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Forest biotechnology: economic aspects and conservation implications

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I N F O

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A B S T R A C T

The importance of forest ecosystems for ecological balance and as a reservoir of genetic heritage and biodiversity is evident, the need for conservation is further exalted by the great anthropic pressure suffered by these ecosystems due to the increasing demand of the forest sector. The possibility of using biotechnological practices to combine conservation with sustainable economic development emerges as a promising alternative for the recovery and use of forest species, especially those threatened with extinction. The aims of the article is to demonstrate the main aspects of Forest Biotechnology with regard to conservation and the continuity of the supply of the demand of the economic sector. The central role of wood in economic development has led to the intense exploitation of forest ecosystems, which has resulted in the loss of biodiversity and reduced capacity to meet the demands of the sector. The tools of forest biotechnology, when employed in the optimization of conservation, allow a compatibilization with commercial production, acting as instruments of sustainable development. Forest Biotechnology acts as an instrument to reconcile conservation with economic development, including forests at the heart of a strategy for a sustainable future.

R E S U M O

Palavras-chave
silvicultura
sustentabilidade
desenvolvimento econômico
b**io**tecnologia florestal

Biotecnologia florestal: aspectos econômicos e implicações na conservação.
É evidente a importância dos ecossistemas florestais para a manutenção do equilíbrio ecológico e para a seguridade do patrimônio genético e biodiversidade. A necessidade da conservação desses ecossistemas é exaltada, ainda, pelas pressões antrópicas devido à crescente demanda de insumos vinda do setor florestal. A possibilidade de utilizar práticas biotecnológicas para combinar a conservação com o desenvolvimento econômico, surge como uma alternativa promissora para a recuperação e uso sustentável de espécies florestais, especialmente aquelas ameaçadas de extinção. O objetivo deste artigo é demonstrar os principais aspectos da Biotecnologia Florestal, no que diz respeito à conservação e a possibilidade de sua compatibilização com a continuidade do atendimento a demanda do setor econômico. O papel central da madeira no desenvolvimento humano e econômico impulsionou a intensa exploração dos ecossistemas florestais, o que resultou na perda da biodiversidade e na redução da capacidade de atender as demandas do setor. As ferramentas da Biotecnologia florestal, quando empregadas na otimização da conservação e regeneração, permitem uma compatibilização com a produção comercial, atuando assim como um instrumento de desenvolvimento sustentável. A Biotecnologia Florestal atua como um instrumento de conservação da biodiversidade, por viabilizar a inclusão das florestas no centro de uma estratégia para um futuro sustentável.

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INTRODUCTION

Forest areas cover about 30% of the Earth's surface, serving as a reservoir of more than one trillion tons of carbon. The intrinsic value of forest ecosystems is mainly represented by the great biodiversity they harbor, providing support for the existence and maintenance of a complex ecological dynamics. Together with other plant associations, forest formations act as large reservoirs of genetic heritage, providing means for the perpetuation, development and evolution of the species that occur in them (TEEB, 2010; FAO, 2016).

Forests are essential for the maintenance of all life forms, but the human development pressures associated with increasing demand for timber inputs represent one of the major contributions to the degradation of these ecosystems (Plomion et al., 2016). Worsening pressure on native forests is associated with deforestation, biodiversity loss and the establishment of invasive alien species (Boerjan, 2005).

Meeting the growing demands for forest products in order to have the least possible impact on the environment depends on the pursuit of increased productivity and intensive research to obtain new products from wood. The advances in biotechnology, obtained in the last decades, when applied in this context, assure benefits for the forest industry, allowing the development of processes and products in a sustainable and economically advantageous way (Bhalerao et al., 2003).

Biotechnology is responsible for the main productive advances of the agroforestry industry in recent years, being implemented as a tool to solve global problems such as raw material availability and climate change (Adenle et al., 2012; Moshelion & Altman, 2015). Forest biotechnology encompasses techniques that combine traditional planting and stabilization practices with tools developed from tissue cloning, gene transfer and molecular biology and genomic techniques (Nehra et al., 2005).

The physical and structural properties of wood have made it a raw material of importance for the development of humanity. Wood is necessary for the world economy, characterizing an indispensable element in the construction of human communities since prehistoric times (Fenning & Gershenzon 2002). Trees represent the major part of the terrestrial biomass produced, and the industries responsible for their processing are major contributors to the economy of developed and developing countries (Bhalerao et al. 2003).

Despite the large-scale production, the demand for products from forest species has increased in recent decades (Plomion et al., 2016). In 2000, the projection was for a 20% increase in wood demand by 2020 (Boerjan, 2005), given the tendency of developed countries to reduce the use of non-renewable resources by replacing them with renewable resources (Bhalerao et al., 2003).

In this context, the objective of this article is to review aspects of Forest Biotechnology specifically regarding the conservation or maintenance of forest ecosystems, in order to maintain forest production to meet the demands of the economic sector. The procedures used to prepare the review involved a bibliographical research, having as an instrument of secondary data collection articles published in scientific journals and made available in the Web of Science.

FORESTRY ECONOMIC DEVELOPMENT

The history of the use and exploitation of forests is confused with the very history of civilization. Throughout the eras, the trees provided material to make the fire, whose use allowed the readaptation of the planet for the human being. Through the fire it was possible to cook food, to inhabit cold weather places, to convert ceramic clay and metal into tools and boats, to create more durable materials such as brick, cement and tiles for the construction of houses and to remove the salt water by evaporation. In addition, charcoal and wood provided power to the machines after the Industrial Revolution, allowing the transportation and manufacturing of large-scale products. The development of human societies has led to an inversely proportional regression of forest areas across the globe. Initially, this reduction was motivated mainly by the fear that the forests caused, being historically related to the existence of mystical and mythological beings. With the discovery of the potential of its multiple uses, there was an increase in the economic value of the forests, which boosted the exploration advance (TEEB, 2010). Figure 1 presents the most significant historical events in the process of forest exploitation worldwide.

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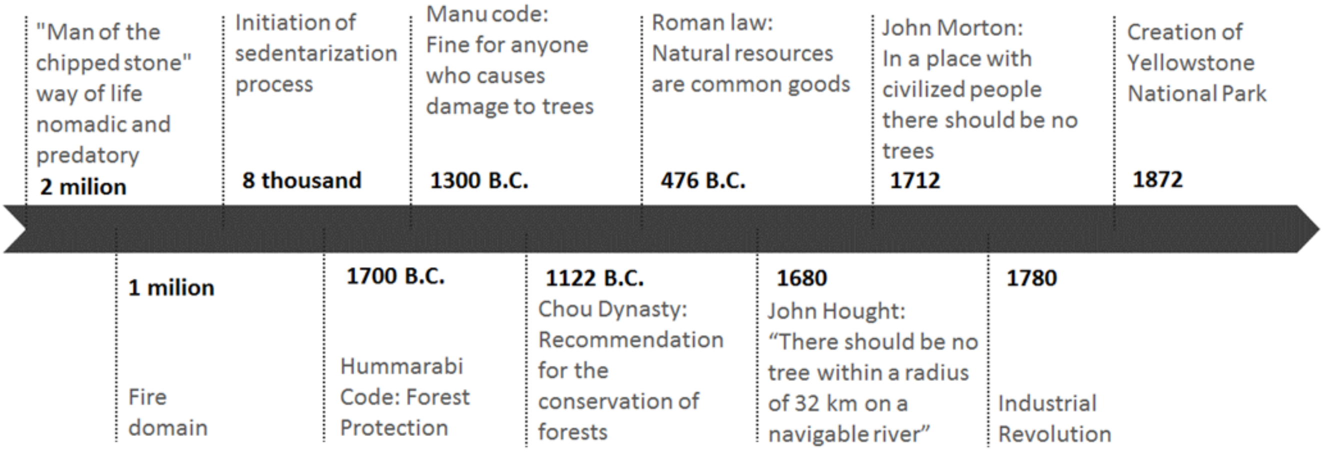

Figure 1 - Timeline showing the most important historical events for the exploitation of forest resources, which culminated in the establishment of the first protected area at the global level.

The process of deforestation had its first historical milestone approximately half a million years ago, with the domain of fire by *Homo erectus*, going through several critical periods throughout history. After the last glaciation, about 10,000 years ago, forests are estimated to have covered about 6 billion hectares of the Earth's surface, and since then have been suffering directly from the expansion and development of human populations (Williams, 2000).

The itinerant hunter-gatherer way of life of the primitive societies of the Paleolithic period (2.5 million years ago), though destructive and predatory, allowed the renewal, even if slow, of the resources exploited. When the nomadic way of life began to be replaced by sedentarization, there was an intensification of the deforestation process, since there was a need to open pastures and crops, and to obtain wood for the construction of houses and structures (Deacon, 1999). Grazing goats and sheep, mainly in Europe, has generated great impacts on the regeneration of forests, since these animals feed on the shoots of the trees, preventing their multiplication (Kaplan, 2009). Improvement of tools, such as the replacement of the stone ax with the metal ax 3,500 years ago and the sawmill, developed in the Middle Age, facilitated, and accelerated the exploitation of forest resources.

In the Middle East and in the Mediterranean basin, the rise of large dynasties and empires almost invariably led to the clearing of large forests for the development of agricultural and pastoral activities, as well as the procurement of wood for construction and fuel (Deacon, 1999). The decline of some of these empires had as its main cause the consequences of deforestation, such as erosion, loss of soil fertility, and eventually desertification, which compromised agriculture and animal husbandry, leading their economies to collapse.

Concern over the sustenance of the economy has led to a growing concern with the preservation of forests, particularly represented by the Codes of Conduct, such as that of Hummarabi, which ruled Mesopotamia around 1700 B.C. and the Manu Code, which was in force in India around 1300 B.C. The precepts of the Chow dynasty that prevailed in China between 1,122 and 225 B.C. involved an imperial recommendation for the conservation of forest areas, and in ancient Rome Cicero considered as "enemies of the state" those who slaughter the forests of Macedonia. Protection against the devastation of forests was also cited in the Law of the XII Tables, in 450 B.C., which encouraged the inclusion of the subject in the Roman Law, which specifies natural resources, involving fauna and flora, land and landscapes as goods that can be used by all (Séguin & Carrera, 1999).

In the more recent past, however, issues of culture and economic development policies have led to the discouragement of conservation, to the detriment of settings made by iconic figures of the time, such as John Houghton and John Morton in 1680 and 1712, respectively.

Houghton enunciated his most important idea in an essay on navigation, in which he affirmed the necessity of the absence of trees within a radius of 32 km of any navigable river. And Morton, for his part, asserted that just as what was observed for Northamptonshire, the English county in which he lived, in a place inhabited by civilized people, trees could not grow, for land should give way to uses of more immediate necessity, such as pastures and crops.

The Industrial Revolution made deforestation easier, faster, and more efficient, bringing timber resources almost to exhaustion. Between the years 1750 and 1920 it is estimated that forests were virtually extinguished in 25 countries, especially

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Europe, with a reduction of more than 90% of the vegetation cover in another 29, totaling about 222 million trees felled in the tropical regions and 40 million hectares of devastated forest between the nineteenth and twentieth centuries in Southeast Asia (Williams, 2000). With the advent of machinery and technology, deforestation, which had almost completely succumbed to temperate forests, also spread through the rainforest, mainly because of population growth, which led to increased demand for energy and other forest resources.

The Industrial Revolution has brought significant impacts to forests around the world, with significant reductions in area of coverage and consequent loss of associated biodiversity. In India, between the nineteenth and twentieth centuries, 33 million hectares of forested land disappeared, and in China, the remaining 26% of the Qin dynasty's forest land was reduced by 17% by the year 1840. In the United States, between 1750 and 1900 the 450 million hectares of forest were reduced to less than 300 million. In Latin America, a loss of 25% of the forests has been estimated since the arrival of the European settlers (FAO 2016). The Araucaria Forest, the predominant Atlantic Forest vegetation in southern Brazil, for example, suffered a 99.2% reduction only in the State of Paraná (Castella & Britez, 2004).

The realization of this decline led to concern for the safety of natural resources, as a means by which the human productive system is maintained and renewed, indicating the need to implement measures to control and maintain the genetic heritage of the world's biodiversity. Although the idea of the institution of preservation areas is not attributed to a specific person, its use is historical and recorded for some ancient civilizations (Morsello, 2001). The official landmark of the creation of such areas arises with the establishment of the Yellowstone National Park in the United States in 1872 and with the creation of protected areas of Europe instituted from the civil initiative as an attempt to conserve natural habitats in the face of changes by countries (Bensusan, 2006; Morselo, 2001). The institution of such areas has had a direct impact on conservation, but also had economic repercussions, represented by the possibility of developing tourism, recreation, environmental education, research, and development activities, as well as fomentation and rebates of specific taxes determined by the legislation of each country.

In general, the exploitation of forest species is one of the bases of the economic development of many countries, which for decades have used the predatory extraction of their native species as a source of wood for civil and naval construction. The intense exploitation of the wood resources combined with the other anthropic pressures and with the ecological characteristics inherent to each species led to the gradual reduction of native populations, with the consequent inclusion of several species in the lists of endangered species (Plomion et al., 2016).

Data compiled by the Food and Agriculture Organization of the United Nations (FAO, 2010) show a direct relationship between population increase and loss of plant cover. In the year 1800, the world population was around 1 billion people, corresponding in the same period to the loss of 0.8 billion hectares of forests. In 1900, the world's population increased to 1.5 billion people, also increasing deforestation, with 1.2 billion hectares lost. In 2000, the world population jumped to 6 billion people, reflecting a loss of 5.7 billion hectares of forest. In 2010, in the last world survey conducted, the world population reached 7 billion and deforestation 6 billion hectares.

The divergences between forest monitoring and control systems in countries make it difficult to analyze and interpret the data in a global perspective. Understanding the dynamics and evolution of the relationship between human beings and forests are fundamental for the design of a sustainable future, which aligns the conservation of nature with economic development. The observed fluctuation in the size of areas for conservation and commercial activities helps to understand this global dynamic. Table 1 shows the prospection of these areas between 1990 and 2010, when the last survey was carried out.

There is a growing projection of forest plantation areas, with an increase of about 5 million hectares per year between 2000 and 2010. In the last survey carried out in 2010, the forest planted areas corresponded to 264 million hectares, about 7% of all forest cover in the world. According to FAO (2010) data, most of these areas were established by reforestation actions, mainly in Asia, with about three-quarters of all planted forests being native species while only one-fourth corresponds to invasive alien species. In South America, 95% of the plantations consist of exotic species, which shows the need for incentive policies and biotechnological research to enable the establishment of plantations with native species.

Areas for forest conservation and preservation have increased by 95 million hectares since 1990, totaling 460 million hectares in protected areas of different categories. These areas account for 12% of the total world forest area, mainly concentrated in North, Central and South America.

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Table 1 - Size of forest area, in millions of hectares, for conservation and commercial plantations, by region, between 1990 and 2010. Source: FAO (2010).

Type of Area	Continent	Year 1990	Year 2000	Year 2010
Conservation Areas (millions of hectares)	Africa	50	51	54
	Asia	59	53	79
	Europe	18	29	36
	North and Central America	93	96	104
	Oceania	06	07	07
	South America	41	52	84
	TOTAL	**267**	**288**	**364**
Commercial Planting Areas (millions of hectares)	Africa	10	11	12
	Asia	76	91	122
	Europe	58	62	67
	North and Central America	10	22	39
	Oceania	04	04	05
	South America	08	10	12
	TOTAL	**166**	**200**	**257**

Regarding the deforestation process, in 2010, a reduction of more than 40 million hectares of primary forest was recorded in relation to 2000, on a global scale. In 2010, primary forests, characterized as those with native species and in which there is no clear evidence of anthropogenic intervention and action, and which do not present a significant disturbance of the ecosystem, corresponded to 36% of the world's forest cover (FAO, 2010). Although data from FAO (2010) show that more than one-third of the entire forest area of the planet consists of primary forest, its definition becomes arbitrary when considering the transboundary and global character of some anthropogenic pollutants, mainly liquid and gaseous that permeate and even impact the most isolated ecosystems.

The decline in natural populations coupled with increased demand for forest products has led to the development of forestry, which seeks natural and artificial methods for the regeneration of forest stands. Silvicultural activity, especially in developing countries, such as the Latin American countries, is based on species of the genus *Pinus* and *Eucalyptus* (Sartoretto et al., 2008; Studart-Guimaraes et al., 2003).

Impacting anthropogenic activities have led to the impairment of the regeneration, regulation, and maintenance capacity of forest ecosystems. This decline in capacity to promote its ecological role has generated negative impacts on productivity in the forestry sector, which has resulted in a decline in capacity to meet demand, which has been growing in the last decades. The lack of concern for the sustainability of the forest production process has had negative impacts on the conservation of ecosystems, being one of the causal agents of the decrease of the world biodiversity, mainly due to the introduction of invasive alien species and the loss of soil quality. This decline in environmental quality, in turn, generated an instability of the sector's income, due to the decrease in the quality and quantity of the final product obtained.

SUSTAINABLE DEVELOPMENT IN THE FOREST SECTOR

The definition of sustainable development or sustainability presents variations according to the historical period and the context in which it is inserted, with a consensus, however, regarding the main elements involved in its conception: concern with environmental issues, economic and social aspects.

The Sustainable Development Strategy in the UK establishes sustainability as the attainment of four objectives, being (1) social progress recognizing the needs of the human population; (2) effective protection of the environment; (3) prudence in the use of natural resources and (4) maintaining the stability of economic development and job creation (Paramanathan et al. 2004). The Cambrigde Research Institute, on the other hand, describes sustainability as the "concept, design and manufacture of goods and services that meet the needs of the future generation without diminishing long-term economic, social and environmental opportunities" (Jansson et al., 2000).

The organizational field of the forestry sector presents members with different behaviors and ideologies regarding sustainability. The projections for the future, represented by the sustainability vision for the forestry sector, are not yet presented as

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a consensus, involving a range of divergent and even conflicting opinions that hinder their application (Nardelli and Griffith 2003). Although the environmental appeal has included in the discussions about forestry issues such as the reduction of the impact generated by the plantation areas, as well as the increase of the production and the maintenance of the logging characteristics of economic interest, its development follows in slow steps (Sampaio & Mazzochin, 2010).

The Declaration of Principles on Forests, launched in 1992 at the United Nations Conference on Environment and Development, also known as Rio 92, provides guidelines for the management, conservation and sustainable development of all types of forest in the world. Almost three decades after its launch, little progress has been made in terms of sustainability in the forestry sector, especially in encouraging the use of native species over exotic ones in productive activities.

The Declaration defines forests as essential for economic development and maintenance of all life forms and is part of a complex ecological process at the global level, which serves as a basis for providing the resources needed to meet human demand. Because of their importance to the economy and social welfare, their conservation is of interest to governments, which must cooperate internationally in forestry issues to address the right to economic development on a sustainable basis even in the poorest countries (United Nations, 1999). Due to its importance as a guiding element for the integration of sustainability in the forest productive sector, its main topics will be discussed individually.

The first and second principles place States as sovereign holders of the right to manage and exploit their forests in accordance with their own environmental policies, with the responsibility to ensure that their activities do not cause damage to other States. Exploitation, however, should be delimited within a social-economic development plan that reflects rational land-use policies. This plan should address the social, economic, ecological, cultural and spiritual needs of present and future generations, considering the protection of forests against pollution, fire and pests (United Nations, 1999).

The main obstacle faced by this principle over time is represented by the poor effectiveness of the legislation in countries where it is not well established and / or delimited or the lack of supervision and control of the legislation implemented. The Brazilian Forest Code, for example, is one of the points of controversy over the world's forestry legislation, generating much criticism in the scientific environment after its restructuring in 2012. Among the most controversial points of the new Code, the reductions of permanent preservation areas and of legal reserve areas, giving greater freedom to rural producers in land use, stand out. These are two instruments considered as essential for the protection of Brazilian vegetal formations. The restructuring of the code was based on ensuring economic development, not demonstrating the necessary balance between the economic, social and environmental sides and is therefore subject to harsh criticism (Sauer & França, 2012; Rroriz & Fearnsside, 2015).

Several principles included in the Declaration refer to the importance of international cooperation in research activities and the sharing of relevant knowledge regarding the sustainable management and use of forests. They also point to the need to provide financial resources for the development of countries in ways that enable them to manage their forest resources sustainably, and to encourage the facilitation of trade in forest products as guiding elements for the achievement of these objectives (United Nations, 1999).

The major obstacle to economic development in Research and Development (R & D) of agroforestry biotechnology is the increase of intellectual property rights. At the same time as it legally protects its creators, it concentrates in the hands of private sector institutions the knowledge necessary for the development of poor countries. Biotechnology-related R & D activities in the United States, for example, went from a $ 8 billion revenue in 1992 to $ 25 billion in 2000, representing gains at the 300% margin over this period (Adenle et al., 2012). The high profitability of the sector and its importance to the economies of developed countries end up causing restrictions on the supply and sharing of technologies, which hinders and limits their implementation in underdeveloped or developing countries.

The principle of number six deserves to be highlighted, as evidencing the possibility of establishing plantations of native species together with non-native species, in a pattern known as mixed system, aiming at the potentialization of production and the demand for forest inputs. Research shows that the inclusion of plantations of native species in regions with a predominance of vegetal cover composed of non-native species, promotes an increase in forest productivity, representing significant gains for the conservation of native populations and allowing the development of the sector based on sustainability (Hildebrandt & Knoke, 2009; Pryde et al., 2015).

Piotto et al. (2004), in a study conducted in Costa Rica, identified a significant increase in the growth of the plants established in the mixed system, which resulted in an increase in the productivity of the system, besides providing high-quality raw material from the native species. Oxbrough et al. (2016), in a research developed in Ireland, identified a

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greater richness and diversity of arthropods in mixed plantations in relation to the plantations composed mainly by nonnative species, indicating the importance of the inclusion of the native species for the maintenance of these populations. Some countries, such as Ireland (Oxbrough et al., 2016), recognize the importance of mixed plantations to minimize the impacts of introducing non-native species for commercial purposes, legally imposing mandatory planting of at least 20% of native species. Unfortunately, the legal measure does not present itself as a worldwide trend, evidencing the need to reinforce the incentive to adopt such measures as a conservation action and a promoter of sustainable development.

The declaration also affirms the need to recognize the vital role of forests as reservoirs of biodiversity and as an abode of indigenous peoples, who must have their cultural conditions and social organization respected for their well-being. In addition, their local knowledge on conservation and sustainable development should be considered, and where relevant, included in the action plans (United Nations, 1999).

Another point of prominence in the Declaration, portrayed in Principles 13 and 15 is the indication of avoiding industrial, commercial, transportation activities, as well as policies and practices that may have consequently the degradation of forests. Pollutants, especially those with cross-border characteristics, should be monitored at local, national, regional, and global levels to avoid impacts on health and the quality of the environment (United Nations, 1999).

Sustainable development in the forest sector arises from the need to suppress the demand for forest resources without compromising the quality of the environment. The increase in demand occurs as a consequence of scarce resources due to poor planning or productivity decrease, which is related to a decrease in the productive efficiency of plantations. Demand is also a consequence of the exacerbated demographic increase of the last decades, as well as the incentive to use renewable resources over non-renewable ones for energy generation.

The production and delivery of forest resources, however, should be aligned with conservation, aiming at minimizing impacts such as species extinction, deforestation, introduction of invasive alien species and climate change. Sustainable development can be instrumented by Forest Biotechnology, which, through the valorization of the biodiversity and the genetic heritage contained in the forest ecosystems, generates profits due to the increase of the efficiency of the processes. Figure 2 presents a schematization of this context.

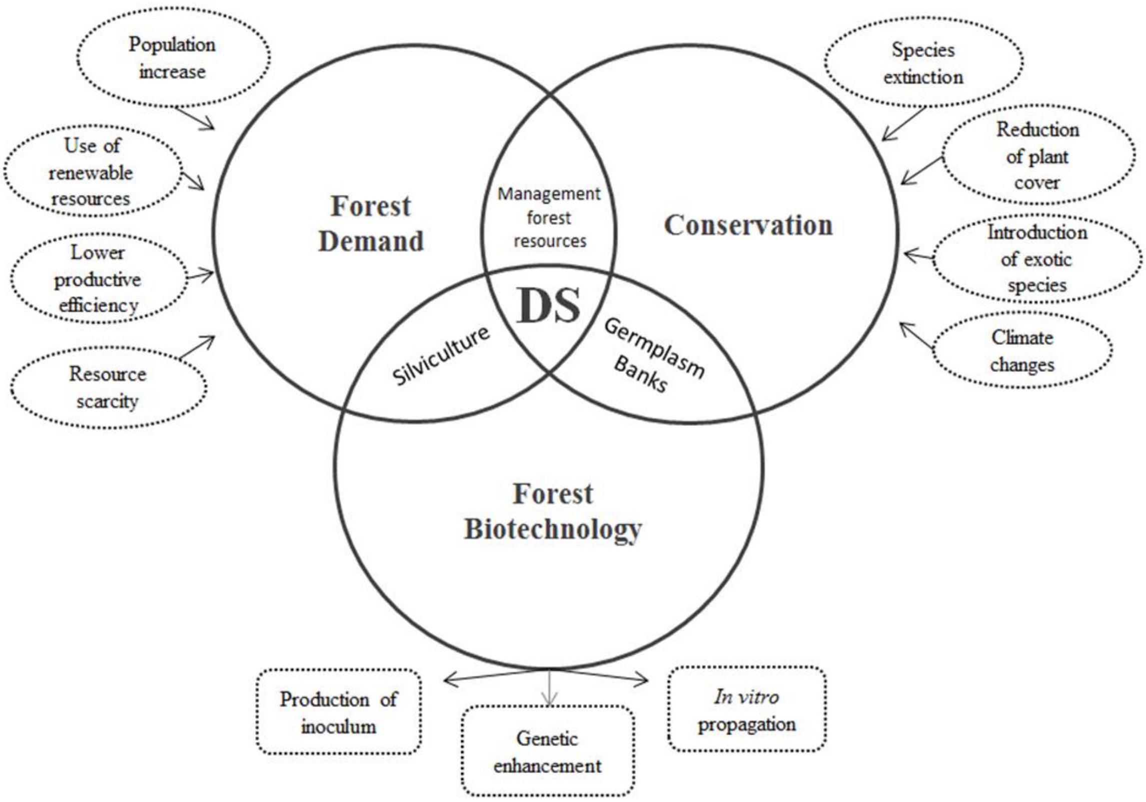

Figure 2 - Scheme representing the relationship between forest demand and conservation, with regard to sustainable development and forest biotechnology.

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FOREST BIOTECHNOLOGY, CONSERVATION AND FOREST PRODUCTION

Forest species are important for the systems in which they occur, acting as a source of food resources and shelter for the fauna and providing shade for the smaller plant species, being vital components of the complex environmental dynamics of the forest ecosystems. The anthropic pressures exerted on these ecosystems have led to the progressive reduction of populations and the risk of extinction for several forest species worldwide.

Although *in situ* conservation, represented by the management and maintenance of protected areas, is an effective measure for the conservation of biodiversity, when combined with *ex situ* techniques its effectiveness is enhanced, especially when applied to endangered species with low regenerative potential (Sarasan et al., 2006). In some cases, *ex situ* conservation techniques represent the only feasible option for the reestablishment of a species, considering the importance of genetic variability and associated factors (Golle et al., 2009).

Studies involving the development of bioprocess for the propagation of germplasm are important for the conservation of species that present mechanisms of natural and artificial propagation that are not satisfactory. In some situations, such techniques applied for *ex situ* conservation may represent the only alternative for the conservation of critically endangered species with little regenerative potential.

In South America, for example, *in situ* management techniques are mostly applied to exotic species, which forms the basis of the logging economy. It is estimated that 95% of the plantations in South America are of exotic species, especially the genus *Pinus* and *Eucalyptus*. The same pattern is observed for other regions, such as Oceania, which has 78% of its forests composed of introduced species, followed by Africa with 39% and Asia with 24% (FAO, 2010).

The current scenario of forest biotechnology is marked by the almost exclusive application of techniques and tools for economic production and development. Figure 3 presents this perspective schematically, also representing the current scenario and the best way to achieve it.

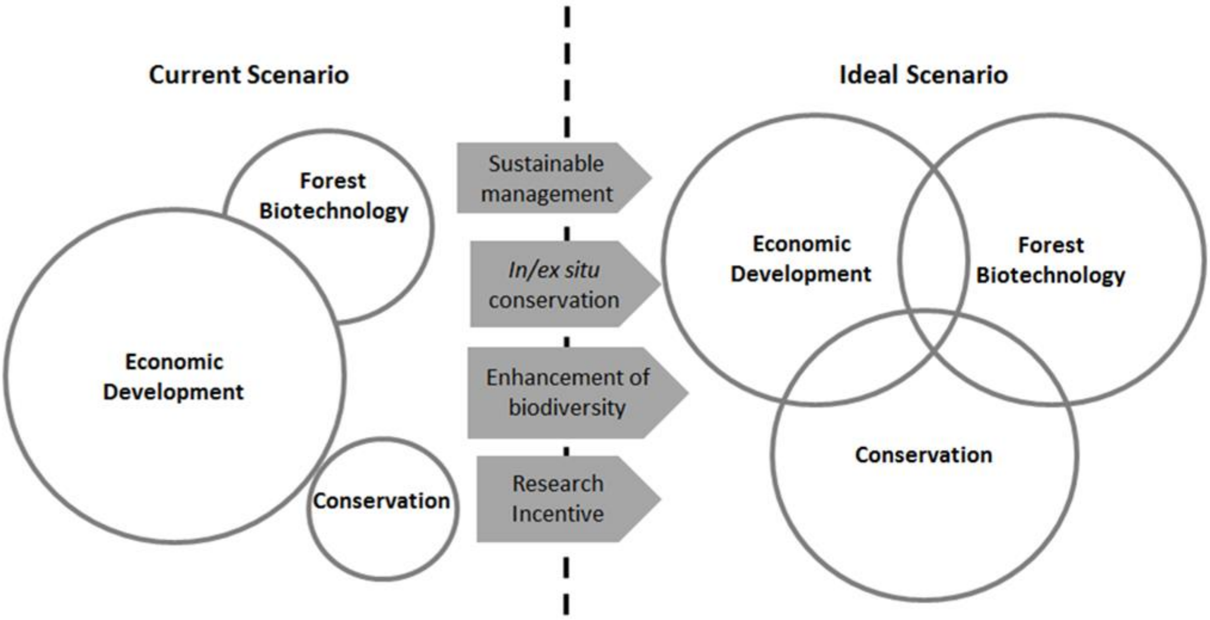

Figure 3 - Bioprospection demonstrating the current scenario and the ideal scenario of the relationship between Economic Development, Forest Biotechnology and Conservation.

The analysis of the current global scenario reveals the small link between conservation and economic development, and the absence of its connection with forest biotechnology, which is used exclusively for forestry purposes. The ideal scenario, on the other hand, presents intersections between the three spheres, allowing the three to be applied jointly in the quest for sustainable development. The scope of the ideal scenario is possible through the implementation of *in situ* and *ex situ* conservation actions, sustainable management, the valuation of the biodiversity and associated genetic heritage, as well as the encouragement of the development of research and development of conservation techniques within Forest Biotechnology.

The scarcity of papers that highlight the potential

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of application of the techniques of Forest Biotechnology for conservation purposes is highlighted when the search in the Web of Science database with the theme "Forest Biotechnology and Nature Conservation" presents only 14 results, only 50% composed of scientific articles. The 14 resulting works were produced between the years of 1995 and 2015, in maximum quantity of two works per year, adding a decade of low scientific production in the area. The highest concentration of publications is Canada, with five published works, followed by Brazil and India and the United States, with two publications each. The authors of the publications do not repeat themselves, which indicates the discontinuity of the line of research in the institutions. The largest sub-areas of concentration of publications are Environmental Sciences, with five publications, followed by Agricultural and Biological Sciences and Biochemistry, Genetics and Molecular Biology, with four publications each.

The environmental appeal included in the discussions of forestry issues such as the reduction of the impact generated by the planting areas, as well as the increase of production and the maintenance of timber characteristics of economic interest. These new demands in the industry have boosted the development of modern forestry, which seeks fundamentals and techniques in biotechnology, which provides the tools needed to optimize production (Sampaio & Mazzochin, 2010).

The process of domestication of forest species is difficult and encounters substantial obstacles such as climate change and the long-life cycle and reproduction (Harfouche et al. 2012). In addition to this, biotechnological techniques such as gene transfer and marker-assisted reproduction present difficulties such as the large size of their genomes and the recalcitrance of their mature tissues when cultured in vitro (Merkle & Dean, 2000).

The Organization for Economic Co-operation and Development (OECD) defines biotechnology as the application of science and technology to living organisms, as well as their parts, products, and models, to change living or non-living materials to produce knowledge, goods and services (OECD, 2016).

The inclusion of biotechnology in productive activities generates significant impacts in science, technology, industry and in the social sphere, being identified as the key to economic development in the 21st century (Vega & Requena, 2015). Its application contributes significantly to the improvement of the quality of life of developing countries, promoting an increase in productivity, with consequent increase in the availability of raw materials and income (Adenle et al., 2012).

Their main contributions are represented by the production of plants resistant to pathogens and pesticides, plants with higher environmental resilience, plants with higher production of biomass and optimized growth, or that present or exalt some economically significant characteristic (Adenle et al., 2012). Optimization of growth, greater resilience and reduction of plant death allow greater productivity, use of crop area and less time for production, with consequent increase in profitability and lower impact on the environment (Oliveira, 2016). Especially in forest species, biotechnology aims to increase the availability of raw material produced in the managed area, which reduces pressure on native forests and contributes to economic development (Canhoto, 2010; Fermino-Júnior & Scherwinski-Pereira, 2012; Oliveira, 2016).

In recent years, researchers have argued over the possibility of maximizing a company's return due to some progress in implementing sustainable business practices. A proactive corporate strategy on conservation concerns can lead to the development of important organizational capabilities, increasing the company's long-term competitiveness. Many researchers argue for the incorporation of sustainability in business planning as one of the most effective ways for companies to increase their efficiency and remain competitive in the market (Aragon-Correa & Sharma, 2003, Sharma & Vredenberg, 2003). In addition, the use of sustainable methods has the indirect effect of improving the image of the industry vis-à-vis society, as well as reducing the likelihood of sanctions and punishment due to non-compliance with the environmental legislation in force in the country.

Forest biotechnology has already been defined by Gaston et al. (1995) as a potential application to (1) tree improvement, (2) control of pests and (3) propagation, restoration, and conservation. Acts as an instrument for the valorization of biodiversity, and as an opportunity for industrial and technological investments aimed at the sustainable use of genetic resources of economic interest (Odalia-Rimoli et al., 2000). Its use allows the achievement of gains in sustainability and productivity (Golle et al., 2009). Among its many applications, it stands out for the opportunity to convert biodiversity into a factor of economic and social appreciation, favoring sustainable use and conservation (Vega & Requena, 2015).

Forest Biotechnology is a comprehensive and promising area that provides viable and innovative methodologies for the implementation of sustainable economic actions. Although it presents great potential of development and application, its techniques and methodologies are still little explored, which can be observed by the scarcity of scientific works available in the area. Given the importance

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of sustainable economic development for the security of natural resources and for the maintenance of productive systems, the development of research that seeks ecologically and economically feasible production methodologies is fundamental.

In this context, the prospects of Forest Biotechnology should be directed towards the development of new methodologies and techniques of production, mainly *ex situ*, that can be applied in a way that enhances local biodiversity and promotes conservation. Silvicultural studies that broaden the horizons of Forest Biotechnology beyond conventional techniques of genetic improvement and micropropagation should also be favored, valuing research based on ecological interactions, for example, relation plant-microorganism, because they are techniques that reproduce the conditions observed in the natural environment providing less invasive and potentially less impactful management tools to the environment.

CONCLUSION

Forests have historically played a central role in the development of human civilizations. They continue and will continue to play it, given the importance of their resources to the world economy and to the maintenance of all forms of life. Including forests at the center of a strategy for a sustainable future is paramount for the future security of humanity. Forest Biotechnology allows the optimization of *ex situ* conservation, providing tools that combine economic development with the maintenance of forest ecosystems. The shortage of works developed in the area highlights the importance of the development of researches that seek methods and techniques of application of Forest Biotechnology as a tool for sustainable development and conservation of nature.

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