ABOVE GROUND BIOMASS FUNCTIONS WITH VEGETATION INDICES FOR MULTIPLE USE SYSTEMS OF TWO EVERGREEN OAKS

Adélia M. O. de Sousa[a], Ana Cristina Gonçalves[b], Paulo G. Mesquita[c], Fabrício Macedo[d]

[(a)] 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. E-mail: asousa@uevora.pt
[(b)] 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. E-mail: acag@uevora.pt
[(c)] Departamento de Engenharia Rural, Escola de Ciências e Tecnologia, Universidade de Évora, Apartado 94, 7002 – 554 Évora, Portugal. E-mail: paulomesquita00@gmail.com
[(d)] Centro de Ciências Agrárias, Departamento de Solos e Engenharia Rural, Universidade Federal da Paraíba (UFPB), Rodovia PB-079, CEP: 58397-000, Areia - PB, Brasil. Tel: (83) 998599169. E-mail: fabriciollmacedo@yahoo.com

INTRODUCTION

The aim of this study is the development of allometric functions of above ground biomass that can be used in both monospecies and multispecies stands of the two evergreen oaks, whose independent variable are vegetation indices derived from high spatial resolution satellite image (QuickBird). As some differences can be found between the stand parameters of monospecies stands of cork oak or holm oak and multispecies stands of these two evergreen oaks, it was also considered the development of allometric functions where stand composition is included as dummy variables.

MATERIAL AND METHODS

The QuickBird image (August, 2006) with a spatial resolution of 0.70 m, had the following main processing steps:

- geometric correction using ground control points , atmospheric correction, conversion of the digital numbers to ToA reflectance;
- the vegetation mask, resulted from the application of object-oriented classification image methods;
- vegetation indices were calculated based on the individual bands of the satellite image. The vegetation index value per grid was calculated as the arithmetic mean and the median of all pixels within each grid.

Other methodological steps were:

- the division of the image in a square grid of 45.5 x 45.5 m (2070.25 m^2) with the same dimension of the field plots;
- random stratified sampling by proportional allocation design was used in forest inventory, where each plot corresponds to a grid. Tree above ground biomass was calculated using the plot data and the functions of Paulo and Tomé (2006);
- the use of linear and multiple regression to fit the functions of above ground biomass (*AGB*) with vegetation indices as independent variable;
- plot species composition was defined as a dummy variable where: monospecies of cork oak (*dQS*), monospecies holm oak (*dQR*), and multispecies of these two evergreen oaks (*dQRQS*).

$$AGB = \beta_0 + \beta_1 \times VI + \beta_2 \times dVI$$

Vegetation Index	Equation	Reference
Normalized Difference Vegetation Index	$NDVI = \frac{NIR - RED}{NIR + RED}$	(Rouse et al., 1973)
Enhanced Vegetation Index	$EVI = \frac{2.5 \times (NIR - RED)}{(NIR + 6 \times RED - 7.5 \times BLUE + 1)}$	(Huete et al., 1996; 1997)
Simple Ratio	$SR = \frac{NIR}{RED}$	(Jordan, 1969)
Soil Adjusted Vegetation Index	$SAVI = \frac{(NIR - RED)}{(NIR + RED + L)} \times (L + 1)$	(Huete, 1988)

The linear regression was fitted with the ordinary least squares, and multiple linear regressions with stepwise method and the selection criteria AIC using Variance Inflation Factor (VIF) to evaluate multicolinearity among explanatory variables .

The statistical properties of the models and validation were done with: the sum of squares of the residuals (SQR), determination coefficient (R^2) and adjusted determination coefficient (R^2_{aj}).

The validation was done using PRESS and APRESS. The error term heteroscedasticity was assessed by ploting the studentised residuals *vs* estimated values. The normality of the studentised residuals was evaluated with the normal Quantile-Quantile plots (QQ-plots) and the Shapiro Wilk normality test, for a probability level of 0.001.

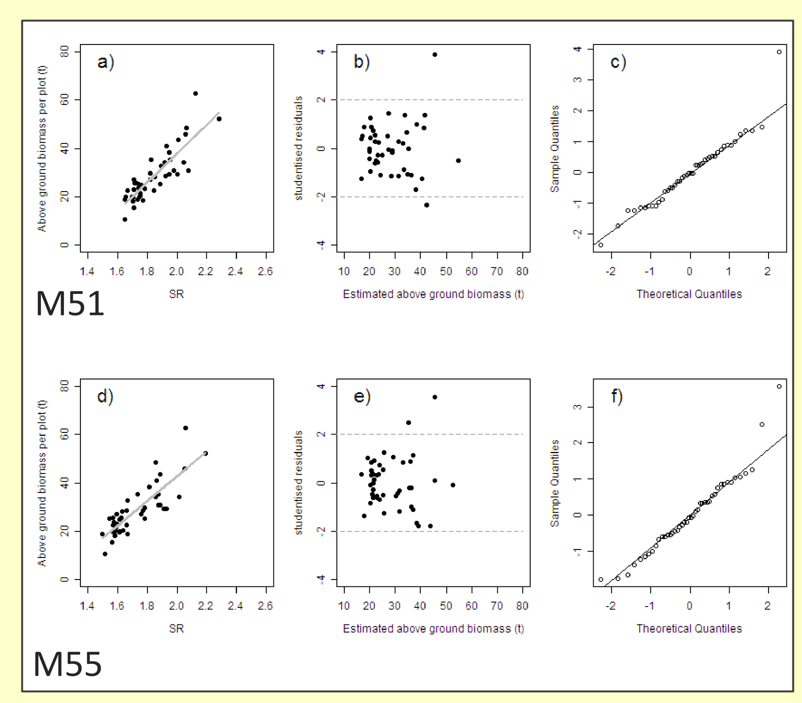
RESULTS

Plots descriptive statistics

	Min	Max	Average	SD	CV (%)
All plots					
AGB (t/ha)	10.4	62.7	28.5	10.4	36.4
GC (%)	13.7	70.5	34.3	14.9	43.6
Monospecific cork oak plots					
AGB (t/ha)	23.8	62.7	39.9	12.9	32.4
GC (%)	23.6	70.5	47.1	14.0	29.7
Monospecific holm oak plots					
AGB (t/ha)	13.7	67.6	36.5	16.7	45.7
GC (%)	18.7	45.9	27.9	8.4	29.9
Multispecies holm oak and cork oak plots					
AGB (t/ha)	10.4	35.2	23.9	6.2	25.9
GC (%)	14.3	45.3	26.9	9.0	33.3

Models with best results for each plot type and statistic measure used

Per plot						Per vegetation mask					
Model	Ind. Var	SQR	R2aj	PRESS	APRESS	Model	Ind. Var	SQR	R2aj	PRESS	APRESS
Holm oak monospecies											
M1	$\overline{NDVI}$	250	0.725	0.01876	0.46757	M9	$\overline{NDVI}$	194	0.769	0.01853	0.43273
M7	$\widetilde{SR}$	276	0.697	0.01743	0.44702	M15	$\widetilde{SR}$	181	0.785	0.01854	0.43718
Cork oak monospecies											
M17	$\overline{NDVI}$	515	0.559	0.00586	0.18576	M26	$\overline{EVI}$	437	0.563	0.00589	0.17820
M23	$\widetilde{SR}$	480	0.589	0.00555	0.17794	M32	$\widetilde{SAVI}$	451	0.550	0.00589	0.17922
Holm oak and cork oak multispecies											
M34	$\overline{EVI}$	296	0.570	0.06756	0.86807	M41	$\overline{NDVI}$	354	0.457	0.07238	0.85708
M38	$\widetilde{EVI}$	296	0.570	0.06756	0.86807	M45	$\widetilde{NDVI}$	344	0.471	0.07238	0.85708
All plots											
M51	$\overline{SR}$	1213	0.733	0.06589	1.33629	M59	$\overline{SR}$	1354	0.694	0.07545	1.33594
M55	$\widetilde{SR}$	1389	0.694	0.06589	1.33629	M63	$\widetilde{SR}$	1372	0.690	0.07545	1.33594
All plots with dummy variables											
M65	$\overline{NDVI}$, *dQR*, *dQS*	1150	0.740	0.06321	1.34521	M75	$\overline{SR}$ *dQR*,*dQR*	2694	0.377	0.08599	1.37854
M71	$\widetilde{SR}$, *dQR*, *dQS*	1156	0.739	0.07327	1.36187	M79	$\widetilde{SR}$ *dQR*, *dQS*	2734	0.368	0.08693	1.37385



CONCLUSIONS

The best models were obtained for holm oak monospecies plots, these models presented lower SQR, PRESS and APRESS values and highest adjusted determination coefficient value, the models for all plots without accounting for vegetation mask also returned good results.
The vegetation mask results show that all the models are very similar within plot composition, revealing that different indices and statistical measures produced very redundant models.
SR and NDVI were the indices with more frequency of overall better results, it was not noticed a relevant pattern in the difference between mean or median usage models, with overall similar results being obtained.
The inclusion of plot composition slightly increases the models performance per plot and a strongly decreases the performances of the models per vegetation mask.

Acknowledgments
The authors would like to thank the forest producers for allowing plot installation. Paulo Mesquita is acknowledged for satellite image processing. The work was financed by Programa Operativo de Cooperação Transfronteiriço Espanha – Portugal (POCTEP); project Altercexa – Medidas de Adaptación y Mitigación del Cambio Climático a Través del Impulso de las Energías Alternativas en Centro, Alentejo y Extremadura (Refª 0317_Altercexa_I_4_E and 0406_ALTERCEXA_II_4_E); TrustEE - innovative market based Trust for Energy Efficiency investments in industry (Project ID: H2020 – 696140); and National Funds through FCT - Foundation for Science and Technology under the Project UID/AGR/00115/2013..