The main goal of this study was the development of allometric functions for the estimation of above ground biomass with crown cover as independent variable, for forest areas of holm oak (*Quercus rotundifolia*), cork oak (*Quercus suber*) and umbrella pine (*Pinus pinea*) in multiple use systems. Crown cover per species was derived from crown horizontal projection obtained by processing high resolution satellite images.

### Materials and methods

Two images, one Quickbird (August, 2006) and another WorldView 2 (June, 2011), with 0.70 m and 0.5 m of spatial resolution, had the following process steps:

1. geometric correction with ground control points;
2. radiance conversion to surface reflectance;
3. vegetation objects, representing crown horizontal projection, were isolated and classified into the three species;
4. definition of a square grid of 45.5x45.5 m² for the Quickbird image and of 45x 45 m² for WorldView 2;
5. crown cover per grid and per species was calculated and grids were aggregated into three strata:
   - i) 10% to 30% ground cover, ii) 30% to 50% ground cover, iii) ground cover higher than 50%.

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 data and the functions of Paulo and Tomé (2006) and Correia et al. (2008).

Linear and multiple regression was used to fit the functions of above ground biomass (AGB) with crown cover (CC) as independent variable. Plot species composition was defined as:

- crown cover per species; and
- as dummy variables, for each dummy composition variable (dc), 1 indicates that the plot is monospecies cork oak (dQS), holm oak (dQM) and umbrella pine (dPP), multispecies cork oak and holm oak (dQSM) or cork oak and umbrella pine (dOSP), and 0 otherwise. Umbrella pine trees pruning of was considered as a dummy variable (dp) where 1 indicates the pruned plots and 0 the unpruned ones.

For multiple linear regression Stepwise method with AIC as selection criteria was used, and Variance Inflation Factor (VIF) to analyse multicollinearity among explanatory variables.

Functions statistical properties were evaluated with sum of squares of the residuals (SSR), the coefficient of determination (R²), the adjusted coefficient of determination (Rₐ²), Validation with mean of the PRESS residuals (PRESSm), mean of the absolute values (PRESSam) and analysis of its 5th and 95th percentile. The plots of studentised residuals vs estimated values were used to evaluate heteroscedasticity associated with the error term. Normal Quantile-Quantile plots and with the Shapiro Wilk normality test, for α=0.01 assessed the normality of the studentised residuals.

### Results

#### Median and interquartile range (IQR)

<table>
<thead>
<tr>
<th>Plots</th>
<th>all</th>
<th>Monospecies</th>
<th>Multispecies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Holm oak</td>
<td>Cork oak</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
</tr>
<tr>
<td>Trees/ha</td>
<td>87.4</td>
<td>26.2</td>
<td>48.7</td>
</tr>
<tr>
<td>ha/m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree density</td>
<td>40.2</td>
<td>18.0</td>
<td>34.0</td>
</tr>
</tbody>
</table>

R is the number of trees per hectare, d the basal area per hectare, CC the crown cover calculated with satellite data and AGB the above ground biomass per hectare.

### Application of the functions to

- In general all fitted models have good performances.
- The inclusion of dummy composition variables improves the model accuracy when compared with the model whose independent variables are the crown cover of each species.
- The inclusion of a dummy variable to differentiate the pruned umbrella pine monospecies stands originates the best performance model but is of difficult implementation if large areas are to be evaluated by inexperienced foresters.
- For forest areas of holm oak, cork oak and umbrella pine M3 is considered the one with the best equilibrium between accuracy and easy to work model.

### Conclusions

- The authors would like to thank the forest owners for allocating the inventories. The work was financed by Programa Operacional Cooperação Transfronteriza Espanha – Portugal (POCTEP) project INVENTO – Investigación de la productividad de bosques alpinos y su sostenibilidad y Adaptación al cambio climático: un enfoque transfronterizo; Grant Ref: 18327.2014.267.0008, the authors acknowledge the financial support of Research and Development Fund (Project POCTI/CTM/56480/2004), and National Funds from FCT Foundation for Science and Technology under the Project UID/00815/2013.