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Pinus pinea above ground biomass estimation with very high spatial resolution satellite images

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Abstract. Above ground biomass is frequently estimated with forest inventory data and an extrapolation method for the per unit area evaluations. This procedure is labour demanding and costly. In this study above ground biomass functions, with crown horizontal projection as the independent variable, were developed. Multi-resolution segmentation method and object-oriented classification based on very high spatial resolution satellite images, were used to obtain the area of tree crown horizontal projection for *Pinus pinea* L. A set of inventory plots were measured and with existing allometric functions for this specie above ground biomass per tree and per plot were calculated. The two data sets were used to fit linear functions to estimate above ground biomass for individual plot and for their cumulative values. The results show a good performance of the models. Errors smaller than 10%, correspond to stand areas greater than 1.4 ha. These functions have the advantages of estimating above ground biomass for all the area under study or surveillance, not requiring forest inventory; allowing monitoring in short time periods and easily implemented in a geographical information system environment.

Keywords. Multi-resolution segmentation – Object-oriented classification – Vegetation mask – Crown horizontal projection – Regression – Biomass estimation.

I – Introduction

Pinus pinea L. is a native of the Mediterranean, occurring from Portugal to Syria (Correia and Oliveira, 1999). In Portugal it is present from North to South, preferring the climates with Atlantic and Mediterranean influence, especially the southern coastal areas. The stands have three main products, namely fruit, timber and resin, and their density varies according to the main production. Presently the first production has more interest due to higher income of the cones when compared with the latter two (*e. g.* Correia *et al*., 2010; Mutke *et al*., 2005a). This specie is shade intolerant, with a leader shoot apical dominance weaker than in other conifers which determines their umbrella shape crown (Mutke *et al*., 2012) and is managed in open growth stands to promote crown growth as flower buds and, consequently, fruit production occurs mainly in the outer crown annual shoots (Mutke *et al*., 2005b).

The Portuguese National Forest Inventory (IFN5, 2010) estimated an area of pure, dominant and young plantations of *Pinus pinea*, of 130,300 ha, corresponding to about 4% of the forest area, with about 73% of the stands situated in Alcácer do Sal region, southern coastal Portugal. Ground cover of pure stands is larger than 50% in 64% of the area and between 30% and 50% in 20% of the area. About 52% of the stands have areas larger than 10 ha, 34% between 2 ha and 10 ha and 14% between 0.5 and 2 ha. The total biomass (aerial and root) for the Alentejo region is 47.6 t/ha with an error of 20.3% for pure stands and 5.1 t/ha with an error larger than 40% for plantations (IFN5, 2010).

Biomass allometric functions at tree level have been developed for *Pinus pinea* for Portugal (Correia *et al*., 2010; Correia *et al*., 2008), Spain (Ruiz-Peinado *et al*., 2011) and Italy (Cuttini *et al*., 2013; Tabacchi *et al*., 2011; Cutini *et al*., 2009).

The purpose of this study is to provide a simple tool, to assist stakeholders, researches and forest technicians, to quantify above ground biomass, regardless of the existence of inventory data, which can be applied both at small and large scales. The objective is the development of allometric functions to estimate above ground biomass as a function of crown horizontal projection per plot and their cumulative values using very high spatial resolution satellite image data for *Pinus pinea* monospecies stands.

II – Materials and methods

The study area, ca. 35 km^2, is located in coastal southern Portugal between Alcácer do Sal and Setúbal (geographical central coordinate of 8° 40’ 28.20’’W and 38° 27’ 45.71’’N). The region is characterized by a Mediterranean climate, and is mainly occupied by *Pinus pinea* and *Quercus suber*, in both pure and mixed stands.

A WorldView2 image (June, 2011) with a spatial resolution of 0.5 m was acquired for this study.

The image is composed by four multispectral bands, three in the visible region (blue, green and red) and one in the infrared region (near-infrared). Ground control points (17 points, evenly distributed by the image) obtained with Global Navigation Satellite System (GNSS) and geodetic vertices, identified on the ground and in the image were used to orthorectified and geometrically correct the image, with ENVI 4.8 (ENVI, 2009). The Root Mean Square Error (RMSE) of the geometric correction was 0.30 m. The radiometric correction was carried out with the dark object subtraction method (Chavez Jr, 1988) with the conversion of the images digital numbers (DN) to Top of Atmosphere (ToA) reflectance and to soil reflectance through the atmospheric correction.

Multi-resolution segmentation method with the Contrast split segmentation algorithm applied in *eCognition* software, version 8.0.1 (Definiens Imaging, 2010), which used as an auxiliary band the Normalized Difference Vegetation Index (NDVI) generated a vegetation mask. The vegetation mask was composed by objects that delimit the tree crowns and separates them from the other land uses. The object-oriented classification with nearest neighbour method was applied to separate the forest species (Sousa *et al*., 2015; Sousa *et al.*, 2010), which in this study were *Pinus pinea*, *Pinus pinaster* and *Quercus suber*.

An area of 2885 ha was selected from the satellite image for the analysis. A square grid of 45 m x 45 m (2025 m^2) was overlaid to the area. The crown horizontal projection of each grid (CHP_{ps}) was calculated using ArcCatalog and ArcMap software version 10, (ESRI, 2010). Grids were classified according to forest species composition and ground cover (GC_s, defined as the percentage of area occupied by the crown horizontal projection of the trees in relation to the grid area). A grid was considered *Pinus pinea* monospecies when all the individuals were of this specie.

The design of the forest inventory was a random stratified sampling by proportional allocation, with strata defined as function of ground cover, namely 10-30%, 30-50% and >50%.The dataset of the forest inventory is composed of 33 monospecies plots of *Pinus pinea*, 5 in the first stratum, 18 in the second and 10 in the third, with a sampled area of 6.7 ha. In each plot, for all the trees with diameter at breast height larger than 5 cm, this measure, total height and crown radii (North, South, East and West directions) were measured (Avery and Burkhart, 1994). The trees geographical location was recorded by a. Tree crown horizontal projection (CHP_t) was calculated as a circle. Its radius is the arithmetic mean of the crown radii measured. The plot crown horizontal projection (CHP_p) has the sum of CHP_t).The tree above ground biomass (W) was calculated using the allometric functions of Correia *et al.* (2008), as the sum of wood (*ww*), branches (*wbr*), leaves (*wl*) and bark (*wb*) biomass ($W = ww + wbr + wl + wb$).

The statistical analysis was based on a correlation analysis with the Spearman test, as normality assumption could not be met (evaluated with Shapiro-Wilk test), and on the linear regression. It was assumed that a null value of above ground biomass corresponds to a null value of crown horizontal projection ($W = \beta x$, where β is the slope). The linear functions were was fitted with ordinary least square linear regression method with the crown horizontal projection calculated from satellite image data as independent variable and above ground biomass estimated from the forest inventory as dependent variable, for their individual plot and cumulative plot values. The allometric functions goodness-of-fit were evaluated with the sum of squares of the residuals (SQR), the coefficient of determination (R^2), the adjusted coefficient of determination (R^2_{aj}). It is recommended that validation is done with an independent set of data. When that is not possible Paulo *et al*. (2015), Myers (1986) and Clutter *et al*. (1983), suggest using predicted residual error. The sum of its square values (PRESS), and the sum of its absolute values (APRESS) as well as their average values (PRESSm and APRESSm), were used as the validation test. The closer to the null value of residuals, the better is the model. Error was evaluated by $error_i$ (%) = $((\hat{y}_i - y_i)/y_i)$ x 100 (where $\hat{y}_i$ and y_i are the estimated and calculated above ground biomass, respectively). Statistical analysis was implemented in R statistical software (R Development Core Team, 2012).

III – Results and discussion

The multi-resolution segmentation and the object oriented classification processes resulted in a vegetation mask with high accuracy (Fig. 1). The agreement between the classification by forest species and the ground truth, evaluated with the Kappa statistics (Congalton *et al*., 1983), was 79% while the global precision was 90%.

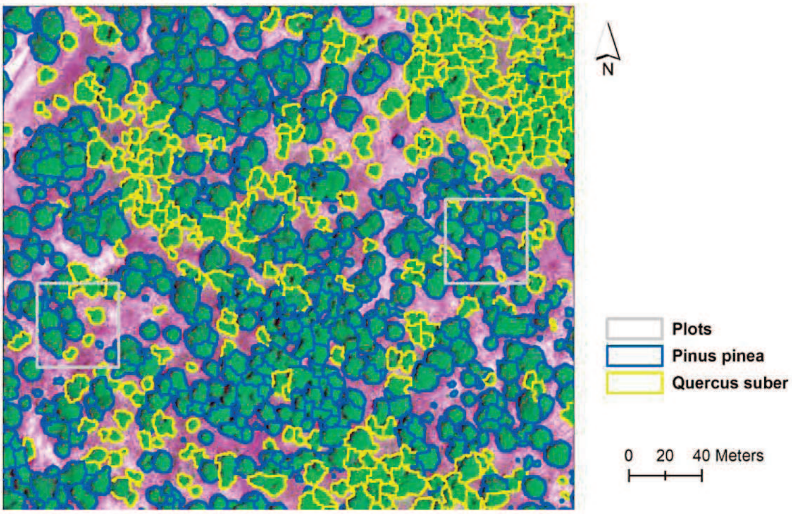

Fig. 1. Illustration of the vegetation mask by forest species over a WorldView-2 image with false colour composite (RGB = red, NIR and blue) and two inventory plots.

The plots have a mean number of trees per hectare of 71 (SD = 23), a mean Chp_{ps} of 885.3 m^2 (SD = 355.1) and a mean W_p of 11792.6 kg (SD = 4200.5). The Spearman's correlation coefficients show that there are strong positive correlations between W and CHP_t (0.851), W_p and CHP_p (0.724), and W_p and CHP_{ps} (0.651). Relation between W_p and CHP_{ps} reflects, at least partially, the inclusion of small patches of soil pixels between tree crowns and also the inclusion of mixed pixels, soil/vegetation and shadow/vegetation in the vegetation mask (Ke and Quackenbush, 2011), which originate a higher area of crown horizontal projection obtained from satellite image when compared with the one of inventory data.

The fitted functions of above ground biomass per plot (W_{ps}) and the cumulative above ground biomass per plot (W_{psc}) have statistical properties that are indicative of their good performance (Table 1), denoted by the large R^2_{aj} and close to zero validation statistics. The variability of the relation of crown horizontal projection and above ground biomass per plot (Fig. 2a) is rather large. This is probably due to *Pinus pinea* growth habit and the competitive relations with their neighbours. Considering for example seven plots with above ground biomass between 40-50 t, the number of trees per hectare varies between 54 and 99 trees/ha, the basal area per hectare between 7.0 m^2 and 8.6 m^2 and ground cover between 17.2% and 48.0%. Spatial distribution pattern in each plot can partially explain the variation in the relation between above ground biomass and crown horizontal projection. It is in the plots where the trees have the crowns touching their neighbours that the relation between CHP and W is smaller while the plots with most of the trees in free growth the inverse occurs. In fact this specie is one of the few pines with weak epinastic control that develops quite wide crowns (Mutke *et al*., 2012). Adult trees can reach 16-20 m of crown diameter. In our study the wider crowns have 15 m of crown diameter. The variation between above ground biomass and crown horizontal projection is related to the available aerial growing space. The trees surrounded by neighbours tend to develop competitive relations, in which high or low shade and branch abrasion, as referred by Oliver and Larson (1996), are the main driving factors. This is especially noticeable in shade intolerant species like *Pinus pinea*, which tend to show crown shyness thus inverting the relation between wood and branch biomass. In opposition, when developing in open growth tend to expand widely their crowns resulting in a higher proportion of branch biomass.

Table 1. Statistical properties of the allometric functions

Allometric function	SQR	R^2	R^2_{aj}	PRESS	APRESS	PRESSm	APRESSm
$W_{pss} = 12.4076 \times CHP_{pss}$	551305965	0.893	0.890	0.000000239	0.0023942	0.000000007	0.000073
$W_{pscs} = 14.1471 \times CHP_{pscs}$	7477064463	0.995	0.995	0.000000006	0.0003334	0.0000000002	0.000010

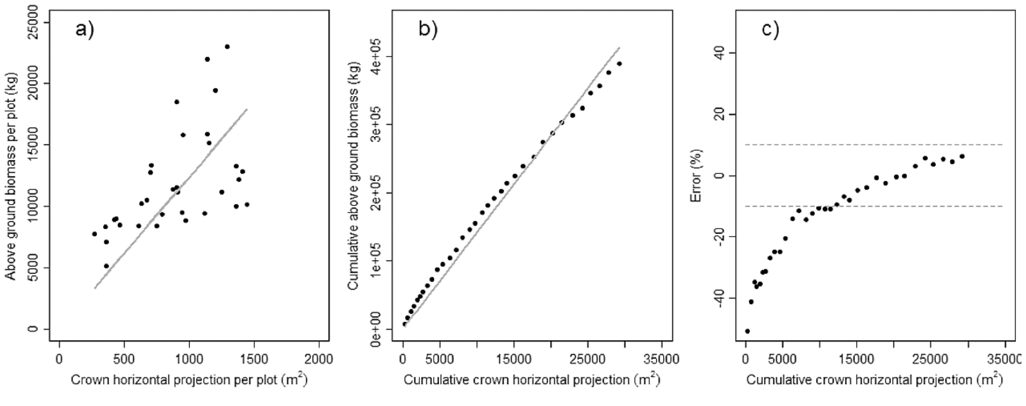

Fig. 2. (a) Crown horizontal projection per tree *vs* above ground biomass (W_{ps}); (b) cumulative crown horizontal projection *vs* cumulative above ground biomass (W_{psc}); and (c) error.

The overall error is 15.4% for W_{ps}, smaller than that of the National Portuguese Forest Inventory (IFN5, 2010). Figure 3 illustrates the estimation of above ground biomass with W_{ps}. The cumulative above ground biomass estimated with Correia *et al*. (2008) functions and the estimated with W_{psc} show some deviation, both negative and positive (Fig. 2b) and errors >20% up to 5000 m^2 of cumulative crown horizontal projection areas (Fig. 2c). The error decreases up to 25000 m^2 stabilising afterwards, and is smaller than 10% for crown projection areas larger than 10000 m^2. Considering the mean crown horizontal projection area obtained from satellite image data (885.3 m^2) and the mean above ground biomass per plot (11792.6 kg), to an error of 10 %, correspond stand areas of 1.4 ha. Noteworthy is that these stand areas cover more than 86% of the stands of this specie.

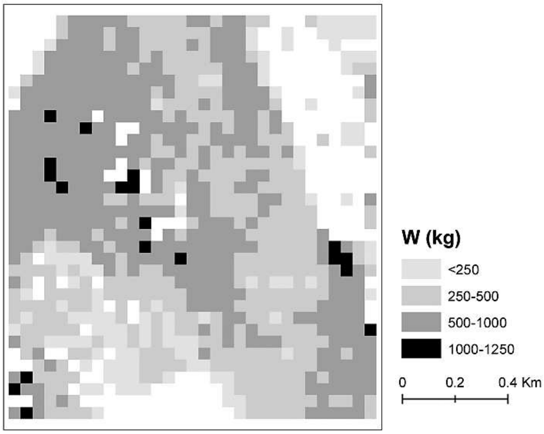

Fig. 3. Illustration of above ground estimation with W_{ps}.

IV – Conclusions

Satellite data with very high spatial resolution images enables above ground biomass estimation, since a vegetation mask per forest species can be obtained with accuracy. Above ground biomass estimation with allometric functions, with crown horizontal projection as the independent variable, can be used for *Pinus pinea* monospecies stand areas equal to or larger than 1.4 ha for an error equal to or smaller than 10%. When compared with the estimation with forest inventory data and an extrapolation method for the per unit area evaluations, three main advantages can be pointed out: all the area can be evaluated without extrapolation; it allows short time periods monitoring; and can be easily implemented in a geographical information system environment.

Nonetheless some limitations can be pointed out. The date of the images acquisition is of the utmost importance. For the Mediterranean region it is during the dry season (June to September) that the higher contrasts between the tree crowns and the understory vegetation are attained, enabling to derive the vegetation mask, by forest species, with high accuracy. Another limitation is that the scenes of WordlView-2 have a swath of 16.4 km at nadir which makes it difficult to evaluate large areas as several scenes have to be worked.

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References

Avery T.E. and Burkhart H.E., 1994. *Measurements*. 4th ed. New York: Macgraw-Hill, Inc.

Chavez Jr P.S., 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing of Environment,* 24(3), pp. 459-479.

Clutter J.L., Fortson J.C., Pienaar L.V. Briester G.H. and Bailey R.L.,1983. *Timber Managment: A quantitative approach*. John Wiley & Sons, Inc, New York.

Congalton R.G., Oderwald R.G. and Mead R.A., 1983. Assessing Landsat classification accuracy using discrete multivariate statistical techniques. *Photogrammetric Engineering and Remote Sensing*, 49, pp. 1671-1678.

Correia A.C., Tomé M., Pacheco C.A., Faias S., Dias A.C., Freire J., Carvalho P.O. and Pereira J.S., 2010. Biomass allometry and carbon factors for a Mediterranean pine (*Pinus pinea* L.) in Portugal. *Forest Systems,* 19, pp. 418-433.

Correia A.C., Faias S., Tomé M., Evangelista M., Freire J. and Carvalho P.O., 2008. Ajustamento simultâneo de equações de biomassa de pinheiro manso no sul de Portugal. *Silva Lusitana* 16(2), pp. 197-205 [in Portuguese].

Correia A.V. and Oliveira, A.C., 1999. *Principais espécies florestais com interesse para Portugal: zonas de influência mediterrânica*. Direcção-Geral das Florestas, Estudos e Informação, 318 [in Portuguese].

Cutini A., Hajny M., Gugliotta O., Manetti M. and Amorini E., 2009. Effect of stand structure on models for volume and aboveground biomass assessment (Castelfusano pinewood, Roma), *Forest@,* 6(1), pp. 75-84.

Cutini A., Chianucci F. and Manetti M.C., 2013. Allometric relationships for volume and biomass for stone pine (*Pinus pinea* L.) in Italian coastal stands, *iForest,* 6, pp. 331-337.

Definiens Imaging, 2010. eCognition Developer 8.0.1 Reference Book, http://www.definiens.com (Accessed 23 October, 2012).

Envi, 2009. *Reference Guide – Exelis Visual Information Solutions*. Boulder, Colorado: Exelis Visual Information Solutions, http://www.exelisvis.com/portals/0/pdfs/envi/envi_zoom_user_guide.pdf. (Accessed 27 November, 2012).

Esri, 2010. *ArcGIS Desktop: Release 10*. Redlands, CA: Environmental Systems Research Institute, http://www.esri.com. (Accessed 23 January, 2013).

IFN5, 2010. *Inventário Florestal Nacional. IFN5 2005-2006*. Portugal Continental. Lisbon: Autoridade Florestal Nacional. [in Portuguese].

Ke Y. and Quackenbush L.J., 2011. A comparison of three methods for automatic tree crown detection and delineation from high spatial resolution imagery. *International Journal of Remote Sensing*, 32:13, pp. 3625-3647.

Mutke S., Calama R., González-Martínez S.C., Montero G., Gordo J., Bono D. and Gil L., 2012. Mediterranean Stone Pine: Botany and Horticulture, *Horticultural Revie*ws, 39, pp. 153-201.

Mutke S., Gordo J. and Gil L., 2005a. Cone Yield Characterization of a Stone Pine (*Pinus pinea* L.) Clone Bank. *Silvae Genetica*, 54(4-5), pp. 189-197.

Mutke S., Gordo J., and Gil L., 2005b. Variability of Mediterranean Stone pine cone production: Yield loss as response to climate change. *Agricultural and Forest Meteorology,* 132, pp. 263-272.

Myers R.H., 1986. *Classical and modern regression with applications*. Duxbury Press, Chicago.

Oliver C.D. and Larson B.C., 1996. *Forest stand dynamics*. Update editions. John Wiley & sons, Inc.

Paulo J.A., Palma J.H.N., Gomes A.A., Faias S., Tomé J. and Tomé M., 2015. Predicting site index from climate and soil variables for cork oak (*Quercus suber* L.) stands in Portugal. *New Forests*, 46, pp. 293-307.

R Development Core Team, 2012. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, http://www.R-project.org. (Accessed 21 February, 2013).

Ruiz-Peinado R., Rio M. del and Montero G., 2011. New models for estimating the carbon sink capacity of Spanish softwood species. *Forest Systems*, 20, pp. 176-188. doi: 10.5424/fs/2011201-11643.

Sousa A.M.O., Mesquita P.A., Gonçalves A.C. and Silva J.R.M., 2010. Segmentação e classificação de tipologias florestais a partir de imagens Quickbird**.** *Ambiência*, 6 (Ed. Especial), pp. 57-66.

Sousa A.M.O., Gonçalves A.C., Mesquita P. and Silva, J.R.M., 2015. Biomass estimation with high resolution satellite images: A case study of *Quercus rotundifolia*. *ISPRS Journal of Photogrammetry and Remote Sensing*, 101, pp. 69-79.

Tabacchi G., Di Cosmo L., Gasparini P. and Morelli S., 2011. *Stima del volume e della fitomassa delle principali specie forestali italiane. Equazioni di previsione, tavole del volume e tavole della fitomassa arborea epigea*. Consiglio per la Ricerca e la Sperimentazione in Agricoltura, Unità di Ricerca per il Monitoraggio e la Pianificazione Forestale, Trento, Italy, p. 412.