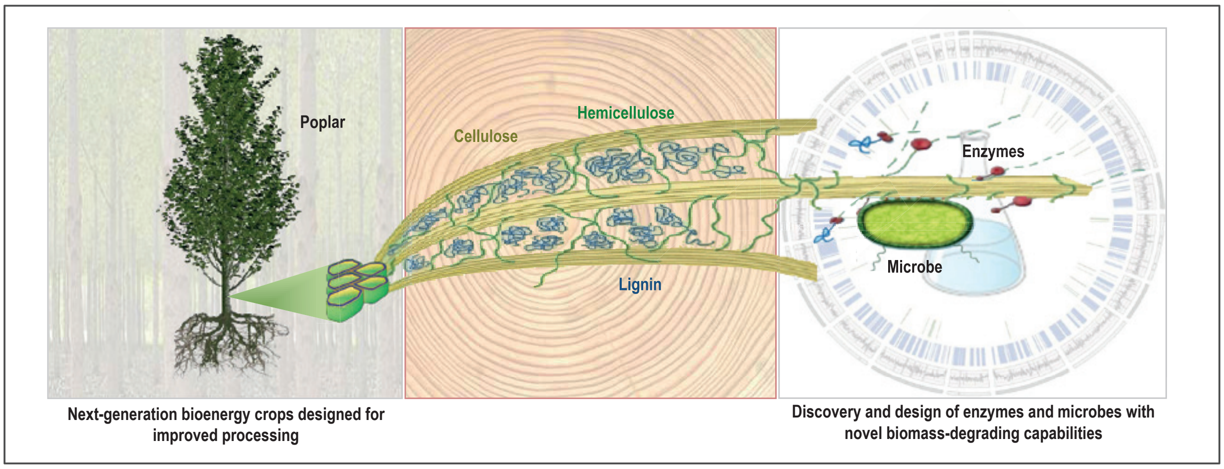

Figure 3 - An integrated multidisciplinary approach linking forest and industrial biotechnology to overcome the recalcitrance of biomass toward processing.

spectral approach. For example, near-infrared spectroscopy, canopy spectral reflectance, and infrared thermography can be used to assess biomass productivity and plant water status, and to detect environmental stresses at the individual-tree level. These sensors can be mounted on drones, which can be directed with a global positioning system to enhance the precision and accuracy of phenotyping under field conditions (Harfouche et al. 2014).

This phenomics approach further creates opportunities to overcome the field-based phenotyping bottleneck and generate phenotyping sets, such as environmental stress tolerance and biomass estimation. Ultimately, it will help to uncover phenotype-to-genotype relationships and their relevance for improving tolerance to environmental stresses in forest trees (Fig. 1). GS coupled with phenomics offers great promise for forest breeders in accelerating the genetic improvement of forest trees as bioenergy feedstocks.

Biotechnology has the potential to not only produce more productive bioenergy crops and minimize inputs, but also to develop more efficient biofuels and bio-materials conversion processes. This offers a great cause for optimism that the global bioeconomy challenges of the new century can be met.

Linking forest and industrial biotechnology to accelerate drive towards sustainable bioeconomy

Undoubtedly, one of the greatest impediments to commercializing second-generation biofuels along with bio-materials that has yet to be solved is that most of the conversion processes are not yet ripe, costly and time-consuming. An integrated second-generation biorefinery can use either a biochemical or thermochemical process, or a hybrid of both, in order to process efficiently biomass feedstocks into multi-purpose products with great added-value (Fig. 2). The biomass-tailored thermochemical conversion system relies on heating the feedstock to high temperatures with little or no oxygen. Whereas, the biochemical system relies on the use of microorganisms and enzymes to process the biomass and on the genetic engineering of these microorganisms for more efficient biological conversion. The concept of coupling green (plant) and white (industrial) biotechnology is proposed here (Fig. 3). R&D focusing on the synergistic interaction between these two biotechnologies are therefore of paramount importance. Plant biotechnology is, on one hand, playing an important role in the development of advanced biomass feedstocks for a bioenergy and bio-products industry. On another hand, industrial biotechnology is involved in the conversion of these renewable and sustainable resources into a wide range of biofuels and bio-materials (Fig. 2 and 3).

Lignocellulosic biomass are mostly composed of cellulose, hemicellulose, and lignin, which serve to maintain the structural integrity of plant cells (Fig. 2 and 3). Lignocellulosic woody materials have great potential for biofuel and bio-materials production. The plant cell wall polysaccharides can be used as a feedstock for biofuel production after being broken down into simple sugars (saccharification) (Ragauskas et al. 2006, Solomon et al. 2007), but lignin strongly impedes this process (Boerjan et al. 2003). A highly degradation-resistant phenolic polymer, lignin is part of a complex matrix in which cellulose microfibrils are embedded. The inhibition of saccharification enzymes by lignin may result from the reduced accessibility of cellulose microfibrils, as well as the adsorbtion of hydrolytic enzymes to the lignin polymer (Weng et al. 2008). Furthermore, current chemical and physical strategies to remove lignin from biomass, such as pretreatment with steam or acid, result in the formation of compounds which can inhibit downstream processes of saccharification and fermentation (Hamelinck et al.

2005). All together, these lignin properties are hard to deal with and make its biosynthesis a key control point in biomass degradation and in determining the efficiency of biofuels production (Weng et al. 2008).

In addition to work being conducted *in planta* using genetic engineering, with the goal of manipulating lignin content and monomer composition, another line of experimentation is to discover novel strategies for lignin degradation. Therefore, R&D aimed at increasing the efficiency and decreasing cost of lignocellulosic biomass pretreatment is currently a high priority along with the metagenomic discovery of biomass-degrading genes and genomes. For example, recent deep sequencing data sets in the cow rumen microbes provided a substantially expanded catalog of genes and genomes participating in the deconstruction of cellulosic biomass (Hess et al. 2011). In addition, recent release of the genome sequence of white rot fungus (*Phanerochaete chrysosporium*) has shown that the genome of this fungus encodes hundreds of enzymes potentially dedicated to lignin degradation (Martinez et al. 2004, Vanden Wymelenberg et al. 2006). Thus, harnessing this rich biological diversity that has recently started with the metagenome sequencing of the gut flora of *Nasutitermes* is an important step forward for lignin degradation (Warnecke et al. 2007). Likewise, a deeper understanding of termite lignocellulose digestion by metagenomics could shed light on the enzymatic mechanisms useful for biomass delignification.

Building skills for Europe's bioeconomy: the role of biotechnology and entrepreneurship

Bioeconomy is one of the world's most educated industries. These creative scientific minds drive the global bioeconomy where Small and Medium Size Enterprises (SMEs) constitute ~80% of the companies in most developed countries' bio-economy. Besides, the bio-economy in Europe is currently worth more than € 2 trillion a year and employs over 22 million people, predominantly in rural areas and often in SMEs (Ernst & Young 2012).

Entrepreneurship education is now recognized as an important part of fostering entrepreneurial activity in the European Union. Entrepreneurship in biotechnology has a great potential to maximize the impact and commercial potential of the bio-economy (Fig. 4). The significant growth of the biotechnology sector over the last decade means that biotechnology enterprises are seen as playing a vital role in creating solutions and jobs in the future. For example, Harfouche et al. (2010) have recently shed light on how to protect biotech-based innovation for the development of feedstock for second-generation biofuels and strategies for technology transfer to show the important role biotechnology Intellectual Property plays in the global bioeconomy (Harfouche et al. 2012b).

Important prerequisites for a competitive bio-economy is the availability of well-trained workforce with the necessary entrepreneurial mindset and business skillsets. To move this forward, European efforts have recently sought to develop new learning and teaching model for entrepreneurship education in biotechnology to train the next-generation of talents to turn vision into reality. A two-year Knowledge Alliance project funded by the European Commission which brings together a knowledge and innovation community through partnership across Europe (www.bioinno.eu) for biotechnology

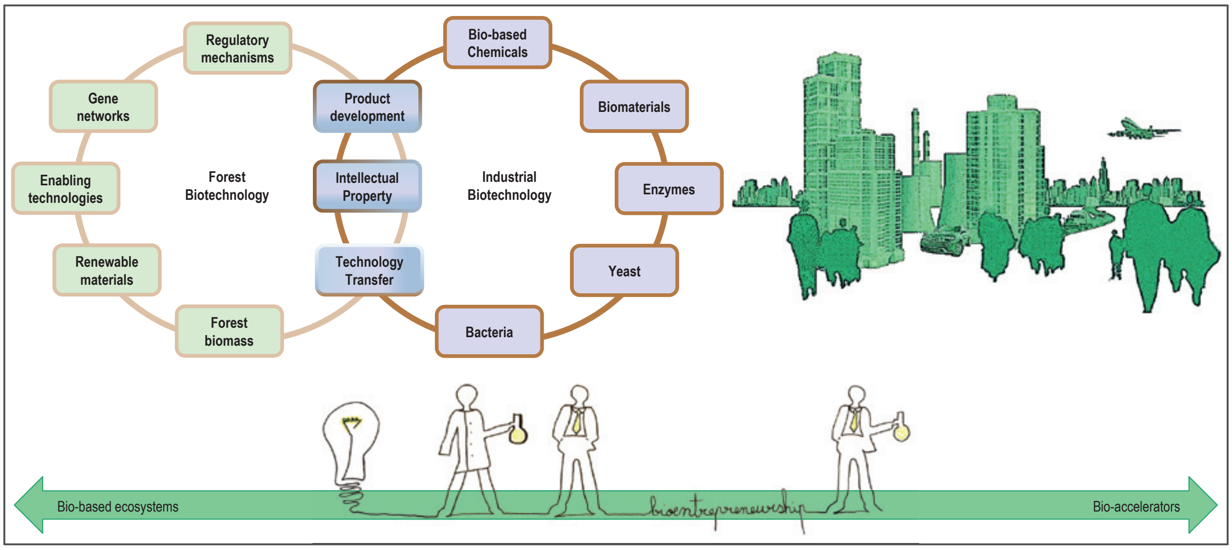

Figure 4 - Building skills for Europe's bio-economy. An increased focus on entrepreneurship, translational sciences, regulatory science, product development, and technology transfer in biotechnology and forestry can help accelerate movement of bioinventions out of laboratories and into markets.

entrepreneurship education has recently initiated. This program will focus on teaching biotechnology entrepreneurship with an emphasis on innovative biotechnology applications in agriculture, forestry, and bio-based economy.

With innovations in biotechnology at the core of the success of global bio-economy, and the world's need for a more accessible and translational science, this challenge will have to be tackled by governments and industry associations. Greater investment in R&D and integration of bio-entrepreneurship education and traineeship are also necessary to react to global bioeconomy challenges.

What next?

Future R&D directions and key actions that need to be taken to tackle the managerial, economic and political challenges facing the forest-based bio-economy are highlighted.

(i) We need to adopt an all-inclusive approach among forest biomass developers, landowners, biofuels producers, end users and policymakers. This will enhance our ability to develop bioenergy crops for the growing bio-economy agenda. Government interventions with subsidies for production, consumption and R&D are instrumental in the promotion of second-generation biofuels.

(ii) With unprecedented recent technological advances in the areas of genomics and phenomics, we are now well poised to capitalize on these strategies to speed up the development of ideal forest biomass feedstocks for bio-economy. Ultimately, this holistic approach will deepen our understanding of forest tree breeding and enhance our ability to develop desired tree phenotypes.

(iii) Water supply is obviously another crucial factor in sustainability of forest biomass production. The scale of its importance is worth highlighting. As it is often necessary to grow forest trees on marginal land, where water and nutrient resources are limiting, it will become increasingly important to improve water and nutrient use efficiency in forest trees using biotechnology to ensure sufficiency and sustainability. To reap these research-proven benefits, biosafety regulations must be improved and public acceptance must be properly addressed.

(iv) Another major obstacle to industrial-scale biofuels production from lignocellulosic biomass lies in the inefficient deconstruction of plant cell wall material. Metagenomics aimed at retrieving novel enzymes from naturally evolved biomass-degrading microbial communities coupled with in planta engineering should aid in the optimization of biofuel and bio-materials production and the development of advanced bioenergy crops.

(v) High octane fuel blends have a great potential to expand the market for advanced second-generation biofuels, increase engine efficiency, and reduce GHG emissions from transportation sector. Before these benefits can be realized, key market and regulatory challenges must be overcome.

With growing global commitments to energy security and climate change mitigation, the world have a great opportunity to reap the benefits of economic growth, jobs creation, and environmental improvements that bio-economy plans promise. We hope these endeavors will encourage greater international coordination and cooperation from both public and private sectors for R&D.

Concluding remarks

The world's ambitious plan to reduce its carbon footprint has led to the emergence of a new bio-economy, one in which non-food forest-based biofuels and bio-products have a significant advantage over fuels and products that are non-renewable and require large amounts of fossil fuel energy to manufacture. Yet, this will require more forest biomass resources and a rigorous forest management, in order to be well positioned to ensure sufficiency and sustainability in the production of new bio-products while creating new jobs and preserving the ecosystem services (e.g., water-quality protection, as well as wildlife conservation).

By producing biofuels and bio-based materials from wood, forest products companies can capture new markets, and support rural communities and government services.

There are numerous viable strategies to convert forest biomass into biofuels and bio-materials. Yet, to maximize jobs and economic returns, these strategies have to be integrated with the existing forest products industry.

In this article, we propose to integrate novel genetics, genomics and phenomics with conventional breeding to expedite forest tree improvement. This integrative approach could prove a useful tool for speeding up future forest breeding programs with the aim of sustainable woody biomass production. For example, the use of genome-wide selection is an emerging approach that will revolutionize the applications of tree breeding. Phenotypic selection or marker-assisted breeding protocols can be replaced by selection, based on whole-genome predictions in which phenotyping updates the model to build up the prediction accuracy. Ultimately, GS could substantially shorten generation time through rapid cycles of breeding, selection and propagation.

Second-generation biofuels produced from forest lignocellulosic biomass represent a renewable, more carbon-balanced alternative to both fossil fuels and corn-derived or sugarcane-derived biofuels. However, forest biomass recalcitrance to saccharification is one of the major impediments to high-yield and cost-effective production of biofuels and value-added bio-chemicals and bio-materials from lignocellulosic feedstocks. Due to the natural recalcitrance of lignocellulose, coupling forest and industrial biotechnology will further improve the conversion process from biomass to second-generation biofuels and bio-products (Fig. 2 and 3). Decreasing lignin content and/or modifying lignin monomer composition of forest biomass by genetic engineering is believed to mitigate biomass recalcitrance and improve conversion efficiency of tree biomass. Likewise, industrial biotechnology involving sequencing the genomes of natural microbes will lead to important insights relevant to biofuels production. Lignin degradation in nature may provide novel resources for the delignification of forest lignocellulosic biomass feedstocks. It is strongly believed that the genome of these microorganisms encode hundreds of enzymes potentially dedicated to lignin degradation. Finally, a better biosafety regulation over the momentous tree genetic engineering and novel breeding technologies and their long-term economic impact would bring valuable contributions towards developing an economically sustainable biofuels and biomaterials markets worldwide.

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Conference paper

Forest genetic resources to support global bioeconomy

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Abstract - A biobased economy implies sustainable and effective use of the biomass. This includes new products from forestry. The sustainable production, use, consumption and waste management of biomass all contribute to a bioeconomy (The European Bioeconomy in 2030).

In the context of bioeconomy the conservation of forest genetic resources assumes a key significance in overcoming global challenges such as climate change. Forests are expected to play a key role in climate change mitigation, but they will only be able to fulfil that role if the trees themselves are able to survive and adapt to changing climate conditions. Genetic diversity provides the fundamental basis for the evolution of forest tree species and for their adaptation to change. The enormous range of goods and services provided by trees and forests is both a function of and testimony to the genetic variability contained within them. Conserving forest genetic resources is therefore vital, as they constitute a unique and irreplaceable resource for the future, including for sustainable economic growth and progress and environmental adaption (The State of the Worlds Forest Genetic Resources 2014). Previous research of population characteristics and the effects of natural and artificial selection on the genetic structure of populations contribute to the conservation and enhancement of the gene pool of the native tree species. The balance model of the population genetic structure reveals the new properties of the populations and requires further investigations, especially of the relations of subpopulations, half-sib families and organisms and the effect of variable factors of the environment, on the exchange of genetic material within natural and cultural populations.

Being of national and international significance, these resources require intensive protection and enhancement *in situ* and *ex situ*. In this paper a general introduction is given to conservation of forest genetic resources in Serbia, Croatia and Macedonia in the context of bioeconomy. Based on the current situation of conservation of forest genetic resources, some strategic suggestions concerning the future development of genetic conservation is given, taking into consideration the conservation objectives and future trends of great impact on existing forest genetic resources.

Keywords - Genetics resources, conservation, bioeconomy

Introduction

The concept of "bioeconomy" or "bio-based society" has become an important component of national, EU and global policies. The social, economic and biological challenges we face, and the scarcity of natural resources combined with climatological changes, necessitate new approaches to knowledge and innovation as well as to knowledge-based policies. The transformation to a bio-based economy means a transition from a fossil fuel-based economy to a more resource-efficient economy based on renewable materials produced through sustainable use of ecosystem services from land and water. A greater focus on research and innovation can provide us with new products developed from biomass that will replace fossil material, combat climate change, reduce waste and create new jobs.

A bio-based economy (bioeconomy) can be defined as an economy based on (The European Bio-economy in 2030):

a) The sustainable production of biomass to enhance the use of biomass products within a number of different sectors of society. The objective is to reduce climate effects and the use of fossil-based raw materials.

b) Increased added value for biomass materials, concomitant with a reduction in energy consumption and recovery of nutrients and energy as additional end-products. The objective is to optimise the value and contribution of ecosystem services to the economy.

Climate change influences both the forest as an ecosystem and also sustainable wood production. The forests need to be adapted to climate change, to continue to secure both their function for use, protection and recreation, and also the role that wood and the forest play in protecting the climate (The State of the Worlds Forest Genetic Resources 2014).

An important objective of the conservation of genetic resources is to maintain the adaptedness of organisms to changing environmental conditions. By conserving sufficient amounts of heritable variation in different species and thus their evolutionary

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potentials, life can continue under changing and even new conditions. The possibilities for future generations to meet their varying demands are thus secured (Rajora and Mosseler 2001).

The genetic variation of most agricultural and horticultural crops as well as of farm animals can be collected and conserved in so-called gene banks. However, forest genetic resources are usually conserved as living trees in growing forests.

Considering the objective of preserving the broadest genetic diversity, not only the most representative trees populations or important single trees should be subject to gene conservation. Populations from marginal localities also need to be conserved, despite their lower economic importance as such populations and trees may carry genes of importance for breeding (adaptability, resistance). *In situ* and *ex situ* measures are necessary to complement each other (Andonovski and Velkovski 2011).

Conservation, testing and utilization of tree species gene pool involves several successive *in situ* and *ex situ* activities such as: a) study of the nature of phenotypic variability in large and small populations, b) improvement of mass and individual selection techniques, c) application of intervarietal and distant hybridization, d) analysis of morphometric characters, e) familiarity with the correlation of growth characteristics and the development of the analyzed genotypes and their progeny (Isajev et al. 1988). Activities contributing to gene pool conservation and utilization imply its conservation *ex situ* - through the reproduction of forest populations and superior genotypes by establishing specialized seed sources, arboretums, live archives, provenance tests, progeny tests, clonal tests and seed orchards (Gustafsson 1950, Jovanović 1972, Isajev et al. 1995, Skrøppa 2005). *Ex situ* populations of forest trees in Serbia, Croatia and Macedonia are established in the aim of protection and directed utilization of the gene pool of physically endangered populations or individuals, as a supporting activity to conservation *in situ* and for the provision of readily available constant supplies of genetically improved reproductive material.

The paper presents preliminary results of multiannual analyses which are being carried out in specialized plantations of different tree species aimed at testing of genotypes of parent individuals as well as their half-sib lines. The results of multiannual analyses lead to a better knowledge of the production and adaptation potentials of analyzed species. Seed orchards and pilot plots, being the specialized plantations, should contribute not only to the conversion of the potential genetic variability into free one, as the base of directed utilization of tree gene pool, but also they are the polygons for testing and conservation of species biodiversity.

Conservation of genetic resources *in situ* in Serbia

In order to conserve gene pool *in situ*, in Serbia there are six National Parks, ten Regional Parks, 50 Reserves and 158 Seed Stands of major economic species of broadleaves and conifers. National Parks are: Fruska Gora – 25'300 ha, Djerdap – 63'608 ha, Tara – 19'200 ha, Kopaonik – 11'810 ha, and Shara – 39'000 ha (total 158'918 ha). In the National Parks Fruska Gora and Djerdap, mostly the communities of deciduous tree and shrub species are represented, in the Parks Tara, Kopaonik and Shara, the communities of coniferous species are predominant. Seed stands, along with the production of good quality seed stock, are also intended for the conservation of the gene pool of tree and shrub species in situ, as they contain plus and normal trees and the trees which represent the average of the population. Seed stands are listed in the Proposed Register of Forest Seed Sources in Serbia, with separate lists of broadleaf and coniferous species. The Register includes 151 coniferous seed sources - total area 1'476.1 ha, of which 36.9 % are fir, 28.5 % spruce, 14.2 % Scots pine, 11.8 % Austrian pine, 4.1 % Serbian spruce. There are 65 seed stands of broadleaf species covering 1'665.2 ha, of which 30.5 % are Sessile oak stands, 31.1 % Pendunculate oak, 17.1 % Common beech, 21 % Turkish hazel, 8.4 % lime and 2 % other species. The Registers of seed stands were made twenty years ago, so on the occasion of their revision, only the best populations, i.e. the best trees should be chosen by which the greatest possible portion of the desirable intraspecies variability will be included. Also the work should be intensified on the study and zonation of seed utilization from the zones containing seed stands of major economic species of trees.

Conservation of genetic resources *ex situ* in Serbia

The opportunities for the singling out of Nature Reserves, and in this respect, the protection of forest natural resources, are proportionally limited. For these reasons, Norway spruce provenance test and specialized sources and plantations have been established in Serbia to conserve the genetic resources of woody species *ex situ*, by the reproduction of selected species in forest populations. They are: (a) seed orchards, (c) provenance tests, and (d) progeny tests. Each of the above categories has a special purpose, which is coordinated with the needs of gene pool protection and enhancement.

Seedling seed orchards were established from 50 Serbian spruce half-sib families on the area of 2.7 ha (Isajev et al. 1990), Austrian pine - 40 families on 3 ha (Tucović and Isajev, 1991), divulge wild cherry - 30 families on 1.5 ha, Pedunculate Oak – 76 ramets (Erdeši 1996, Orlović et al. 1999 and 2002), Pedunculate Oak – 122 families (Orlović et al. 2001). The yield in these plantations has not yet reached the level of commercial exploitation. However, the progeny from seedling seed orchards will be more variable than that from clonal ones, and consequently seedling seed orchards are better for the purpose of gene pool conservation.

Norway spruce provenance test in Serbia

Morphological variability and changeability of physiological properties of intraspecial taxons of Norway spruce are described, among other researches, on the bases of provenance tests in Europe and North America (Lines 1967, Kleinschmit 1970, König 2005). The results obtained in the analyses of these tests enabled better familiarity with the production and adaptive potential of the Norway spruce gene pool and the ecological factors which determine the range of its horizontal and vertical distribution were established (Isajev et al. 1990).

For the establishment of a provenance test in the vicinity of Ivanjica 3 locations with different altitude, exposition and area as well as different site characteristics were chosen (Isajev et al. 1992). In the test plantations, five Norway spruce provenances from Serbia are comparatively examined: Golija, Zlatar, Cemerno, Radocelo and Kopaonik, as well as three Slovenian provenances - Jelovica, Menina and Masun. On the basis of data of the Hydro meteorological service in Belgrade regarding the area of Ivanjica, climatic conditions of all three locations were studied. In the very areas in which the test plantations were established topographic surveys were carried out and a total of 8 soil profiles were opened.

The first test plantation is in the department 51, at an altitude of 570 to 610 m, northern exposition and the total area of 2.02 ha, on deep acid soil (dystric cambisol) and the geological base were schists. The second test plantation with the area of 0.65 ha is in the department 38 of FMU Kovilje- Rabrovica: south-eastern exposition, altitude of 1’105 to 1’125 m on dystric cambisol on schists. The third test plantation was established in the department 46, section C in FMU Golija at an altitude of 1’560 to 1’570 m. The exposition was north-eastern and the area was 0.73 ha, the soil was podzolic brown. The number of Norway spruce seedlings planted in test plantations was 2’442.

The results of prior analyses show that the impact of natural selection is the most distinguished in field experiments realized at three altitudinal levels, in which Serbian provenances demonstrate greater adaptability to very different ecological condition (Ivetić 2004). It was recorded that even in sites of submontane beech which is not within the natural range of spruce its growth and adaptability were successful which proves that besides its natural optimum in the zone of spruce belt *Picetum abietis serbicum* s.l., its technogenic optimum can also be reached in sites of other species. The results obtained from all three altitudinal belts contribute to the explanation why Norway spruce in Serbia has a specific climatogenous belt compared to other countries of the Balkan Peninsula. From the expert perspective prior researches play an important role in the economy because they facilitate the choice of a provenance, or a group of provenances, suitable for certain sites as part of planning of afforestation and reclamation works in degraded stands and sites.

Austrian pine seed orchard in Serbia

Large areas of bare land and degraded sites which require urgent afforestation as well as the capability of Austrian pine to achieve good results in extremely bad sites, set forth the need for organized seed production and seed forests as priority aims. In the aim of fulfilling these needs adequately, there is a need for intensified scientific and expert activities on the establishment and management of Austrian pine seed orchards.

Generative seed orchard of Austrian pine in Jelova Gora, with the area of 2.70 ha on the site *Fagetum montanum* Rud. was established in 1991 from 5’422 two-year-old seedlings in 40 half-sib lines of the test trees selected in seed forests Sargan-Mokra Gora and Crni Vrh-Priboj (Fig. 1) (Isajev et al. 1992). Austrian pine seed orchard with 40 half-sib lines, with three repetitions each, in each of the five subplantations and dynamic environmental factors-altitudinal difference of 20 m, two expositions and two soil types is the first generative seed orchard of metapopulation structure established in Serbia. Its structure enables the realization of genetic and development mechanisms and mechanisms of regulation on the one hand and realization of the effects of ecological mechanisms on the other. The above mentioned will benefit gene pool conservation of this species.

Multi-annual research involved detailed study of the variability of nine morphological seedling parameters - seedling height, annual height increment, root-collar diameter, diameter of horizontal crown projection and the number of branches in the

Figure 1 - Generative seed orchard of Austrian pine in Jelova Gora.

last three whorls. The obtained data revealed great variability even in case of slight site changes, as well as great adaptability of the incorporated planting stock. Analysis of correlation confirmed significant positive correlation of almost all elements of growth.

The research of qualitative characteristics also illustrates great genetic diversity. The following was observed: flowering at the age of five years, seedlings with grey needles, three-needle pines, smaller sized needles, proliferation.

The investigation of variability of the root system of Austrian pine seedlings created a base for the selection of genotypes with favourable characteristics in the sense of better adaptation to shock after transplanting or growing in extremely arid stands.

The analyses of the participation of photosynthetically active pigments - chlorophyll a and b and carotenoids are among the first analyses of that kind carried out regarding conifers in this country. These researches contribute to the improvement of familiarity with the correlation of the analyzed photosynthetic matters and basic elements of growth. Prior research of the variability of juvenile Austrian pine and the correlation of morphological and physiological parameters have their multiple importance for science as well as for practical application, being the base for the improvement of the good quality seed and planting stock with favourable characteristics. On the basis of one-way analysis of variance of all the examined morphometric properties it was concluded that significant differences appear at the inter-line and inter-provenance level which indicates that the differences among half-sib lines and provenances are not the consequence of random errors i.e. random variations. By using an LSD - test groups of half-sib lines according to the years of research were homogenized, which confirmed statistically significant differences and the superiority and inferiority of certain lines, previously determined on the basis of relative percentage of average heights and half-sib line diameters in average values of certain provenances. Connecting of clusters of half-sib lines with the highest and the lowest average values of all the examined quantitative parameters within the seed forest (1) is at a shorter total distance than in the seed forest (2) on the basis of which it is also confirmed that the sample of seed forest (1) shows higher homogeneity and lower intra-population variety. The applied statistical analysis indicates great genetic diversity within the seed orchard, but clear differences between certain half-sib lines cannot be strictly determined because that would require full-sib progeny tests.

The obtained results are important for the directed utilization of the gene pool of this species and as directions for the improvement of techniques used in the establishment of Austrian pine seed orchards of the second, third and later generations.

Serbian spruce seed orchard

On the basis of the applied analyses of multi-

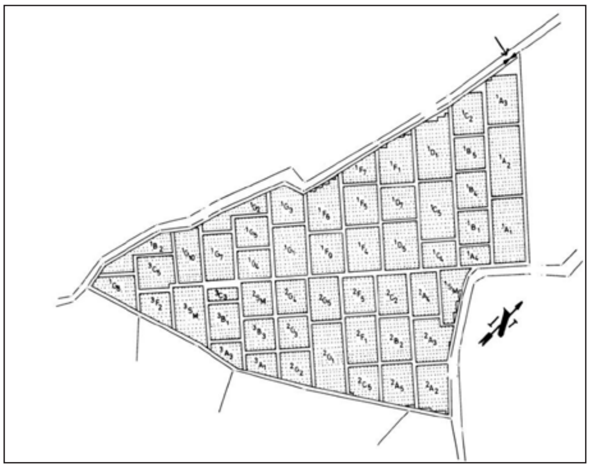

Figure 2 - Generative seed orchards of Serbian spruce (*Picea omorika*/Panć/Purkyne).

annual research of the genetic variability of Serbian spruce (Isajev 1987), generative Serbian spruce seed orchard was established in Western Serbia in 1987 (village Godovik, near Pozega), on an area of 2.70 ha. As much as 5'959 seedlings (age 2+3) were incorporated into the seed orchard. The seedlings from the same family were planted in the same block, with random distribution in the form of a square-shaped planting scheme 2 x 2 m (Fig. 2).

The applied selection and hybridization produced reliable data on general and specific values of half-sib lines and incorporated genotypes. In this seed orchard, based on the planting scheme in which genotypes of the same line are in one block, we made possible, for the first time simultaneously, the three basic types of Serbian spruce reproduction: inbreeding, outbreeding and uniparetal. The study data are a base for further work on the directed utilization of Serbian spruce genetic potential.

By multiannual analyses of individual and line variability of a great number of continuous and discontinuous vegetative and reproductive characters, parental genotypes were selected in order to direct seed crop parameters by spontaneous and controlled hybridization. The study of several flowering parameters, intra- and inter- half-sib lines, such as abundance and regularity of micro- and macrostrobile formation, differentiation of genotypes into functionally male, i.e. female ones, analysis of pollen quality and seedling analysis, resulted in valuable information necessary for successful hybridization. After controlled hybridization performed by the model of incomplete diallel cross, which included 48 different parental combinations, we studied a part of genotype structure of parent individuals and their hybrid combinations, based on the analysis in the salts of soluble proteins of seeds, as the most common polymorph markers at the level of gene products. In these analyses, we used the seed from free pollination of half-sib lines, which were functionally female i.e., male, and the seed of parental genotypes and their hybrid combinations. In parental genotypes and their hybrid combinations, the obtained electrophoregrams were used for the calculation of the coefficient of similarity, at the levels mother-hybrid, father-hybrid and mother-father. Electrophoregram analysis of hybrid combinations shows the existence of different types of protein fractions - bands: bands common to both parents, bands originating one from father, one from mother (codominance of parent gene expression in the hybrid), bands originating from mother only, bands originating from father only, and bands specific for the hybrid.

Based on the results of multiannual study, we differentiated such hybrid combinations which show the highest mean values of the analyzed morphometric characters of the cones, i.e. seed crop, as well as better parental genotypes which show good general and specific combining ability. The obtained data were the basis for the construction of the model of experimental clonal seed orchard for the production of Serbian spruce intraspecific hybrids.

Balkan maple seed orchard in Serbia

Forest Estate "Golija" from Ivanjica established a Balkan maple (*Acer heldeichii*) seed orchard in 1994 (Isajev 1994). The location of the orchard is on the site *as. Fagetum montanum Rud.s* in the forest management unit "Kovilje-Rabrovica", department 12. The altitude of the location is 950 to 1020 m and the exposition is north-eastern. The area of the seed orchard is 1.05 ha (Ćurčić 1997 and 1999). The planting stock was produced in the forest nursery in Ivanjica from the seeds of 26 seed trees, selected in Golija, which had above-average morphologic (technical) and physiological (abundance and regularity of seed yield) characteristics in the population (Isajev et al. 1994).

Planting of seedlings of the age 2+0 was carried out in the spring of 1994. Distribution of planting was planned and realized in blocks. There are 6 blocks in total, 4 of which have a regular rectangular shape and 2 are in the shape of a scalene triangle. The irregular shape of the blocks depends on the shape of the area determined for seed orchard establishment. The realized distribution of the seedlings in blocks is based on the so-called metapopulation strategy of the establishment of generative seed orchards of forest trees (Tucović and Isajev 1991).

Planting of 2'962 seedlings from 26 half-sib families created the base for further works on the testing and becoming familiar with the gene pool of the populations in which mother trees were selected, as well as for the improvement of this interesting and precious species of our valuable broadleaves.

After the application of the appropriate tending, good quality seed for further reproduction will be produced. On the basis of multiple analysis of the genetic value of the incorporated genotypes, decisions on further works on the improvement of Balkan maple and the establishment of seed orchards of future generations will be made.

Taking into account the advantages of the lower, warmer locations for the establishment of seed orchards due to their favourable effect regarding the abundance and frequency of flowering and seed yield and the applied method of metapopulation structure, it can be expected with certainty that the established generative seed orchard of Balkan maple near Ivanjica achieves the expected production of good quality seed.

Pedunculate oak seed orchards in Serbia

There are two seed orchards of Pedunculate oak (*Quercus robur* L.) in Serbia – clonal and generative. They are established at the territories of Forest Units "Morović" and "Klenak", which belong to the Public Enterprise "Vojvodinašume", Forest Estate "Sremska Mitrovica".

Clonal seed orchard was established in the period between 1979 – 1983 (Erdeši 1996). It is established of phenotypically superior genotypes from natural populations. The main criteria for selection of stems were the straightness of stem, branching, fast growth and resistance to oak powdery mildew (*Erysiphe alphitoides* (Griffon & Maubl.) U. Braun & S. Takam.). The seed orchard was established at the area of 7 ha, from 86 genotypes, which were multiplied by grafting into 2'520 remets. Depending on the scion thickness, five techniques of grafting were applied: simple copulation, English copulation, "mjesok"– little sack, cutting and "goat leg". The seed orchard is composed of four varieties indigenous in the valley of the Sava river: early pedunculate oak (*Q. robur* var. *praecox*), typical pedunculate oak (*Q. robur* var. *typica*) and two varieties of late pedunculate oak (*Q. robur* var. *tardiflora* and *Q. robur* var. *tardissima*) (Orlović et al. 1999, 2001 and 2002). Clonal seed orcharad has been an object of numerous researches focused on genetic variability of acorn and leaf morphological and anatomical characteristics (Nikolić and Orlović 2002, Nikolić et al. 2003, 2005, 2006 and 2010). Likewise to the previously mentioned researches, in order to give the first insights into the genetic structure and diversity in the clonal seed stand, the aim of recently conducted study was to characterise the genetic structure related to different phenology of sampled oak genotypes using a system of established microsatellite molecular markers. Leaves from fifteen individuals were sampled from four different varieties of pedunculate oak (*praecox*, *typica*, *tardiflora* and *tardissima*). Seven microsatellite primer sets were used designed to be specific to the sequences flanking the $(GA/CT)_n$ and $(AG/TC)_n$ dinucleotide repeat motives in oak genome. *Quercus* species have revealed high levels of polymorphism suggested that these markers are well suited for studies of genetic diversity within oak population and between different varieties. Successful amplification of all observed microsatellite loci revealed allelic polymorphism between and within all varieties established the variety specific genetic structure (Galović et al. 2014).

Generative seed orchard is founded in the period between 2000 – 2004 at the area of 10 ha. It is established from the acorn that was sown. Acorn is collected from clonal seed orchard previously mentioned and phenotypically superior genotypes from natural populations. Orchard is composed from 129 families, in different number of replication (min. six replications), so the total number of plants (genotypes) in orchard amount 2'585. The space between trees is 7 x 5 m. Similarly to clonal seed orchard, all for varieties indigenous in the valley of the Sava river is represented in the generative orchard. Researches in the orchard have been started recently, collection of acorn from various families and establishing of progeny test.

European beech provenance trials in Serbia

European beech (*Fagus sylvatica* L.) provenance trials in Serbia were established in the spring of 2007. One of the trials is situated on the territory of National park "Fruška Gora" (Northern Serbia), while the second one is located on the territory of the Scientific Centre of the University of Belgrade, Faculty of Forestry – "Majdanpečka Domena", in Debeli Lug (Eastern Serbia) (Stojnić et al. 2012a). The trials are founded within the European network of beech provenance trials. On that occasion, in order to study the genetic variation relevant for adaptation among provenances in the Balkan region, 20 provenances of Croatia, Serbia and Bosnia and additional 12 for comparison from Austria, Germany, Hungary, Italy, Switzerland, and Romania were planted, of which 15 provenances are common to all trials. A total of seven provenance trials were established in Bosnia and Herzegovina, Croatia, Serbia (2), Germany (2) and Italy (von Wuehlisch et al. 2010). The main objectives in these trials could be arranged into four groups: 1) tree improvement, 2) gene conservation, 3) evolution biology and 4) stimulation of European co-operation in forest research (von Wuehlisch 2004).

Previous studies in the provenance trials in Serbia have been focused mainly on the examination of genetic variation within and among different provenances, as well as research of phenotypic plasticity. The aforementioned studies have included numerous parameters that could be, roughly, classified into: physiological, biochemical, morphological, and the parameters of the anatomy of wood and leaves. The research results indicate the existence of significant genetic variation both within and between different provenances, as well as ecotypic pattern of genetic variation (Stojnić et al. 2010, 2012b and 2013, Štajner et al. 2013). Also, given that some authors believe that in order to improve the adaptability of the population, special attention should be paid to phenotypic plasticity, as an alternative to genetic adaptability (Šijačić-Nikolić and Milovanović 2010), attention has been devoted to the study of phenotypic plasticity of wood anatomical structure. The results showed an existence of a plastic response of provenances, as well as the ability of provenances originating from moist sites to adapt to drier habitat conditions (Stojnić et al. 2013).

In situ conservation of forest genetic resources in Macedonia

In Macedonia, *in situ* gene conservation is mainly achieved through the establishment of protected areas and so-called gene reserve forests. In addition to these there are also long-term genetic studies and breeding populations (Andonovski 1995).

National parks and nature protected areas are of great importance for maintaining or improving the forest genetic resources. These areas in Macedonia are classified as follows (Andonoski 2011):

A comprehensive resource inventory on the nature protected areas was set up and management regulations were established for the natural reserves.

Table 1 - National parks and nature protected areas (coniferous species).

Name	Area (ha)	Description
National park "Pelister"	12'500.0	The best preserved natural stand of Macedonian pine (*Pinus peuce*)
National park "Mavrovo"	73'088.0	Natural stand of fir and spruce (*Abies borisii-regis, Picea abies*)
Nature reserve "Rozden"	3.5	Crimean pine (*Pinus nigra ssp. pallasiana*)
Nature reserve "Tumba"	5.0	Fir (*Abies borisii-regis*)
Nature reserve "Golem Kozjak"	4.0	Scots pine (*Pinus silvestris*)
Nature reserve "Popova sapka"	5.2	Norway spruce (*Picea abies*)
Nature reserve "Rupa"	7.6	Fir (*Abies borisii-regis*)
Natural reserve "Tsam Tsiflik"	490.0	Crimean pine (*Pinus nigra ssp. pallasiana*)
Natural reserve "Rutsica"	1'785.0	Dwarf mugo pine (*Pinus mugo var. mughus*)

According to the Law on Forests, selected natural seed stands for production of seeds belong to category of forests with special purposes and they are under special management regime. During the latest period, an increased effort to conserve and enhance the forest genetic resources has been undertaken on the basis of present knowledge about variability and heritability.

The first mass and individual selection in Macedonia was performed in 1962-1965 and the following coniferous seed stands of were selected and registered (Andonoski 1994):

Table 2 - Selected seed stands (conifers).

Species	Area (ha) Total	Area (ha) Reduced	Age (years)	Provenance
Abies borisii-regis	182.9	84.4	81	Indigenous
Pinus nigra ssp. pallasiana	258.9	137.5	73	Indigenous
Pinus silverstris	45.5	32.8	80	Indigenous
Pinus peuce	5.0	3.4	95	Indigenous
Pseudotsuga menziesii	2.8	2.1	35	Exotic

In 2008, new program for conservation of forest genetic resources in Macedonia started with the revision of the current seed stands of various economically important native and exotic tree species. This program includes preregistration of the current seed stands and seed orchards and registration of new, including those of broadleaved species. Following is the table of registered seed stands under the latest Law on forest reproductive material:

Table 3 - Registered seed stands under the latest Law on forest reproductive material.

Species	Number of seed stands	Area (ha)
Pinus nigra ssp. *Pallasiana* (native)	8	218.7
Pinus sylvestris (native)	7	131.8
Abies borisii regis (native)	16	375.9
Pinus peuce (native)	3	68.3
Larix decidua (exotic)	3	34.9
Pseudotsuga menziesii (exotic)	9	59.2
Sequoiadendron giganteum (exotic)	1	4.4
Robinia pseudoacacia (exotic)	1	1.2
Fagus moesiaca (native)	7	326.1
Quercus petraea (native)	2	35.2
Total	**57**	**1'255.7**

In situ forest genetic conservation in Macedonia includes the "dynamic" approach which encourages the adaptation of forest trees to the changing environment through naturally occurring evolutionary processes. This can maximize adaptability with the sufficient number of trees in the genetic resource population (Andonoski 1974).

Ex situ conservation of forest genetic resources in Macedonia

Ex situ conservation of forest genetic resources in Macedonia includes establishment of *ex situ* gene conservation stands, seed orchards, clone archives or individual trees. Conservation of individual coniferous tree species was carried out using "plus" trees selected for the development of tree improvement programs. The following "plus" trees were selected (Andonoski 1988):

Abies borisii-regis	42 "plus" trees
Pinus silvestris	62 "plus" trees
Pinus nigra ssp. pallasiana	82 "plus" trees
Pinus peuce	20 "plus" trees

On the basis of these selected "plus" trees the following Seed orchards were established:

Table 4 - Seed orchards (conifers).

Species	Type	Year of rising	Area (ha)	Fructification
Pinus peuce	clonal	1963	1.1	full
Abies borisii-regis	clonal	1963	0.5	full
Pinus silvestris	clonal	1978-1980	2.5	full
Pinus silvestris	generative	1978	5.0	full
Pinus nigra ssp. *pallasiana*	clonal	1988	1.5	started

Outlook

In the past more emphasis was placed on the conservation and study of "plus" trees, so now it is necessary to focus on study and conservation of the most valuable populations. The majority of gene reserves were selected in the early 1960, thus it needs repeated inventory with biochemical, cytological and molecular genetic methods.

It is necessary to get more information about genetic structure and differentiation of the tree species.

In situ conservation activities should be integrated part of the regular forest management. The major challenges for the conservation of forest genetic resources in Macedonia include population decline and population structure changes due to forest removal and conversion of forest land to other uses, forest fragmentation, forestry practices, climate change, disease conditions, introduced pests, atmospheric pollution, and introgressive hybridization. Developing scientifically sound conservation strategies, maintaining minimum viable population sizes, and deployment of genetically engineered organisms represent other important challenges in conservation. Both *in situ* and *ex situ* forest genetic resource conservation strategies must include the use of various biochemical and molecular genetic markers, adaptive traits, and genetic diversity measures. So, major opportunities for conservation of forest genetic resources in Macedonia include: use of molecular genetic markers and adaptive traits for developing conservation strategies; *in situ* conservation through natural reserves, protected areas, and sustainable forest management practices; *ex situ* conservation through germplasm banks, common garden archives, seed banks, DNA banks, and tissue culture and cryopreservation; incorporation of disease, pest, and stress tolerance traits through genetic transformation; plantation forestry; and ecological restoration of rare or declining tree species and populations.

Conservation of forest genetic resources in Croatia

Croatia, with its area of forest and forest land (2.49 million hectares, which is 44% of mainland Croatia) has 260 indigenous wood species. 50% belongs to forest ecosystem and 60 of them make economical richness of Croatian forests while there is more than 100 species which are added to the forest ecosystem to implement their biodiversity. Conservation of genetic diversity of our forest species represents the foundation of a sustainable forest management and preservation of natural structure of our forest stands, currently making 95% of the total woodland area. Croatia's richness in diversity of geographical regions has resulted in various ecological types and a large number of forest trees that are directly affected by habitat degradation, different types of soil, air and water pollution, excessive use of some more valuable species of forest trees, increasing impact of global climatic changes, as well as by anthropogenic effects (Kajba et al. 2006).

The need for conservation of genetic variability is related to the species pertaining to social broadleaves which are economically the most prevailing species (Pedunculate oak, Sessile oak, and Common beech). Among the conifers, Silver fir (*Abies alba*) is the most endangered species, with more than 70% of its population being permanently damaged. Other native coniferous species must be preserved from the deprivation of genetic variability as well.

Conservation of noble broadleaves should encompass a larger number of species from various genuses (*Fraxinus*, *Alnus*, *Ulmus*, *Prunus*, *Juglans*, *Castanea*, *Sorbus*, *Acer*, *Malus*, *Pyrus*, *Tilia*). They are partially endangered because of their exposure to different diseases and pests, as well as by continuous exploration caused by their technical value. Changes in hydrological conditions of our rivers have generated difficulties in restoration of riparian forests, and decreased genetic variability of European black and white poplar in their habitats. In coastal areas of our country, there is a need for conservation of genetic resources of Dalmatian black pine (*P. nigra* ssp. *dalmatica*) and our Mediterranean oaks.

Genetic diversity conservation of various species of forest trees is conducted within the programs that include in situ dynamic methods and ex situ static methods.

Conservation of native species within in situ method is based on concept of status quo of natural conditions protections on local environment, where is optimal alleles frequency to survive and reproduction in that environment reached. Starting point is that local population of certain species are resistant and adapted to environment stress, diseases and injurers impact. Conservation of genetic diversity researches contains knowledge about the smallest population size (MVP) which is required for their relative safe survival according to genetic, demographic, environmental and other factors. According to the size and type of areal of each species (continuous and discontinuous areal, genetic drift, etc.), we need to define number of subpopulation and units which will successfully present, include and conserve complete variability of each species. Conservation within *in situ* method differentiate populations in categories of protected objects of biological and landscape diversity, natural forest stand and population which already are or will be excluded from regular management (e.g. seed stands).

Protection by *ex situ* method represents forest tree species conservation out of their natural habitat. This method is used parallel to *in situ* method, especially with species where conservation of population or their parts is not possible. For that cause, setting of experimental surfaces with *ex situ* methods is required and includes researches on provenance, progeny and clone tests. Genetic diversity of each species can be saved by establishing collections (provenance trials, progeny tests, clonal archives, clonal seed orchard, seed bank, pollen and plant tissue banks) using this method.

In Croatia there are more than 350 forest seed objects: forest stands, seed stands, clonal seed orchard and group of tree. Croatian Forest Research Institute (CFRI), as official body, according Forest reproductive material legislative, supervises the production and marketing of forest reproductive material. Also Croatian forest research institute set up a register of forest seed objects constituting a gene bank of forest trees of Republic Croatia. Total area of all seed stands (category of seed: selected) in Croatia is 3'898.35 ha and for conservation of genetic diversity (gene bank) are suggest 1'103.60 ha (*in situ*). During the past 50 years, researchers Croatian Forest Research Institute were founded by dozens of provenance experiments. In this paper, we mention the provenance experiments involved in the gene bank of forest trees Croatia, where it is still carried out by scientific research like: Pedunculate oak provenance trials established in 1988, 2008 and 2010 (Gračan 1999, Perić et al. 2006, Ivanković et al. 2011), Silver fir provenance trials established in 2000 (Ivanković 2003) and International beech provenance trials established in 1998 and 2007 (Gračan and Ivanković 2001, Gračan et al. 2006, Jazbec et al. 2007, Ivanković et al. 2008).

In Table 5 is list of Clonal seed orchard nominated for registration in Genetic bank, while in Table 6 is list of provenance trials which are included in genetic bank (*ex situ*).

Table 5 - List of Clonal seed orchard nominated for registration in Genetic bank.

Species	No. of orchards	Type	Year of rising	Area (ha)
Pinus sylvestris	2	clonal	1966	3.0
Pinus nigra	2	clonal	2006	1.5
Larix europea	2	clonal	1985	2.5
Quercus robur	4	clonal	1996, 2000, 2001, 2008	47.0
Quercus petrea	1	clonal	2008	7.3
Alnus glutinosa	2	clonal	1985	1.7
Fraxinus angustifolia	2	clonal	2005, 2007	3.5
Prunus avium	1	clonal	2001	3.0
Pinus strobus	1	clonal	1965	-

According the same legislative, Croatian forest research institute take care about forming and conservation of reserve forest seed material in seed bank.

Table 6 - List of provenance trials which are included in Genetic bank.

Tree species	No. of trials	Year of establishing
Quercus robur	4	1988, 2008, 2010, 2010
Fagus sylvatica	2	1998, 2007
Abies alba	1	2000
Larix decidua	1	1959
Pinus sylvestris	1	1959
Pinus nigra	1	1959
Picea omorika	1	1959
Picea abies	1	1959

Conservation of forest trees genes represents maintenance of the evolutionary created adaptation potential of a particular species, i.e. its forest community and the entire forest ecosystem. For the purpose of conservation of forest genetic reso¬urces, we must protect the existing genetic variability, its adaptability to processes of natural evolution and forest tree breeding, as well as improve our knowledge and ways of identification of those individuals that have developed tolerance to certain diseases and pests. That way, we will be able to prevent a decrease in genetic resources of the endangered species. The research should be supplemented with data including making of species inventories, legislation, practical use, coordination on national and paneuropean level, together with promotion of public awareness on the importance of conservation of the endangered species in forest ecosystems.

Conclusions

Beside gene pool conservation and testing *in situ*- in natural populations in different sites, conditions for biodiversity testing as well as the familiarity with the range of potential variability *ex situ* are provided by establishing of separate plantations. Starting from the floristic, genetic and applicative potential of Serbian spruce, Norway spruce, Austrian pine, Balkan maple, Pedunculate Oak, European beech, the paper presents multi-annual researches aimed at becoming familiar with their gene pool as well as its conservation and directed utilization by the establishment of specialized plantations.

The obtained results enable better familiarity with the potential of production and adaptability of the analyzed species. Seed orchards and pilot seed forests, as specific plantations, should contribute to the conversion of potential genetic variability into the free one, as the base for directed utilization of tree gene pool, and serve as polygons for testing and preservation of biodiversity of these species.

The presented research objectives and methods and the results of the genetic valuation of forest tree species are up-to-date methods in gene pool conservation and testing, as well as planning and establishment of future plantation communities of these species.

The activities on conservation and use forest genetic resources lead to produce superior genotypes which are important for increasing of wood production and climate change mitigation. Those activities support global bio-economy by enhancement of use genetic potential of forest trees.

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Conference paper

Natural capital and bioeconomy: challenges and opportunities for forestry

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Abstract - Over the last decades, the stock of natural capital has been globally reduced by human-induced effects such as climate change, and land use and cover modifications. In particular, the continuous flow of goods and services from ecosystems to people is currently under threat if the current human activities still remain unsustainable. The recent bioeconomy strategy is an important opportunity to halt the loss of biodiversity and the reduction of services provision, from global to local scale. In this framework, forest sector plays a fundamental role in further enhancing the sustainable development and the green growth in degraded environments, such as marginal and rural areas. This paper provides an overview of the bioeconomy-based natural resources management (with a focus on forest ecosystems), by analyzing the related challenges and opportunities, from international to national perspective, as in Italy. At first, the role of forest sector in addressing the purposes of green growth is analyzed. Secondly, the most suitable tools to monitor and assess natural capital changes are described. Finally, the most important research contributions within the bioeconomy context are reported. To create the suitable conditions for bioeconomy and green growth, the following insights have to be denoted: (i) a deeper understanding of natural capital and related changes; (ii) the improvement of public participation in decision-making processes, especially at landscape scale; (iii) the effective integration of ecological, socio-cultural, and economic dimensions while managing natural resources.

Keywords - Natural capital, bioeconomy, forest ecosystems, ecosystem services, land use and cover change

The need for bioeconomy-based natural resources management

The concepts of "green-growth" and "bioeconomy" have been developed on the consciousness that population is expected to rapidly raise in the next 40 years (Rosegrant et al. 2012). This trend most probably will cause an increase of pressures on natural resources use and a growing inequality for their distribution among people, especially with regards to wild and seminatural ecosystems, soil, water resources, and croplands, and, as a consequence, an erosion of the largest part of the Ecosystem Services (ES) strictly related to Land Use and Cover Change (LUCC), the main driver of global change.

Overcoming these situations specifically requires responsibility in subsidiarity and innovation in order to achieve concerted changes in lifestyles and resource use, across all levels of society and economy (EU 2012). There are a number of key-drivers for the development of a green economy, as follows (Rosegrant et al. 2012): (i) the demand for renewable biological resources and bioprocesses; (ii) the need for improving the management and the sustainable use of renewable resources; (iii) facing substantial challenges, such as e.g. energy and food security, in the context of increasing unpleasant social phenomena like the neocolonialism (i.e. "land grabbing") or the prevalence of export-driven cropping systems, and several constraints on water, productive lands and carbon emissions (e.g. Sheppard et al. 2011); (iv) the rapid uptake of biotechnologies in agricultural productions; and (v) the opportunity to reduce environmental degradation through more sustainable production procedures. Other important challenges derive by the fact that the bioeconomy proposal is not about protecting the environment, but instead it is about promoting the economy – in spite of clear indications of the harmful impacts that are already resulting from massive new demand for biomass, including soil loss (a long-term renewable resource), biodiversity at gene, species, stand and landscape level, as well as escalating hunger and conflict (Hall et al. 2012).

Taking under consideration the past human-induced changes and their consequences on the increasing depletion of nature, the current stock of natural capital is almost compromised and is passing through several safety thresholds of planetary boundaries (Hughes et al. 2013), such as the CO_2 atmospheric composition, i.e. gaining 395 ppm in 2013, despite a tipping point of 350 ppm (Hansen et al. 2013). But also soil and forests and water are strongly threatened. The key necessary condition for

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achieving sustainability lies at least on the constancy of the natural capital stock over the time (Pearce et al. 1990). In this way, natural capital properly refers to "a stock that yields a flow of valuable goods and services into the future" and can be differentiated into "renewable natural capital (active and self-maintaining using solar energy, such as forest growing as known since the XVIII century) and non-renewable natural capital (passive)" (Costanza and Daly 1992). For instance, to sufficiently unravel the past anthropogenic effects on natural resources and the more recent shifting from Holocene to Anthropocene era, Ellis and Ramankutty (2008) globally identified and mapped the "Anthromes", namely Anthropogenic Biomes. In this way, the evaluation of ecosystem functioning (including biodiversity as main supporting element; see e.g. Cardinale 2013) is extremely important to globally reduce the impacts of the main drivers of change. For this purpose, monitoring the land use changes (one of the most accelerators of human-induced environmental modifications; Foley et al. 2005) is useful to orient the current overexploitation of natural resources towards a more "resilience-based" trajectory (e.g. Ellis et al. 2013).

Green economy and natural resources: the role of forest sector

Beside these general considerations, in forestry the green economy benefit starts when and occurs through management tools and investments that could limit trade-off effects of traditional multi-functionality and expand the ES availability for the society with a scope of fairness within and among generations (see also Atkisson 2012). Indeed, green economy improves human well-being and social equity, and significantly reduces environmental risks and ecological scarcities (UNEP 2011a). Sustainably managed forests play an essential role in the carbon cycle and provide essential environmental and social values, and ES, beyond their contribution as a source of wood, such as biodiversity conservation, protection against erosion, watershed protection and employment in often fragile rural areas. In this perspective, in order to promote the effectiveness of green economy in managed forests, the UNECE Committee on Forests and the Forest Industry (COFFI) and the FAO European Forestry Commission (EFC) decided to take action and prepared the Rovaniemi Action Plan for the Forest Sector in a Green Economy (ECE/TIM/SP/35). This Action Plan consists of 5 pillars with their respective goals, which are: (i) sustainable production and consumption of forest products (patterns of production, consumption and trade of forest products are truly sustainable); (ii) a low carbon forest sector (the forest sector makes the best possible contribution to mitigation of, and adaptation to, climate change); (iii) decent green jobs in the forest sector (the workforce is able to implement sustainable forest management, and the forest sector contributes to achieving the social goals of the green economy by providing decent jobs); (iv). long-term provision of forest ES (forest functions are identified and valued and payments for ES - PES (Payment for Ecosystem Services)– are established, thus encouraging sustainable production and consumption patterns); (v) policy development and monitoring of the forest sector in relation to a green economy (policy-makers and institutions in the forest sector promote sustainable forest management, in a way that is adequate to mainstream the green economy in forest sector policies).

To operationalize these broad guidelines, it is recommended to follow the Ecosystem Approach (EA). EA is a method for sustaining or restoring natural systems and their functions and values. It is goal-driven approach, and is based on a collaboratively-developed vision of desired future conditions that integrates ecological, economic and social factors (Inter-Agency Ecosystem Management Force 1995). Furthermore, EA is not a static model but is a holistic process for integrating and delivering in a balanced way the three objectives of the Convention on Biological Diversity (CBD): conservation and sustainable use of biodiversity, and equitable sharing of the benefits (Maltby 2000). Therefore, only an ecosystem-based management of natural resources can halt the loss of biodiversity and the degrade of resources quality. This is exactly one of the purposes of the Bioeconomy Strategy, properly aimed at improving the knowledge base and fostering innovation to increase productivity, while ensuring sustainable resource use and alleviating stress on the environment (COM 2012).

According to the evolution of classical economic theories, the need to consider forests both as factors of production and ecological infrastructures is always stronger. In particular, the contribution of forest management and land use planning (especially in fragile forest areas, as mountain environments) in the context of green economy growth has to consider also the biodiversity of forest ecosystems and the related ES as results of complex ecological processes and interactions amongst different ecosystems in a holistic view (Ciancio and Nocentini 2004, Mace et al. 2012).

At European level, Bengtsson et al. (2000) argued that the next generation of forestry practices would need to: (i) deeper understand natural forest dynamics; (ii) analyze the role of biodiversity (i.e.

key species and functional groups) in supporting the ecosystem functionality; (iii) implement and adapt management prescriptions in accordance with natural dynamics; (iv) consider ecology, forestry, economy, and social fields in order to establish a value of the important ES from forest ecosystems. Furthermore, in line with these good practices, forest management needs to avoid the impact of disturbances (such as e.g. anthropogenic eutrophication, toxic pollution, habitat loss, disconnection from adjacent ecosystems, species invasion, climate change, etc.), which can induce long-term ecosystem changes (see e.g. Ellis et al. 2013).

Although natural resources have an intrinsic value for improving sustainability, the vision of the natural capital has become the subject of ethical and conceptual discussion and debate, especially in conservation topics. This led to divisions between those who intend the conservation of nature as such, by virtue of its intrinsic or existence value with an assessment meaning (Soulé 2013), and those, instead, who intend it as an element of supporting for human well-being (e.g. Reid et al. 2006, Kareiva and Marvier 2012, Toledo and Barrera-Bassols 2014), translatable, therefore, in an instrumental value. Nevertheless, in recent years, the concept that the integration of different views and philosophies underlies the conservation, protection and restoration of natural resources has been clarified (Tallis and Lubchenko 2014). Therefore, it is important to remind that the value of a stock of natural resources, such as in particular a forest, is more than the sum of various functions that are assigned to that forest from time to time, which means recognizing that forest has intrinsic value (Ciancio and Nocentini 2004).

In order to further improve the contribution of the forest sector and its intrinsic awareness for a responsible green economy, it is essential to assess (EFI 2014): (i) the forest products market changes and, in particular, the C substitution rate stored in forest products (in general throughout the whole production chain, including the entire Life Cycle Assessment - LCA), and its trade-offs with other ES; (ii) the changes in cultural and non-marketed ES, which are difficult to price, such as tourism and recreation, and aesthetic, historical and cultural values, etc.; (iii) the current and future investments in the business sector related to forests and timber production, taking into account the enhancement of multi-functionality and a responsible and sustainable management; (iv) the changes in the ownership of the forest and the enterprise sector, considering the participation as a strong element of identity, belonging, proximity and protection of the territory; (v) the global demand for expertise services in forest governance, forest administration, inventory and information systems, as well as in forest education. Therefore, the major challenges for the forest sector in the context of the green economy partly refer to land use change and market failures, or to forest policy and planning. The socio-economic processes play a key role in ecosystem modifications, thus directly influencing human welfare (Ellis et al. 2013). For example, all the forestry activities are increasingly knowledge-intensive and address challenges, such as those related to natural resources assessment and monitoring in a context of global change (EFI 2014). In a context of change, the preservation of intrinsic and utilitarian values of natural capital has to be encouraged, as it is a key element for the reconciliation and the building of a sustainable, responsible and resilient human-nature relationships.

Linking natural and cultural capital

The need of a strong interconnection between the natural and cultural capital assets is well expressed in the "Chart of Rome" (CoR, Presidenza Italiana del Consiglio dell'Unione Europea 2014), whose aim is to broaden the scope of nature and biodiversity policy without changing it, but rather mainstreaming it into other policies related to the territory and the economy. Although the main target groups of CoR are scientists, stakeholders and policy-makers, its message is also for citizens. It is a European initiative and develops on the EU cornerstones of Natura 2000 and the EU Biodiversity Strategy to 2020. The primary role is the promotion of a better conservation and valorization of the natural and cultural diversity. Moreover, the CoR acts as a platform for further collaborations on biodiversity in general, and in particular on ES, as well as on their societal implications (i.e. climate mitigation, clean water, clean air, protection against floods and erosion).

Furthermore, it finds its roots in the CBD, specifically with regards to protecting and encouraging the customary use of biological resources in accordance with the traditional cultural practices that are compatible with conservation or sustainable use requirements (UNEP 1992). CoR is strongly connected also with the Convention for the Safeguarding of Intangible Cultural Heritage, because communities and groups are able to constantly recreate their intangible cultural heritage, since it is the product of the interaction between nature and history, and it is transmitted from throughout generations, according to the environment they live in. In this way, people enhance their own sense of identity and continuity, and, as a consequence, promote the respect for cultural diversity and human creativity (UNESCO 2003). Another bridge built by the CoR with the EU biodiversity-related policies is the Green Employment Initiative (COM/2014/446). This initiative aims at indicating the way for job creation potential in the green economy sector with reference to skills, education and training, green public procurement, promotion of entrepreneurship, increasing of data quality (including statistical definition of employment in the environmental sector) and promotion of social dialogue.

CoR is strongly related to the adaptive capacity of human populations to deal with and modify the natural environment (Berkes and Folke 1992), the natural capital, which is composed by the ecosystems. Therefore, healthy and resilient ecosystems can provide society with a full range of economically valuable goods and services. To maintain healthy ecosystems, the following responsible actions are needed (Presidenza Italiana del Consiglio dell'Unione Europea 2014): (i) making use of good knowledge and data on biodiversity, ecosystems, their structures and functions, and on links with ES and associated benefits; (ii) maintaining, restoring and enhancing capacities to provide a range of goods and services and associated benefits; (iii) exploring natural capital as a solution to major challenges such as those related to urban areas, climate change and adaptation, agriculture and soil, forestry, hydrological risks, tourism and recreation. In this sense, good knowledge, research and data gathering on biodiversity and ecosystems are essential, because they make the knowledge base accessible to citizens and decision-makers, thus ensuring that policy-makers continue to understand and consider complex environmental state and dynamics.

In addition, cultural and economic scientists (e.g. Throsby 1999) contributed to identify cultural capital as a set of three main features, such as (Sukhdev et al. 2014): (i) knowledge, including traditional and scientific dimensions; (ii) capacities, as the way knowledge is retained, increased, elaborated and developed; and (iii) practices and human activities producing tangible and intangible flows of goods and services.

In order to maintain a positive link between cultural and natural capital, the following goals have to be reached (Presidenza Italiana del Consiglio dell'Unione Europea 2014): (i) taking into account social and cultural dimension of ecosystem management; (ii) promoting locally adapted knowledge, capacities and activities with positive impacts on natural capital; and (iii) connecting benefits, goods and services from ecosystems (supply) with patterns of culture, society and economy (demand). Moreover, green infrastructures can contribute to these goals, since they connect natural and semi-natural areas with urban and rural areas. They are also drivers of a transition towards a green economy and are able to guarantee many natural, cultural, social and economic linkages. In Italy, the recent report concerning the socio-economic assessment and monitoring of natural capital and Protected Areas (PA) is the first attempt to contribute to the pillars of green economy at national level (MATTM and Unioncamere 2014). The report results mainly reveal what is the current condition about biodiversity conservation, what ES are correlated to cultural capital and local communities, and how sustainable practices effectively contribute to the green economy concerns.

Even green economy-related contributions are increasing, the concepts of natural capital, ES, and cultural capital require further operational definition and understanding. A knowledge-based improvement of the concept and its operationalization are in line with the EU nature and biodiversity strategies, directives and overall policies, which are expected to enhance and promote biodiversity conservation, the sustainable use of natural resources, while improving communication, mainstreaming and policy consideration in a wide societal and political context.

Monitoring changes of natural capital: land use and ecosystem services relationship

An important issue in many debates concerning the policies and the governance of the landscape is the ES assessment. Public interest in ES assessment has been starting since the milestone work on the economic assessment of natural resources made by Costanza et al. (1997). Mostly after the CBD (UNEP 1992), biodiversity and ES in general were placed at the base of the most important global, European and national processes focusing on the enhancement and preservation of natural resources and ecosystems as sources for multiple services and benefits for the society (see European Biodiversity Strategy to 2020 (EP 2011/2307(INI) and the Italian Biodiversity Strategy (MATTM, Decree 6 June 2011)).

Although the ES concept is already central in conservation policies and environmental impact assessments (Burkhard et al. 2010), useful methodologies for its practical application are still needed, in order to support the sustainability in natural resources management. Following the needful for quantifying the natural capital and ES, both biophysical and economic aspects have to be considered. If the goal is to measure the efficiency of natural resources management as a whole, then the quantification of benefits from ecosystems is necessary, especially to preserve the stocks of natural capital useful to generate ES. Indeed, the approach of the Millennium Ecosystem Assessment (2005) is based on the notion that the resource management involves the study of the relations between the ES and their quantitative estimation. As a consequence, there is nowadays a considerable interest to establish innovative approaches to calculate ES at different spatial and temporal scales.

Among terrestrial ecosystems, forests (including other wooded lands) are one of the most important sources of services and benefits for the entire humanity. Forests (Vizzarri et al. 2013): (i) protect biodiversity, providing habitats to more than half of the plant and animal known species; (ii) play a significant role in regulating biogeochemical cycles and, consequently, in the mitigation of climate change at different spatial scales; (iii) generate a large set of goods and products (timber and non-timber); (iv) host and protect sources and catchment areas accessible to man, often characterized by high quality water; (v) protect the traditional, cultural and spiritual values of many societies in the world.

In particular, considering the provisioning services, forests can assure the availability of wood for building, firewood and other non-timber forest products (e.g. cork, tannin, mushrooms, truffles, berries, etc.), which represent important economic components for the economies of many Countries. In addition, forest soil and topsoil have an enormous capacity to filter out most of the chemical components of pollutants and to reduce the surface runoff, thus preventing and reducing the risk of erosion and slope instability. In many cases, the presence of forest areas reduces the need of treatment (and, therefore, of the related costs) for the production of drinking water available to the local population, as shown in several case study around the world (Dudley and Stolton 2003).

Amongst the regulation services, forests are integrated in climate mitigation processes. In particular, forest stands have a threefold relationship in the face of climate change, as follows: they are adapting themselves to the effects of climate change, but at the same time, are subject of the general causes (emission source, from deforestation) and of the solution (major terrestrial sink). Indeed, among the different contributions of forests to climate change mitigation, there is the absorption of carbon from the atmosphere. Especially in “fragile” landscapes (such as mountain areas), forests are of primary importance to protect infrastructures and buildings from disasters, like avalanches, landslides, debris flows, rolling stones, and erosion processes in general. The vegetation strongly affects the water supply to the ground directly intercepting rainfall, attenuating the incident solar radiation and by controlling the evapotranspiration rate.

Supporting services are considered intermediate services as predisposing conditions so that a final service can be provided. In this case, forest biodiversity is the key element to support the provision of all other services, as it directly affects the properties of self-regulation and adaptation of forest ecosystems, and the capacity of a forest to produce timber or to be resilient and resistant against natural or anthropogenic disturbances. In this context, the role of biodiversity is essential for enabling to the availability of other services, because it (Vizzarri et al. 2013): (i) supports ecosystems in the structural, compositional, and functional diversification; (ii) influences the productivity, stability and resilience of ecosystems; (iii) increases the cultural and aesthetic value due to the presence of particular organisms and habitats; (iv) indirectly provides diversified products for rural populations (food, fiber, etc.).

Around the forest ES provision, forest landscapes have also intrinsic traditional, cultural and spiritual values, because they result from a profound historical interaction between man, its activities, and the surrounding nature. In addition, forest landscapes offer unique experiences, such as combinations of suggestive images (e.g. the colors of the vegetation, the behavior of wildlife, remote and unspoiled landscapes, etc.), echoing sounds (e.g. the birds chirping, the hum of insects, superior animal sounds, etc.) and strong scents (e.g. the smell of flowers or berries, etc.).

Considering forests as natural integrated systems, inside and outside ecological processes play a key role in governing the energy and material flows between ecosystems and man. Therefore, the potential of “supply” of services by a forest ecosystem is closely linked to its “health”, namely the balance of its resilience characteristics, durability, low vulnerability and stability over time. The analysis and quantification of forest ES may be in conflict with an economic approach, because the intrinsic values that people attribute to ecosystem structures and processes are often not corresponded by economic “market” value (Farber et al. 2002). Consequently, the quantification and economic evaluation of forest ES must take into account the following critical issues: (i) how to separate “stocks” from “flows”; (ii) counting for potential beneficiaries of a given service, as well as its durability and availability in time; (iii) distinguishing the production of the service that may potentially be used with the one that is currently being consumed. The use of indicators can be an effective strategy to “quantitatively” measure and monitor complex phenomena such as ecological ones. In the ES assessment, indicators should be as inclusive as possible and properly selected on the basis of ecosystem properties and structures. They should also be easy to understand, allowing easy communication between institutions, technicians, professionals, and stakeholders at the local scale (Vizzarri et al. 2013).

While analyzing and evaluating forest ES, the anthropogenic impact on ecosystem functioning and, therefore, its ability to provide a set of services (and, consequently, benefits) must be considered. During the evolutionary history, humans excelled due to their ability to model ecosystems throughout the use of tools and techniques, which are beyond the capabilities of other living organisms (Smith 2007). Therefore, the importance of the "human factor" is essential: currently more than 75% of the land in the world shows disturbance caused by human action, with less than a quarter remained as wild land, able to support only 11% of the net terrestrial primary productivity (Ellis and Ramankutty 2008). Consistently, some scientific theories define Anthropocene as the current time that the Earth is living (Zalasiewicz et al. 2008). Lambin et al. (2001) stated that LUCC: (i) has an heavy impact on biodiversity at a global scale; (ii) contributes to climate change at the local and regional level; (iii) represents the main source of soil degradation and water depletion; (iv) alters ES and affects the capacity of natural systems to support human needs. There is indisputable evidence linking changes in the use / land cover to the loss of ES, especially in cases of services as carbon sink, hydrological processes and climate change. A complete ES assessment must be considered as spatially explicit, because it serves as a basis to implement LUCC (and therefore the human impact), as well as to provide a complete overview of offered services, including their current availability and future-oriented simulation (modeled according to various hypothetical scenarios). Furthermore, mapping ES can facilitate the economic evaluation, and provide the balance (trade-off) amongst multiple ES, which is necessary to support decision-making and landscape planning processes (Chirici et al. 2014).

The use of monitoring tools, such as Land use / Land Cover Inventories (Inventario dell'Uso delle Terre in Italy – IUTI, Corona et al. 2012) allows to identify and quantify in a quick way and at low cost the key dynamics characterizing the landscape changes, as well as the monitoring of their impact in ecological and functional terms (Sallustio et al. 2013, Marchetti et al. 2012b, Corona et al. 2012). As an example, for the period 1990-2008 in Italy the following important changes have been identified: (i) the forest area has increased of about 500,000 ha. At that time, the urban areas have expanded of the same amount, especially to the detriment of agricultural land, which recorded a loss of about 800,000 ha; and (ii) the registered urban sprawl can be mainly referred to the downhill and plain territories, and correlated to the increasing pressure on already fragmented and degraded ecosystems. The recovery of human-modified landscapes is necessary to create a socio-economic cohesion between urban and forest area. Furthermore, recreating the lost agricultural fabric offers enormous ecological potential, including e.g. the reduction of fragmentation and degradation (especially of soil), a significant increase of biodiversity (creation of corridors and ecological niches) and the recovery of an important band transition having the function of mitigation systems between natural and manmade assets (vacant land or derelict land; Marchetti and Sallustio 2012). Delivering and keeping the identity to the rural landscape increases the awareness about the primary sources location of power and energy in urban areas, thus enhancing processes of historical and cultural identity, and improving health and social welfare.

It is important to note that the trends observed at the national level in Italy are not very different from those observed within the National Parks, both for land cover modifications and services provided (Marchetti et al. 2012a, Marchetti et al. 2013a). This trend directly reflects on the landscape planning development, especially taking into account the problem of maintaining grasslands, pastures and agricultural activities of extensive type, which are important for the historical, economic and cultural landscapes heritage, and are essential elements for the conservation of the environmental mosaic, which is typical of the Italian peninsula and of its biodiversity (Marchetti et al. 2013b). Taking apart how the urban sprawl develops over the time, it is important to deeper understand in which way policy instruments and regulations are currently used and implemented in these areas (also within PA- Protected Areas). For instance, the abandonment of silvicultural practices within National Parks and High Conservation Value Forests (HCVFs; Maesano et al. 2011) can reduce the forests growth and productivity, making them less resilient while facing natural disturbances (pest outbreaks, forest fires, etc.).

While contrasting the urban sprawl phenomena, agriculture represents a key activity, because it is able of recreating a balanced landscape by preserving areas which are not built-up and, where possible, by restoring ecological integrity of degraded and fragmented environments (i.e. mountain areas). Farming is the essential and long-lasting territorialization factor, as well as the energy basis of the life cycle in the country. However, it can become central to a regenerative vision of the landscape only if integrated with the ecological characteristics. The productive function of the countryside must be flanked by the importance of the concept of its capacity to be a producer of social cohesion, of a good and healthy environment where people can live a quality lifestyle, feeling a sense of belonging. By the contrary, from the urban point of view, there is mainly the problem of defining, perceiving and recognizing the countryside as an area where food and energy come from, according to conceptual models which focus on the ecological footprint (Wackernagel and Rees 2004, Iacoponi 2001).

Moreover, the participatory aspect is necessary in order to carry out one of the founding principles of the European Landscape Convention (Council of Europe 2000), as well as that of the Italian Constitution, which underlines the fundamental need of enabling local participation in decision-making processes at landscape level (articles 3 and 9). Participation has not to be considered as a simple accessory to democracy, but as a real possibility that local communities have, on different levels, to influence and orient the decision-making processes within a given area, irrespective of their individual, specific interests (Settis 2010). Indeed, the engagement of stakeholders may increase the likelihood that environmental decisions are perceived as holistic and fair, accounting for a diversity of values and needs and recognising the complexity of human-environmental interactions (Richards et al. 2004). Furthermore, in a shared management strategy of the landscape, which takes local interests and concerns into account primarily at an early stage, it may be possible to inform the project design with a variety of ideas and perspectives. In this way, public participation increases the likelihood that local needs and priorities are successfully met (Reed 2008). By establishing common ground and trust between stakeholders, participatory processes have the capacity to transform adversarial relationships and find new ways for participants to work together (Stringer et al. 2006). This may lead to a sense of ownership over the process and outcomes, thus enhancing long-term support and active implementation of decisions (Richards et al. 2004).

Considering the above-mentioned issues, it is important to remark that managing the landscape is another of the many duties carried out by the agricultural establishments, with economic and labour-related repercussions, which factors that cannot be ignored in transitional periods such as that of today. The main goal is to create a new culture, which, while starting with the enterprises, can stimulate interaction amongst businesspeople, public authorities and professionals in order to shape new ways for organizing the land. This takes into account the close connections between urban areas, nature and the world of farmers to guarantee that the principles of sustainable development are fulfilled. This action way can be possible if local and scientific knowledge are integrated to provide a more comprehensive understanding of complex and dynamic natural systems and processes (Reed 2008).

Perspectives for the future implementation of bioeconomy

In this composite changing world, the availability of data and easily upgradeable models that can describe these processes are important, since they allows the creation of future scenarios supporting public and private decision makers, in planning and designing the responsible growing of green economy and its activities. The possibility to calculate uncertainty and accuracy of models being used, the substantial reduction of errors of commission and omission are common issues in the field of land use inventories and maps, especially while focusing on practical forest management (Corona 2010). The evaluation of LUCC effects on biodiversity and ES should be the main element in supporting planning processes. Even if it could appear as a choice linked to particular sensitivity or marketing issues for administrators or ordinary citizens, it is now clear that this must be the *modus operandi*, as already established at international level.

Indeed, many efforts have been made to include the evaluation of the ES within decision-making contexts. For example, in 2012 the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) was established, as a tool for linking the scientific community to policy makers, putting the first track on what are the needs and requirements in applied contexts (http://www.ipbes.net/). Similarly, at the European level, the Action 5 of the EU Biodiversity Strategy to 2020 requires that the Member States start to map and assess the state of ecosystems and their services within their own boundaries in order to support natural capital conservation. For the development of a knowledge framework to support the contexts and needs of different States, the Working Group "Mapping and Assessment on Ecosystems and their Services" (http://ies.jrc.ec.europa.eu/news/468/155/Mapping-and-Assessment-of-Ecosystems-and-their-Services.html) was established. At national level, the first results obtained in research projects such as the "MIMOSE" (Development of innovative models for multi scale monitoring of ES indicators in Mediterranean forests) are promising. MIMOSE specifically aims to develop an innovative monitoring approach to estimate the capacity of a given forest area to provide ES under different management scenarios (Chirici et al. 2014). Key elements of this approach are connected to an integrated set of ES indicators and methods oriented to their spatial estimation. In this perspective, the primary project purpose is to bridge the gap between the concept of ES and their operational implementation in the management of forest ecosystems and environmental planning. The results of the project are expected to provide a real contribution for the incorporation of ES in decision-making processes and the forest landscape management and planning, thus providing an opportunity to understand the trade-offs between the different forest ES. This is expected to be useful to inform local stakeholders, sensitizing them towards a certain management that maximizes net benefits from ecosystems for the society.

For the forest sector, the most important challenges are to find innovative approaches for managing forest resources, in a way that simultaneously increases wood and non-wood production, improves the food security and energy supply against poverty, and safeguards other environmental services and biodiversity (Alexandratos and Bruinsma 2012). Under the current (unsustainable) conditions, forest resources cannot continue to contribute to the natural capital flows in the future, thus reducing the transferring of important services to people, especially in degraded environments, and reducing the ecosystem capacity to sustain the green growth. As a consequence, monitoring changes in forest cover (e.g. Hansen et al. 2010) and relative attributes (e.g. Butchart et al. 2010) is extremely important to make the future-oriented management guidelines coherent with the bioeconomy bases. More recently, several authors pointed out the urgent need to put the bases for a persistent monitoring of forests and their services (Maes et al. 2012). However, further research is required to bridge the gap between ecologic and economic fields (Cardinale et al. 2012), especially considering the emerging international commitments, both at European (EP 2012) and global scale (UNEP 2011b, UNEP 2014).

In this perspective, the nodal points lie in the efficiency evaluation of conservation strategies, in the assessment and monitoring of ES, and in the ability to translate these measures in estimating the cost implications. Similarly, the analysis of ES shall provide an integrated and holistic approach, which has to be able to grasp the complexity of functional processes For this purpose, there are several tools available for orienting conservation policies, such as e.g. the use of biophysical indicators (e.g. Noss 1999), the mapping of natural resources and habitats (e.g. Weiers et al. 2004), and the implementation of economic instruments for the market of "natural products" (e.g. Engel et al. 2008). Time and spatial scales (at which conservation strategies are planned and the effects assessed) are also key issues in mapping ES and related changes. It should be always kept in mind how the resilience of natural systems and their adaptability and susceptibility to change go far beyond the administrative limits or times of programming and planning. Indeed, there is also a "resilience thinking", which describes the collective use of a group of concepts to address the dynamics and development of complex socio-ecological systems (Folke et al. 2010). This implies a profound reflection on how, where and who has to deal with conservation, preferring detailed, solid and shared strategies to "niche" policies (Pressey et al. 2007).

Furthermore, the economic evaluation, despite much closer to a utilitarian view of natural resources, is currently the most effective tool to persuade and influence the people choices, especially waiting for the consolidation of a collective consciousness, more sensitive to the issue of conservation and use of natural resources in general. In this perspective, it is therefore also necessary to review the strategic role of PA. It is no longer enough to establish new PA or expand the existing ones, but it is necessary to strengthen and make more efficient and effective the management in existing ones (Watson et al. 2014). PA must be not only "Shrines of Nature", but real laboratories in which testing the best practices to enhance the natural and cultural capital can be to be exported and implemented in heavily populated surrounding matrix.

The forest sector can offer many opportunities in the context of bioeconomy, such as: (i) the proper and effective implementation of Criteria and Indicators for Sustainable Forest Management, (C&I-SFM; see also EFI 2013); (ii) the expansion of PA network; (iii) the development of initiatives related to projects for reducing global emissions (e.g., Reducing Emissions from Deforestation and forest Degradation, REDD+; http://www.un-redd.org/); (iv) the acceptance of PES in the current economic and productive systems; (v) the implementation of policies aiming to more active management and sustainable conservation of natural capital. Within this context, the research is essential to (Vizzarri et al. 2013): (i) analyze the degree of complexity, the value and quality of forest ES through innovative tools that can simulate the complexity of ecosystems themselves (process-based modelling and mapping); (ii) collect the most complete set of available information relating to the health and resilience of forest ecosystems (new techniques for monitoring and detection); (iii) consider the active involvement of stakeholders in planning decisions and forest management through statistical analysis multi-criteria techniques (agent-based techniques); (iv) reduce the uncertainty associated with estimating the value of ES, as well as reducing the gap between ecological and socio-economic research.

By the other hand, among the critical issues currently found in scientific research in the context of the bioeconomy applied to forest resources, worthy of mention are: (i) the limited availability of spatialized data on a national scale; (ii) the deficient multidisciplinarity in analyzing forest ES; (iii) the absence of widespread and consistent use of models, quantitative analysis and evaluation of ecological, economic, and socio-cultural indicators related to the provision of services delivered by forest ecosystems; (iv) the lack of implementation of EU policies at the local level.

In order to determine, and subsequently improve the competitiveness and the role of the forest sector in relation to other productive sectors as part of the bioeconomy, governments, public administrations, and sector managers need a complete picture of the stock, streams, and balance of costs and benefits of services provided by forest ecosystems.

Therefore, investments have to be oriented towards the improvement of management practices in existing forests and agroforestry systems, in order to ensure the continuous supply of the widest range of services provided. In this context, the development of new methods for supporting planning processes and especially to improve the ability to transfer the skills and knowledge to policymakers are essential elements for implementing the pillars of bioeconomy and green growth, also in the forest sector.

At conclusion, the future-oriented research is expected to be interdisciplinary and multi-purpose, and able to translate theories and concepts in models and methods particularly suitable for analyzing the *status quo* and the potential impact of different policy scenarios and management on ecosystem resilience. In the frame of bioeconomy, research is called to provide scientific bases, models and decision support tools for implementing sustainable growth and local development, which have their roots on paradigms less anthropocentric and more focused on coupling human and natural systems.

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Conference paper

Research and innovation in sustainable forestry: lessons learnt to inform the policy making community

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Abstract - From an already rich experience of cooperation between scientists and policy makers in the framework of international research institutions such as the International Union of Forest Research Organizations (IUFRO), the Center for International Forest Research (CIFOR) and the European Forest Institute (EFI), as well as through the promotion and development of EU research projects and programs, some lessons can be drawn considering the possible role of scientists at the science-policy interface. Today, on the example of the global change - and especially the climatic changes that policy makers are demanding about-, most of the researches to be carried out have to answer social questions the solutions of which require the support of science. This is especially the case in the forestry field, which is characterized by the particularly long term of cycles and the great number of stakeholders interested in. Whilst decision making processes are complex systems, science is not the only source of knowledge useful for taking decisions, so that in a democratic context, research results have to be confronted to other lessons learnt (for instance from technical expertise, or from traditional knowledge) in order to get accountability in terms of instrumentation. In scientific terms, it should certainly lead to multi-disciplinary approaches of the multifunctionality of forest and related techniques to be implemented. But this does not mean that research activities have to be assessed only against their instrumentality. However, research and public decision-making are very contrasting spheres, where the principles and professional types of behavior are basically different. This situation calls for a need for a clear separation of the respective roles. In addition, all scientific developments should not be driven from practical needs of decision-makers, since theoretical questions may indirectly build up the future reality.

Keywords - Forest research, forest policy, decision-making, science/policy interface

Since the last 15 years, more attention has been paid in the scientific sphere to the quality of the message brought by the scientists to the policy makers. In the field of environment and forestry, the discussion on the impacts of global change has been determinant. Nowadays, it has become almost impossible either to justify a research program or to present research conclusions without referring to what it means in terms of public decisions to be taken. Science specialists speak to policy makers.

What science can tell

The experience of policy science

This evolution has been especially determinant in the research field of policy science, where since the last 10 years, a shift in topics to be addressed and concepts to be used has occurred. During the years 1980 and 1990, a focus was made on formulation and evaluation of national policies, through social studies and policy analysis. Since the last 15 years, this has been changed, shifting from policy aspects (what to do and why) to governance aspects (how to do it).

One of the effects of this shift is a progressive move from policy analysis as distant from the social questions, to an empirical positioning at the science/policy interface. Progressively policy scientists are even associated to some discussions and orientations of the policy and governance of the sector.

One example is the process of formulation of international criteria and indicators of governance. In support to donors and funding agencies which were giving the highest attention to governance issues, there was an urgent need to identify relevant tools for assessing and guiding their action in support to forestry development. In the early 2010s, an initiative of the World Bank has associated UN agencies and international scientific networks (EFI, CIFOR) in defining a framework for reviewing forest governance.

Another issue that has played a central role in promoting the importance on science/policy interface in the forest sector is the discussion on the orientations to be taken at the management and policy levels in order to take into consideration the possible impacts of global (both climatic and social) change. Scientists from different fields of research

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(especially climatology, ecology and sociology) have been clearly asked by the decision-making community to transfer their results in a way that could result in action. However in this case, the association between scientists and policy makers has been more difficult so far than in the previous example (because the disciplines retain concepts and theoretical schemes that are far from action, and because experts may have different views on the topic).

EFI and EU as drivers

In this important change, 2 international institutions have played the major role.

The European Union (EU) has become a key partner in orientating the research carried out in the member Countries. In some identified strategic domains (resilience to global change, biodiversity conservation, sustainable development, governance), the EU has defined principles for attributing its support which pay a major attention to the applicability of the results to be provided. Through this strategy, the EU intends to orientate the researches towards topics of high interest in terms of decision making. In some programs (such as the COST program), the association of stakeholders and decision makers is even stated as a condition for acceptance and funding of the research project proposals that are submitted.

A second international body which has actively contributed to the shift from academic research to science/policy interface is the European Forest Institute (EFI) that has clearly stated as one of its major objectives the provision to the deciders' community of concrete useful results. EFI has permanently reflected on the topics that were considered as hot spots, as well as it has discussed the approaches and techniques in order to reach the decision makers' community. In this framework, EFI has developed 2 types of publications: (i) the "*What science can tell us*" studies on various topics, eg. water and forest, European forest governance, living with storm damages in forests, or forest bio-energy in Europe; (ii) a series of policy briefs resulting from high level expertise developed in a think-tank named "ThinkForest" merging scientists and policy makers (especially European parliamentarians).

A result of this global interest is a re-definition of the norms of quality to be used as for evaluating researches and research institutes as well. In Europe but also in North America where the same move is observed, the best-ranked scientific teams are those who benefit from an important dotation, means those who aim at providing deciders with consistent tools for taking management and policy decisions.

The science/policy interface

This spectacular development of relations at the science/policy interface finds its basic determinants in:

- the restriction of public and private funds to research activities, which brings both policy deciders and academic institutions to select priorities (all cannot be done considering the global capacities);
- a need for funding agencies to prioritize researches that are able to bring results in as short term (in a period of economic crisis, the society has to solve urgent questions first).

Innovation in support to public decision

On one hand, the main role of science is to bring elements of knowledge that can be useful for the society, even if it is not necessary for direct immediate concrete actions. Knowing about a topic makes sense only if the gain obtained in culture or technique may allow a benefit in terms of welfare. From this viewpoint, knowing just for knowing makes no sense, so that as a conclusion, research activities need anyhow to justify what they bring to the society which is at the end the last level in assessing the scientific results.

In all cases, the scientific questions addressed by the research activities are a translation of the economic, social or cultural questions raised by the society. In a way of another, would they want or not, the scientists work in the framework of bringing innovations that will be used more or less directly by the society, and at the end they are supposed to support public decisions. In a democratic context, the question is not so much to ask whether a research should be policy oriented, but rather who defines what is useful (budgeting?, policy?) for the society, and consequently what is a useful research.

In most of the cases, the rationalist framework, where once needs to know before to act, is used as a reference: scientific knowledge is supposed to give the truth of laws derived from verified facts and figures; thus it is more considered as a justification for a decision than the other forms of knowledge (technical-empirical and traditional-locally based). A linear sequence characterizes the track form knowledge to decision, as a segmented path with specialized actors:

- the policy deciders allocate the budget to research;
- the senior management of research institutes defines research priorities;
- the labs organize the work to be done, do the job and disseminate the results towards the

scientific community;
- the extension structures test the results at larger and more concrete scale, and make necessary adjustments;
- the policy deciders receive more knowledge in order to take better decisions at the end, and finally ask new questions to research.

Up to now, very few attempts have been made to reconsider this linear deductive framework and consider a dynamic process of iterative interrelations between the science and policy spheres, retaining knowledge as a result from a process of permanent mutual learning, where various actors interact in producing what is called knowledge.

An important challenge in the future of the science-policy interface for the next years will be to re-consider the whole process of linking scientists' work, deciders' job and citizens' demands, through promoting a new systemic vision that is more conform to the reality, where the construction of knowledge comes from social interrelations.

What decision makers ask scientists

On the other hand, and as a general principle, it is also clear that policy makers are supposed to ask the research to respond concrete questions that they have, just because any type of decision needs to be taken basing on the most accurate information. Through the international dialogue on forest and environment developed since the beginning of the years 1990s, the idea has emerged that researchers should be included into the discussion community, with as a role to provide to decision makers the mast insights about the main issues raised. A strong hypothesis in the rationalist vision of decision making is to consider that deciders should decide basing on the best possible knowledge.

But this linear vision does not necessary correspond to the most common situation, whilst usually scientists are asked for in very different contexts:
- when something decided before has not worked so far, and that there is a need for a change that is not well mastered or that needs to be strongly justified (*eg.* the case of the industrial plantations facing problems of pests and difficulties in marketing);
- when the usual way to decide is made too much difficult in case of changing context and paradigms (*eg.* the case of climate change);
- when decisions are very hard to take, and thus comes the need for the decision makers to find an outsider as a possible "responsible" actor (*eg.* the case of re-definition of users' duties in a more inclusive management scheme).

In any of those cases, one result of the rationalist vision is certainly a pressure from the society, thus from the policy deciders, on the research to "find out" (result-oriented research) more than to "search for" (processed oriented research).

Making scientists and decision-makers working together

Research and decision: two different spheres

There is a difference of logic between social and scientific questions. Social demands, those raised by the decision makers for instance (usually after a first proper translation), address results, gains and concrete actions, so that basically short-term responses are expected. On the opposite, scientific questions relate to the rationale and the cognitive aspects, and deal with mechanisms, and that implies long-term involvement.

In addition, in most of the cases, translating social demands into research questions is not an easy task, for at least 2 reasons:
- first, social needs are changing over time, and many of them are contradictory, whilst they are expressed by stakeholders who compete for the solution;
- second, the translation into scientific terms uses different languages and concepts (wording, but also logic) related to various disciplines.

This may lead to two very different types of knowledge and two very different types of responses and solutions.

Science may bring doubt and complexity to the decision making process. It can complicate the issue, and thus make the solution more difficult or long to find. Science can also contest or deny the validity of present or previous decisions taken, even in the case when policy deciders do not ask scientists to address the related issues.

Opposite to this, decision-making needs a certain degree of certainty and simplicity (simplification). Deciders like science when it makes their action easier and more credible, or when it confirms their initial vision. At the end, they may look for science only in 2 very different types of situation (i) when they are already sure of the results (and they look for a validation from science), or at the opposite (ii) when they really do not know what to decide (and they look for science taking the responsibility of difficult choices instead of them).

Can scientists and decision-makers build-up knowledge together?

Although the discussion between scientists and decision-makers may still be difficult, there are more and more situations where a constructive dialogue works.

This is especially the case as far as mutifunctional management/policy is concerned. Science is a very segmented sphere, whilst it works through various disciplines that use different concepts, approaches and methods. At the opposite, any decision-making process usually needs to integrate various aspects, involving different fields of research. Most of the success stories in working at the science-policy interface organize a constructive debate among scientists from different fields. The most successful examples are even those when scientists are able to build up a multi-disciplinary vision to be submitted to the decision-makers as the scientific knowledge.

Some guidelines come from experience, in order to promote a better dialogue between scientists and decision-makers:

- make scientific results visible to raise deciders' awareness and willingness to cooperate: the scientific message should be simple, modern, clear and concise (one idea only, in order to avoid from confusion); usually deciders react.
- take initiatives and propose conclusions directly to the deciders; when they see that scientists come by themselves to the social debate, deciders find interest in developing interactions that can be promising.
- develop multi- or even inter-disciplinary researches, in order to reach a common comprehensive speech, sometimes the only one audible by the decision-makers.

If scientists are part of the social construction of actions (they take part in the knowledge development system, through interactions with other stakeholders) and thus in a way may appear as acting as stakeholders in the decision making process, only the decision-makers are responsible for the actions taken and implemented. The scientists' role is just to bring to the discussion rigorous demonstrations. Otherwise, there still exists a risk of instrumentalization of science as an alibi by the deciders, against which scientists need to be guaranteed by a "free thinking" context and institutional framework.

Do scientists always need to respond decision makers?

The need to have scientists and decision-makers working together should not occult that in frequent cases scientists cannot or have not to respond directly the questions that they are asked for:

- there may be a need for more distance, for more abstraction or for a re-conceptualization, *eg.* in case of a lack of rigor of the social debate as it is developed, or in case of important changes in the context that make the question as formulated by the decision-makers irrelevant;
- sometimes an ethical questioning is absolutely needed;
- some results brought by science in specific conditions need to be tested in various contexts in order to be implementable, just because there is a great heterogeneity of space and time in all aspects dealing with the decision process (techniques, management, governance). Opposite for instance to physics, there exist no universal laws in management and policy sciences, as well as in social sciences in general, because solutions vary a lot from place to place and from time to time.

Whilst it can take more time than required by decision-makers who are under a strong pressure of time, many studies and experiments are usually required for a good response to the society. This is also why international cooperation in scientific studies is needed.

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