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Research paper

Estimation and dynamics of above ground biomass with very high resolution satellite images in *Pinus pinaster* standsAna Cristina Gonçalves^{a,*}, Adélia M.O. Sousa^b, Paulo G. Mesquita^c^a Departamento de Engenharia Rural, Escola de Ciências e Tecnologia, Instituto de Ciências Agrárias e Ambientais Mediterrânicas (ICAAM), Instituto de Investigação e Formação Avançada, Universidade de Évora Apartado 94, 7002–554 Évora, Portugal^b Departamento de Engenharia Rural, Escola de Ciências e Tecnologia, Instituto de Ciências Agrárias e Ambientais Mediterrânicas (ICAAM), Centro de Inovação em Tecnologias de Informação (CITI), Instituto de Investigação e Formação Avançada, Universidade de Évora Apartado 94, 7002–554 Évora, Portugal^c Departamento de Engenharia Rural, Escola de Ciências e Tecnologia, Universidade de Évora Apartado 94, 7002–554 Évora, Portugal

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ABSTRACT

Biomass estimation is a tool for evaluating stands and forest dynamics. Traditional indirect methods use forest inventories and allometric functions at tree level to evaluate biomass at plot level, and an extrapolation method to assess an area. The goal of this study was the development of allometric functions for *Pinus pinaster* with crown horizontal projection derived from very high spatial resolution satellite images as an independent variable, as well as their application to the analysis of above ground biomass dynamics. The fitted functions show a good performance. The function used to estimate the above ground biomass per grid in 2004, 2007 and 2011 for the study area enable the evaluation of their temporal dynamics. From 2004 to 2007 it decreased in 90.5% of the study area, due to forest fires and cuts to control the pinewood nematode; from 2007 to 2011 increased in 45.6% and decreased in 51.6%, the latter corresponding to cuts to control the aforementioned disease. In 76.4% of the burnt areas, natural regeneration resulted in an increase of above ground biomass. The method's main advantages are the simultaneous evaluation of small or large areas and, when implemented in a GIS, it allows straightforward monitoring over a short period of time.

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1. Introduction

Maritime pine (*Pinus pinaster* L. Aiton) is native to the western Mediterranean basin and southwest coast of Europe [1,2] and distributed from Portugal to Greece [3]. In Portugal it is the predominant species in terms of area, occurring from the north to the south, preferring climates with stronger Atlantic influence, especially northern and coastal areas. Its main product is timber, though resin can also be considered as a second product. It is a pioneer species, primarily because it is frugal in terms of soil. It is a shade intolerant species occurring in stands with low crown cover and leaf area index when compared with other pine species. Natural regeneration is easy, with abundant annual fruit production and high rates of germination and establishment. The stands can also be installed artificially, with an initial density varying from 1000 to

2000 ha⁻¹, managed for timber production, with a final density of between 150 and 350 ha⁻¹. More frequently, in Portugal, the stands are pure even-aged, though pure uneven-aged and mixed stands can also be found [3].

According to the Portuguese National Forest Inventory, maritime pine stands account for 27.9% of the forest area. Their density ranges from less than 300 to more than 1500 ha⁻¹, with 54% of the area with less than 300 ha⁻¹ and 36% between 300 and 900 ha⁻¹; crown cover of pure stands is $\geq 50\%$ in 71% of the area and between 30% and 50% in 24% [4]. The biomass (dry weight), estimated with allometric functions of Tomé et al. [5] is 49.8 Mg ha⁻¹ with an error of 15.8% for pure stands, varying among regions. In central Portugal it is 59.7 Mg ha⁻¹ with an error of 7.0%, while in the southwest it is 32.3 Mg ha⁻¹ with an error of 16.8% [4].

In Portugal the maritime pine area increased up to the middle of last century and then diminished for two main reasons: forest fires and pinewood nematode. Forest fires are frequent in Portugal especially during the dry hot season, occurring mainly from May to September, and consuming large areas of forest. Maritime pine

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