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Biomass assessment for sustainable bioenergy utilization in a Mediterranean forest ecosystem in northwest Greece

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ABSTRACT

Worldwide bioenergy proportion from biomass for heat, electricity and transportation fuels is increasing since biomass conversion through various processes can supply solid, gas and liquid products. As Europe's energy policy integrates renewable sources to a great extent, an efficient smart-grid policy in the Euro-Mediterranean area highlights the pivotal role of lignocellulosic biomass exploitation in a rational way. Thus, biomass quantification and qualification are a prerequisite in Mediterranean region, of primeval forests and fragmented agroforestry landscapes. Sustainable management of oak coppice forests for bioenergy products is essential, as they play a vital role in Mediterranean landscapes and their resprouting ability ensures biomass productivity. Detailed field sampling design and dimensional analysis techniques between various tree parts and biomass content focus on such an ecosystem. Thus power functions were revealed with high variability explanation particularly in aboveground biomass, where the diameter at tree's breast height was an impartial and accurate predictor. Biomass conversion technique's requirement for moisture content and the proportion of each tree component in total biomass distribution, combined with the reliable biomass prediction model were applied in a theoretical harvesting scenario in order to assess the residual potential for energy purposes.

1. Introduction

In worldwide biomass production, forest ecosystems play a key role as they contribute to this chain about 68% (Apostolakis et al., 1987). Globally, bioenergy from biomass for heat, electricity and liquid fuels accounts for 14% of the total energy consumption (Nicholls et al., 2009; Vamvouka, 2009). One recent report predicts an increase in the global demand for biomass at a compounded annual rate of 9% by 2020 (Pfeifer, 2013). Internationally, total biomass size which is traded has not been determined but it is estimated at a minimum of 50 PJ yr^{-1} (Lunnan et al., 2008). The wood is utilized and stored in various ways and thus there are many formations of biofuels (Strehler, 2000). In the developing world, biomass from the agroforestry sector contributes more to the primary energy production compared to the developed countries. In the European Union, the primary energy consumption from biomass is just 3% of the entire energy consumption (Röser et al., 2008). Until 2020 the 20% of the total European energy consumption will come from renewable resources (Suchomel et al., 2012). Many European countries implement Renewable Energy Sources (RES) for their energy needs to an important degree. Europe seeks to take advantage of a rational forest biomass exploitation and management, investing more in innovation and research in the forest biomass sector. Forest biomass exploitation and utilization in the Euro-Mediterranean region could not only prevent forest fires on account of high biomass accumulation in ecosystems, but also the higher rates of unemployment. Bioenergy is considered to play a significant role in order to expand the share of local and natural energy resources (Zambelli et al., 2012), thus quantification of local forest biomass is a key point in start-up pursuit.

The quantitative research of relative growth and its correspondence to other components in many scientific fields has a reference time since the beginning of 20th century (Huxley, 1932). The attempt of aboveground tree biomass estimation is served by

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various biomass equations. In environmental, biological and chemical sciences, the research about the relationship between a specific component of a structure and the entire structure is called allometry. Accordingly the functions that estimate the dry weight of a tree from the stem diameter or the crown length of the tree are called allometric relationships and thus have wide applications in biomass research. In addition, these equations are a prerequisite in order to assess the consequences on nutrient balances under various harvesting scenarios associated besides with biogeochemical cycle studies. During a comprehensive reference search, in vast scale, the total number of compiled aboveground biomass equations is 279. Twenty of these developed in Europe (Zianis and Mencuccini, 2004). This indirectly indicates a scarcity of data for this region and especially a deficiency of biomass equations for the Mediterranean area. Accurate biomass equations can contribute through detailed biomass potential maps to a smarter land use policy. Reliable biomass quantification and allocation modeling can assist towards a more cost-effective supply chain for managing biomass feedstock, since 56–76% of the operating cost of the total biomass utilization system comes from logistics (Rentizelas et al., 2009). Research-based tools, ecological engineering actions and pertinent approaches are significant to many applied processes and functional tasks (Mitsch and Jørgensen 2003; Yang et al., 2015). Also unbiased biomass models are essential in evaluating forest's productivity state, structure and sequestered carbon content.

In the Mediterranean region, coppice stands have notable existence (Greece 48%, Italy 63%) in the total forest area, which at the same time is evidence of low quality and quantity production (Grigoriadis and Zagas, 2005). At the same time, there is an extremely small number of equations for oak trees and in numerous regions are still missing (Cienciala et al., 2008). Not only in central Europe (Suchomel et al., 2012) but also internationally (Aguilar et al., 2012), there were no published equations for oak coppice stands until the very recently. Oak has the highest density in stem wood (571 kg/m^3) at 50% moisture content compared to Spruce, Beech, Pine, Aspen and Birch (Schmidt, 2003), in addition to the highest heating value (2467 kWh/m^{-3}) among them (Röser et al., 2008).

Greek fuelwood production is estimated at an average of 450.000 tons of oil comparable (Koutroumanidis et al., 2009). Greece is a typical Mediterranean country, on the southeastern edge of Europe, which is dependent on external energy procurement. By 2020, Greece is obliged to integrate 18% of energy from renewable sources in gross final energy consumption compared to the 6.9% that the country had reached in 2005 (EU.Directive, 2009). Countries with high ranking renewable energy share (EU.Directive, 2009) like Sweden, Finland and Austria have implemented biomass in their total energy policy. In the Greek territory, biomass covers 0.2% of the total energy portion or 4% of the renewable energy part (Report, 2008), and despite the fact that forests cover 26.5% of the country (Dafis, 2010), the share of forestry in the national GDP is quite low (0.15%) (Koutroumanidis et al., 2009). Greece is a country with an agroforestry framework with considerable unexploited forest biomass quantities which can be used as a competitive feedstock for bioenergy basis. Similarly, a recent study in other countries estimated that only 12% of silviculture residues are harvested (Yoshida, 2012). Forest biomass could be a significant renewable source in providing heat and energy in rural regions (Bungart et al., 2000). In small scale investments for biomass utilization many socio-economic aspects are benefited.

Greece's energy trading policy and the needed preservation of its primeval forests endorse extensive tools for integrating small scale decentralized energy systems and rational biomass exploitation in a sustainable way. In order to achieve the above golden mean in the future, we set as the primary objective of the current study the development of an extremely rare, practical and reliable biomass equation for the quantification of above ground biomass for sprouting oaks, which represent a significant share of the Greek forests. In addition, we focus on experimental research on allometric relationships between various independent tree variables and different tree biomass compartments, like unmerchantable tree tops which serve in a more applicable way biomass harvesting for bioenergy purposes or leaf biomass which keep nutrient balances in ecosystem. Finally, results from literature review are compared and stand productivity is surveyed through stem discs analysis.

Fig. 1. The study area (Lat: 39°56′41.4″ Long: 21°18′39.5″) in Gorgiani oak forest encompassed in an imaginable rectangle of 1700 ha with a mean elevation of 924 m. It is part of Grevena regional division (purple colour).

2. Materials and methods

2.1. Study area

Our study area is the Gorgiani oak forest (Lat: 39°56′41.4″ Long: 21°18′39.5″) is located in regional division of Grevena (Fig. 1) in the West Macedonia region of Greece, which is part of the Epirus-Western Macedonia decentralized administration. The West Macedonia region had 31.8% unemployment in 2013, the highest rate among all regions in Greece (ELSTAT, 2013). Generation of employment opportunities is one of the benefits of biomass utilization (Ilavský and Oravec, 2000). Also there is a growing demand for autonomous and decentralized bioenergy provision in rural regions (Gruenewald et al., 2007). A considerable quantity of woody stock in Greece is located in the decentralized administration of Epirus-Western Macedonia to which Grevena belongs. Thus forest bioenergy can support this local economy. Ecological engineering has the intention of designing ecosystems in a sustainable manner that facilitates the incorporation of society to its natural environment for their common benefit (Mitsch and Jørgensen, 2004; Mitsch 2012, 2014). The benefits for the social and economic structure from a finite amount of harvested biomass could be increased, if the effectiveness of its utilization would be magnified (Haberl and Geissler, 2000). Gorgiani's oak forest is positioned amidst four villages with a total of 1300 residents.

From phytosociological approach of the Braun-Blanquet scale, Gorgiani's oak forest belongs to the sub-mediterranean vegetation zone of *Quercetalia pubescentis,* in the sub-zone of *Quercion confertae* and the growing zone of *Quercetum confertae*. This sub-zone of xerophilous deciduous forests takes up a significant space in Greek forests. It is an interesting Greek oak forest, with resprouting ability, as it encompasses the 3 most important oak species of Greece. *Quercus conferta*, which is the most common in this area and also the dominant in our study area. *Quercus pubescens* and *Quercus petraea* are following after in a sparsely frequency rate.