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Making Forest Values Work: Enhancing Multi-Dimensional Perspectives towards Sustainable Forest Management

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ABSTRACT

Background and Purpose: Sustainability, sustainable development and sustainable forest management are terms that are commonly, and interchangeably used in the forest industry, however their meaning take on different connotations, relative to varying subject matter. The aim of this paper is to look at these terms in a more comprehensive way, relative to the current ideology of sustainability in forestry.

Materials and Methods: This paper applies a literature review of the concepts of: i) sustainable development; ii) sustainable forest management; and iii) economic and non-economic valuation. The concepts are viewed through a historical dimension of shifting paradigms, originating from production- to service-based forestry. Values are discussed through a review of general value theory and spatial, cultural and temporal differences in valuation. Along the evolution of these concepts, we discuss their applicability as frameworks to develop operational guidelines for forest management, relative to the multi-functionality of forests.

Results and Conclusions: Potential discrepancies between the conceptual origins of sustainable development and sustainable forest management are highlighted, relative to how they have been interpreted and diffused as new perceptions on forest value for the human society. We infer the current paradigm may not reflect the various dimensions adequately as its implementation is likely to be more related to the distribution of power between stakeholders, rather than the value stakeholders' place on the various forest attributes.

Keywords: sustainable forest management, ecosystems multi-dimensionality, value theory, sustainability, forest policy, forest governance

INTRODUCTION

The use of the term sustainability to describe environmental, social or development issues presumes some shared understanding of the significance and application of the term, and what it is referring to. For instance, the term sustainability can be associated with sustained economic development, continued profitability or with the dynamic resilience of a system to reorganise and continue after a shock. Earlier uses of the term can be linked to the concept of 'maximum sustained yield' [1] in the field of natural resource management, a term used in calculating the use of renewable resources like timber or fisheries.

Since the Brundtland Commission[1] first defined sustainable development (SD), the term 'SD' has entered the lexicon of research and in economic, environmental and social policies. SD as defined by the Brundtland Commission in 1987 is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. The ideology of Sustainable Forest Management (SFM) is frequently based on the same principles and is for instance defined in 1993 by the Ministerial Conference for the Protection of Forests in Europe as: "The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems" [3].

The activities of the Brundtland Commission contributed to the convening of the 1992 Earth Summit in Rio de Janeiro, Brazil which played a crucial role in promoting the ideology of SFM under the Commission's framework of SD [4]. The United Nations Conference on Environment and Development (UNCED) final report [5] includes a 'Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests', which infers recommendations to further define forest management principles. Inter alia, it states that forestry issues and opportunities should be examined in a holistic and balanced manner within the overall context of environment and development, taking into consideration the multiple functions and uses of forests, including traditional uses, and the likely economic and social stress when these uses are constrained or restricted, as well as the potential for development that SFM can offer. All types of forests resources and forest lands should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations. These need to include forest products and services such as wood and non-wood products (as water, food, fodder, medicine, fuel, shelter, employment, recreation, habitats for wildlife, landscape diversity, carbon sinks and reservoirs), and measures should be taken to protect forests against harmful effects of pollution, including air-borne pollution, fires, pests and diseases, in order to maintain their full multiple value [5].

The acknowledgement and recognition of multiple forest services or functions that forests provide, besides timber, is still relatively new. In the 18th Century, high rates of deforestation were occurring in Central Europe due to the overuse of forests for commercial timber production and for extending agricultural land [6]. However, in order to regulate forest utilisation in a way to ensure wood availability for future generations, the German landlord Hans Carlo von Carlowitz formulated the rule to take only as much timber off the woods as would regrow in one generation [7]. Other forest services or functions such as forest regeneration or the provision of clean air have only been relatively recently integrated into the concept of SFM. As such, the way forests are valued by professional forest managers and for society as a whole is continuously evolving, with noticeable national and regional differences. The process of creating a shared understanding or meaning of what makes a forest sustainable is continually developing [8].

DOES SUSTAINABLE FOREST MANAGEMENT DEPEND ON THE VALUES A SOCIETY HOLDS?

In Europe, SFM is defined as a forest management practice that should fulfil the demands of society, both now and in the future [9]. A recognition of changes in the relationship between society and forests has led European ministers to call for a greater dialogue between the forestry sector and society in Europe. This was one of the main themes expressed in the Ministerial Conference for the Protection of Forests in Europe (MCPFE) Resolution L1 'People, Forests and Society', signed in Lisbon in 1998. The relationship between society and forests is well recognized by this MCPFE process and is reflected in the Vienna Declaration signed by European Community in 2003, which states as Resolution V1 'Preserving and Enhancing the Social and Cultural Dimensions of SFM in Europe'. However, in a review of surveys carried out by Rametsteiner against various countries in Europe [9], the results showed that only one quarter of Europeans are satisfied with the status of their forest regarding health and vitality, biological diversity and forest area.

Attempts at fairly and equitably representing forest users' diversified views poses great challenges for forest managers and policy makers alike, because the expectation of the public, and the various uses of forests relative to their needs is changing over time, and differs amongst regions [9]. As part of the theoretical framework of SD, on which SFM is based, environmental policies incorporating SFM take environmental, social, and economic components into consideration in their development. However,

1 - The Commission is formally known as the World Commission on Environment and Development (WCED) of the United Nations. It was formed and led with the aim to highlight the importance of sustainability among the members of UN. Its four year work concluded in defining the term "sustainable development" and publishing its famous report Our Common Future which is also known as the Brundtland Report.

this concept fails to provide a practical framework for interpreting and applying this concept in decision-making and implementation of the concept [10]. For example, the prioritization of forest use and how different groups of society would like to use forest land, depends on the economic, social and environmental awareness and values they hold [11]. For instance, many Europeans tend to oppose forestry measures that disregard nature, except when compensation measures are taking place, e.g. tree felling is only accepted in combination with afforestation [9].

People value forests for a wide range of reasons and receive benefits from them in various ways, both in the form of tangible and intangible benefits, which had not, until recently, been taken into account [12]. 'Sustaining' existing (and future) benefits from the forests is complex as multiple benefits create multiple values, but many of these do not have a market value in economic terms, i.e., the price of biodiversity [13-15]. The transformation of values to concepts is also complicated by differences in spatial, temporal and socio-cultural value perceptions. Valuing forests and their underlying provision of ecosystem service is multi-dimensional as it covers multiple genetic resources, species, different adaptations, habitats and ecosystems [16]. All these dimensions of biodiversity are tightly interconnected, affecting the state, stability, and productivity of the ecosystem as well as ecosystem services [17], thereby making biodiversity not only an ecological, but also a social and economic issue [18]. As Rametsteiner's survey in Germany [9] showed, only a few survey respondents knew the concept of SFM, even though e.g. in Germany the number of people who know the concept increased considerably from 1997 to 2003. Despite that, more than 50% of the Europeans think that the principles of SFM are actually not practiced in Europe [9]. This gap of information should be closed through targeted education programs, and the cause of such a perception should be assessed and dealt with if necessary.

Values and Sustainability

The current conceptualisation of SD can be interpreted as a reflection of multiple values. Value, although a broad term, is considered a part of the underlying conceptualisation, which is fundamental to translating a broad concept like sustainability into long-term, policy objectives [19]. The values that are embodied within the concept (e.g., resource protection) are shifting in their importance in the development of policies some have taken precedence over others which were previously held as more important, which are not always reflected in the behaviours by all actors.

For example, forest management was traditionally based on principles for sustained yields in timber production. As underlined by Spears [20], the shortcomings of this approach included ignorance towards non-wood values and uses. The recognition of other non-timber values, and also, during recent decades, social and ecological values have given rise to broader concepts used in policy-making and research. This concept is, thus, a reflection of the shifting values of a society which, although seeking consensus on subjective values (e.g. income, biodiversity, carbon sequestration), is constantly changing.

In addition, everyday decision-making in forest management is based on long-term objectives (i.e. needs), institutional (i.e. policy goals) and situational aspects (i.e. timber market). Building capacity to achieve these desired needs has a dynamic influence on some of these aspects as capacity can be enhanced, for instance, through the establishment of associations or civil society organizations with various interest groups. Within this line of thinking, several theories (e.g. Logic of Collective Action) have been built which outline the importance of increasing power to pursue common objectives held by the wider group [21]. Since different interest groups, i.e., forest owners, processing industry, energy industry etc. have different values and needs, there is a need for consensus about what will go into policy and how.

For the aim of sustainability to bridge the gap between economic development and socio-environmental interconnectivity [2], a clear understanding of what it actually means has yet to be seen in practice, as the concept itself is broadly used in the political spectrum [18]. As noted by Mansfield [22], much of the discussion over what sustainability is, or is not, takes place in political arenas. How sustainability is used to frame environmental or socio-economic issues and is shaped by political relations and reflects a highly normative stance of deciding what is or is not desirable, meaning what should be sustained.

The values related to the concept of SD have been broadened into a new, wider paradigm which seeks to create a response to societal concerns on the processes of current production and consumption versus the future of the planet. On the one hand, there is some consensus around the implementation of the concept while, on the other hand, there is great indecision in the values themselves. A crucial reflection is needed on the representation of needs in the current definition of sustainability, i.e., whose needs are being reflected and how are certain needs are prioritised over others? Secondly, although there is an acknowledgement of different values in society, and in-between different stakeholders, there are no mechanisms to objectively and weigh them to reflect the various views of society. This can contribute to the difficulty in equitable policy development, which inequitably favours particular groups of society. The application of a singular definition of sustainability in policy practice is reflective of the theoretical and ontological assumptions of the actors involved in their development. Hence, it is important to address power relations and their balance in the structure of implicit and explicit values.

Evolution and Change of Values

Social and economic development in recent decades has influenced human values, likely due to the interdependency, changeability and influence of the social experience [23]. Forest values differ on a local scale because physical, geographical, institutional, or historical configurations differ [24]. However, forest policies and the governance of forest use are being increasingly organised at a global level, overlooking an optimisation on the local scale, which takes into consideration differentiated local contexts [25, 26]. People generally judge forest use in their own country as better than in other countries [9], which might indicate a strong sense of place that, in turn, can be considered a local cultural value provided by the forest. This sense of place has an influence on people's beliefs/values, and what is valued on a local scale, relative to the physical distance between the forest and people.

Taking into account the changes of the social and economic environment throughout human history, should be considered when assessing the drivers or influences over social normative values. Through history, forests have been constantly impacted by anthropogenic changes to the landscape, where past decisions on forest management can influence present management. Up to the beginning of the 20th Century, European forests have been exploited for mining, charcoal production, and shipbuilding. Large areas of forest have been transformed into agricultural land and livestock graze [27].

More recently, European studies indicate an increasing awareness of ecological issues [9]. This includes also a public acceptance towards allowing large predators like wolf and lynx to live in natural habitats [9]. Even though broad empirical studies are mixed, regarding the perception of general public on the SFM options, several regional studies have indicated that people generally prefer mixed stands with native species over monocultures of non-native species [9]. In Scandinavia, for instance, public preferences for forest structures have changed in recent decades and moved towards preferences for more wild structures as people are becoming more conscious of the variety ecosystem services provided by forests besides timber production e.g. an increasing importance for the role of fallen trunks for biodiversity [28]. A study on French forests showed that the main consideration for forest roles is changing over time, with natural habitat and leisure becoming more important, and wood production decreasing in importance [29].

Besides variation of temporal, spatial and socio-economic characteristics, values also vary among the social groups and different cultures. Edwards *et al.* [30] claim that the recreational value of forest stands are perceived differently by different social categories such as age, gender, socio-economic group, level of education and profession. Furthermore, values on nature perception are closely related to cultural identity: Hoyos *et al.* [31] showed that Basque people who have traditionally had a close relation to nature would be willing to pay 28-33 percent more for the protection of a natural area, than other people from Spain. A comparison of surveys from different European countries showed that people from Central Europe have mentioned ecological functions of forests like biodiversity, carbon sink, protection from natural hazards more often as than people in Northern and Western Europe, where more direct economic issues and multiple forest use were more dominant [9]. Another factor influencing people's value of forests and sustainability depends on how, and if, they physically interact with and enter the forest. For instance, data from Austria and Scotland suggests that 98 percent of forest visitors use the forest for walking, dog-walking, cycling and jogging [30].

The SD concept cannot be limited to an exclusive form of implementation. In fact, limiting the concept is a purely quantitative development. For example, restricting the definition of SD towards reducing environmental impacts through technological advancements (i.e., industrial logging under an environmental management system) does not consider the relationship between the exploited environment and local societies and cultures that lost benefits provided by the same local resource (e.g., spiritual, cultural, economic, aesthetic values, etc.) in the absence of the action causing environmental damage. These advances, which are commonly described as SD initiatives, undermine the multidisciplinary aspect of sustainability that needs to be based on qualitative advances of all of its all dimensions [2], not just a reduction of current negative environmental impacts or a slowdown or reversal of current damaging trends.

What is currently occurring in SFM, is the embracing of market-based ideology as environmental policy. The trade-offs generally considered for decision-making frameworks for SFM are impacts on the environment as well as economic factors such as profitability or sustained yields. Relying on market-based instruments such as pollution charges or tradable permits requires the consideration of characteristics of the environmental resource, and the social, political and economic context in which it is being managed. It is difficult to define a universal objective for SFM, as forests, society and values are in constant dynamic flux. This is reflected by the wide range of forest institutions that practice various types of SFM, and in ways that the methods and tools applied in these systems differ significantly, and they have been continuously developing over the time. Questions which undoubtedly relate to SFM should be clarified before using the concept to frame what is currently occurring in our human well-being or natural world. Often the application of environmental, social and economic spheres seems to be overlooked. To know what is meant by the term sustainable or how to apply it to forest management practices is crucial. Defining what makes a forest-based system sustainable, or not, may help in developing new questions or debates which allow recognising the value and normative differences of interactions between humans and the environment [22, 32, 33].

Because the forest management is an economic activity, it is reflecting also the existing economic accepted values. Therefore the paradigm for SFM changed over time, from reflecting the values and assumptions of the neoclassical economic model which allows an unlimited economic growth which was theoretically possible by the substitutability of the resources [34] to a more reserved paradigm (i.e. Bioeconomy concept), aware of the limitations of the ecosystems. Even so, sometimes the limited growth capacity of the economic system as restricted by the biophysical limits of the Earth is often not taken into account [35] leading to challenges for all the stakeholders in order to ensure sustainability [36]. The changing needs and values of the society are more and more refined ranging from forest products to all kind of ecosystems services such as recreation or spiritual ones [37].

Even if past economic policy has made little room for the environment as an economic value [38] the development of transdisciplinary thinking is currently considered to be a must in order to provide the foundation for a sustainable future for the forest economy [38, 39]. Therefore, it seems that in the last decades there was a shift of paradigm concerning sustainability, SD and SFM from a unidimensional value perspective to a multidimensional, integrative value perspective.

This means replacing the unique objective of economic growth (GDP), typical for neoclassical economics, with objectives for human well-being and sustainability, which is typical for ecological economics. The reason for this shift is due to the fact that the both the general public and the policy makers understood that humans without nature cannot exist, while nature can exist without humans. Sustainability itself became one of the most desired social values and it is reflected in all the concepts used by policymakers [40].

Due to this perpetual evolution and change of values the problem of institutional sustainability arises. This institutional sustainability is a value by itself and can be addressed by referring to one of two perspectives on institutions: 1) they are either considered a set of rules, or 2) they are considered a set of roles [41]. Such a change, in the institutional dimension of the SFM, is reflected for instance in the Convention on Biodiversity (CBD) which makes a call to respect, preserve and maintain the knowledge, innovations and practices of indigenous and local communities, promote their wider application with the approval and involvement of communities and encourage equitable sharing of benefits from their use [42].

In order to ensure this sustainability of the perceived forest values, participatory approaches are desired and research is developing measurable indicators for understanding the perceived values and their changes [43].

Participatory Approaches and Power Relations

Traditional forest actors are still more prominent in forest policy than environmental actors [24]. The influence of the local community in forest management is rather low and tools for a better incorporation of societies' values into management practices need to be developed. The participation process has to be improved with a greater role for the social sciences [24]. In a review of surveys from different European countries, half of the general public mentioned more positive aspects of forests and the other half more negative aspects; thereby, the positive ones were mainly related to feelings, whereas the negative ones seemed less feeling-dominated but rather cognitively formed opinions [9]. Furthermore, only a few respondents mentioned specific terms related to forest management or the forestry sector itself [9]. This might indicate that local communities are not aware that forest management is actually shaping forests and their character, it seems they do not realize that they have the choice to shape forest management.

An open question is about how the culture-dependent concept of power is actually present in the current definition of sustainability. When talking about politics - defined as 'the authoritative allocation of values for a society' [44] - we can assume that certain interest groups, depending on the dominating power regime, will have more power than others in defining sustainability. Finkelstein [45] defines power as the capacity of individual actors to exert their will. Willingness is associated with the well-being of the individual and thus is related to the values s/he has. There are different dimensions of power and [45] outlines four dimensions of power – structural power, ownership power, expert power and prestige power. However, dimensions of power relations differ with geographical context (e.g., local, regional and global relations) and vary between research disciplines [46].

To enhance the participatory process, it is therefore necessary to engage local communities and stakeholder more. Interdisciplinary science can help to shape the participation process through standardised procedures [47].

How to Represent the Multi-Dimensional Concept of Sustainability

The challenge in integrating society's values into forest policy could be analysed through a Post Normal Science (PNS) framework. This framework is utilised in complex situations when urgent decision making is needed, but facts are uncertain and values are in dispute [48].

Studying policy impacts as well as evaluating policy programs are crucial to understand and improve local SD [37]. Moving towards SFM, the ecosystem services approach is likely to be a suitable instrument to include non-market services provided by forests in the valuation [49]. Although there has been progress in the development of valuation methods for those ecosystem services there are still big obstacles to incorporate this approach into sustainable policy and practical implementation [50].

A sustainable society cannot be neatly drawn to fit into geometric forms, such as a triangle or circular diagram, but a new vision is needed in order to show how this system is constantly evolving and making room for different dimensions' perceived importance in society [51]. These elements of what make a sustainable society, at any given moment, are never universally agreed upon nor fixed. Ideally, society would be capable of increasing well-being in an equitable and balanced way in terms of resource consumption, neither limiting the economy of material inputs nor the expansion into several dimensions [52, 53, 54]: these may be numerous and differentiated but a complete list of these will never be possible (thus presuming there will always be gaps) and points of overlap are unavoidable. Such a possible conceptual model can be given by a tree-like fractal model (Figure1).

In such a model, each dimension perceived as important by society can be represented as a branch or root. The importance in society of one dimension can increase or decrease, while the dimension itself can appear or disappear, as the society is evolving. This dynamic depends by the pattern of the values accepted by the society at a certain moment in its existence, which can obviously vary in time even for the same society [55].

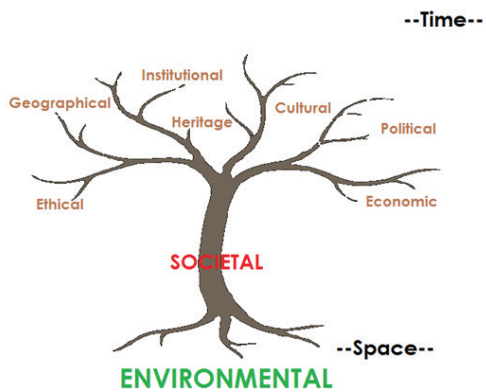

FIGURE 1. "Tree of multidimensional sustainability": conceptual dynamic model of a sustainable society based on cybernetic systems and fractal models.

The environmental space is influencing the society and is reciprocally influenced by the society, like in a cybernetic system. Such a system is characterised by the feedback component which generates changes in the system in order to adapt to the changes of the environment. The short term existence of the society is not determined by the existence of one dimension, but its sustainability is. Considering the development of fractal models [56] such an approach could prove useful in estimating and integrating different dimensions for better and adaptive policies.

DISCUSSION

Despite its overarching influence, science-practice interface should be strengthened [57]. In order to be closer to practice, policy makers, who actually depend on scientific advice, should be able to combine research findings with daily life experiences [24, 57]. However, Janse [58] argues that research studies are often in forms different from what is required by policy- and decision makers. One possible solution may be found in a better cooperation and integration of different kinds of knowledge and values between scientists, policy makers and policy implementation [57 - 59]. Various national and international cooperation projects between scientists and practitioners have been started supported by policy makers (some examples in South Eastern Europe are the following projects: FOPER [60], PRIFORT [21], PROFOR [61]). These projects are often coordinated by leading scientists and also involve young researchers and usually have some impact on policy making or policy implementation.

To truly understand values, it is necessary to develop indicators which are capable of expressing the various values over multiple time periods, for different regions, and among different groups. Although we recognise the difficulty in defining forest values, it is possible to define a time component for them, temporal and spatial limitations should be recognised as influential in the changing values of any society [51]. As each society holds different values which are more influenced by the social, historical cultural and economical factors, rather than environmental changes [51], the changing values of that sustainability system might not be reflecting the environmental considerations adequately.

CONCLUSIONS

Enhancing SD and SFM requires a stronger integration and application of the knowledge gained from scientific study as well as the lessons learned through societal transitions. In order to do so, two major weaknesses of the current concept of sustainability in forest management have been identified:

i) multi-dimensional perspectives of forest management need to be enhanced in order to allow for the use of transdisciplinarity for forest management definition and implementation.
ii) decision making processes need to be enhanced to allow for mechanisms which are more inclusive of multiple perspectives since power relations can affect an effective participation in such processes.

As forest values are personal in nature, it is difficult to create sufficient indicators resulting in subjectivity and partiality. In other words, there is a need of enhancing the multidimensional perspectives towards a more sustainable forest management to encompass multi-dimensional values, as the dynamic fractal model for the society presented in Figure 1. The challenge is not only integrating the different needs into the concept of SD, but also to understand who actually had power to design and to implement the concept. A wholly participative process in decision making, including a wider group of actors and stakeholders, must go beyond traditional public consultations and public-private collaboration in order to realize a shared vision of sustainability and implement a concept which is capable of recognising the inherent power relations embedded within its definition.

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Partnerships for Urban Forestry and Green Infrastructure Delivering Services to People and the Environment: A Review on What They Are and Aim to Achieve

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ABSTRACT

Background and Purpose: Partnerships are a key mechanism in the planning, delivery and management of urban forestry (UF) and green infrastructure (GI). They can facilitate locally rooted co-management and polycentric governance. They can also achieve synergies by combining the resources, commitment and expertise of diverse stakeholder groups in order to generate valuable outcomes and build social capital. Unfortunately, the term "partnerships" is not used consistently in literature and requires clarification. The characteristics which distinguish a partnership approach from other modes of co-operation are identified and described. The diversity of existing UF and GI oriented partnerships is outlined, with reference to their stakeholders, drivers, activities and goals, together with potential advantages of the partnership approach. Considerations to be made in their evaluation are derived from this background analysis and possible success factors are discussed.

Materials and Methods: The diversity, aims and defining characteristics of a partnership approach are based on an extensive literature review.

Results: Partnerships focus on diverse aspects and delivery phases of UF, ranging from the planning, design and creation of urban forests and GI to their management and use. Benefits delivered by such partnerships include environmental and economic services as well as social and cultural services such as environmental education, health, leisure and tourism. Generating valuable services whilst at the same time nurturing relationships between stakeholders helps to develop social capital and build capacity. In addition to environmental, economic and social benefits, the evaluation of partnerships may also address internal process variables such as social learning, the relationship between partners, and motivational outcomes that can influence future co-operation.

Conclusions: Co-operative partnerships offer a promising approach for delivery in UF. The development of relationships between partners maximises the potential for developing effective long term co-operation and for building social capital as an aid to the promotion of sustainable development.

Keywords: urban green space, partnership approach, urban forestry partnerships, definition, coalitions, co-operation, sustainability, governance, social capital

INTRODUCTION

Urban forests, parks and trees enhance the quality of life of people living in cities as they provide valuable environmental, social and economic services. Environmental services include the removal of pollutants and improvement of air quality, noise reduction and provision of shade and temperature regulation [1, 2]. Social services include health benefits, increases in wellbeing, provision of attractive and openly accessible places for social interaction, informal recreation, reduction of stress and support for such physical activities as walking and outdoor sports [3-9]. Economic benefits include increased inward investment into greener cities, higher property values in well treed neighbourhoods and the improved productivity of labour forces which have green surroundings. The environmental, societal and political significance of urban forestry (UF) and green infrastructure (GI) for a broad range of urban stakeholders is widely recognised and corresponds to the many services which it provides [10-15].

GI and UF for People

UF has been defined as "the art, science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society" [16]. The urban forest has been described as "the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan areas" [17]. Urban forests accordingly comprise different elements, such as urban woodlands, parks, civic squares, green corridors and single trees. They form part of the urban and peri-urban GI that is usually shaped and managed, by professionals from different disciplines and public authorities [11, 18].

In recent years the term GI has become increasingly adopted in European countries. The European Commission defines GI as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" [19]. Importantly GI is expected to deliver social and economic benefits as well as environmental ones. Natural England [20] for example, considers that GI should be "designed and managed as a multifunctional resource capable of delivering those ecological services and quality of life benefits valued by the communities it serves and needed to underpin sustainability". The related term "green network" has been used to define "a set of connected areas of green space and habitats such as parks, paths and woodlands within an urban or suburban region which provide a range of social, ecological and economic benefits such as improving the quality of life within an area, and creating more sustainable communities" [21].

The European Commission stresses the social benefits that GI delivers, noting that, "implementing GI features in urban areas creates a greater sense of community, strengthens the link with voluntary actions undertaken by civil society, and helps combat social exclusion and isolation. They benefit the individual and the community physically, psychologically, emotionally and socio-economically" [19]. With the development of GI concepts, landscape scale planning interventions are now increasingly recognised as providing multi-functional solutions, which can provide habitat connectivity, social and ecosystem service benefits [19]. The development of GI is being further promoted through national and European policies that encourage local authorities to think beyond their own boundaries and to develop polycentric approaches to land-use planning and management in partnership with diverse stakeholder groups [22]. Management practices which cut across traditional ownership and administrative boundaries and which satisfy a broad range of interests including nature conservation, landscape character, ecological connectivity, and recreation demands are becoming increasingly relevant. The cross-cutting nature of the challenges which GI planning, design, implementation and management face requires close co-operation between diverse professionals, scientific disciplines and stakeholder groups [23]. Partnerships represent a distinct and common format in which such co-operation can be initiated, developed, and implemented [24].

From Consultation and Public Involvement to Integrated Co-operation in Partnerships

Providing sufficient and adequately designed urban forests and GI is a challenging task. Opinions on how much urban forest is needed and how it should be designed, managed and maintained may differ between local residents and the various other stakeholders who have an interest in urban planning [25]. To find sustainable and well-accepted solutions therefore requires inclusive participatory processes and collaborative planning [26-28]. The degree of involvement and empowerment of the local population or other stakeholders in such processes varies. It can range from involving the public by informing people and encouraging them to formulate and express their opinion in consultations or public hearings to more active forms of participation and empowerment [29]. For example, some UF partnerships achieve active co-operation, co-management and empowerment of local partners through devolution of decision making powers, responsibilities and/or funding from government institutions and programmes to local bodies [10, 30, 31]. Empowerment and involvement of the general public in the planning and management of urban green space triggers social interaction between residents [15]. This can enhance social cohesion and may promote a sense of ownership and a sense of place. Such participation can be organised as a democratic, open process, which can facilitate co-operation between different stakeholder groups and involve residents and local organisations [32-37]. In Europe there are many examples where community-led initiatives (which ultimately obtained active support from public agencies) have led to the establishment of urban or peri-urban forests and parks [38]. Many of these examples have involved the formation of partnerships with close relationships and collaboration between different stakeholders [20, 21, 24].

Aim of This Paper

The use of the term "partnership" in scientific literature on UF and GI is rather inconsistent. Some articles covering participatory approaches do not mention partnerships at all, though cases of partnership-working have implicitly been included [15, 29], some do not distinguish between partnerships and other forms of co-operation [10, 31] or use the term only for specific partnership models such as economic partnerships [39]. Though the term "partnerships" has been used to name and describe many diverse examples of co-operation in the field of UF, some clarification of the concept therefore seems necessary.

The aim of this paper is to outline characteristics which distinguish "partnerships" from other terms used to describe co-operation in UF, such as "coalitions" and "alliances", "networks" or "umbrella groups". The diversity of existing partnerships will be illustrated through a description of the various stakeholders, and their motives, goals and activities. The broad variety of UF or GI partnerships will be addressed comprehensively. Considerations for the evaluation of partnerships will be derived and success factors discussed in literature will be briefly reviewed.

A lack of studies on partnerships has recently been identified in a review on forestry related discourses [12]. The current paper will help to fill this gap, to better understand, develop and manage partnerships in UF and GI.

MATERIALS AND METHODS

A review of literature on partnerships and other approaches of co-operation in UF and GI has been conducted. Predominantly peer-reviewed scientific articles have been considered, as well as some scientific books and so-called grey literature from various countries (see References). Known literature was used as a starting point leading to further references and an informal internet search for additional studies was made. In addition a search in the SCOPUS database was conducted with the keywords "partnership AND forestry" and further keyword combinations including the terms "urban forestry", "participation", and "green infrastructure". Since approaches towards co-operation, participation and partnerships are not confined to UF and GI, it also seemed helpful to consider some literature from other domains where these concepts play a role (e.g. social psychology, environmental and sustainability sciences).

Also the Merriam Webster Dictionary, as a well-known general English Dictionary, was consulted for the broader use(s) of the term "partnership" and to relate it to the scientific realm. Inter- and transdisciplinary documents were accordingly integrated with the UF literature to constitute a broader basis for this review.

Furthermore, informal discussions among the authors and other experts from various countries during COST Action FP1204 [see Acknowledgement] working-group meetings allowed for a scientific discourse which supplemented the study of literature and contributed to a shared understanding of central concepts. Concepts such as "partnership" and "co-operation" represent social constructs and their definitions are thus contentious and rather vague. The viewpoints presented here contribute to an ongoing discourse from which a revised understanding may grow and develop in the future [12, 40].

PARTNERSHIPS FOR GI AND UF

What are Partnerships?

There are many different forms of partnerships related to UF and GI. These may be involved in diverse activities such as planning, implementation, management, protection, promotion and facilitation of the use of urban forests, trees and green spaces [24, 41]. Partnerships can centre around projects, programmes, activities at different spatial scales (e.g. neighbourhood, city, region, national, European) and can focus at different types of environmental and social services which urban green spaces and GI provide to society [42, 43].

Partnerships provide a mechanism for organising co-operation between different stakeholders, which can span different sectors and geographical scales, but have similar or partially shared interests and goals and experience common challenges [11]. Co-operation is often needed in UF as various stakeholders and different fields of expertise are involved and often the challenges which have to be faced cannot be solved effectively by one party alone [15, 26, 29]. In some cases partnership is formalised through an agreement which requires participants to contribute to tasks and problem solving. The degree of formalisation of such partnership agreements may vary greatly [31]. Agreements can take the form of legally binding contracts or well-documented Memoranda of Understanding in which the areas of responsibility of the partners and the rules and obligations of engagement are explicitly agreed and documented. However, partnerships may also develop over time with informal rules which have not been codified or explicitly discussed [31].

The variation in formalisation and the degree of shared legal liability is also reflected in the general definition of the term "partnership" in the standard Merriam Webster Dictionary [44] which distinguishes four related meanings:

1. the state of being a partner: (participation);
2. a) a legal relation existing between two or more persons contractually associated as joint principals in a business, b) the persons joined together in a partnership;
3. a relationship resembling a legal partnership and usually involving close co-operation between parties having specified and joint rights and responsibilities.

Partnerships accordingly represent dynamic systems as they are comprised of elements (partners: e.g. persons, organisations) and relationships between them. They involve co-operation and collaboration between distinct persons or social entities (groups, organisations, institutions) and their members or representatives. Stakeholders are individuals and organisations that have an interest in the urban forest either as potential beneficiaries, or because they are affected in some other way by its creation or management [24]. By forming a partnership, two or more stakeholders agree to co-operate and bring together diverse resources to generate significant outcomes. The commitments within a partnership are usually ongoing and do not merely represent just one isolated incidence of co-operation between two stakeholders. If partnerships are longer term, this can be advantageous in an UF and GI context. It can help to ensure implementation and monitoring of measures and long term achievements [42, 45-47]. However, short term partnerships may also exist, and the degree of continuity, level of interaction, power-sharing, and distribution of responsibilities required to turn interacting stakeholders or members of networks or umbrella groups into partners cannot be determined precisely. Therefore, it will not always be easy to decide whether some people or organisations are partners within an UF and GI governance context or whether they are "simply" stakeholders with shared interests, members of a network, participants or volunteers in a forestry activity.

As a basis for co-operation, the parties should agree on common strategies and actions, while their own interests are respected and represented in corresponding decisions. Equity and fairness, commitment, mutual trust, respect and consideration of mutual goals and values between the partners are crucial [24, 31, 48]. Thus partnerships are usually more than marriages of convenience. This distinguishes partnerships to some extent from similar terms such as "coalition" or "alliances. "Coalition" is an appropriate term to use when actors with partially shared interests collaborate to achieve certain goals through increasing resources, power and influence [22], whereas the term "partnership" emphasises the (positive) social relationship and interaction between the partners. There is often considerable competition and conflict between the members of a coalition, in particular when it comes to benefits which are derived and are to be distributed among coalition members [49, 50]. However, relationships may also turn negative in phases of a partnership and in some cases coalitions and alliances can be regarded as partnerships and vice versa [38, 51]. Likewise, co-management as a governance approach seems closely related to a partnership-like relation between the co-managing parties, and networks or umbrella groups may also involve partnerships between members. However, networks may also be constituted on the basis of loose affiliations without closer co-operation.

A working partnership involves direct interaction and co-operation between those involved. However, specific partnerships are often embedded in complex partnership structures and stakeholder networks of an UF governance domain [31, 52]. In such a network polycentric governance can be achieved and organisations on different levels (national, regional, local) are involved [51]. Some stakeholders co-operate directly with each other, whereas others are only remotely linked in a complex web of relationships within a governance structure. Figure 1 gives a schematic example depicting the inter-regional Green Network Partnership Governance model in Scotland [53]. It shows how a partnership structure may achieve an efficient polycentric devolvement of government responsibility to the local level.

Why Partnerships?

Partnerships can bring together diverse stakeholders. This can create valuable synergies if the resources and ideas of the partners are pooled and combined effectively. Partnerships are therefore a key requirement for successful urban management and planning in the context of UF and GI. For example, building partnerships can be important for securing the social and political support required for achieving urban green space programmes, projects or initiatives [54]. Partnerships between various stakeholder groups such as public administration, cities, local communities, landowners, resident initiatives and NGOs represent an effective approach towards inclusive, participatory planning and management of GI and urban forests that is well accepted and takes account of the diversity of interests. Through partnerships, polycentric governance may be achieved as agencies and individuals at regional and local level can become directly involved in the creation and management of urban forests and green infrastructure [22, 35, 36]. They are of strategic importance for promoting continuity of co-operation and long-term sustainability [55]. Partnerships also allow for cost effective provision and maintenance of urban forests and GI [14]. For example, resident groups involved in urban forest initiatives such as the "NeighbourWood" scheme in Ireland, Heiðmörk Forest near Reykjavik or at Bosco della Citta in Milan have planted urban forests at low cost to the public purse through contributions of free time and voluntary labour on the project [24, 38, 41]. However, partnerships have not only proved economically efficient by reducing the costs of providing UF and GI services. They have also been successful when it comes to the acquisition of funding and the physical resources required for providing UF and

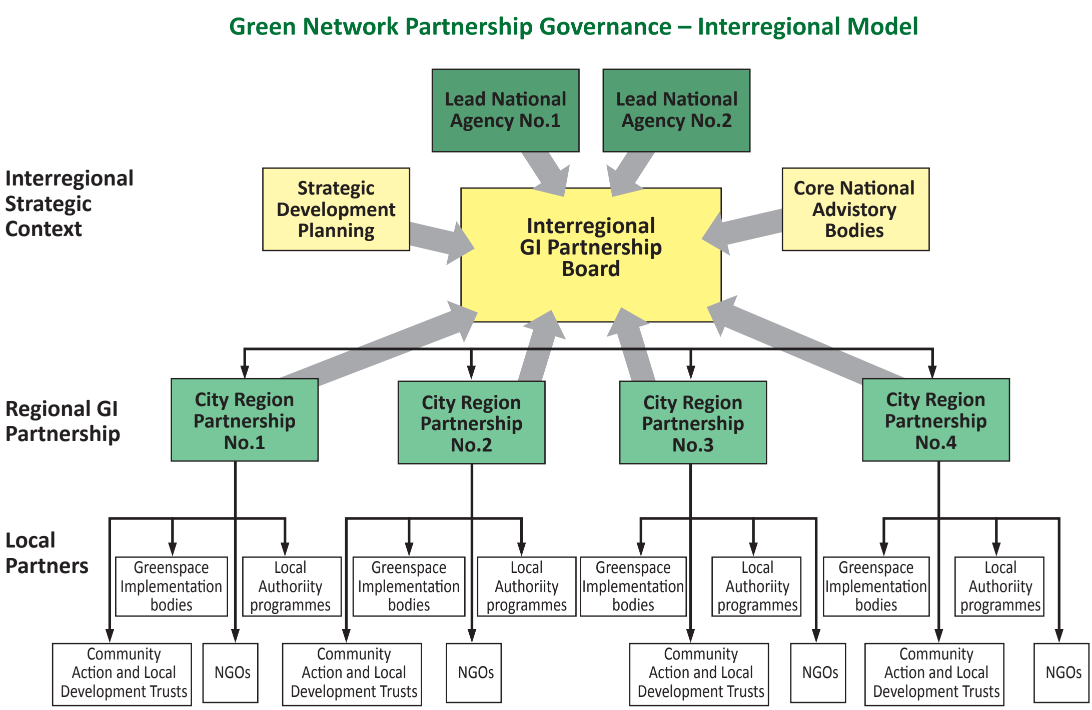

FIGURE 1. Green Network Partnership Governance – Interregional Model

GI, e.g. by involving landowners, acquiring donations or mobilising private investments or public resources [43, 51, 53, 56, 57]. Cross-sectoral networks and partnerships between cities, communities, forest owners and commercial enterprises which provide UF services to the public can also be regarded as a viable way to generate income for the forest sector based on the environmental and social services of forestry [58].

According to Teitelbaum, "empirical research reveals that community forestry generally involves, at best, a form of partnership between government and communities, but that there is also clear resistance amongst central governments to relinquish authority to communities" ([30] p 259). Partnerships represent a socially connected and cohesive form of co-operation that may have potential for developing social capital: an outcome that purely delivery-oriented forms of collaboration often lack. Developing social relationships while retaining autonomy are central aspects of successful partnerships. According to self-determination theory by Ryan and Deci [59] both aspects are crucial for promoting processes of social learning. There is broad consensus that social learning is a foundation for sustainable development [60]. Partnerships offer great potential for positioning social learning as a key element of sustainability-oriented learning and sustainable development [47, 61-63]. Social learning may for example, involve the collective development of rules and collective action to promote sustainable management of natural and social resources within polycentric governance [35, 64].

A VIEW ON THE VARIETY OF PARTNERSHIPS

Main Activities and Goals

In line with the multifunctionality of urban forests, there are also different drivers for partnerships. They focus on various activities which relate to the planning, creation, management, improvement and maintenance of urban or peri-urban forests, woodlands, parks, green corridors and other urban greenspaces of different spatial scales [21, 24, 29, 31, 39, 42, 56]. Specific objectives of existing partnerships include:

- the development of methodology and scientific support for urban green space strategies (e.g. Multi-Criteria Analysis concerning Ghent's Urban Forest, Belgium [24], GreenKeys approach [56]);
- afforestation, creation of new urban forests, planting of trees, woodland expansion (e.g. Heiðmörk, Iceland [24], Glasgow and Clyde Valley Green Network Partnership, UK [21, 39, 41, 53]);
- redevelopment of areas with UF and GI, greening vacant or derelict sites [42, 53];
- community forestry (e.g. Community Forests programme, sponsored by the UK Government, delivered through local partnerships [24, 39]);
- creation, improvement and maintenance of community gardens, community orchards, allotment gardens, pocket parks, urban gardening [14, 42, 41];
- landscape laboratories, cultural aspects, arts, land art, increasing personal involvement with trees (e.g. Trees of Time and Place campaign, UK [24]);
- forest kindergardens and schools, outdoor environmental education (e.g. forest schools in the Nature experience Park Zurich Sihlwald, Switzerland [65], woods for learning [57]);
- development of recreation areas, nature parks, tourism [21, 31, 66];
- promoting health, providing healthy living conditions in urban areas [21, 24, 39, 56, 57, 67];
- sports, training and physical activity programmes (e.g. The Green Gym project, UK [24], Commonwealth Woods project, UK [53]);
- nature protection and conservation, promotion of biodiversity, green networks, habitat connectivity (e.g. Central Scotland Green Network, Garnock Valley Futurescape project, UK [14, 21, 53, 57]);
- Securing clean groundwater resources (public-private partnership in Aabo Forest, Aarhus, Denmark [42]);
- building stronger, more resilient communities [14, 21, 39, 57];
- increasing the use of urban forests and green spaces in neighbourhoods [24, 39, 14];
- scientific research and enhancement of civil science [28, 29, 56, 66];
- lobbying and campaigning [51];
- cleaning up urban forests and greenspaces, keeping them free from litter [68];
- the political support for woodland, parks and urban green space to protect them from being destroyed and transformed to built environments [51, 69].

Partnerships are dynamic and their main activities and the composition of the stakeholders may change over time. To some extent these developments can be related to the phases of a lifecycle of urban forest and greenspace projects (Figure 2), which typically involve a) planning (conceptual), b) implementation (generation and design), c) sustaining (keeping, tending, protecting) and d) utilisation (providing, enhancing specific services) of the green space. This allows partnerships to be distinguished by the following categories:

a) Concept-oriented partnerships focusing on planning and generating ideas for the design and implementation of new urban forests and greenspaces. This may also involve plans or ideas for the redesign of existing urban space or green space.
b) Implementation-oriented partnerships for the generation and realisation of new urban forests, green space, GI or implementation of plans or ideas for the redesign of UF and GI.
c) Maintenance-oriented partnerships for sustaining the urban forest and greenspace. Here, forest management for retaining aesthetic, ecological and socio-economic-value can be distinguished from political protection of the urban forest from urban densification and development.
d) Partnerships aiming at the provision of additional services for increasing the social and economic value and use of existing urban forest and green space. This category may involve the extension of existing partnerships focused on a), b) or c) through additional partners who can provide specific services e.g. for education, health or leisure activities and tourism.

Some partnerships can undertake some or all of the elements (a to d) described above. The scope and time-frame of partnerships can vary considerably. Some partnerships may only form and exist for specific short term activities (such as tree planting at

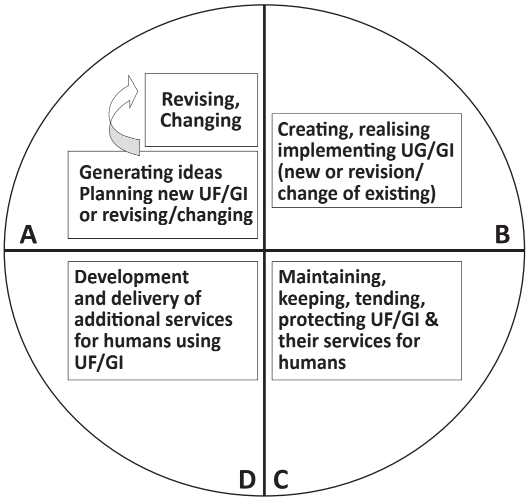

FIGURE 2. Circle of activities including planning, creation, maintenance, revision and change of urban forestry and green-infrastructure as well as for additional services focused directly on serving humans

a specific location) whereas others may be established around a particular tree planting project and then might continue to maintain the new urban forest and manage the services which it provides. Informal partnerships focused on implementation and maintenance may turn into formal economic partnerships, if income can be generated through the provision of services [39]. There are also strategic, long term partnerships which mobilise resources to address diverse UF and GI challenges, rather than merely focusing on one GI project or entity. For example, a strategic research-practice partnership between a university and a local authority environmental department (located in the same administrative area) may exist for many decades and can be effective in implementing diverse urban and peri-urban projects (e.g. between City of Skopje and Forestry Department of University of Skopje).

The formation of coalitions or alliances to protect urban forests and parks from destruction through building projects can constitute a special form of "maintenance-oriented" partnership. Such partnerships or coalitions have apparently not been granted much attention in previous research, though they are of importance, since population growth in towns and cities increases demand for construction land and development pressure on urban park and forest areas is high [11]. Examples are coalitions of citizens and environmental NGOs, such as the Citizens' Movement for Environmental Justice, which emerged in South Korea and which conducted campaigns in several cities to protect urban forests which were threatened by governmental or corporate urban development projects [51]. Another example is the coalition and partnership which has been formed between an association of citizens, the State Institute for Nature Protection of the Republic of Serbia, and the Secretariat for Environmental Protection of the City of Belgrade to protect Zvezdara Forest of Belgrade and oppose the urban building plan developed by the Secretariat for Urban Planning. By campaigning against the urban plan, raising awareness of its consequences, organising public events, involving the media and alerting the general public, this coalition effectively managed to gain the support of city organisations and the mayor and achieve its goal to protect the forest area [69].

Number and Type of Partner Organisations

Obviously, the complexity of partnerships tends to increase with the number of partners. However, the power and potential availability of resources also increases proportionately. This also creates the potential for greater synergy. Potential partners include professionals from many different disciplines. These may include "arboriculturalists, foresters, horticulturalists and landscape designers, planners, engineers, legislators, transport and utility managers, health practitioners and commercial developers" [24]. Further examples such as professionals from the culture, tourism and education sector can also be added to this list.

The organisations or collectives that form partnerships may include citizen groups, special interest groups (that were formed specifically for a particular UF or GI endeavour) or existing well-established non-governmental organisations (NGOs), commercial enterprises, public institutions, governmental bodies, local authorities and scientific organisations (such as universities, private research institutes). Depending on the participating organisations partnerships can thus represent public-public partnerships (e.g. between a forestry department and a school department of a community), private-private, or public-private partnerships [42, 43].

Partnerships are often cross-sectoral and may be classified on the basis of the societal or professional sectors involved. Examples might include a forestry-nature protection partnership, a health-oriented partnership [8, 23], a nature-based education partnership [65] or research and practitioner partnerships [29].

EVALUATION AND SUCCESS FACTORS

Considerations for an Evaluative Framework

The identification of the factors which facilitate effective partnership work seems crucial for the promotion of UF and GI. In order to identify success factors for effective partnership working, the criteria defining success need to be identified and this may profit from a general evaluative framework.

For the evaluation of participatory natural resource management in community forestry, direct outputs (products, services or benefits delivered as a direct result of interventions and activities), indirect outcomes (effects brought about by the delivery of outputs or from the people taking part in delivery), and process variables (contextual and behaviour-based factors that might affect both output and outcome) have been distinguished [39]. The diversity of goals and activities amongst UF and GI partnerships makes it difficult to specify particular criteria for outputs and outcomes within a general evaluative framework. However, it seems reasonable to take the interests of internal partners into account as well as those of external stakeholders. Data on environmental, social and economic benefits for both groups would need to be integrated with reference to multi-dimensional sustainability. Furthermore, when evaluating partnership work process variables and social learning should be thoroughly considered (Figure 3).

The focus on social learning implies that these learning processes and their cognitive, affective, motivational, personal development and social learning outcomes need to be considered [60, 61]:

- Cognitive learning outcomes (examples): Acquisition of knowledge, skills (e.g. about tree species, how to plant);
- Affective: Satisfaction with and enjoyment of co-operation;
- Motivational: Desire for continuation of co-operation or even closer co-operation; desire for more urban green and trees;
- Personal development, personality: Increase of self-confidence, satisfaction with life;
- Social outcomes: Social interaction, social network, friendships, mutual trust, mutual esteem, reputations, social capital.

Relationships need to be taken into account when analysing partnerships. Mutual respect and acceptance of the interests and values of individual partners is a precondition of effective social learning [59]. However, aspects of relationship quality such as positive mutual attitudes, perceived fairness of the social exchange and development of mutual trust are also acquired through social interaction and thus represent social learning outcomes.

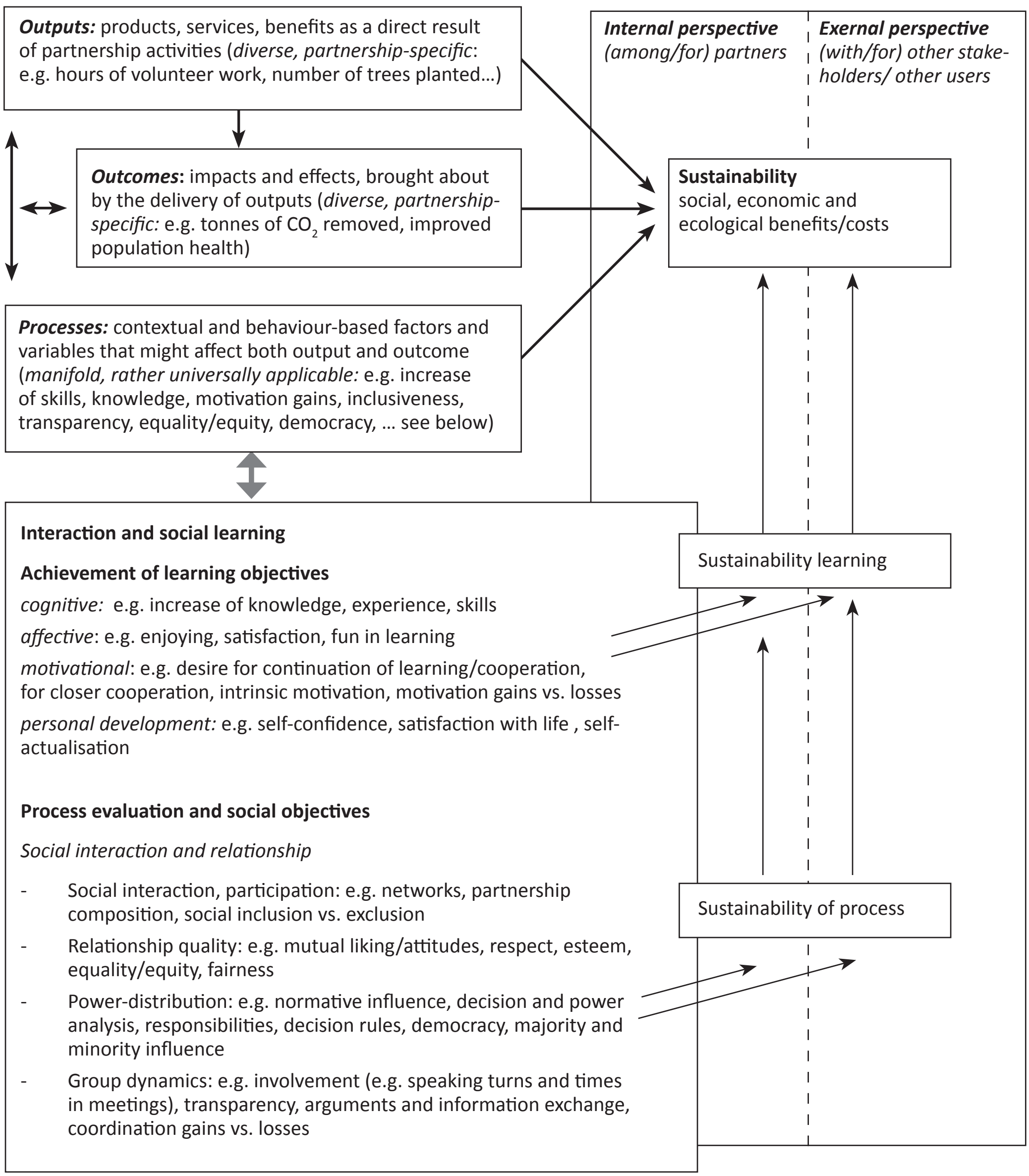

FIGURE 3. Considerations for an evaluative framework for the investigation of outputs, outcomes, and processes (social learning, relationships, interactions) of UF/GI partnerships with reference to dimensions of sustainability

The relationship between partners and relationships between members of the partnership and external stakeholders (external users or organisations) may be considered in an evaluation. Internal relationships are a central aspect of the partnership itself, but relationships with other stakeholders show how it is embedded in the wider context.

The power balance is a specific aspect of these relationships and indicators of involvement, empowerment and power-sharing in decision-making need to be considered. Possible criteria are subjective measures and perceptions elicited via questionnaires or data based on the direct observation of decision processes such as the distribution of speaking times in meetings.

A lack of evaluation studies using such indicators of participation and group dynamics has been identified in the field of community forestry partnerships and there is also an absence of longitudinal evaluation studies [39]. Longitudinal studies seem particularly helpful for the evaluation of partnerships as a means of assessing their sustainability, development (and eventually decline) and other dynamic aspects (e.g. the role of earlier relationships, the outcome of social learning and the motivation for volunteer work).

Success Factors Discussed in Literature

According to Jones *et al.* [24] complementarities of skills and other resources of the involved parties, a clear definition of aims, mutual benefits for the partners, efficiency, adaptability, formation of a distinct partnership identity, and good leadership are all important criteria for success. The latter may be provided by an effective chair with good communication skills who can guide the direction of the partnership and motivate the various players to build and maintain momentum, and to mediate differences between partners [31].

Mutual trust has been identified as crucial for effective partnership work in urban forestry [48]. A history of reciprocal co-operation can promote positive reputations and encourage mutual trust. This reduces the effort required for monitoring and shared supervision of partners [35, 36, 64]. Important personal factors include enthusiasm and creativity, competence and engagement. With respect to the degree of formalisation of partnerships, legally binding contracts have been recommended for larger scale partnership projects which have considerable funding [31]. However, bureaucracy has been mentioned as a factor which can inhibit the effectiveness of co-operation, in particular with public organisations [31].

The further investigation, elaboration and empirical validation of these and further potential success factors may profit substantially from a meta-analytic approach which combines the systematic description of partnership case studies with their objective evaluation. There is great need for a consolidation of knowledge that would lead to recommendations for good practice in the field of UF and GI. A useful descriptive framework for UF governance which considers existing partnerships as an important element has recently been developed by Lawrence *et al.* [38].

CONCLUSION

Urban and peri-urban forests constitute a conjunction between built environments and nature, as “city forests are cultural forest landscapes that are social and cultural constructs, created on/at the meeting point of culture and nature, of the human and non-human” [70]. The cross-sectoral, interdisciplinary nature of UF and GI partnerships fits well with this and offers possibilities for integrating skills, expertise and resources to achieve complementary benefits. Participating organisations may be located in different fields such as research, politics, environmental protection, health, tourism, urban gardening and forest management. Partnerships have potential for developing synergy and can achieve participation, inclusion and engagement of various stakeholders, including local people and green space users [24, 39]. Enhanced public involvement brings more legitimacy, public support and awareness and can lead to decisions which are acceptable to all those involved parties [26]. Therefore a trend towards more partnerships for UF and GI seems promising for promoting sustainable urban development.

Insufficient funding and lack of political support represent major difficulties for successful UF initiatives and projects. Both may be a consequence of an incomplete understanding by politicians and the public of the benefits of urban forests and trees for human health and well-being in urban areas [13]. Involving people through partnership can help to secure funding, increase cost-effectiveness through the involvement of volunteers and can help to overcome these barriers. Cross-sectoral partnerships with a focus on education, campaigning and lobbying in support of UF and GI may be helpful in gaining political support for greener urban development in the future. This is important at a time when UF and GI are increasingly under threat from urbanisation [11].

Partnerships are key to capacity building in a world of globalisation and constant change. They bring actors together from different fields of experience in order to share in something new.

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The Decline of Vitality Caused by Increasing Drought in a Beech Provenance Trial Predicted by Juvenile Growth

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ABSTRACT

Background and Purpose: Due to rapidly changing environmental conditions, locally adapted tree populations are likely to experience climate conditions to which they are not well adapted. Common garden experiments provide a powerful tool for studying adaptive responses in changing climates. Out of the 1998 series of international beech provenance trials, one experiment was established in Bucsuta, SW Hungary. Because of its peripheral location, this is probably the most apposite site in the experimental series to study and predict responses of populations to sudden climatic changes, simulated by transfer.
Material and Methods: 15-year diameter data of 28 beech populations from different regions of Europe were used to mimic responses to climate change by transplantation to the test site. The effect of 17 climate variables and five derived climate indices on growth have been compared, while Ellenberg drought index (EQ) was selected for calculating a linear regression (transfer function) to project a growth trend for future climate change.
Results: Out of the bioclimatic variables, Ellenberg drought index at the location of the origin of provenances has shown the best correlation with 15-year diameter. The regression of growth vs. the ecodistance of transfer (difference between data of the trial site and of the site of origin), expressed in EQ, explained 25% of the total variation between provenances and indicated a clear trend of declining performance with the increasing change of climate the populations were adapted to.
Conclusion: Negative effect of rapid climate change on beech populations cannot be denied, and the results draw attention to the importance of using appropriate planting stock matching with future climate conditions at the planting site.

Keywords: common garden, xeric limit, increment loss, Ellenberg drought index, adaptation

INTRODUCTION

Tree species are threatened by projected increasing temperatures and an increased frequency of extreme events [1]. In Central-Southeast Europe, the increasing magnitude and frequency of summer droughts is a particular threat [2]. While climatic warming in the northern part of the range may lead, with sufficient precipitation, to production increase, under the stressful and uncertain conditions at the receding, xeric limit growth depression and vitality loss are expected [3, 4]. It is assumed that many tree species will be unable to adapt to rapid climate change due to their low migration rate [5, 6] and to highly fragmented landscapes [7].

In Southeast and South Europe, the most important factor limiting the occurrence of European beech (*Fagus sylvatica* L.) is precipitation, and therefore peripheral or marginal populations at the low-elevation (xeric) limit require special attention [8]. In some studies growth decline caused by the worsening of climate conditions has been demonstrated already at the xeric limit [4, 9, 10].

It has been demonstrated that different genetic architecture of beech populations exist. However, there is no complete agreement on reasons for the transeuropean variation pattern, which depends on how much weight is given to the effect of postglacial migration [11, 12]. In this paper we trace possible effects of adaptation to local climatic conditions on the tolerance of populations to rapid climate change, not excluding the possibility of other effects shaping the within-species genetic variation pattern of beech. In common garden experiments important adaptive traits such as frost and drought resistance or growth characteristics of populations may be compared, and therefore these tests provide a valuable basis for recommendations for the use and transfer of forest reproductive material in the face of climate change [13, 14].

MATERIALS AND METHODS

Concept of the Analysis

Differential climate selection pressure as the main reason for genetic variation in beech between provenances has been taken as basic the hypothesis to be proven in this study. For studying climatic adaptation and population-specific response of trees, common garden (provenance) experiments provide a powerful tool. The importance of these experiments lies also in their potential to mimic projected climate change effects [15-18]. According to this interpretation populations are adapted to certain ecological (climatic) conditions and if they are transferred to a new environment, their phenotypic response to climate depends not only on the climatic conditions where the population is tested, but also on the magnitude and direction of environmental change experienced due to the transplanting, which is related to the macroclimate they had been adapted to originally. The ecological difference between the two climates was termed "ecodistance" which expresses the environmental (climatic) effect of transfer [19]. For instance, in case of temperature, positive ecodistance values mean that provenances are subjected to warmer conditions at the test site than at the original site.

Consequently, common garden tests may yield estimates for the effects of climatic changes and it is therefore advisable to reanalyze and utilize all available information and data not evaluated before, even in tests which do not meet rigorous statistic requirements. In what follows 15-year data of a test of particular interest in Hungary have been assessed, applying the ecodistance concept.

The International Beech Provenance Trials of IUFRO

In 1995 and 1998 international beech provenance trials were established across Europe, organized by the Institute for Forest Genetics, Grosshansdorf, Germany, initiated by H.J. Muhs and G. von Wühlisch [20]. Seeds were collected from the whole distribution area and raised in Hamburg in the nursery until age two. With support of a large number of participants, 42 tests were successively planted across Europe. The layout of the planting was uniform at each site. Provenances were planted in randomized plots of 10×10 m size, 50 plants per plot (5 rows each with 10 plants, in 2×1 m spacing) and replicated in three blocks. The provenances represented in the parallel trials were not always the same and the dates of measurements were also different.

The Hungarian Provenance Trial in Bucsuta

Out of the 1998 series of the international beech provenance trials, one experiment was established in Bucsuta, SW Hungary. The experiment was initiated by Cs. Mátyás. The trial is located in the Forest District of Bánokszentgyörgy (SW Hungary), subcompartment Bucsuta 10B (46°35'N, 16°51'E) managed by the Zalaerdő State Forest Company. It is situated at the altitude of approx. 220 m above sea level on a southeast-facing slope with an inclination of about 5-10°. The site belongs to the hilly forest region of Göcsej with temperate-continental climate with some Alpine/sub-Mediterranean influence. The soils are deep, lessivé brown forest soils on loess bedrock, with favorable water holding capacity. The dominant tree species in the region is beech, frequently associated with sessile oak (*Quercus petraea* (Matt.) Liebl.), non-autochthonous Scots pine (*Pinus sylvestris* L.) and hornbeam (*Carpinus betulus* L.). On the selected site a 31-year-old Norway spruce forest stand was originally growing, heavily damaged by spruce bark beetles (*Ips typographus*) It was clear-cut the previous winter, tree stumps were removed and the trial area was fenced.

In the Hungarian trial four provenances out of the 36 are Hungarian (Table 1). The provenance Magyaregregy belongs to the international set, i.e. it is represented in some other trials, while the three others were added to complete the trial set to 36. One of these, Bánokszentgyörgy, originates from the nearby forests and may be considered local. The outplanting of the 36 provenances in 3 replications followed the original plans.

Bucsuta is a particularly interesting location for studying adaptive responses. Because it is situated at the edge of the distribution area (at the xeric limit), most provenances here experience warmer and drier climate than at their site of origin. Figure 1 shows climate location of Bucsuta and of all provenances which are represented at the site. In Bucsuta, mean average rainfall was 707 mm per year and the mean temperature in July was 21°C for the analysis period. There is only one provenance (Pyrenées, FR) which had a higher July mean temperature than Bucsuta. The majority of sources were adapted to higher rainfall at their places of origin (Figure 1).

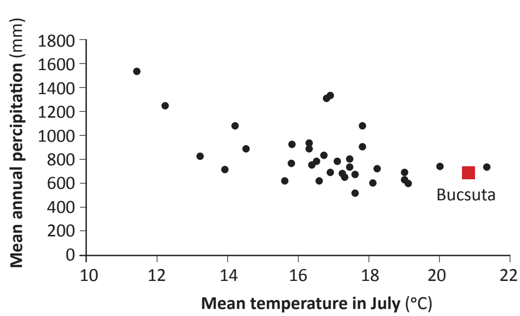

FIGURE 1. The location of Bucsuta and of the analysed provenances in the climatic space of annual precipitation and July mean temperature [20]

TABLE 1. Geographic data, the annual sum of precipitation and July mean temperature (for the period 1950-2000) of provenances, as well as their ecodistance, expressed in Ellenberg drought index (ΔEQ), ranked by 15-year diameter data in Bucsuta (in % of the "theoretical local" performance*; see explanation in the text).

Name of provenance	Country	Latitude	Longitude	Altitude (m)	Annual sum of precipitation (mm)	Mean temperature in July (°C)	ΔEQ	Mean Diameter (%)
Magyaregregy	HU	46.22	18.35	400	707	19	2.57	122.09
Farkasgyepű	HU	47.2	17.65	na	625	19.1	-1.11	108.41
Soignes	BE	50.83	4.42	110	810	17.4	7.97	106.64
Bánokszentgyörgy (local)	HU	46.6	16.85	200	747	20	2.67	101.81
Pidkamin	UA	49.95	25.38	na	612	18.1	-0.13	101.25
Farchau	DE	53.65	10.67	55	676	17.3	3.86	100.78
Perche	FR	48.42	0.55	205	691	17.6	3.98	98.92
Tarwana	PL	49.47	22.33	540	704	16.9	5.44	98.27
Jaworze	PL	49.83	19.17	450	950	16.3	12.29	96.78
Nizbor	CZ	50	14	480	541	17.6	-3.08	93.62
Bordure Manche	FR	49.53	0.77	80	689	17.6	3.9	91.76
Pyrenées	FR	42.92	2.32	670	754	21.3	1.2	91.29
Graf von Westphalen	DE	51.52	8.78	375	941	15.8	12.66	90.82
Idrija	SI	46	13.9	930	1318	16.8	16.7	90.82
Dillenburg	DE	50.7	8.3	520	751	17.4	6.28	87.85
Koino	PL	49.92	20.42	400	729	18.2	4.48	86.36
Bilowo	PL	54.33	18.17	250	631	15.6	4.73	82.82
Oberwil	CH	47.17	7.45	570	923	17.8	10.16	82.64
Ebrach	DE	49.85	10.5	406	701	17.2	4.91	81.70
Aarnink	NL	51.93	6.73	45	797	17.1	7.99	81.61
Brumov-Sidonie	CZ	49.05	18.05	390	799	16.5	8.8	79.75
Buchlovice	CZ	49.15	17.32	410	669	17.3	3.59	78.45
Westfield	GB	57.4	-2.75	10	836	13.2	13.66	75.94
Jablonec	CZ	50.8	15.23	760	731	13.9	10.43	71.65
Urach	DE	48.47	9.45	760	894	16.3	11.22	69.79
Grasten	DK	54.92	9.58	45	780	15.8	9.19	69.05
Heinerscheid	LU	50.08	6.12	423	844	16.7	9.66	68.30
Domazlice-Vyhledy	CZ	49.4	12.75	760	893	14.5	13.21	65.70
Eisenerz	AT	47.53	14.85	1100	1259	12.2	19.76	excluded
Postojna	SI	45.63	14.38	1000	1346	16.9	16.89	excluded
Hinterstoder	AT	47.72	14.1	1250	1539	11.4	22.04	excluded
Horni Plana	CZ	48.85	14	990	1097	14.2	16.5	excluded
Jawornik	PL	49.25	22.82	900	764	16.4	7.98	excluded
Ördöglyuk	HU	48.49	21.36	450	651	19	0.26	excluded
Plateaux du Jura	FR	46.8	5.83	600	1097	17.8	13.22	excluded
Torup	SE	55.57	13.2	40	634	16.6	3.27	excluded
Bucsuta (mean of the period 1998-2012)*		46.57	16.67	220	707	20.8	0.00	100

* Bucsuta is considered as the "theoretical local" reference; na – not available.

Screening Diameter Data

Height measurement was not practicable for most provenances due to the strong crown closure, and therefore the diameter data were used to compare growth. The assessment was carried out in the spring of 2013, when trees were 15 years old (from outplanting) at the trial site Bucsuta. Unfortunately, due to heavy losses only a part of the trial could be evaluated. The low survival was caused either by vole damage, local site problems or tolerance limitations, i.e. by the ecological effect of transplantation. In total, eight provenances were excluded from the analysis of growth response to improve the focus of the investigation. Four provenances were excluded due to very low survival (Plateaux du Jura (FR), Torup (SE), Jawornik (PL), Ördöglyuk (HU)). The other four provenances from higher altitudes were also excluded from the analysis because of their very different behavior tested before [21]. They originated from altitudes above 1000 m (Hinterstoder (AT), Eisenerz (AT), Horni Plana (CZ), Postojna (SI)) and have shown mostly vigorous growth despite of their high ecodistance values, which indicates that the selected climatic variable (EQ) could not capture the climate-related adaptation properly. Therefore separate analyses are needed to interpret the response of high-elevation populations.

Finally, 28 provenances out of 36 were included in the present analysis. Many plots even from these provenances had to be also disqualified due to low survival; only data of 44 plots were utilized. As no significant repetition effect was found, the plot means were pooled without adjustment for the analysis as random entries. In every plot, the mean diameter of the 5 thickest individuals has been calculated in order to minimize bias (statistical "noise") caused by suppressed or damaged trees. This method of the reduction of input data has proven to improve significance in other experiments. It has its silvicultural relevance, i.e. it concentrates on the most competitive individuals ("future trees") in the stand.

Table 1 shows data of all provenances, as well as the ones excluded from the analysis. The diameter data are presented in percents of the "theoretical local" (see further below). The listed data are means of single plots or provenance averages where more than one plot was analysed (in the statistical analysis all plots were evaluated separately).

Determination Method of Climatic Ecodistances

Climate data for the provenance's origin were obtained from the WorldClim database (www.worldclim.org), referring to the 1950-2000 period. This period was considered as an approximation to characterize the past climate to which the parent populations had to adapt in their lifetime – and during earlier generations. The database included interpolations of station data with a spatial resolution of about one square kilometer. Regarding the reference climate data of the trial site, the weather data of only those years to which the provenances were concretely exposed was averaged, explicitly from the date of planting to the date of measurement (e.g. 1998-2012). Therefore the trial site climate does not refer to the meteorological standard of 30-year averages. This way we used two different types of weather references. For the trial site at Bucsuta, the weather data of 15 years were obtained from the nearest station (Nagykanizsa, latitude: 46.45, longitude: 16.967, elevation: 141 m). Comparisons of locally measured data and station data have shown acceptable agreement (not shown).

For the analysis, 17 bioclimatic variables were considered, as well as two continentality- and three aridity indices which were derived from monthly temperature and precipitation averages (Table 2).

RESULTS AND DISCUSSION

In order to select the most significant bioclimatic factor, correlation analysis was performed between climate variables of the original locations of provenance and 15-year diameter data (Table 2). Statistical analysis was conducted using STATISTICA 12. Significant correlations were obtained for the variables EQ (p=0.007), Tmax (p=0.018), TQW (p=0.018), DMI (p=0.031). Ellenberg drought index (EQ) showed the strongest relationship; Tmax as the numerator of the index was also significant. Earlier studies have already demonstrated the importance of EQ in determining the climatic niche of beech [8, 22; the two studies resulted in practically identical EQ values, see in latter paper].

Consequently, ecodistance was expressed by the change of the most influential climate parameter, while Ellenberg drought index (ΔEQ) was calculated to describe the effect of climatic transfer on diameter. A linear response regression of diameter growth vs. ΔEQ has been calculated with plot means of the selected 28 provenances. The intercept (at ΔEQ=0) of the function has been considered to be the performance of the "theoretical local" provenance. The trial site Bucsuta is considered to be the "theoretical local" reference (see Table 1). Subsequently diameter data were transformed into percentages of the "theoretical local", i.e. into relative diameter (D') to better illustrate the observed change in response. Figure 2 shows the linear function of growth response which explains 25% of the total variation between provenances (R^2=0.247, p=0.0006).

The function predicts the increment loss caused by sub-optimal adaptedness, i.e. when a population is planted in an environment to which it is not fully adapted. The function may be interpreted also as the indicator of the growth decline of native populations caused by projected rapid climate change. For example, a temperature increase by 3.5°C (the magnitude projected by IPCC for 2100, [23]) and unchanged precipitation brings about a climatic change of 5 ΔEQ units on a site with 700 mm annual precipitation and 20°C mean July temperature. The function predicts for this case 10% increment loss. (The projection is optimistic, as summer precipitation will decline too.)

The provenance with the highest relative diameter (D') was a Hungarian one, Magyaregregy (122%), from a slightly cooler site, with the same amount of precipitation as the test site (Table 1). It indicates that if precipitation is sufficient, the warming may enhance growth even close to the xeric limit. The other Hungarian

TABLE 2. A list of tested climatic variables and results of the correlation analysis data of original sites versus 15-year diameter in Bucsuta (variables significant at p<0.05 (*) and at p<0.01 (**) are marked).

Climate variables	Abbreviation	Pearson correlation coefficient	Significance
Mean annual temperature	Ta	0.345	0.190
Mean diurnal range	Thh	0.369	0.160
Isothermality	Izoterm	-0.110	0.680
Max temperature of the warmest month	**Tmax**	**0.582**	**0.018***
Min temperature of the coldest month	Tmin	-0.014	0.960
Temperature annual range	Tah	0.430	0.096
Mean temperature of wettest quarter	TQH	0.060	0.826
Mean temperature of driest quarter	TQA	0.014	0.958
Mean temperature of warmest quarter	**TQW**	**0.582**	**0.018***
Mean temperature of coldest quarter	TQC	0.059	0.828
Annual precipitation	Pa	-0.405	0.120
Precipitation of the wettest month	Pmax	-0.181	0.503
Precipitation of the driest month	Pmin	-0.436	0.092
Precipitation of the wettest quarter	PQH	-0.303	0.254
Precipitation of the driest quarter	PQA	-0.345	0.191
Precipitation of the warmest quarter	PQW	-0.298	0.263
Precipitation of the coldest quarter	PQC	-0.237	0.377
Gorczinski's continentality index [25]	GCT	0.460	0.073
Continentality index	CONT	0.399	0.126
De Martonne aridity index [26]	**DMI**	**-0.540**	**0.031***
Ellenberg index [27]	**EQ**	**0.642**	**0.007****
Forest aridity index [28]	FAI	0.415	0.110

provenance, Farkasgyepű, also performed well (108%). This provenance also experienced warmer climate at Bucsuta with more precipitation. The ecodistance of the “truly” local provenance (Bánokszentgyörgy) is not 0 but has a positive value (ΔEQ=2.67), which shows the magnitude of local climate warming, comparing the mean of the past 50 years with the current data. For the period 1998-2012 precipitation has decreased by 40 mm and July temperature has increased by nearly 1°C compared to the climate period of 1950-2000. The climate data of the “theoretical local” reference population are identical with the current means of Bucsuta, whose relative diameter is 100% (Table 1).

Both Atlantic and continental provenances from lower elevations had on average similar mean annual precipitation, but usually much lower mean July temperature than the current conditions in Bucsuta. Provenances Jaworze and Tarwana (PL), as well as Perche (FR) were growing equally or insignificantly worse than the “local” reference provenance, originating from much cooler climates (ΔEQ: +3.98 to +12.29).Apparently, the transfer to the warmer site with sufficient precipitation caused no significant decline. Some provenances, such as Pidkamin (UA) and Nizbor (CZ) performed also relatively well. They had negative ΔEQ values, not because of higher July temperatures, but due to significantly lower precipitation than Bucsuta. Domazlice-Vyhledy (CZ), Heinerscheid (LU), Grasten (DK), Urach (DE), Westfield (GB) and Jablonec (CZ) were among the weak performers; all of them had high or very high positive ecodistance values above 9 ΔEQ, indicating a serious decline of vitality due to a strong warming effect following the transfer. There were also a few “correlation breakers”: Soignes (BE) and Farchau (DE) displayed a surprising growth in spite of a

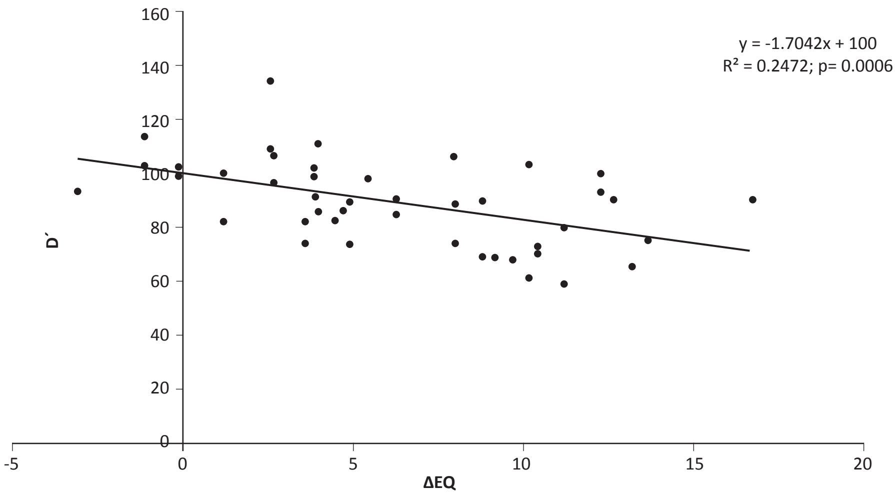

FIGURE 2. Increment decline caused by sub-optimal adaptedness. The "transfer function" defines the decline in percents of the mean diameter (D') of the "theoretically local" provenance, in function of the change of the Ellenberg's drought index (ΔEQ). Data points are plot averages [13].

considerable warming effect. The latter also shows excellent stem form (Figure 3). Graf von Westphalen (DE) and Jaworze (PL) had still shown a good diameter growth in spite of very high ecodistance of above 12 ΔEQ. Some of the unexplained error variance and "correlation breaking" might be explained by incapability of the drought index to correctly characterize climate conditions, particularly the effect of moisture content in coastal zones, e.g. in case of Torup (see below), and in general by the uncertainties in interpolated precipitation data.

The breakdown of populations (mortality, low survival) reaching the limit of their inherited tolerance could not be modeled by growth data because of few surviving individuals. Out of the provenances excluded from the analysis due to high losses, one provenance seems to indicate this limit of tolerance under Bucsuta's climate: Torup from Sweden. However, the ecodistance expressed in ΔEQ is relatively small, only 3.27. It may be argued that the ecodistance is not well captured with ΔEQ; the population close to the northern (thermic) limit of the species is most probably adapted to low water deficit. The seemingly low mean precipitation at the original location is compensated by higher air humidity in vicinity of the sea coast. In addition, the large latitudinal distance probably affects photoperiodic behavior. It has to be mentioned that in a recent study of Norway spruce it was observed that long-day provenances from Scandinavia were more sensitive to the increase of temperature than the Central European ones [24].

Another population of high mortality, Plateaux du Jura (FR), has an extreme ecodistance value of ΔEQ=13.22, which offers evidence of survival difficulties in a definitely drier environment. The cases of the other two provenances,

FIGURE 3. In addition to growth and survival, stem quality of provenances is an important trait. Left: Farchau (D) with an excellent stem form. Right: Farkasgyepű from Hungary presumably shows the effect of dysgenic selection in the past.

Jawornik (PL) and Ördöglyuk (HU) cannot be explained by the available parameters. Some random effects may have caused their failure and the subsequent exclusion from the analysis.

The transfer function calculated indicates a linear decline with increasing drought index change, which is different from the theoretically expected exponential decline. The reason is the high uncertainty in the dataset which did not allow a more exact expression of the response to warming and precipitation loss. Still, due to the peripheral location of the Hungarian trial the clearly negative effect of the projected climate change may be perceived.

CONCLUSION

The test site has proven stressful to almost all tested populations. The majority of sources were adapted to higher rainfall and lower July mean temperature at their locations of origin. The effect of climatic maladaptation was tested by a specifically calculated ecodistance, expressing the change of climatic stress through transfer. Diameter data at the age of 15 indicate that in general, the warming of climate, i.e. the transfer from somewhat cooler origin, may enhance growth only if precipitation is sufficient. Populations adapted to and transferred from significantly cooler/wetter climate were under stress in Bucsuta. The obtained, linear transfer function predicts a relatively mild growth decline of juvenile populations responding to an increasing dryness. Transfers causing drastic increase of moisture stress have led to a serious loss of vitality. Strong mortality in some extreme cases offers evidence for survival difficulties when genetically set limits of tolerance are reached. There remained, however, a few “correlation breakers” the existence of which might be explained by incapability of the applied drought index to correctly characterize certain climate conditions, e.g. in high-elevation and coastal zones and by the uncertainties in interpolated precipitation data in general. In addition, the existence of other impacts on the genetic diversity such as the drift caused by postglacial migration or isolation, as well as the effects of dysgenic or positive selective pressure caused by human interference, cannot be excluded. All these uncertainties, enhanced by the survival problems at the test site, contributed to the relatively constrained adaptive response indicated by the transfer function (Figure 2). Field observations [29] support the idea that the assumed vitality decline and the appearance of large-scale mortality may be more severe than established by the discussed statistical analysis. Unquestionably, in case of predictions about the future fitness of populations on the basis of these results, it has to be remembered that these data have been obtained from juvenile trees. Further observations are indispensable to increase reliability.

In spite of the admittedly high uncertainties in the dataset, the general negative effect of rapid climate change on beech populations cannot be denied, although contradicting results also surfaced [30] which have to be carefully investigated. The results draw attention to the importance of using appropriate planting stock, matching with the future climate conditions at the planting site [13, 14].

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Dendrochronological Investigations of Valonia Oak Trees in Western Greece

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ABSTRACT

Background and Purpose: Valonia oak (*Quercus ithaburensis* subsp. *macrolepis* (Kotschy) Hedge & Yalt.) is an east Mediterranean endemic, xerothermic and deciduous tree of particular interest in forestry. There has been a growing demand lately to include the species in reforestations in Greece which also increased the interest to investigate its response to climate change. The main purpose of this research is to study valonia oak from a dendrochronological – dendroclimatological point of view within its Mediterranean distribution range.

Materials and Methods: Sampling took place in characteristic valonia oak stands where cross sections or tree-cores were taken from 40 trees. The cross sections and the tree-cores were prepared and cross-dated using standard dendrochronological methods and tree-ring widths were measured to the nearest 0.001 mm using the Windendro software program. The ARSTAN program was used to standardize the tree-ring data and to calculate dendrochronological statistical parameters. The inter-annual variability of tree-ring width and the radial growth trend were examined. Finally, tree-ring widths to climate relationships were calculated by orthogonal regression in combination with the bootstrap procedure using master residual chronology and monthly precipitation, temperature data and scPDSI drought index, from October of the n-1 year up to November of the n year.

Results: The master chronology of valonia oak trees in Western Greece reaches 365 years, with an average ring width of 0.89 mm and with mean sensitivity being 0.21. The variation of the tree-ring widths indicates the influence of climate and human intervention in the past. Tree-ring to climate relationships show that valonia oak growth is positively affected by precipitations in January and March and by drought reduction during June and July.

Conclusions: Valonia oak in Western Greece is a species of great interest for dendrochronological and dendroclimatological studies due to the old age of the trees and the species response to climate variation. The climate factors that mostly affect its growth are winter and spring precipitation and summer drought.

Keywords: dendrochronology, dendroclimatology, tree-ring, *Quercus ithaburensis* subsp. *macrolepis*, old trees, east Mediterranean

INTRODUCTION

Quercus ithaburensis is an east Mediterranean endemic, deciduous oak tree species, present as two subspecies: a) *Q. ithaburensis* (Kotschy) Hedge & Yaltirik subsp. *ithaburensis* (tabor oak), found mostly in Anatolia and the Middle East, and b) *Q. ithaburensis* subsp. *macrolepis* (Kotschy) Hedge & Yaltirik (valonia oak), found mostly in South-East Italy, Albania, Greece, and west Anatolia [1-4]. In Greece, valonia oak covers an area of 29,631.80 ha in lowlands and uplands of continental and insular territory, usually in the form of open forests managed as traditional silvopastoral system [4, 5]. From the 17th to 19th century these forests highly contributed to the local economy by dye production extracted from the acorn cups, the production of wood for shipbuilding and their usage as silvopastures [4, 6]. During the 20th century many of these forests were cleared and converted to agricultural fields or rural establishments, while the remaining ones were left to natural succession that resulted in the formation of old-aged oak stands. Nowadays their importance is mainly of an ecological basis, while there is also an increasing economic interest in them ,reviving their traditional uses including silvopastoralism [7].

This species is one of the few deciduous oak species thriving in the Mediterranean xerothermic conditions [8, 9], which makes it an interesting option for reforestation in Greece and other Mediterranean countries. Indeed, the anticipated climate change effects on the growth, productivity and present distribution of the Mediterranean vegetation [10, 11], renders necessary the quest of species that would easily adapt to the new conditions and the investigation of their behaviour. Based on a study about the impact of climate change in Greece [12], the expected temperature increase and precipitation decrease will result in the expansion of heat tolerant forest plant species by 2-4% and desertification by 1-2%, depending on the climate change scenario. Valonia oak with its ability to grow in xerothermic environments, even within phrygana [5], could be one of the recommended species for the future, being less flammable than xerothermic conifers and easily regenerating after a forest fire [4].

In this context, the exploration of valonia oak tree-ring width variability and its climate-growth relationships that can be examined through dendrochronological studies is essential for predicting its future growth trend. The long time series of tree-ring width measurements can substantially contribute to this study. Radial growth combines the effects of climate, site-specific factors, and natural and human disturbances [13-15]. There are many large deciduous oak trees throughout Greece and some are particularly close to historical sites. However, only few of the Greek deciduous oaks species have been used to construct tree-ring chronologies from samplings carried out on living trees [16] and mostly from wood of historical monuments [17, 18]. Concerning valonia oak, there have been few dendrochronological studies in Greece and the Mediterranean region [19, 20]. The objectives of this study were the construction of a local tree-ring width chronology of this species in Western Greece and the investigation of tree-rings to climate relationships.

MATERIALS AND METHODS

Sampled trees were growing in Xeromero, a typical valonia oak forest of the Aetoloakarnania prefecture, Western Greece (Figure 1). It is an old forest with rich fauna and flora [21] and old-age stands that have not been harvested for centuries. It is the largest forest of valonia oak in the Balkans and probably one of the largest within its distribution area in the Mediterranean basin. This forest had particular value in the past due to the superior quality of the acorns produced, compared to others from similar Greek forests in terms of tannin content and its grazing-pasture use and value [22]. Within this area, valonia oak usually forms stands of open canopy, growing on shallow calcareous soils at an altitude ranging from 0 to 580 m a.s.l. Based on the Agrinion Meteorological Station, located 20 kilometres from the sampling site, for the period of 1956-2012 (Hellenic National Meteorological Service), the mean annual precipitation in the region is 938.5 mm and the mean annual temperature is 16.8°C. The drought period, based on the ombrothermic diagram [23], lasts for 3.5 months from late May to early September.

Forty trees were sampled based on dendrochronological criteria [13, 15], from an area of approximately 5 ha representative of the valonia oak stands characteristics and with homogeneous topography (Figure 1). The sampling included cross sections that were taken at breast height (1.3 m) from 20 trees during previous loggings and 20 tree cores that were extracted, also at breast height, from the remaining ones. Tree diameters at breast height ranged from 27.7 to 98.1 cm. It should be noted that trees of diameter at breast height over 25 cm were not easy to be found in the area. The tree-ring cores were extracted using Pressler's increment borers of 40 and 60 cm long, with special care to avoid ramifications and irregular wood structure, as much as possible. The trees cross-sections and cores were dried, planed and sanded with progressively finer grades of sandpaper (80, 100, 200, 400 and 600 grit) until the tree-rings were distinguishable under a stereomicroscope.

Radial increments and selected radial directions of cross sections were measured to the nearest 0.001 mm by Windendro program [24] and cross-dated using a stereoscope, pointer years [15], skeleton plotting and other methods [25-27]. The cross-dating was statistically checked in the course of tree-ring width measurements with Windendro. To remove the low-frequency variation in the elementary tree-ring series and to quantify the tree-ring to climate relationships, index chronologies were constructed using ARSTAN program [28]. A double detrending procedure was done, first by using a negative exponential or linear regression and then by using a cubic smoothing spline function preserving 50% of variance at wavelength of 30 years. Tree-ring widths were converted into indices by dividing observed values with expected values derived from the above-mentioned detrending line. In these indices, the remaining first-order temporal autocorrelation was removed by autoregressive modelling [28]. Finally, the produced individual residual series were then averaged using a bi-weighted robust mean to obtain the master residual chronology. Standard dendrochronological statistical parameters [13] were calculated for the master raw tree-ring chronology and for three age classes (a group of young trees of ages between 100 and 200 years; the middle group of ages between 200 and 300 years, and an old-tree group of trees older than 300 years): mean tree-ring width, standard deviation (Std), mean sensitivity and first-order autocorrelation coefficient. Additionally, the EPS statistic [29] was computed on the dataset after detrending in ARSTAN. The mean raw-chronologies for the above mentioned age-classes were used for the visualization of the growth trend, while the master residual chronology was used to identify the very narrow and wide characteristic tree-rings (greater than 3 Std of the mean value).

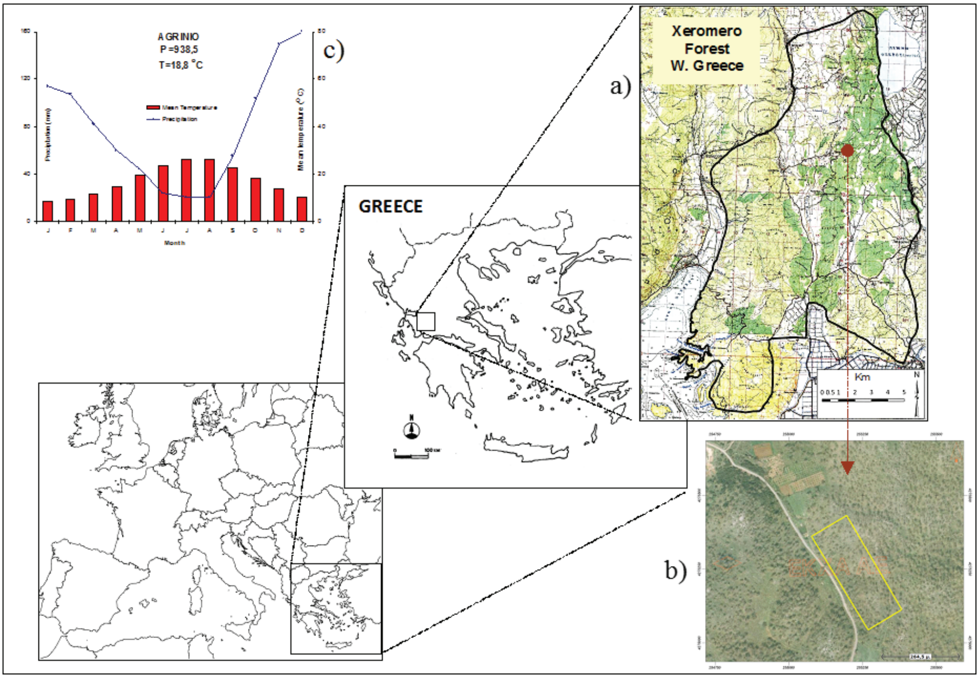

FIGURE 1. (a) Map of the Xeromero forest, **(b)** satellite image of sampling site (www.ktimatologio.gr) and **(c)** the ombrothermic diagram of the nearest meteorological station of Agrinio (24 m a.s.l.) for the period from 1956 to 2012.

Climate-growth relationships were calculated for the period of 1981-2013 by orthogonal regression in combination with the bootstrap procedure [30, 31] using the 3PBase software [32]. The independent variable of this regression was the master residual chronology of tree-ring widths, whereas the regressors were 28 monthly parameters (14 monthly precipitation in combination with 14 mean monthly temperatures: P-Tmean), or 14 monthly drought indices (self-calibrated Palmer Drought Severity Indices: scPDSI) from October of the preceding year to November of the current year. This period of 14 months was chosen taking into account that tree growth in the southern most Mediterranean regions may continue until November or even until the beginning of winter. As for scPDSI, according to Wells *et al.* [33], this index is calculated from precipitation and temperature data as well as from the available local soil water content and it varies from -4 (extreme drought) to +4 (extremely wet). The climatic data were obtained from the KNMI Climate Explorer [34, 35] due to the incomplete data from the local meteorological stations in the proximity of the study area. We used monthly precipitation and mean temperature data of the CRU TS3.22 [36] and monthly UCAR scPDSI drought indices [37]. The closest grid point to the site studied was selected from each gridded data category. The results of the climate-growth relationships are presented as a ratio between the regression coefficient of each monthly climatic parameter and the associated standard deviation (mean of 50 simulations) [30].

RESULTS

Cross-Dating and Tree-Ring Chronologies

From the cross-dating procedure it derives that, due to the wood structure of valonia oak trees (in many cases tree-rings are very thin and not distinguishable, there is presence of discoloration and wood abnormal structure), cross-dating in the middle and old-age group is difficult (Figure 2). The difficulty degree increased with narrow tree-rings. For this reason, cross-dating was possible for 19 out of the 20 cross sections (rate 95%) and 11 out of the 20 cores (rate 55%).

Based on the total cross-dated elementary series, master chronology length was 365 years, mean tree-ring width was 0.89 mm, standard deviation 0.31 mm, mean sensitivity 0.21 and the first-order autocorrelation 0.67 (Table 1). The above mentioned statistics do not differ substantially if calculated separately for each tree age class of 100 years. Tree-ring width in the three age classes tested ranged from 0.86 to 0.90 mm (std 0.28 mm), mean sensitivity from 0.19 to 0.21 and first-order autocorrelation from 0.60 to 0.67 (Table 1). The EPS value for the common period of the series (1815-2010) was 0.68 and exceeded the threshold value of 0.85 [29] in the year 1981.

From the graphical representation of the tree-ring raw mean chronologies and the 20 years mean moving average for each age class (Figure 3), an intense appearance of low frequency variation has been observed throughout the period without noticing any periodicity. The examination of

TABLE 1. Descriptive statistics of valonia oak tree-ring width raw data, for all trees and for the three age classes.

Tree age	Total	100-200	200-300	>300
Number of trees	30	7	20	3
Period A.D.	1650-2014	1815-2013	1718-2014	1650-2010
Chronology length (years)	365	199	297	361
Mean ring width (mm)	0.89	0.90	0.93	0.86
Standard deviation	0.31	0.28	0.28	0.28
Mean sensitivity	0.21	0.19	0.21	0.21
First-order autocorrelation	0.67	0.67	0.67	0.60

FIGURE 2. Cross section of a valonia oak tree from the study area.

the tree-rings growth trend indicated a growth reduction from the beginning of the chronologies until the period of 1880-1900. Then, an increase trend was observed which was, however, halted in the period of 1990-2000 with a tendency to revert afterwards. Focusing on the master residual chronology (Figure 4), it shows a more intense inter-annual variation in the period of 1650-1745 compared to the following period with the exception of the years 1990 and 2000 when particularly narrow tree rings were observed. Characteristic narrow tree-rings were also observed in the years 1661 and 1715, with particularly wide rings appearing in the years 1660, 1687 and 1718. Many of these years were used in cross-dating as pointer years.

Tree-Rings to Climate Relationships

Statistically significant ($p<0.05$) positive correlations were calculated between tree-ring width and January and March precipitation (Figure 5). No significant correlations were found between tree-ring widths and mean temperature of any month. Regarding the scPDSI drought index, a positive significant correlation ($p<0.05$) appeared in June and July (Figure 6).

DISCUSSION

This dendochronological study of valonia oak trees created a new master chronology for the time period of 1650-2014 that may contribute to the densification of the dendrochronological network in South-East Europe [18, 38-41]. It may be used in comparison with new chronologies of the species but also with other oak species. Furthermore, it may contribute to climate reconstruction studies that have been the subject of several researches in the eastern Mediterranean region who used long tree-ring time-series [42-48]. At this stage, due to low EPS value found before 1981, the constructed chronology needs to be upgraded with more elementary chronologies from new cores or cross sections.

Regarding the ages of valonia oak trees it appears that the observed forest is composed of uneven-aged stands, although they seemingly resemble to be even-aged. This impression is given because of the single-layer structure of the forest, the open canopy cover and the lack of lower diameter class trees. The presence of old-age trees in the study site and the region in general [20] indicates that these stands have evolved after the French-Hellenic exploitation of Western Greece forests in the 17th century [6], a period during which many large-diameter trees were harvested to produce shipbuilding timber. After this period, according to data from the local Forest Service, there has not been any systematic logging and the stands were only used for the production of acorn cups for tannin production collected mainly from large, sparsely scattered trees. These old-age trees are nowadays reserved mainly for ecological purposes.

The small tree-ring widths, on average did not exceed 1 mm (Table 1) and did not show any significant decreasing trend with age, is a species-specific characteristic which is slow-growing and usually developing on shallow, degraded calcareous soils. Mean sensitivity (mean value 0.21) is relatively high compared to the Greek coniferous species [49] and is almost proportional to the values of Aleppo pine in the sub-humid bioclimate type [50], whereas it is higher than the mean sensitivity of other deciduous Greek oak species [16]. The relatively high mean sensitivity values found suggest a significant climatic signal, as reflected by valonia

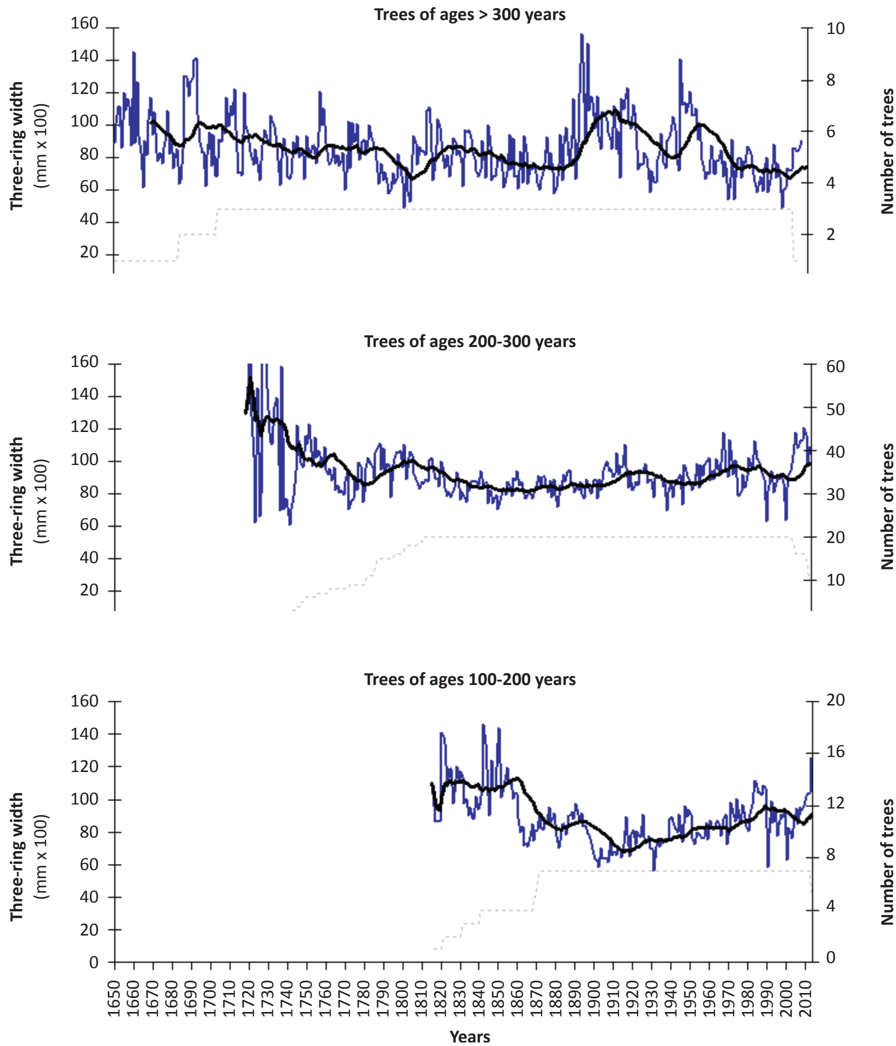

FIGURE 3. Tree-ring width mean chronologies for three age classes; the bold line superimposed indicates the mean moving average of 20 years and the dashed line shows the number of samples used in each chronology.

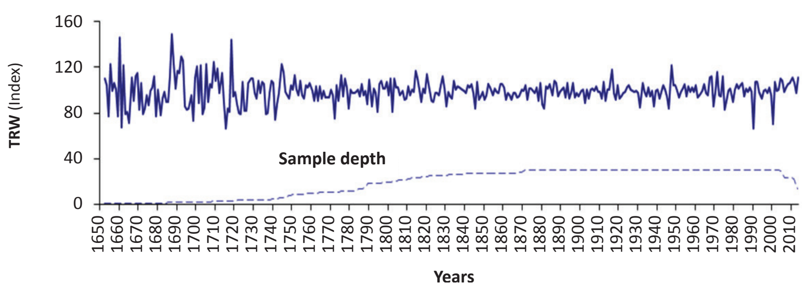

FIGURE 4. Master residual chronology of tree-ring widths (TRW); the dashed line shows the number of samples used in the chronology.

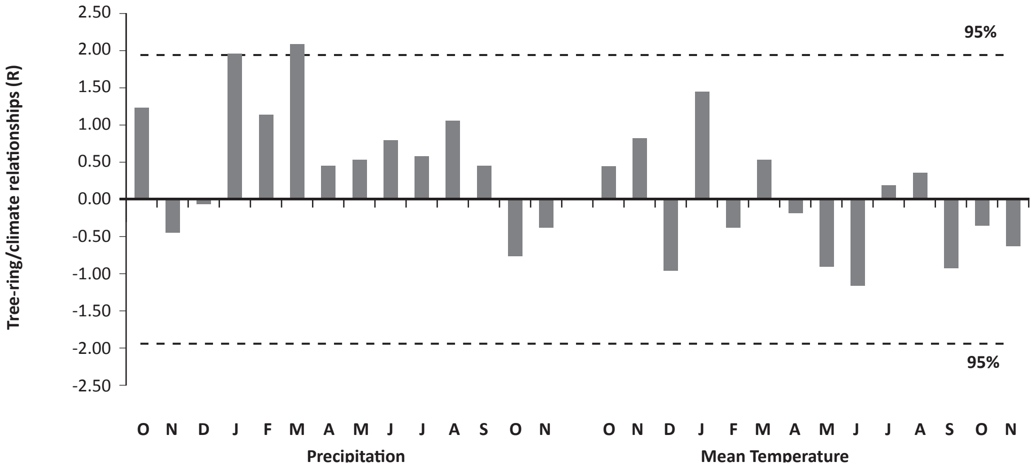

FIGURE 5. Tree-ring to climate relationships calculated between master residual chronology and 28 climatic parameters (monthly precipitation and mean monthly temperature) for the period of 1981-2013. Dashed horizontal lines indicate 95% significance level, R=r/s, r= mean regression coefficient, s= mean standard deviation (for 50 simulations).

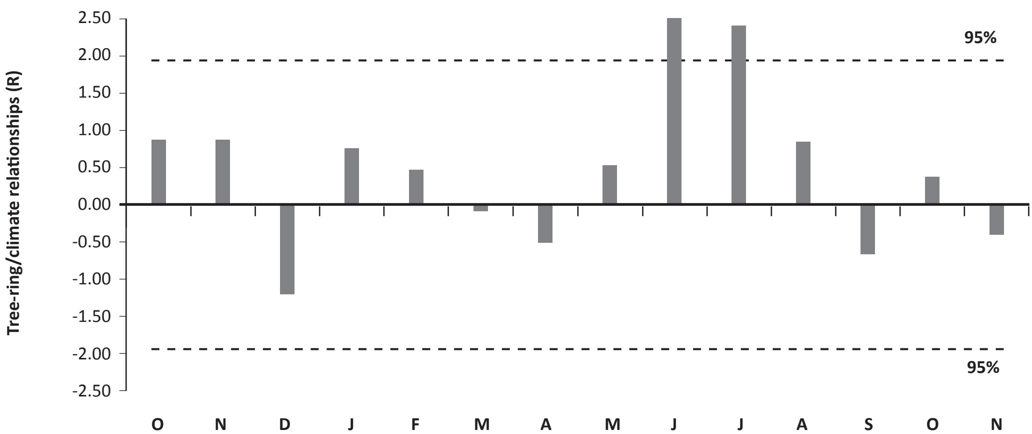

FIGURE 6. Tree-ring to climate relationships calculated between master residual chronology and 14 climatic indices (monthly scPDSI) for the period of 1981-2013. Dashed horizontal lines indicate 95% significance level, R=r/s, r= mean regression coefficient, s= mean standard deviation (for 50 simulations).

oak tree-rings, and are indicative of the appropriateness of the species to be used in dendrochronological studies. The high first-order autocorrelation indicates a low frequency variation in the tree-ring chronologies, revealing the residual action of certain site factors during the formation of successive tree-rings [13]. This variation can be interpreted mainly by the effects of anthropogenic factors that have affected those forests in the past, such as pruning for higher acorn production and grazing, and the influence of different environmental factors such as climate. The analysis of the low and high frequency variation in the chronologies, in relation to other research or historical data, enhances the hypothesis of climate effect. For example, the last decade of the 20th century is a period of a decreasing tendency in tree-ring width, noted and characterized as dry and warm for Greece and East Mediterranean [51, 52]. Furthermore, the year 1715, with the distinctive narrow tree-rings, was marked with long dry periods and was characterised as a year of great famine, especially for the central and southern Greece [53].

Concerning tree-rings to climate relationships, January precipitation that precedes the tree-ring formation phase as well as March precipitation coinciding with the commencement of tree-ring growth, play a prevailing role in valonia oak tree-ring growth. The positive effect of winter precipitation could be attributed to water available in the soil for use during the tree-growing season. Moreover, spring precipitation could attribute to the increased water demands for various physiological processes such as the intense cambium reactivation and growth release after winter dormancy. For the same species in Jordan, Touchan and Hughes [19] showed a relatively high positive correlation between October and May precipitations. The positive correlation of tree-ring widths with June and July scPDSI drought index explains the positive effect of drought reduction during the tree-ring growth period. Climate to growth relationships calculated signify, in a way, the xerothermic character of valonia oak. The adaptability of the species to grow in xerothermic environments confirms the results of the previous research on its ecophysiological response to summer drought [54]. According to personal observations in south Greece, valonia oak in periods of very intense summer drought sheds its leaves and re-sprouts smaller new ones, in late summer or early autumn along with the first rains after drought.

CONCLUSION

Valonia oak in Western Greece is of particular dendrochronological-dendroclimatological interest due to the old age of the trees, but also due to its response to climate variations. Tree-ring widths to climate relationships analysed in this research help us to adequately decode the role of climate on the inter-annual growth variability of the species. Winter precipitation and drought during the summer period play a major role in the radial growth of valonia oak. The study of these relationships combined with the scenarios of climate change can be a guide for predicting valonia oak forests future growth, but also for the usability of the species in reforestation practices in the Mediterranean area. Nevertheless, this study contributes to the dendrochronological research and, generally, to the knowledge of the species autoecology.

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The Level of Utilization of Secondary Timber Species among Furniture Producers

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ABSTRACT

Background and Purpose: Inadequate supply of wood raw material is one of the major obstacles for the global furniture industry's growth. Several secondary timbers/Lesser-Utilized-Species (LUS) that could substitute the scarce traditional timbers for furniture production exist in tropical forests. However, the industry continuously faces persistent timber shortages. The extent to which manufacturers utilize LUS as alternatives is unclear, which this study sought to ascertain.
Materials and Methods: Data were collected from 300 Timber Firms from Ghana primarily through questionnaires using the stratified random sampling technique.
Results: Continuous decline and non-availability of preferred traditional timbers and competition from imported furniture were the main challenges confronting the furniture industry. Data obtained indicated that most manufacturers (85%) hardly use any LUS; 44% of these mentioned lack of information on their properties and prospective uses and 32% attributed it to non-availability on the domestic timber markets. However, 22% of these producers rely on traditionally 'well-known' timbers (e.g. mixed red wood, *Guarea cedrata* and *Tectona grandis*) owing to their strength properties, 20% due to their strength and durability and 14% because of their strength and aesthetic properties. Many LUS (with prospects for furniture-making) available in great quantities in many tropical forests could substitute the over-dependent timbers. However, information on their properties and uses are hardly available to local producers, which affects their popularity among timber suppliers and manufacturers.
Conclusion: To improve on the level of utilization of secondary timbers, wood workers must be supplied with comprehensive information about their properties and economic values. This will contribute to reducing pressure on the primary timbers, ensuring consistent supply of timber and keeping the sector operational.

Keywords: Furniture industry, joinery production, office furniture, primary timber, timber market, wood technical data

INTRODUCTION

Production activities of the wooden furniture industries continuously get hindered by the decline in the supply of raw materials [1]. Purnomo *et al*. [2] and Zhou *et al.* [3] explained that increasing scarcity of preferred (especially the traditional/primary) timber species limits the output and growth of the timber companies globally. For instance, supply of *Hevea brasiliensis* (rubberwood), a major timber for furniture production in Malaysia, decreased from 489,378 m^3 in 2001 to 91,605 m^3 in 2008 due to overexploitation [4]. Consequently, Sarawak, a leading furniture producer contributed less than 0.5% of Malaysia's furniture export [1]. Hashim [5] reported that sustainability of Thailand's furniture industry continues to face serious risk because deforestation has reduced the country's forest cover from 53% to 28% of the total land area between 1961 and 1998. A further reduction to 24% was anticipated by 2010. Currently, wooden furniture is giving way to the metal type in Taiwan, one of the world's largest furniture producing countries, due primarily to wood raw material shortage [5]. The impacts of timber shortage on furniture industries in these countries are not different from those experienced in other parts of the world. Nutassey *et al*. [6] noted that many companies in Accra and Kumasi have folded up because the traditional timbers for furniture are not available, while a few are very expensive to acquire.

Adupong [7] reported that about 78% of wooden furniture on the national market is imported from Asia, Italy and South Africa partly due to a reduction in the processing capacities of the local industries from timber shortage. Importation of wooden furniture increased by about 400% between 2005 and 2011 [6]. This has led to a decline in the contribution of the wood industry to the national economy. For instance, Attah [8] reported that the nation's timber industry's contribution to Gross Domestic Product (GDP) dropped from 4.1% in 2006 to 3.7% in 2010. The decline was attributed to poor performance of the industry on the export market due to operational challenges such as reduced supply of wood raw material.

Timber importation is one attempt at solving the challenge of inadequate raw material supply. In 2012, 66% of wood used for furniture production by Vietnam was imported from the USA [9]. Hansen *et al.* [10] mentioned that logging ban placed by the Chinese Government on natural forests due to shortage of domestic timber supply has resulted in a surge in the amount of timber imported into the country, which is estimated at 70% of China's total timber consumption. Similarly, Ghana imports timber from neighboring countries including Cameroon to augment the local supply [11]. However, continuous importation of wood increases the cost of operation and furniture products, which subsequently slows the growth of the local industries [12]. Hansen *et al.* [10] observed that China's continuous dependence on imported timber is a source of industry insecurity. Donovan and Nicholls [13] and Smith *et al.* [14] mentioned that the introduction of Lesser Utilized timber Species (LUS) with known properties on the market is one of the best strategies that would widen the raw material base and ensure continuous supply of timber resources for furniture production. LUS are available in great quantities in many sustainably managed tropical forests and are likely to obtain legality assurance certificate for exploitation. The cost of secondary timber species is generally low due to their abundance. For instance, while *Loxopterygium sagotii*, a popular traditional species for furniture in Guyana was sold for about $250/Bm, *Hymenolobium flavum*, a LUS with similar properties and utilization potential as *L. sagotii* was sold for $180/Bm. In the USA, previously underutilized species such as *Alnus rubra* Bong. are making substantial contributions to the growth of the furniture sub-sector [15]. Manufacturers in Malaysia have accepted alternatives such as *Dipterocarpus confertus* v. Sloot, *Pseudolachnostylis maprounaefolia* Pax, *Shorea* spp. and *Koompassia malaccensis* Maingay ex Benth., which have similar properties as rubberwood [4]. In Ghana, several LUS (e.g. *Klainedoxa gabonensis* Pierre ex Engl., *Celtis* spp., *Borassus aethiopum* Mart., *Strombosia glaucescens* Engl., *Pycnanthus angolensis* (Welw.) Warb., *Canarium schweinfurthii* Engl. and *Azadirachta indica* Adr. Juss.) that have the potential to substitute the scarce traditional timbers for furniture production have been investigated [16-18]. However, there is still high uncertainty about the survival of the industry due largely to persistent wood shortage [19-21]. It is therefore unclear the extent to which manufacturers utilize LUS as alternatives to the dwindling primary timbers. This work sought to ascertain among manufacturers the level of utilization of LUS (including *Klainedoxa gabonensis*, which occurs widely in East and West African countries, has great amount of biomass and superior physico-mechanical properties) for furniture production and to identify the current challenges associated with their utilization by the furniture industry and their solution so as to ensure reliable timber supply.

MATERIALS AND METHODS

Study Area

The study was conducted in selected 300 furniture manufacturing companies randomly sampled [from a total of 550 active companies in Accra and Kumasi (Ghana), registered with Furniture and Wood Products Association of Ghana (FAWAG)] and interviewed between October 2014 and February 2015 since most of these firms which produce furniture and joinery products are concentrated here [22]. Kumasi lies in the moist semi-deciduous forest zone (60°35' - 60°40' N, 001°30' - 001°35' W), is Ghana's largest wood product manufacturing District [23, 24] and is dominated by small to medium-scale firms which produces bedroom, office, living room and kitchen furniture. Accra is located on latitude 5°33'N and longitude 0°15'W [25] and hosts many of the large-scale furniture companies in Ghana [6]. These firms largely depend on timber markets in Kumasi and other forested areas in Ghana (e.g. Koforidua, Oda, Sunyani etc.) for raw materials [22].

Sampling Technique

Data were collected from the FAWAG Secretariat at Kumasi about the active Furniture Production Firms in the country. These have been stratified into Small-, Medium- and Large-scale companies based on staff strength, capacity of logs processed as well as the machinery and technology employed. Large companies included those with more than 80 workers, advanced technology/machinery and efficient processing techniques with a capacity of over 20,000 m^3 of wood Per annum while medium-size had 60-80 workers, used simple technology involving hand tools and few automated machines with a processing capacity of 5,000–20,000 m^3 of wood Per annum. Small-scale furniture firms had 10 - 60 workers, used only simple hand tools and processed about 5,000 m^3 of wood or less Per annum. The number of companies (n) sampled from each stratum was determined by Slovin's formula [26]:

$$n = \frac{N}{1+Ne^2}$$

where: N = total number of companies in each stratum; e = margin of error (0.05).

Data Collection and Analysis

Data were collected from respondents through questionnaires. Personal observations were made to confirm responses to the question on the furniture products manufactured. Furniture producers provided information on the types of products they manufacture, their choice of timber species and the use of LUS in their operations. Statistical Package for Social Scientists (SPSS) and Microsoft Excel were used to analyze the data and are presented in Figures and Tables.

RESULTS

Size of Firm

Table 1 shows that majority of the firms in both Accra and Kumasi were small-scale (70%) while the least were large-scale (5%). More small-scale firms (56%) were observed in Kumasi than Accra (14%), while large scale-firms were greater in Accra (3%) than Kumasi (2%).

TABLE 1. Respondents sampled from the various categories of firms in Accra and Kumasi

Location of firm	Category of firm (%)			Total
	Small	Medium	Large	
Accra	14	12	3	29
Kumasi	56	13	2	71
Total	70	25	5	100

Furniture Products Manufactured by Firms

Most of the firms (33%) manufactured office chairs, tables as well as bedroom furniture. Living room, dining furniture, bedroom furniture and others (e.g. garden benches and kitchen stools) were produced by about 1% of the firms. About 40% of the companies indicated that their choice of products depended only on market availability, 27% mentioned profitability and market availability, while 1% cited profitability and other reasons such as vocation.

Choice of Markets for Sale of Furniture Products

Figure 1 shows that 93% of the manufacturing companies sold their products on the local market and 7% on the international market (UK, Germany, Italy, USA). About 92% of those who sold their products on the domestic market explained that their choice was due to their inabilities to meet international demand (Figure 2).

Timber Materials Used for Furniture Production

Choice of Wood Species

Timber species such as mixed red wood (e.g. *Cedrella odorata* L., *Entandrophragma* spp., *Khaya* spp., *Afzelia Africana* Sm. ex Pers.), *Aningeria robusta* (A.Chev.) Aubrév. & Pellegr. (asanfena), *Guarea cedrata* (A. Chev.) Pellegrin. (guarea) and *Tectona grandis* L. f. (teak) were used for furniture production by majority of the manufacturers (32%) (Table 2); 22% of these firms indicated that their choice of wood species was based on the timbers' strength, 20% attributed it to strength and durability and 14% due to strength and aesthetics (Table 3).

Utilization of LUS for Furniture Manufacturing

Only 15% of the manufacturers use LUS (e.g. *Celtis* spp., *Magnifera indica* L. and *A. indica*) for furniture production (Figure 3). The others (i.e. 85%) rely on only the primary timbers. Specifically, none of the respondents use *K. gabonensis* in their operations. For those who do not use any LUS for production, 32% attributed this to market unavailability, while 44% indicated lack of information about the properties and uses of LUS as challenges that hinder their utilization (Table 4).

Sources of Timber Materials

Timber markets; contractors served as the major suppliers of wood for most manufacturers (26%), followed by timber markets (23%), timber markets; sawmills (21%), timber contractors (18%), sawmills (8%) and then sawmills; timber contractors (4%).

Challenges Faced by Firms in Furniture Manufacturing

For the major challenges faced by the companies, 31% mentioned non-availability of preferred wood, while 19% stated non-availability of preferred wood and competition from imported furniture (Table 5).

DISCUSSION

Size of Firms

The Ghanaian wooden furniture industry is steadily declining in performance, productivity and profits due to lack of raw materials, skilled labour, competition brought about by trade liberalization and high operational costs [27]. These challenges are more pronounced among the large scale companies [28]. According to Söderbom *et al.* [29], many Ghanaian large-scale firms have shut down due to increasing costs of operations. A few of those remaining have reduced their production capacities drastically due to raw material shortage. It was therefore not surprising to find more small- (70%) and medium-scale (25%) furniture firms than the large

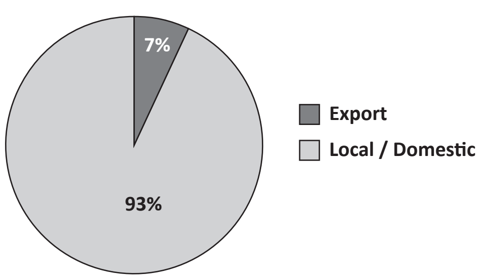

FIGURE 1. Choice of market for the sale of furniture products by the manufacturing firms

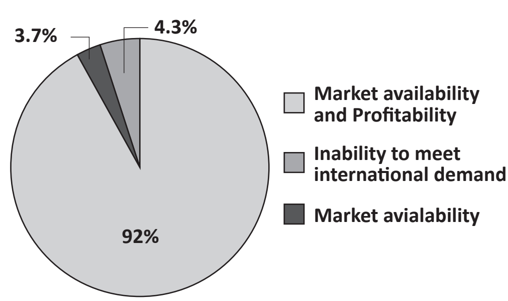

FIGURE 2. Reasons for manufacturers' choice of market for furniture products

TABLE 2. Timber species used by firms for furniture production

Timber species	Respondents/Firms (%)
Mixed red wood; *A. robusta*; *G. cedrata*; *T. grandis*	32
G. cedrata; *T. grandis*	11
Mixed red wood; *A. robusta*; *Milicia excelsa*; *G. cedrata*; *T. grandis*	9
Piptadeniastrum africanum; *G. cedrata*; *T. grandis*	5
Mixed red wood; *A. robusta*; *M. excels*	5
Mixed red wood, *A. robusta*; *D. ogea*; *G. cedrata*; *T. grandis*	4
Mixed red wood; *A. robusta*; *Mansonia altissima*; *G. cedrata*; *T. grandis*	3
A. robusta; *G. cedrata*; *T. Grandis*	2
Mixed red wood; *A. robusta*	2
M. excelsa; *P. africanum*; *G. cedrata*; *T. grandis*	2
M. altissima; *D. ogea*; *G. cedrata*; *T. Grandis*	2
M. excelsa; *Celtis* spp.; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *M. altissima*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *Celtis* spp.; *P. africanum*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *Celtis* spp.; *G. cedrata*; *T. grandis*	1
A. robusta; *M. excelsa*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *Celtis* spp.; *P. africanum*	1
Mixed red wood; *A. robusta*; *D. ogea*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *M. excelsa*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. altissima*; *D. ogea*	1
A. robusta; *P. africanum*; *G. cedrata*; *T. Grandis*	1
A. robusta; *M. excelsa*; *D. ogea*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *D. ogea*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. altissima*; *D. ogea*; *G. cedrata*; *T. Grandis*	1
Celtis spp.; *P. africanum*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *D. ogea*; *P. africanum*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *P. africanum*,	1
A. robusta; *M. excelsa*; *G. cedrata*; *T. grandis*	1
M. excelsa; *M. altissima*; *G. cedrata*; *T. grandis*	1
Mixed red wood; *A. robusta*; *M. excelsa*; *D. ogea*	1
Mixed red wood; *A. robusta*; *D. ogea*; *P. africanum*	1
Mixed red wood; *M. excelsa*; *Celtis* spp.; *G. cedrata*; *T. grandis*	1
Total	100

type (5%). Small- and Medium-scale Enterprises (SMEs) are recognized as catalysts for sustainable development of many countries [30, 31]. They provide about 50% of all jobs in Nigeria [32] and make up about 70% of all industrial establishments and 90% of all businesses in Ghana. According to Oppong *et al*. [33], Ghanaian SMEs employ 60% of the labour force, contribute about 22% to the GDP and support the development of indigenous entrepreneurship. Ranabijoy [34] observed that a major bottleneck to the survival of small-, medium- and large-scale industries in the forestry sub-sector is the limited supply of timber materials. Policies aimed at boosting innovation and increasing the availability of raw materials would promote the competitiveness and growth of these firms [35]. Zziwa *et al*. [36] explained that in order to increase the raw material base for furniture product manufacturing, an increase in the use of LUS to supplement the supply of primary timbers need encouraged. This, according to Ssseremba *et al*. [37], would preserve firms, keep the sector operational and prevent job losses.

TABLE 3. Reasons for choice of timber used for furniture manufacturing

Reasons	Respondents /Firms (%)
Strength	22
Strength; durability	20
Strength; aesthetics	14
Durability	8
Strength; aesthetics; consumers' choice	6
Strength; consumers' choice	6
Strength; durability; aesthetics	6
Consumers' choice	3
Durability; consumers' choice	3
Strength; durability; consumers' choice	2
Strength; durability; others (good carving properties)	1
Durability; consumers' choice; others (good carving properties)	1
Strength; consumers' choice; others(good carving properties)	1
Durability; others (good carving properties)	1
Strength; durability; consumers' choice; others (good carving properties)	1
Strength; aesthetics; others (good carving properties)	1
Strength; others (good carving properties)	2
Strength; durability; aesthetics; consumers' choice	1
Durability; aesthetics; other (good carving properties)	1
Total	100

Furniture Products Manufactured by Firms

The study revealed that most of the manufacturers (33%) engaged in the production of office chairs, tables as well as bedroom furniture. Centre for Industrial Studies [38] observed a faster growth in the office trade on the European market. Ponder [39] explained that the emergence of new businesses and expansion of existing ones have led to the growth in trade of office chairs and tables. Ha [40] and Kazemifar and Khodadadeh [41] also noted that every individual spends about a third of their lives in bed for relaxation and privacy. As a result, most families rank bedroom furniture as the most important product to be purchased for the home. Consequently, Drayse [42] and Kingsway Furniture Co. Ltd. [43] observed that office and bedroom furniture were the main commodities traded on the global furniture market. Flow control magazine [44] noted that the household and office furniture sectors accounted for about two-thirds of the furniture sector's revenue in USA over the last decade. The high availability of market for office chairs, tables and bedroom furniture could explain the frequency of their production among manufacturers. The high rate of production also implies that large amount of wood would be needed by the office and bedroom furniture manufacturers.

TABLE 4. Reasons for low level of utilization of LUS among furniture manufacturers

Reasons	Respondents/Firms (%)
LUS unknown; lack of technical data on the properties and uses of LUS	44
Unavailability of LUS on the market	32
Unavailability of LUS on the market; lack of technical data on the properties and uses of LUS	8
LUS unknown; unavailability of LUS on the market	5
LUS unknown	5
Lack of technical data on the properties and uses of LUS	4
LUS unknown; unavailability of LUS on the market; lack of technical data on the properties and uses of LUS	1
None of the options	1
Total	100

TABLE 5. Challenges faced by firms in furniture manufacturing

Challenges facing firms	Respondents/Firms (%)
Non-availability of preferred wood	31
Non-availability of preferred wood; frequent power outage	31
Non-availability of preferred wood; competition from imported furniture	19
Non-availability of preferred wood; high cost of operation	8
Competition from imported furniture	4
Competition from imported furniture; frequent power outage	3
Non-availability of preferred wood; competition from imported furniture; frequent power outage	2
Frequent power outage	2
Total	100

Choice of Markets for Sale of Furniture Products

Most of the firms (93%) sold their products on the domestic market; 92% of them attributed this to inability to meet international demand. According to Oppong *et al.* [33], inadequate financial resources, lack of export marketing strategies and inability to meet international demands/ standards are responsible for the reliance of the furniture industry on the local market for sale of products. Ward and Gilbert [45] explained that firms choose to sell their products on the local market because export marketing requires more time, greater financial resources and greater ability to withstand far wider and more intense competition. As a result, about 73% of middle-market firms in North America currently sell their products on the domestic market [46]. However, Julian [47] observed that the international market helps local industries to grow fast, improve their innovation, credibility and competitiveness by enhancing their operating capabilities. Biggs [48] mentioned that due to the relatively small size of domestic markets, firms looking to expand their businesses must take advantage of the export markets. Thus, the growth of the Ghanaian furniture sector could be enhanced when more firms are supported to produce furniture in quantities that meet international demand. However, this will partly be dependent on continuous supply of timber resources [49]. With decreasing quantities of popular timbers for furniture, producers could rely on secondary timber species to augment supply and promote the competitiveness of the sector.

Timber Materials Used for Furniture Production

Choice of Wood Species

Timber is the single most important raw material in the furniture industry [50]. Adebara *et al.* [49] noted that certain products require specific timber species. Therefore, Ayarkwa [51] asserted that timber users in Ghana are very selective in their choice of wood, such that furniture products are usually made from a small number of preferred timbers. It was observed from this study that mixed red wood (e.g. *Cedrella odorata*, *Entandrophragma* spp., *Khaya* spp., *Afzelia africana*), *A. robusta*, *G. cedrata* and *T. grandis* were the timber species used by majority of the manufacturers (32%) due to their strength, durability and aesthetics. In a study to determine the factors influencing the choice of timber for furniture and joinery production in Ghana, Dadzie *et al.* [52] and Boampong *et al*. [50] similarly found that among a list of 22 wood species, only few including mixed red wood, *G. cedrata* and *T. grandis* were mostly patronized by furniture manufacturers. Trevallion and Strazzari [53], Zziwa *et al.* [36], Louppe [54], Binggeli [55], Derkyi *et al.* [56], Govorčin *et al*. [57] and Chernyh *et al.* [58] confirmed that factors such as strength, cost, durability, beauty and availability influenced the choice of timber for furniture. This accounts for the high patronage of mixed red wood, *A. robusta*, *G. cedrata* and *T. grandis* among manufacturers. Consumers preferred to spend more money to purchase products made from strong and durable timbers that would reduce maintenance and replacement cost [50]. Tropical timber species with great strength and good aesthetic properties such as *Khaya anthoteca*, *Pericopsis elata*, *Simarouba versicolor* and *E. cylindricum* are therefore common on the Italian furniture market [59]. Thus, in seeking alternatives for the over-dependent primary timbers, secondary timber species that are strong, durable and aesthetically good could gain acceptance by furniture manufacturers. For instance, *K. gabonensis* is a naturally durable and strong timber with attractive grain pattern; it is abundant in most tropical forests and has prospects for furniture-making [60]. However, it has no information in trade statistics. Based on its characteristics, it could contribute to satisfying the raw material needs of the furniture industry.

Utilization of LUS for Furniture Manufacturing

Acquah and Whyte [61] explained that the volume of high-valued commercial timbers used for furniture production has reduced drastically over the years. The remaining amount of wood in the forests faces stiff competition from all the other wood-related sectors. Oteng-Amoako *et al.* [60] found that LUS could serve as substitutes to and reduce the pressure on these commercial timbers. Boampong *et al*. [50] noted that several LUS whose properties make them suitable for furniture are in large quantities in the tropical forests. However, this study showed that only 15% of manufacturers use LUS such as *Celtis* spp., *M. indica* and *A. indica* for furniture production. Sseremba *et al.* [37] found *M. indica* among several other secondary timbers used for furniture-making in Uganda. It was further observed that none of the respondents had ever used *K. gabonensis* in their operations. Manufacturers indicated unavailability of secondary timbers on the market and lack of information regarding their properties and uses as some of the hindrances to their utilization. Smith [62] found that utilization of timber by wood product manufacturers depends on accessibility on the market and availability of comprehensive technical data on its properties. Similarly, Ayarkwa [51] and Effah and Osei [63] mentioned that dissemination of research results among wood workers about new timber species that could serve the same purpose as their already utilized counterparts would enhance their utilization. Sseremba *et al.* [37] explained that accessibility of data regarding the characteristics and uses of LUS such as *M. indica* and *Artocarpus heterophyllus* improved their acceptance and utilization by Ugandan furniture manufacturers. It could be understood from the results that the level of utilization of LUS, the likely alternatives for furniture-making, is low among manufacturers because information on their characteristics and uses are not readily available. To increase the utilization of secondary timber species for wood products, adequate information about their abundance, properties and uses must be made available to manufacturers [64].

Sources of Timber Materials for Furniture Production

Raw materials supplied to furniture manufacturers are obtained through a network of buyers who purchase timber from both private and public forest landowners [65]. About 26% of the respondents sourced wood from timber markets and contractors (loggers). Nketiah and Wieman [66] and Marfo [67] explained that wood procured from these two sources are comparatively cheaper than those sold by sawmills. Therefore, many furniture manufacturing firms prefer to buy lumber from the former [50]. Since firms do not use secondary timber species due to market unavailability, it could be stated that timber contractors and operators do not supply LUS to furniture manufacturers. Boyes and Melvin [68] mentioned that the level of supply of raw materials for any production process depends on demand for those materials by producers. In Northern India, although many secondary timber species that could be used for housing construction existed in great numbers in the forests, timber providers did not risk bringing them on the market due to their low demand among users [69]. Therefore, the failure by timber contractors and operators to supply LUS on the market may be due to low demand for the species. Venn and Whittaker [70] also mentioned that most timber sellers are unaware of the properties and the prospective uses of a lot of the LUS in the forests as well as profits that might be obtained from their sales. This leads to total neglect of the non-traditional timbers in the timber trade. Providers of timber for furniture production do not make available LUS to manufacturers due likely to a lack of understanding of their quality and profitability [71]. Thus, in encouraging the use of secondary timbers for furniture and other wooden products, information on the characteristics, uses and profitability of LUS should also be made available to wood suppliers.

Challenges Faced by Furniture Manufacturers

According to Center for Industrial Studies (CSIL) [72], about US$376 billion was obtained on the global market from the production of furniture in 2010. Ngui *et al*. [73] explained that furniture has greater monetary value than other wood-based products such that furniture manufacturing is an ideal option for countries that seek to earn more from the timber-processing industry. Nonetheless, furniture industries face serious challenges that have led to the collapse of many [6]. Nutassey *et al*. [6] explained that the number of industries in Ghana's tertiary wood sub-sector declined by over 60% between 1990 and 1999. Norini *et al.* [74] estimated that only 26% of the total furniture firms in Sarawak State in Malaysia remained active as of 2009 due to myriad of problems such as decline in quantities of raw materials and rising costs of operations.

Respondents mentioned that non-availability of preferred wood raw material and competitions from imported furniture (due partly to poor design and quality of the domestic types) were among the challenges confronting the furniture industry. Similarly, Adupong [7] observed in a survey commissioned by Wood Workers Association of Ghana-Western Region (WWAG-WR) that decreasing quantities of primary timbers hindered the activities of furniture-making firms. Respondents from that survey explained that the volumes of timbers had declined drastically over the years. The few amounts remaining were difficult and expensive to acquire partly because sawmills that had large forest concessions were export-oriented and did not provide for the local market. Local manufacturers were therefore unable to meet customers' increasing demand for furniture and have resorted to their importation to supplement local production [75, 76]. This situation has led to stunted growth of the local industry, while rendering many manufacturers jobless [77]. The challenges associated with the drastic decline in timber supply could be reduced by encouraging the use of secondary timber species to widen the raw material base for the sector [75]. However, the present study has shown that manufacturers hardly use LUS primarily due to market unavailability and lack of technical information about them. Thus, to increase the use of secondary timber resources by the wood industry, wood suppliers, product manufacturers and end users must be fed with reliable and sufficiently detailed information about the characteristics and uses of the large amount of neglected timber species in the forests. This will help meet the raw material requirement of the industry, while reducing pressure on the current commercial timber species.

CONCLUSION

Wood strength, durability and aesthetics were the major factors for the selection of timber for furniture-making due to reduced future maintenance and replacement cost of products. Thus, with decreasing quantities of the conventional timbers, many of the secondary timbers with comparable strength, beauty and durability (e.g. *K. gabonensis*) could substitute the traditional timbers to ensure regular wood supply. However, most manufacturers rely on only the well-known timbers (e.g. mixed red wood, *G. cedrata* and teak) and hardly use the secondary timber species due to market unavailability and lack of information about their characteristics and uses. This has led to pressure on the demand for and exploitation of few primary timbers. Thus, the furniture industry's ability to meet future demand for wood products is unsustainable, which requires adequate efforts for the promotion and utilization of the secondary timbers (or LUS). To increase the level of utilization of the secondary timber species to ensure consistent wood supply for the furniture industry, adequate information about their abundance, properties and uses must be made available to wood workers.

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Radial Variation in Selected Physical and Anatomical Properties Within and Between Trees of 31 Year Old *Pinus caribaea* (Morelet) Grown in Plantation in Nigeria

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ABSTRACT

Background and Purpose: Variation in wood is a common phenomenon. Eliciting information on the pattern and extent of variation in wood properties is crucial to knowing the end use of wood species. This to a larger extent helps in the efficient and sustainable utilization of wood. *Pinus caribaea* has been internationally affirmed to be suitable for the manufacturing of pulp and paper. Since its introduction into Nigeria, the possibility for its use for pulp and paper has been grossly undermined because of the non-functional paper mills in Nigeria. Hence, the established plantations of the species in the country have gradually been exploited for timber. In order to ensure the efficient use of the species for structural purposes, it is therefore pertinent to understand the variation pattern in its anatomical and physical properties.
Materials and Methods: Five trees of 31 year old *P. caribaea* wood were harvested at Shasha Forest Reserve, South-West Nigeria. Bolts of 50 cm in length were obtained from each felled tree at breast height (1.3 m). Discs of 5 cm thickness were obtained from each bolt which were used for the anatomical investigation. The bolts were used for the investigation of the physical properties. The data generated were subjected to ANOVA and Regression Analysis.
Results: The results show that considerable differences exist in the anatomical properties among trees ($p<0.05$). The physical properties show no marked difference among trees ($p>0.05$). Both the physical and anatomical properties differ insignificantly within the tree ($p>0.05$). Tree's basic density, tracheid wall thickness and lumen diameter only explained 49% of the variation in the preservative absorption within the tree ($R^2=0.4884$, P-value=0.053), re-emphasizing the major role played by bordered pits in the permeability of softwoods.
Conclusions: Due to the high preservative absorption observed using a non-pressure treatment, it is concluded that the species is very porous. Its porosity may pose a disadvantage when moisture absorption is concerned. Thus, it is recommended that the wood be properly treated in order to reduce its potentials in absorbing excessive moisture during service.

Keywords: tracheid, absorption, bordered pits, pit aspiration, density, preservative, structural application

INTRODUCTION

Globally, natural forests are rapidly on the decline. Due to the slow growth of natural forests and hence their inability to cater for the growing demand for wood and wood products, plantation forestry has therefore been practised over the years and as such, it has been the major supplier of wood for the wood industries. Industrial plantations of economic species in Nigeria were established in the 20th century, with concentrations of these plantations in the southern part of the country. The main exotic species under plantations in Nigeria include *Tectona grandis*, *Gmelina arborea* and *Pinus caribaea*, mainly due to their fast growth rate.

Pinus caribaea (Carribean Pine) was primarily introduced to Nigeria for the production of long fibre pulp [1]. Currently, Nigeria imports pulp in order to manufacture her paper and paper products [2]. The inability of the pulp and paper industries in Nigeria to produce pulp, and consequently, depending on its importation led to the tree species established under plantations, which were initially intended to feed these pulp and paper mills outgrowing the stage of their suitability for pulp and paper. As a result, these species have been diverted to other uses. *Pinus caribaea*, even though a softwood species, has recently started gaining prominence for use as structural timber in Nigeria. As a fast growing species in Nigeria, it is therefore a promising species which can augment other structural timber species in the wake of increasing demand for solid wood in Nigeria. However, understanding its wood properties will provide a better insight into the ideal types of structural purposes it can be used for so as to ensure its efficient utilization.

Wood microstructure has long been recognised as an important tool in identifying the suitability of a wood species for a particular purpose [3] Also, it is unanimously agreed among researchers that wood density is a major factor affecting wood quality [4, 5]. Interestingly, within and between variability studies in wood properties of matured trees of *P. caribaea* in Nigeria are limited, given its value and the potentials it holds as a promising wood species in the country. Information on wood variation are essential for the improvement of properties which play crucial roles in its use as a raw material for both domestic and industrial uses [4]. Oluwadare [1] investigated the variation in some selected wood properties among different age classes of *P. caribaea* grown in Nigeria. Udoakpan [6] studied within tree variation in density, ring width and anisotropic shrinkage of Nigeria grown *P. caribaea* and observed little variability in the studied wood properties. However, within and between tree radial variation in the anatomical and physical properties of Nigerian grown *P. caribaea* within the same age class is unknown, which are also crucial determinants of wood quality [7].

Known to be a non-durable species, utilizing it for external structural applications therefore makes the treatment of *P. caribaea* wood with wood preservatives against biodeteriorating agents imperative in order to extend its service life, hence, promoting a more sustainable use of the wood. However, with several studies revealing a significant within-tree variation in wood properties [8], while variation in wood is expected to affect the uniformity in preservative uptake of the wood [9, 10] - an important index which determines the effectiveness of a wood preservative, it is therefore necessary to investigate the extent to which radial variation in the wood properties of *P. caribaea* will affect preservative absorption by its wood. Information gained from this will enable the development of an appropriate preservative treatment regime for this species in order to aid its efficient utilization.

In order to contribute to the existing knowledge on the variation in *P. caribaea* wood, this study aims to quantify radial variation in selected anatomical and physical properties within and among trees of *P. caribaea* with a view to advancing further knowledge on the species.

MATERIALS AND METHODS

Wood samples and Site Characterization

Wood samples used for this research were obtained from a 31 year old pine plantation grown in Shasha Forest Reserve, South-West Nigeria. The forest reserve is located on latitude 7^0 and $7^0 30'$ N and longitude 4^0 and 5^0 E [11]. The total annual rainfall ranges from 887 mm to 2,180 mm, and it has a minimum and maximum annual temperature of 19.5^{0}C and 32.5^{0}C respectively [12]. Five defect-free trees of *P. caribaea* with absence of reaction tendencies were harvested. Bolts of 50 cm in length were obtained from the breast height (1.3 m) of the trees. From each of these bolts, discs of 5 cm thickness were collected for use in the anatomical investigation. The breast height was chosen as the point of sampling along the tree bole because of the strong correlation of wood density with whole tree density (r^2=0.99) at this point [13, 14]. Thus, it is expected that results obtained from this chosen sample will reflect the wood properties for the whole tree since density is strongly correlated with all other wood properties.

Determination of Basic Density

Each of the remainder bolts (45 cm in length) were partitioned radially from pith to bark into three zones: inner wood (rings 1-10), middle wood (rings 11-20) and outer wood (rings 21-31) based on the number of rings. Ten wood samples of dimensions 6 cm x 1.5 cm x 1.5 cm were obtained from each wood zone and oven-dried at 103^{0}C for 18 hours. Basic density was estimated as the ratio of oven-dried weight of wood to green volume of wood [1].

Determination of Tracheid Dimensions

The discs were partitioned in a similar pattern as the one described above. From each of the discs, splints were obtained from each ring and macerated in equal volume (ratio 1:1) of 10% acetic acid and 30% hydrogen peroxide [15]. The macerated slivers were then washed; distilled water was then added after which they were shaken vigorously to separate the fibres. The suspension was mounted on a slide with the aid of a rubber teat, stained with safranin and 10 tracheids were measured in swollen condition [16], using the Rheichert visopan microscope for length (mm), diameter (μm), lumen width (μm) and cell wall thickness (μm). Two slides were prepared for each wood sample.

Determination of Preservative Absorption

The samples used in estimating the basic density for each partitioned wood zone, as described above, were subsequently treated by soaking for 24 hours in a preservative formulated from a mixture of castor oil (*Ricinus communis*) extracted mechanically from its seeds and kerosene (an organic solvent used as the diluent) in the ratio 3:7 using the volume dilution method [17]. Preservative absorption of the wood samples was determined by using the method employed by Olajuyigbe *et al.* [17]:

$$Absorption = \frac{(10^6 \cdot WPA)}{(1000 \cdot V)} \ (kg \cdot m^{-3})$$

where WPA is weight of preservative absorbed (kg), and V is volume of wood sample (m^3).

Statistical analysis

The data obtained were analyzed using descriptive statistics and two-way analysis of variance (ANOVA) in order to evaluate the variation in the wood species' anatomical and physical properties among trees (tree effect) and within tree (radial effect). A multivariate regression analysis was used to model the preservative absorption as a function of the basic density and anatomical properties investigated. During the model development process, predictor variables which contributed insignificantly to preservative absorption were eliminated.

RESULTS

Between-Tree Variation in Wood Properties

The pattern of radial variation in the tracheid biometry and physical properties investigated among trees are presented graphically in Figures 1-6. The figures show no consistent pattern of variation from pith to bark in the physical and anatomical properties among the trees. The standard errors for each wood property among the trees greatly differ (Table 1), further indicating heterogeneity among the trees.

Values of wood properties for individual trees are presented in Table 1. The mean range of tracheid length is 1.85-2.68 mm, with the wood having an average tracheid length of 2.31 mm. Tracheid diameter ranged between 45.37-60.72 µm, with an overall average of 53.25 µm. Mean values of 34.86 µm and 9.2 µm were recorded for tracheid lumen diameter and cell wall thickness respectively. However, it was observed that all the anatomical properties differed significantly ($p<0.05$) among trees (Table 3).

For the physical properties, basic wood density ranged between 413.85-536.95 $kg{\cdot}m^{-3}$, while preservative absorption of the wood ranged between 110.17-158.93 $kg{\cdot}m^{-3}$. Mean preservative absorption and basic density of the wood were 126.28 $kg{\cdot}m^{-3}$ and 500.41 kgm^{-3} respectively. Both the wood basic density and preservative absorption were not statistically significant ($p>0.05$) among trees (Table 3).

Within-Tree Variation in Wood Properties

The within-tree radial variation in the wood properties of *P. caribaea* from pith to bark is shown in Table 2 below. Tracheid length steadily increased from the core (2.16 mm) to the periphery (2.45 mm). Tracheid diameter and lumen width, as observed in this study decreased from the core outwards. However, an inconsistent pattern of variation was observed for the cell wall thickness, with a gradual increase from the core wood (8.65 µm) to the middle wood (9.54 µm), and then further declining in the outer wood (9.38 µm). The physical properties investigated

TABLE 1. Physical and anatomical properties of *P. caribaea* wood

Wood properties	Tree No.					Grand mean
	1	2	3	4	5	
Tracheid length (mm)						
Mean	2.16	2.68	1.85	2.49	2.39	2.31
Standard error	0.06	0.14	0.08	0.06	0.07	
Tracheid diameter (µm)						
Mean	58.92	60.72	45.37	47.85	53.21	53.25
Standard error	1.17	1.62	1.3	0.96	0.98	
Tracheid lumen width (µm)						
Mean	41.99	39.79	31.46	28.51	32.33	34.86
Standard error	0.99	2.19	1.08	0.88	0.81	
Cell wall thickness (µm)						
Mean	8.49	10.47	6.95	9.67	10.44	9.2
Standard error	0.42	0.67	0.21	0.67	0.34	
Basic density ($kg{\cdot}m^{-3}$)						
Mean	413.85	510.93	526.98	513.34	536.95	500.41
Standard error	11.23	23.95	11.55	12.39	20.04	
Absorption ($kg{\cdot}m^{-3}$)						
Mean	158.93	117.21	131.04	110.17	114.02	126.28
Standard error	12.35	4.33	4.38	3.68	5.43	

TABLE 2. Radial variation in wood properties of *P. caribaea* wood

Wood properties	Radial wood zones		
	Core wood	Middle wood	Outer wood
Tracheid length (mm)	2.16	2.31	2.45
Tracheid diameter (mm)	54.8	53.87	51.3
Tracheid lumen width (mm)	37.53	34.78	32.55
Cell wall thickness (mm)	8.65	9.54	9.38
Basic density ($kg{\cdot}m^{-3}$)	441.46	521.71	538.06
Absorption ($kg{\cdot}m^{-3}$)	119.16	119.21	140.46

(wood basic density and preservative absorption) both showed a consistent increase from pith to bark. Within-tree differences observed for all the wood properties from pith to bark were however not statistically significant (p>0.05) (Table 3).

The Relationship Between Wood Properties and Preservative Absorption

The model presented in Table 4 reveals the key variables that significantly influenced preservative absorption in the wood of *P. caribaea*. A positive relationship was observed between tracheid diameter and absorption. Wood density was positively related to preservative absorption, while an inverse relationship was observed between cell wall thickness and preservative absorption. From the model, tracheid diameter, wall thickness

TABLE 3. The analysis of variation among and within trees of *P. caribaea* (radial)

Wood properties	df	Mean square	P-value
Tracheid length			
Trees	4	0.398	0.038*
Radial wood zone	2	0.242	0.134ns
Residual	8	0.092	
Total	14		
Tracheid diameter			
Trees	4	136.778	0.001*
Radial wood zone	2	15.942	0.24ns
Residual	8	9.308	
Total	14		
Tracheid lumen width			
Trees	4	101.219	0.008*
Radial wood zone	2	29.942	0.166ns
Residual	8	13.193	
Total	14		
Cell wall thickness			
Trees	4	6.601	0.035*
Radial wood zone	2	1.086	0.513ns
Residual	8	1.493	
Total	14		
Basic density			
Trees	4	7358.781	0.41ns
Radial wood zone	2	13367.556	0.193ns
Residual	8	6556.949	
Total	14		
Absorption			
Trees	4	1185.692	0.541ns
Radial wood zone	2	754.449	0.609ns
Residual	8	1426.6	
Total	14		

* - significant at (p<0.05); ns - not significant at (p>0.05)

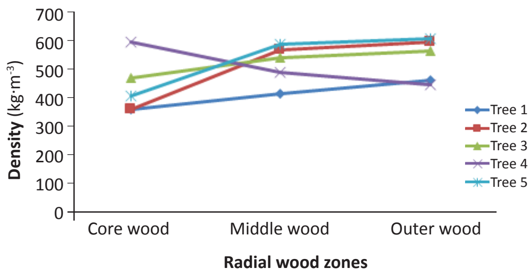

FIGURE 1. Radial variation in wood density among trees of *P. caribaea*

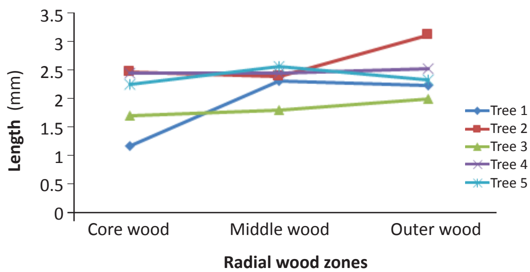

FIGURE 2. Radial variation in tracheid length among trees of *P. caribaea*

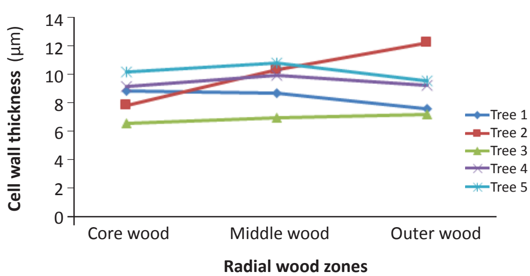

FIGURE 3. Radial variation in tracheid wall thickness among trees of *P. caribaea*

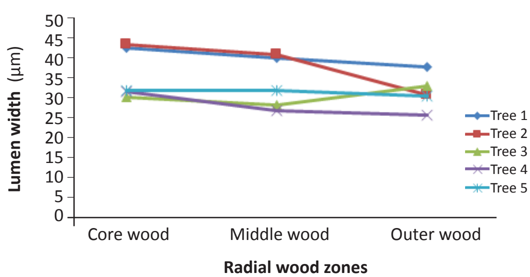

FIGURE 4. Radial variation in tracheid lumen width among trees of *P. caribaea*

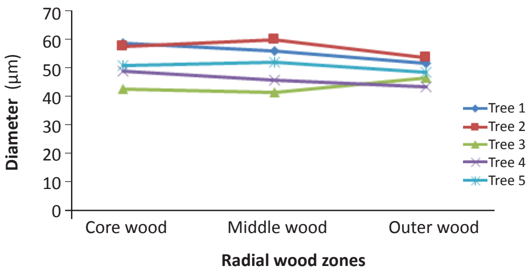

FIGURE 5. Radial variation in tracheid diameter among trees of *P. caribaea*

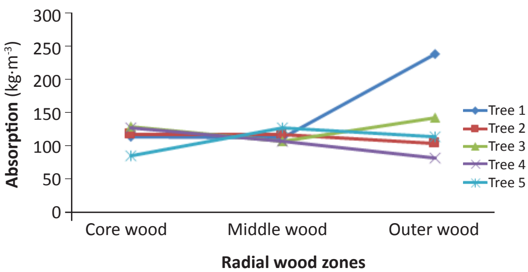

FIGURE 6. Radial variation in preservative absorption among trees of *P. caribaea*

TABLE 4. The relationship between wood properties and preservative absorption in *P. caribaea* wood

Parameters	Estimates	Std. Error	P-value
Intercept	-3.09345	3.2219	0.36ns
In Diameter	1.11843	0.48454	0.04*
Wall thickness	-0.11444	0.03698	0.01*
In Density	0.72866	0.32929	0.049*

* - significant at p<0.05; ns - not significant at p>0.05

and wood density only explained 49% of the variation in preservative absorption (R^2=0.488) by the wood of *P. caribaea*, with the developed model being significant at 94% probability level (p-value=0.053).

DISCUSSION

Generally, this study shows that the anatomical properties of the wood varied significantly from the inter-tree comparison, while no marked differences were observed in the physical properties. Furthermore, the within-tree analysis revealed that individual trees were uniform in both their physical and anatomical properties. Ideally, anatomical properties of a particular wood should reflect its physical attributes [18, 19]; however, this is in contrast to the findings of this study. The non-association between both wood properties (anatomical and physical) among the trees suggests that differences in other anatomical properties and extrinsic factors such as extractive content, number and distribution of resin canals, earlywood/latewood ratio within rings, etc which were not examined in this study may have contributed greatly to the differing variation patterns between the anatomical and physical properties observed among the *P. caribaea* trees [18, 19]. The haphazard pattern of variation observed among trees for each wood property may be a result of the differences in the genotype of individual trees [20]. Nonetheless, the noticeable between-tree variation observed in the anatomical properties on the other hand may prove advantageous in tree breeding programmes, giving way for future improvement on its anatomical attributes.

The anatomical features investigated show a mixed result in comparison with existing literature. The radial pattern of variation in anatomical features has been extensively reported by several studies [14, 16, 21]. While the mean values obtained in this study for tracheid diameter and cell wall thickness were consistent with the results reported by Oluwadare [1], tracheid length and lumen width were, on the other hand, considerably low compared to his findings. The difference observed in the lumen width may possibly be due to differences in site conditions, silvicultural treatments, tree age, or tree genetic make-up [14, 18, 22]. The wood tracheid length, apart from being considerably lesser to that reported by Oluwadare [1], is also low when compared to some other pine species [14, 23] and to the average tracheid lengths of 3-5 mm generally reported for softwoods [24]. Possible reasons for this outcome may be due to erroneous measurement of some broken tracheids or, perhaps, due to the reduced number of sampled tracheids in the study when compared to other similar studies [e.g. 1], thus making the sampled tracheids poor representatives of the entire tracheid population of the trees.

The increasing trend from pith to bark observed for the physical properties is consistent with that reported for some softwood species [16, 18, 19]. The mean basic density for the wood observed in this study (500.41 kg·m^{-3}) is similar to that reported by Oluwadare [1] and Hashemi and Kord [6] for *P. caribaea* grown in Nigeria, although a little bit higher than that reported in Sri Lanka [25]. This contrasting result with that obtained in Sri Lanka may be due to differences in tree age or silvicultural treatments [22, 26]. The increase in preservative absorption from pith to bark can be explained by the reduced number of aspirated pits from pith to bark, consequent of the increasing proportion of latewood percentage from the inner wood to the outer wood [27]

Apparently, the moderate basic density of the wood shows that it will be suitable for light construction works. However, the relatively uniform density of the wood observed in this study makes it ideal for veneer production by peeling or slicing [28]. More so, the preservative absorption values of the wood indicate that sufficient absorption levels can be obtained through treatment by non-pressure methods rather than the use of the higher energy-consuming pressure treatments. It is worthy to note that even though the average tracheid lumen width and basic density are comparable to some other pine species [e.g. 14], it may pose a problem in joinery works due to the high preservative absorption observed in this study. The implication of this, by extension, is that the wood will permit excessive moisture absorption during fluctuations in atmospheric moisture which may result in high swelling and shrinkage.

The observed relationship between the wood properties and preservative absorption was weak due to the low predictive power of the wood properties. The positive relationship observed for both diameter and density with preservative absorption implies that wider tracheids and thick-walled tracheids with fewer aspirated pits enhanced absorption. This finding further reinforces the assertion that bordered pits play a prominent role in the flow of liquids in softwoods [27, 29]. Nonetheless, the observed positive relationship between density and absorption in this study is in contrast with observations of Ahmed *et al.* [30]. This disparity possibly is as a result of the wood type since permeability in hardwoods is primarily determined by wider vessel lumen and, by extension, a lower wood density. The inverse relationship between wall thickness and preservative absorption suggests that higher pressure is needed to achieve better preservative penetration into the tracheid cell walls, consequent of the type of preservative treatment method employed in this study. This observation however strongly suggests that radial variation in earlywood/latewood proportion significantly influenced absorption given that pit aspiration, and hence lateral fluid permeability within the wood along the radial direction was quite pronounced.

CONCLUSION

It can be concluded from this study that inter-tree variation in the anatomical properties was considerable while the trees exhibited uniformity in their physical properties. Within-tree variation on the other hand was insignificant. Interestingly, the wood can be described as being very porous, which is evident from the high preservative absorption recorded under a non-pressure method of treatment. This shows that the wood does not belong to the group of refractive wood species, since most softwoods are observed to be due to the pit aspiration phenomena. While the easy treatability of the wood might be an advantage, the possibility of absorbing excessive moisture which can result into pronounced wood movement needs to be addressed through proper treatments to reduce its moisture absorption capacity and thus, to improve its dimensional stability. Furthermore, this study clearly affirms that bordered pits largely determine permeability in softwoods. Although a high preservative absorption was observed, the depth of penetration and uniformity of the preservative absorption may largely be impaired by the extent of pit aspiration in the wood.

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Drought Effects on Physiology and Biochemistry of Pedunculate Oak (*Quercus robur* L.) and Hornbeam (*Carpinus betulus* L.) Saplings Grown in Urban Area of Novi Sad, Serbia

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ABSTRACT

Background and Purpose: Water stress is one of the major problems for urban trees. It affects a wide range of plant responses, from changes at the cellular level to the reduction in growth rates. Irrigation of trees in urban areas may provide numerous benefits important for increasing tree vitality to withstand other stresses that might occur. The aim of this study was to compare drought effects on some physiological and biochemical performances of Pedunculate oak (*Quercus robur* L.) and Hornbeam (*Carpinus betulus* L.) saplings grown in the urban area.
Materials and Methods: The study was conducted during August 2012 at the Boulevard of Europe (Novi Sad, Republic of Serbia). Measurements were carried out on saplings grown in the part of the boulevard with drip irrigation system installed (Site 1) and on the saplings cultivated in the part without any irrigation system (Site 2).
Results: Soil moisture content was significantly higher at Site 1 with approximately 57.2%, compared to 18.7% at Site 2. The results showed that irrigated saplings were characterized by significantly higher stomatal conductance in *Q. robur* and *C. betulus*. Similarly, the content of free proline, FRAP units and the amount of malonyldialdehyde showed increased values in trees subjected to soil water deficit. In contrast, net photosynthesis, chlorophyll and carotenoid contents did not differ notably in irrigated and non-irrigated *Q. robur* and *C. betulus* trees.
Conclusions: Water stress significantly affected stomatal conductance and some biochemical properties of *Q. robur* and *C. betulus* saplings cultivated at the non-irrigated site. The results showed that the implementation of drip irrigation system in urban landscape is an important tool in the prevention of drought stress effects on the physiological processes of plants.

Keywords: drought, irrigation, physiology, biochemistry, pedunculate oak, hornbeam, urban area

INTRODUCTION

Urban trees are integral components of urban ecosystems and provide a wide range of ecosystem services important for urban citizens [1, 2]. By transpiring water, removing air pollutants, reducing noise, altering wind speeds, enhancing urban biodiversity, shading surfaces, changing the microclimate, and modifying the storage and exchanges of heat among urban surfaces [3, 4], urban trees contribute to improving environmental quality, quality of life, and sustainable urban development [5, 6].

However, there are a number of biotic and abiotic stressors that urban trees have to cope with, such as: heat island effect, limited soil moisture, the presence of detrimental contaminants in the soil (e.g. salt, oils, heavy metals and organic pollutants), air pollution, tree pests and diseases, constructions, mechanical damages to root, trunk and branches, etc [7]. Lack of moisture in the soil is one of the most common problems that affect trees in urban environments [8]. Water stress affects a wide range of plant responses, from changes at the cellular level to the reduction in growth rates [9]. For example, Popović *et al.* [10] found that photosynthetic efficiency of pedunculate oak seedlings was significantly affected by short-term water stress. Bréda *et al.* [11] reported that sap flux densities and stomatal conductance were reduced by almost 70% at maximal drought intensity in adult *Quercus robur* and *Quercus petraea* trees. Ježík *et al.* [12] found that reduced water availability caused much lower tree water status and stem circumference increase in non-irrigated Norway spruce trees. Similarly, a study by Pšidová *et al.* [13] showed significant reduction of net photosynthesis and stomatal conductance in beech seedlings subjected to water deficit.

In urban conditions soil moisture is often limited due to soil compaction and reduced soil volume [14]. In such circumstances, water supply decreases in the root system because compacted soils, together with street structures, prevent infiltration of water into the root zone. At the same time, access to the ground water and subsurface drainage is often eliminated due to restricted rooting volume [15]. As a consequence of aforementioned disturbances, the life-span of trees growing in urban environments can be significantly shortened in comparison with trees growing in natural habitats [16].

In the present study we examined drought effects on physiological and biochemical performances of Pedunculate oak (*Quercus robur* L.) and Hornbeam (*Carpinus betulus* L.) saplings grown under two watering regimes – irrigated and non-irrigated. The objective of the study was to examine to which extent, for period of one month, the soil water deficit at the site without irrigation system will affect different physiological and biochemical proceses in trees and to indentify those traits that react most sensitively, and thus might be used as early signs of water stress. Since the mortality rate of saplings is the highest in the first year after planting, the present study was conducted at newly established boulevard and involved recently planted saplings of the same age.

MATERIALS AND METHODS

Experimental Location and Plant Material

The study was conducted during August 2012, at the Boulevard of Europe (Novi Sad, Republic of Serbia). The Boulevard of Europe was built in 2010. After finishing the constructions of the road, the bicycle path and the footpath, green area was established along the entire boulevard. For that purpose, six-year-old saplings of Pedunculate oak (*Quercus robur* L.) and Hornbeam (*Carpinus betulus* L.) were planted. The space between the saplings was 10 × 10 m. In order to prevent the negative effects of drought stress on the saplings, drip irrigation system was installed in one part of the boulevard. In order to examine how irrigation affects plants' physiological performances, the measurements were carried out on saplings grown in the part of the boulevard with irrigation system installed (between Futoška Ulica and Bulevar Vojvode Stepe) (Site 1) and on the saplings cultivated in the part without any irrigation system installed (between Bulevar Vojvode Stepe and Rumenačka Ulica) (Site 2).

The climate of Novi Sad is temperate continental with a mean annual temperature of 11.4°C and annual precipitation sum of 647 mm. Mean air temperature during the vegetation period (April–September) is 18.3°C, while the sum of precipitations for the same period amounts to 379 mm. The climate records were acquired from the weather station Rimski Sancevi (N 45°20', E 19°51'; 84 m a.s.l.), at 10 km distance from the city (http://www.hidmet.gov.rs). Temperature and precipitation have been averaged for the time period between 1981 and 2010.

Soil Analysis

Soil samples were taken from irrigated and non irrigated sites (two samples per each site). The physical characteristics of soil were determined according standard laboratory analyses. Particle size distribution (%) was determined by the international B-pipette method with preparation in sodium pyrophosphate [17], while the determination of soil textural classes was carried out based on particle size distribution using Atteberg classification [18] and pH in H_2O electrometric method with combined electrodes on pH meter. Soil moisture content was determined according to Bošnjak *et al.* [17], whereas humus percentage (%) in soil was determined by Tjurin method in Simakov's modification [19]. The Kjeldahl method was applied for the determination of nitrogen percentage (%) in soil [20].

Gas Exchange Measurements

Net photosynthesis (A) and stomatal conductance (gs) were measured using the ADC BioScientific Ltd. LCpro+ Portable Photosynthesis System. Leaves were enclosed in the broad leaf chamber until the values of A and gs had stabilized (usually about 60 seconds) [21]. Measurement was conducted in 5 replications on 5 plants per single species. Fully expanded leaves of the same developmental age, with the same orientation, placed in the upper part of the crown were used as samples. Measurements were done in sunny and clear weather, in the period between 09:00 and 11:00 a.m. Measurements were done under constant light conditions (PAR 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$) and CO_2 concentration (350 $\mu mol \cdot mol^{-1}$). The air supply unit provided a flow of ambient air to the leaf chamber at a constant rate of 100 $\mu mol \cdot s^{-1}$. Temperature and humidity inside of chamber were at the ambient level [22].

Determination of Photosynthetic Pigment Concentration

The contents of chlorophyll a (Chl a), chlorophyll b (Chl b) and carotenoids (Car) were determined according to Wettstein method [23] in acetone solution. Absorbances at wavelengths 662 nm (chlorophyll a), 644 (chlorophyll b) and 440 nm (carotenoids) were measured by spectrophotometer and expressed in $mg \cdot g^{-1}$ of dry weight (DW).

Determination of Oxidative Stress

Extracts were homogenized and macerated with 10 ml 0.1M K_2HPO_4 at pH 7.0 on cold porcelain mortar [24]. Homogenate was centrifuged for 10 minutes at 4000 g. Finally, the resulting supernatant was mixed with glycerol in 1:1 ratio and the mixture was used for the determination of: (a) free proline (FP) accumulation, (b) total antioxidant activity and (c) lipid peroxidation intensity. Proline accumulation was determined by the method described by Bates *et al.* [25]. Proline was determined after the extraction with 5-sulphosalicyclic acid and the reaction with ninhydrin. A standard curve of proline was used for calibration. Total antioxidant capacity was estimated according to the FRAP (Ferric Reducing Antioxidant Power) assay [26]. Total reducing power was expressed in FRAP units. FRAP unit is equal to 100 µmol·dm^{-3} Fe^{2+}. FRAP value is calculated using the formula: FRAP value=$\Delta A_{sample}/\Delta A_{standard}$.

Lipid peroxidation was determined by the thiobarbituric acid (TBA) method. Values were given based on the quantification of an end-product malonyldialdehyde (MDA) and expressed as nmol MDA·g^{-1} fresh weight (FW) [27].

Statistical Analysis

The data were analysed with statistical software package Statistica 10 [28]. Differences between two treatments were analyzed using One-way ANOVA procedure. Significance was determined at p<0.05 throughout the entire analysis.

RESULTS

Site 1 was characterized by textural class of sandy loam, contrary to Site 2 where predominant texture classes were loam (Site 2, S3) and sandy-loam (Site 2, S4). In irrigated area (Site 1), instantaneous soil moisture content ranged from 38.1% to 61.0% in the surface layers (0-10 cm), while in the deeper layers (10-40 cm) soil moisture content increased due to the reduced evaporation, and ranged from 36.0% to 93.8%. In contrast, lower soil moisture content was observed in non-irrigated area (Site 2). Soil mosture content varied between 12.9% to 13.8% in the surface layers, and between 21.6% and 26.4% in the lower layers (Table 1).

The results of irrigation effects on physiological performances of pedunculate oak and hornbeam saplings are shown in Figure 1. On the non-irrigated site both species had significantly decreased gs ($p_{Q.robur}$<0.003; $p_{C.betulus}$<0.002), whereas differences in net photosynthesis were not statistically significant, even though *A* decreased in non-irrigated saplings of both species. Notable differences between treatments were also observed for free proline content ($p_{Q.robur}$<0.003; $p_{C.betulus}$<0.001), FRAP ($p_{Q.robur}$<0.001; $p_{C.betulus}$<0.001) and lipid peroxidation ($p_{Q.robur}$<0.005; $p_{C.betulu}$ <0.022) (Figure 1).

The chlorophyll and carotenoid content was not significantly different between saplings grown under two watering regimes. In oak saplings, Chl a, Chl a+b and Car were higher in the leaves of irrigated plants, while Chl b content was higher in plants subjected to water deficit. On the contrary, higher content of Chl a, Chl b, Chl a+b and Car occurred in stressed hornbeam plants.

DISCUSSION AND CONCLUSIONS

The results of our study showed that *A* and *gs* were reduced in non-irrigated saplings of both tree species. It corresponds to the results of Gallé and Feller [29] who reported that A and gs in beech seedlings decreased in parallel with increased water deficit. Similar findings were reported by Krstić *et al.* [21] for *Acer pseudoplatanus* and *Platanus acerifolia* saplings cultivated on undeveloped alluvial soil. However, even though net photosynthesis declined at Site 2, the analysis of variance did not reveal statistically significant differences between saplings grown at Site 1 and Site 2. In contrast, stomatal conductance was more sensitive to soil water deficit, displaying a proportionally greater reduction under stress compared to the rate of photosynthesis, as it was already detected by Valadares *et al.* [30] for eucalyptus hybrids. Although a number of studies demonstrated synchronized decline of stomatal conductance and net photosynthesis [13, 29, 31, 32], recent studies showed that net photosynthesis may not be necessarily affected by the reduction of stomatal conductance. Indeed, Hasanuzzaman *et al.* [33] reported that stomatal conductance showed

TABLE 1. Physical and chemical soil properties at the sites with irrigation (Site 1) and without irrigation (Site 2), at the Boulevard of Europe (Novi Sad, Republic of Serbia).

Site	Soil samples	Depth (cm)	Soil moisture (% vol.)	pH (in H_2O)	Humus (%)	N (%)	C/N	Textural class
Site 1	S1	0-10	60.97	8.18	2.73	0.137	11.56	Sandy loam
		10-40	93.83	8.13	2.14	0.113	10.98	Sandy loam
	S2	0-10	38.11	8.18	1.61	0.089	10.51	Sandy loam
		10-40	36.00	8.15	1.62	0.089	10.52	Sandy loam
Site 2	S3	0-10	13.76	8.63	1.29	0.073	10.32	Loam
		10-40	21.61	8.43	1.46	0.081	10.41	Loam
	S4	0-10	12.87	8.18	1.25	0.070	10.31	Sandy loam
		10-40	26.39	8.23	1.19	0.067	10.30	Sandy-clay loam

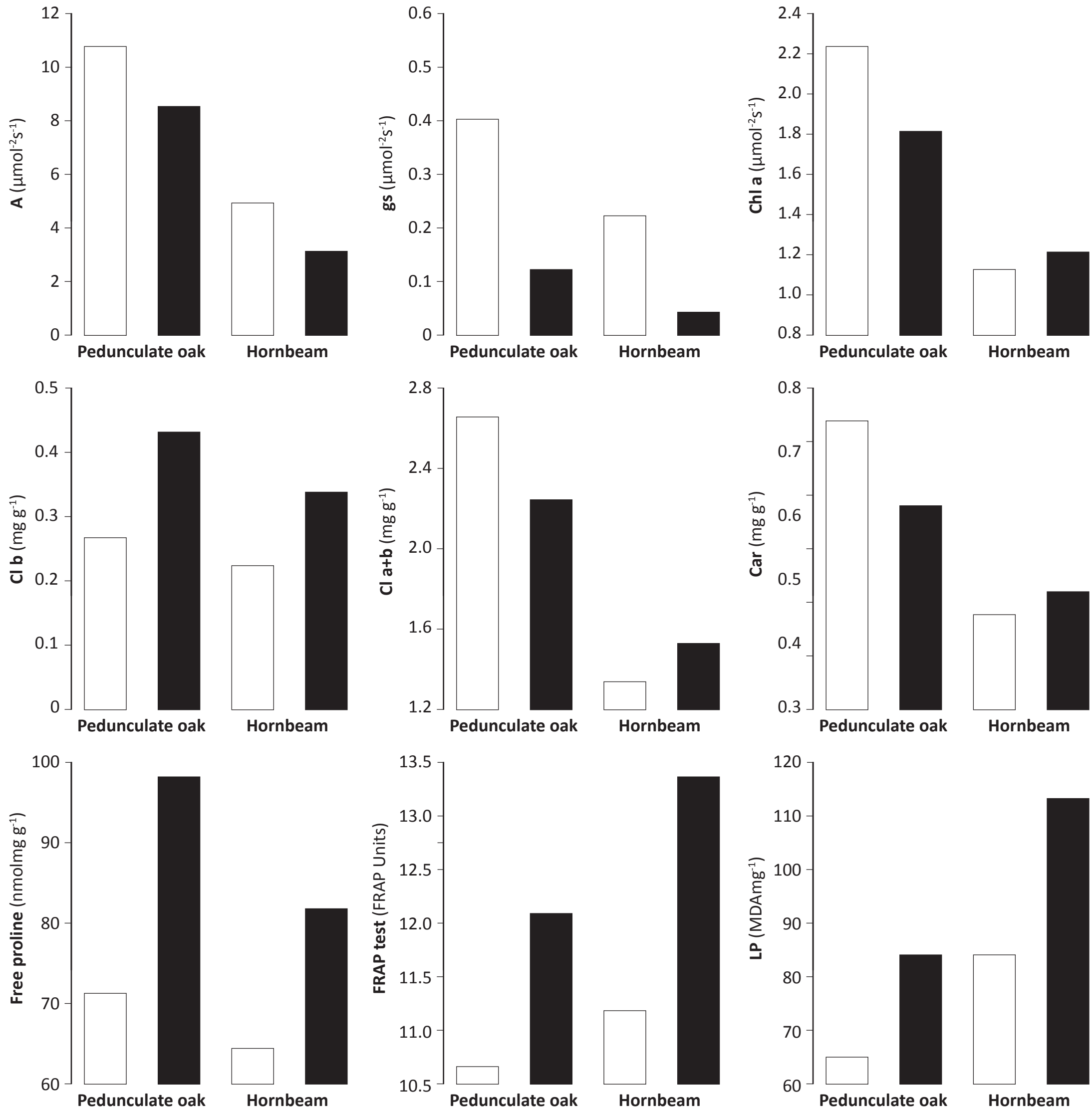

FIGURE 1. Physiological and biochemical performances of irrigated (□) and non-irrigated (■) Pedunculate oak and Hornbeam saplings grown in urban area of Novi Sad, during August 2012.

an earlier decline under mild to moderate stress than net photosynthesis, which abruptly dropped only at severe stress. Likewise, study on drought stress response in *Jatropha curcas* showed that despite the tight stomatal regulation under mild and moderate water stress, stomatal limitations to photosynthesis only occurred under severe stress [34]. Since the photosynthesis was not affected in *Q. robur* and *C. betulus* saplings even under sustained reductions of stomatal conductance, we might assume that the photosynthetic apparatus of both species is likely to be resistant to mild to moderate water stress. It corresponds to the findings of Michelozzi *et al.* [35] for Aleppo pine provenances.

Several studies demonstrated that under drought stress leaf chlorophyll contents often decline as a consequence of chlorophyll degradation [36, 37]. In this study we found no reduction in photosynthetic pigment contents. In fact, some increase was observed in hornbeam saplings, but it was not significant. This has also been reported for *J. curcas* [34] and *F. sylvatica* [38].

Significant increase of total antioxidant activity estimated by FRAP test was recorded under drought treatment in both species inspected. These results indicate that drought induces biosynthesis of chemical compounds with high antioxidant properties in order to cope with oxidative stress which is a direct consequence of drought due to fact that reactive oxygen species (ROS) are generated abundantly under drought conditions. Within these groups of metabolites the most dominant are the products of secondary metabolism; in first line the phenolic compounds, both glicosides and aglicons, tannins, polyamines and conjugated polyamines all with a high capacity to scavenge reactive oxygen species. Štajner *et al.* [39] presented similar results where they tracked radical scavenger capacities as well as ferric reducing ability of extracts under different stress conditions in six melliferous woody plant species where they stated similar results of significantly increased FRAP value under the drought stress dominantly observed in *Fraxinus* and *Tillia* species.

Another plant mechanism to suppress consequences of drought conditions is by accumulation of osmoprotective compounds which have an important role in osmoregulation and in the maintenance of the water regime. Proline, like immino acid, due to its polarity is very often referred to as one of the main osmoprotectants. In this study, the concentration of free proline was significantly increased under the non-irrigated conditions both in oaks (increase of 28%) as well as in hornbeams (increase of 30.7%) compared to watered controls. Our findings are consistent with the results reported by Hu *et al.* [40] who evidenced that foliar proline levels were enhanced in the drought plus air warming treatment across three oak species (*Quercus robur*, *Quercus petraea* and *Quercus pubescens*). Similarly, the simultaneous measurement of proline and related compounds on the leaves of drought stressed *Quercus robur* plants showed that fifty-six days of water deficit exposure resulted in increased foliar free proline levels of drought stressed oak compared to well-watered control [41]. Finally, Topić [42] found that free proline content in the leaves *Quercus robur* seedlings subjected to drought stress was almost twice higher in comparison to control treatment. Our findings are in accordance with the results that were gained from other tree species as well. For example, studying the influence of three different water regimes (100, 50, and 25% of the field capacity) on two contrasting populations of *Populus przewalskii*, Lei *at al.* [43] found that drought not only significantly affected decreased chlorophyll pigment contents but also caused accumulation of the free proline and total amino acids as well as abscisic acid and hydrogen peroxide. In their research, Szabados and Savoure [44] highlighted the important role of proline as an antioxidant that is acting as a single oxygen quencher and a H_2O_2 scavenger, but that it can also reduce lipid peroxidation intensity.

Furthermore, the intensity of lipid peroxidation process measured by the quantification of its end-product malonyldialdehyde was also found markedly elevated under drought stress, which implies that drought stress caused by a lack of irrigation stimulates a very detrimental process of peroxidation of membranes' lipids. Schwanz and Polle [45] in their comparative study also found a significantly elevated intensity of lipid peroxidation under the drought stress in *Q. robur* which they characterized as a more drought tolerant species compared to *Pinus pinaster.* This is due to the features of *Q. robur* such as higher activities of superoxide dismutase, ascorbate peroxidase, catalase, dehydroascorbate reductase and glutathione reductase. Also, same authors referred to the significant loss of chlorophylls and carotenoids as well as soluble proteins under the drought stress.

All the gained results confirmed that both oaks and hornbeam species share same physiological and biochemical mechanism to cope with water limitation, which is reflected in the decline of stomatal conductance, the increase of total antioxidant activity through the induction of biosynthesis of compounds with high antioxidant properties as well as the elevated accumulation of proline as an osmoregulatory amino acid. This all as a consequence leads to mitigation of lipid peroxidation and general oxidative stress which were induced significantly under the inspected drought stress. Considering all the facts, our main conclusion is that irrigation in urban areas could drastically improve the general fitness of the plants since in this study it was confirmed that irrigation beneficially affects plants on physiological and biochemical level, which enables them more feasible growth and development, which contributes to healthier environment, affects the microclimate, provides more shade and filters the air.

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Flower Bud Differentiation in *Quercus suber* L.

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ABSTRACT

Background and Purpose: Cork oak (*Quercus suber* L.) is one of the most important forest species growing in the Western Mediterranean region. This investigation intends to assess the timing of flowering differentiation of cork oak and contribute to the deepening of the knowledge about the process of the sexual reproduction of the species.
Materials and Methods: In 2010 four trees were selected (9, 14, 24, 25) from a plot of 25 trees located at Quinta da Serra, Portugal. A total of 240 buds were collected from these four trees, on three days (8, 14 and 23 March), from 4 branches per tree and 5 positions per branch for the assessment of meristem differentiation.
Results: Meristem differentiation analysed on the sampling days revealed there were only vegetative structures by 8 March; a few male and female primordia on 14 March; and fully differentiated reproductive structures on 23 March.
Conclusions: Flowering sex determination of cork oak occurs about one month before the flowering onset.

Keywords: bud histology, cork oak, flower sexual determination, meristem differentiation, phenology

INTRODUCTION

Cork oak (*Quercus suber* L.) is one of the most important forest species growing in the Western Mediterranean region and it provides the only natural and renewable product for making wine stoppers. Apart from stoppers, cork also provides raw-material for vast panoply of industrial products that enhance the great ecological value of cork oak for the Mediterranean ecosystem [1].

Sexual reproduction in cork oak is the key process to generate genetic diversity for its evolution and adaptation and the dynamics of the flowering processes plays an important role in gene flow and population kinship [2, 3].

Cork oak is a monoecious species with sub-continuous growth, annual and biennial fruiting, while the prevalent flowering occurs in spring in unisexual inflorescences. Atypical male and female flowering events may occur, especially the autumn / winter male flowering [4].

The reproductive cycle, flower morphology, as well as leaf and seed development have been studied by several authors for different *Quercus* species [5, 6]. Reproductive phenology for *Quercus suber* has been studied by Varela and Valdiviesso [2] and Varela *et al.* [3], but flowering differentiation timing has not been studied so far.

In a plot studied through long run observations on reproductive behaviour since 1993 [7, 8], we selected four trees with the aim to assess the timing of flower differentiation in cork oak, by identification of the internal structures of the buds. The results provide new insights useful in reproductive biology studies, flowering prediction and climatic influence on the reproductive process.

MATERIAL AND METHODS

Plant Material and Site Characterization

The studies were carried out, during 2010, on a permanent plot in the cork oak forest "Quinta da Serra" located in the centre of Portugal (38°29'14"N, 09°0'31"W, 116 m altitude) near Azeitão. The site's edaphoclimatic conditions are very favourable for cork oak. The stand comes from natural regeneration, it is irregularly spaced, unevenly aged, and is intensively managed for cork production. The climate is typically Mediterranean, smoothed by oceanic influence, with 4-5 months of drought, an average maximum temperature of 29.0°C, an average minimum temperature of 8.3°C and the mean annual rainfall of 690 mm.

The controlled and permanent plot includes 25 trees within an area of about 1.5 ha. The trees have been used for long run population genetic studies since 1993, analysing the reproductive behaviour at the level of flowering/fruiting ability and flowering phenology. Flower and fruit production is evaluated by degrees of 1, 2 and 3 [3]:

- degree 1 - null or negligible production of male flowers or fruits,
- degree 2 - about half of the productive part of the crown exhibits male flowers or fruits,
- degree 3 - the tree exhibits male flowers or fruits in large quantity.

For this study we chose four trees (9, 14, 24 and 25) with a discriminating pattern of reproductive profile characterized from 1993 to 2009 [7, 8], and assessed in terms of phenology, the amount of male flowering and acorn production (Figure 1).

Regarding bud burst and male flowering phenology, tree 24 was always the first to flower and above plot-average on male flowering quantity and acorn production; tree 14 was late in phenology, with a large quantity of male flowers and average in acorn production; tree 9 was intermediate in phenology, with a large quantity of male flowers and under plot-average in acorn production. Tree 25 was added to the plot in 2009 due to significant atypical female flowering by the end of June.

The choice of the sampling dates as well as the number of buds per branch (5) was based on our previous knowledge [7, 8] about the species and plot flowering behaviour. The study used a total of 240 buds. In each tree we picked four branches and five buds per branch on three days (8, 14, and 23 March) to a total of 60 buds per tree. On each tree the branches were randomly chosen and the buds were numbered from 1 to 5 (from top to bottom). After collecting these sampling data, we also collected the material during flowering season (13 May) needed for the assessment of gamete synchronization and embryo development (9 October).

Histology

Buds were fixed, during at least 48 hours, in FAA 1:1:18 - formalin:acetic acid:ethanol (70%) at 4°C [9, 10]. Hydration was achieved through progressive ethanol/water series. Buds were put into polyethylene glycol - PEG. Embedded specimens were sectioned on a rotary microtome Reichert in increments of 10 µm and were stained with tuluidine blue. Permanent mounts were prepared using Canada balsam for light microscope observation.

Digital images of the histological sections were obtained with a ProgRes® CapturePro 2.8 - JENOPTIK Optical Systems coupled to an Olympus BX41 microscope, and were electronically processed using the software ProgRes® Systeme - JENOPTIK Optical Systems.

RESULTS

Meristem Differentiation

Through histological observation we could identify four stages of meristem differentiation within the buds:

- vegetative (Figure 2a),
- differentiated for reproductive structures but sexually undetermined (Figure 2b),
- primordium of male flowers with anther primodia developed (Figure 2c),
- primordium of female flowers/vegetative, i.e. mixed buds which are in accordance with cork oak ovuliferous flowers' developmental behaviour that occurs always at the axil of the new leaves (Figure 2d).

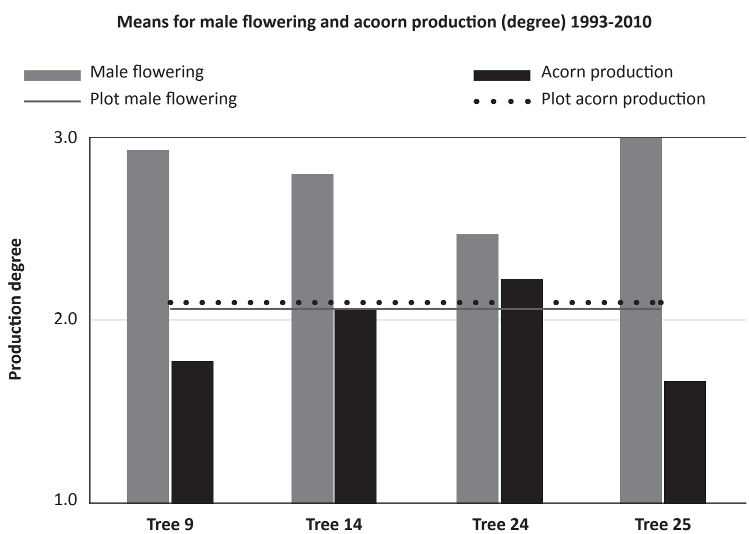

FIGURE 1. Male flowering and acorn production of *Quercus suber* trees selected for the study based on degree rate: degree 1 - null or negligible production of male flowers or fruits; degree 2 - about half of the productive part of the crown exhibits male flowers or fruits; degree 3 - the tree exhibits male flowers or fruits in large quantity. Trees are compared through the mean production from 1993 to 2010.

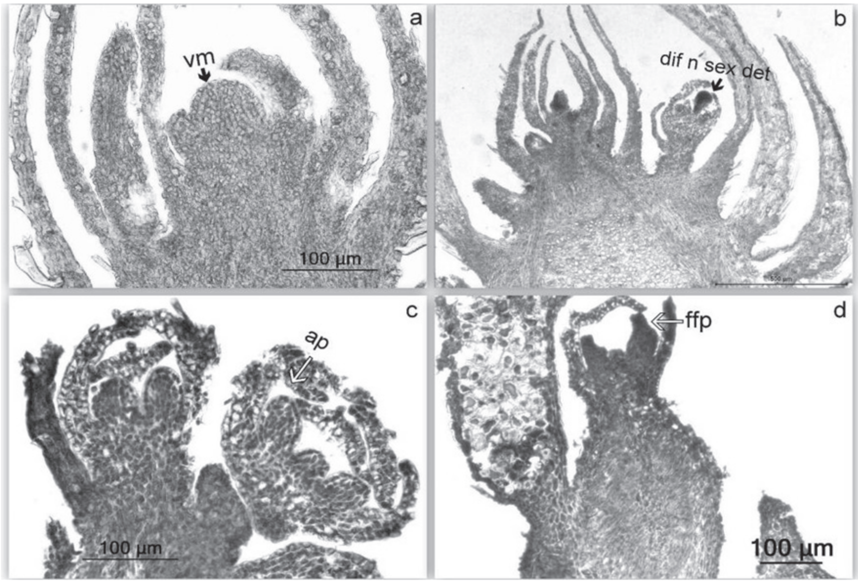

FIGURE 2. Histological longitudinal sections of key bud stages: **a)** vegetative bud (vm - vegetative meristem), **b)** differentiated bud without sexual determination (dif n sex det), **c)** primordial of male inflorescence (ap - anther primordium), **d)** female inflorescence (ffp - female flower primordium).

On 8 March, all the trees had meristematic activity dominated by leaf primordium (vegetative structures). A small part of the buds already had meristematic differentiation, but without sexual determination being therefore classified as "Sex-Undetermined". Sexual determination was patent only on a very small proportion of the buds for male flowers and only on trees 14 and 24 (Figure 3a, b). No sex differentiated structures were visible on buds in position 2 and female structures were patent only on buds in position 4. On this day tree 9 and tree 25 revealed to be the latest on sex flower determination.

On 14 March about 40% of structures were still "Sex-Undetermined" on trees 14, 24 and 25 (Figure 4a, b). Tree 9 had the smaller proportion of "Sex-Undetermined" structures and the higher amount of anther-primordia developed structures. On this day ovuliferous flowers were evident in all buds except in position 1. For all positions the proportion of "Sex-Undetermined" meristematic development was still significant.

On 23 March, all structures were fully determined on all four trees studied (Figure 5a, b). Undifferentiated structures were no longer present and sexual structures were already defined. Male flowering was dominant on buds in positions 2 and 4. Tree 9 kept the pattern of male flowering dominance over the ovuliferous structures, which is consistent with the pattern observed during the period of 1983-2010.

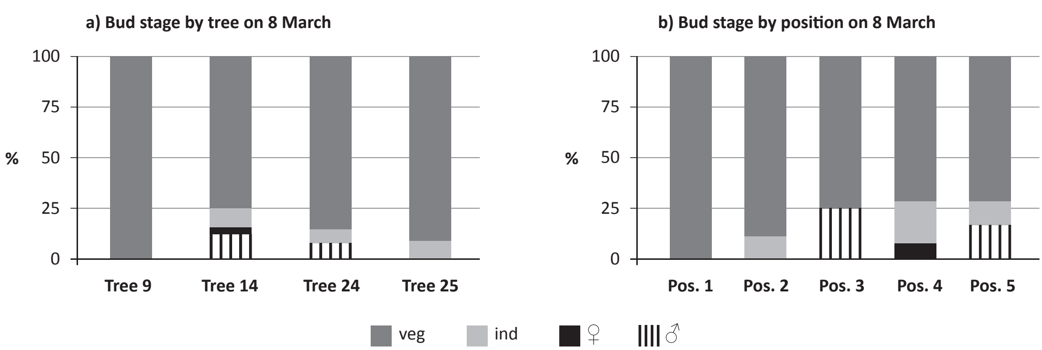

FIGURE 3. Quantification of bud determination comparing tree and bud positions (pos.) on a branch (veg - vegetative, ind - undifferentiated, ♀/veg - primordia of female inflorescences with vegetative buds, primordia of male inflorescences by 8 March 2010).

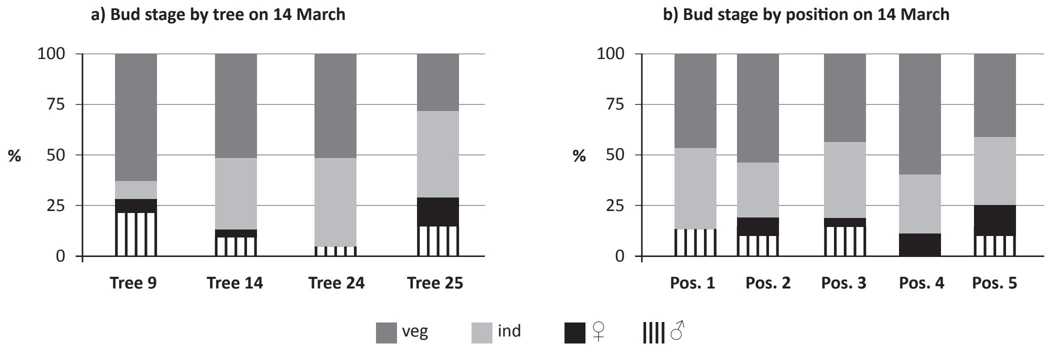

FIGURE 4. Quantification of bud determination comparing tree and bud positions (pos.) on a branch (veg - vegetative, ind - undifferentiated, ♀/veg - primordia of female inflorescences with vegetative buds, primordia of male inflorescences at 14 March 2010).

After the last samplings, we also collected the material during flowering season for the assessment of gamete synchronization and embryo development (between 13 May and 9 October).

On 13 May we found male flowers in different phenological stages, both on and between trees, although four trees maintained the characteristic time lag phenological profile. A part of male flowers were immature, before anthesys, having the tetrads visible (Figure 6a) and another part with dehiscent anthers had pollen grains fully developed (Figure 6b). On the same date female flowers were externally formed and receptive in general, but ovules were immature, exhibiting only primordia as patent in Figure 6c. On 9 October the fruits were not mature but the embryo was completely formed (Figure 6d) i.e. one or two months before acorn falling.

DISCUSSION

On 8 March, about 6-8 weeks prior to flower emergence, the meristematic activity was dominated by leaf primordia (vegetative structures) and only a few sex-determined structures were patent, with male dominance. Yet leaf primordia which were visible may envelop axillary meristem which will evolve for female flowers. On 14 March, differentiation towards sex determination was in progress, but the sex of many of the inflorescences remained of undetermined profile. Only on 23 March, about one month prior to the emergence of flowers, both male and female inflorescences were clearly sexually defined.

With the histological observations of samplings in May we could confirm the immaturity of the female gametophyte during the pollination phase [4]. In October we found that although the fruit was still in development, the embryo was fully formed.

Further observations over a period of several years on trees of different reproductive behaviour and under different climatic/weather conditions should be performed in order to obtain a comprehensive model for *Quercus suber*.

Since no signs of aborted structures from the opposite sex were visible at any flower primordia, we considered the hypothesis that cork oak's unisexual flowering is of 'type II' [11], i.e. sex determination occurs before the initiation of stamens and carpels.

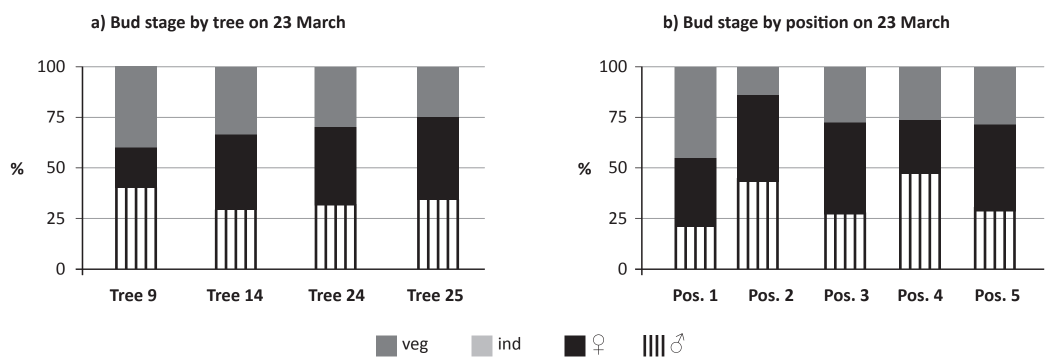

FIGURE 5. Quantification of bud determination comparing tree and bud positions (pos.) on a branch (veg - vegetative, ind - undifferentiated, ♀/veg - primordia of female inflorescences with vegetative buds, primordia of male inflorescences at 23 March 2010).

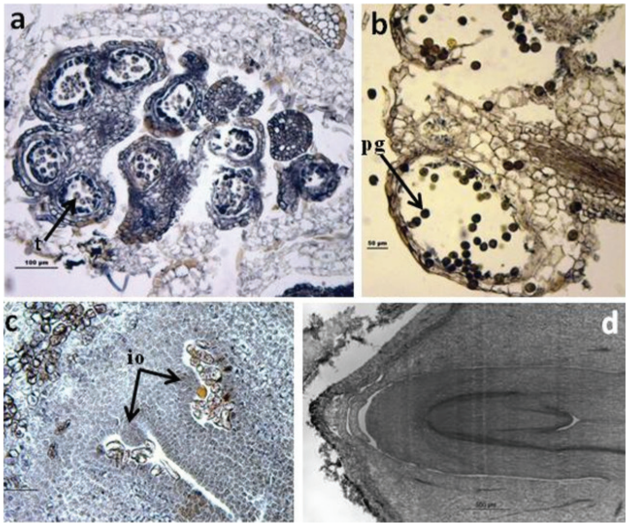

FIGURE 6. Histological sections on 13 May: **a)** male flower with tetrads (t), bar 100µm; **b)** pollen grains (pg) within an anther, bar 50µm; **c)** female flower with immature ovules (io), bar 50µm on 9 October; **d)** embryo completely formed, bar 500µm.

The results point out that the flowering sex determination in cork oak may occur very late devoid of well-defined differentiation season as it happens with the *Fagacea* species *Juglans regia* [12] and *Castanea sativa* [13] which is consistent with the sub-continuous growing profile of the species.

If the pattern observed in this study will remain in other regions of cork oak distribution, reliable flowering prediction by bud sampling, for further use on flowering genomics, fruiting preview, gender balance on seed-orchards, the management of effective size on conservation of genetic resources on endangered small populations, shall be performed only about one month before bud burst is foreseen.

CONCLUSIONS

The results indicate that at Quinta da Serra the flowering sex determination of cork oak occurs in close proximity to the flowering onset, i.e. about one month ahead, which is consistent with the sub-continuous growing profile of the species.

The results of the histological study confirmed the long-run phenological and reproductive profile of the selected trees, reinforcing that the behaviour is systematic and most likely under genetic control. Indeed the tree 24 was the first to begin bud differentiation which is in accordance with its early flowering phenology and tree 9, whose flowering profile is predominantly male, was the one with higher percentage of male primordia.

We consider that the results provide useful insights for the management of acorn production, the conservation of genetic resources, the adaptation of the species under climate change scenarios and evolution.

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