Regulating agro-forest areas for a sustainable cork harvest

Coelho ANA¹, Cristina ALEGRIA²

¹EMPEV - Gestão de Espaços Verdes, Lda.

²Politechnical Institute of Castelo Branco, School of Agriculture, Department of Natural Resources and Sustainable Development
The aim of this study was to apply the classical methods for forest regulation (Davis & Johnson 1986) in a management unit after fire disturbance.

The area control method combined with the volume control method were used to achieve a sustainable annual cork harvest while regenerating old stands.
Methods

Study area

• Located in a Mediterranean region of Portugal.

• An agro-forestry management unit of cork oak partial affected by fire was considered.

Fig. 1 Geographic location of the study area
• 2003 – Fire
• 2005/06 – plantation (burnt areas were forested with cork oak)
Field measurements

• 2010 - Forest inventory (old stands); support forest management plan

Fig. 4 Current compartments (old stands): a) harvest years and areas; b) sample plots (n=12)
Cork yield simulation
Individual tree growth and yield model Suber v3.0
Cork extraction cycle – nine years

Simulation along 27 years:
- 1st cycle: 2010-2018
- 2nd cycle: 2019-2027
- 3rd cycle: 2028-2036

Fig. 5 Suber model (Tomé et al. 2001)
Area control method
Harvest and regenerate the same number of ha each year (Davis & Johnson 1986).

<table>
<thead>
<tr>
<th>Cork stands</th>
<th>Areas (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old</td>
<td>845.82</td>
</tr>
<tr>
<td>Young 1</td>
<td>207.08</td>
</tr>
<tr>
<td>Young 2</td>
<td>1523.00</td>
</tr>
<tr>
<td>Total</td>
<td>2575.90</td>
</tr>
</tbody>
</table>

- Management surface \( (S) \)
- Cork extraction cycle \( (R) \)
- Annual harvest area \( (s) \)
\[ s = S/R \]

New compartment's areas were tied to the ground using a GIS.

Fig. 6 Compartments - 2010

Table 1 Old and young stands
- Silvicultural prescription (Louro et al. 2000)

<table>
<thead>
<tr>
<th></th>
<th>2010-2018</th>
<th>2019-2027</th>
<th>2028-2036</th>
<th>2037-2045</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Old stands (&gt;60 years)</td>
<td>&gt;69 years</td>
<td>&gt;78 years</td>
<td>&gt;87 years</td>
<td>&gt;96 years</td>
</tr>
<tr>
<td>Young stands (4-5 years)</td>
<td>14 years</td>
<td>23 years</td>
<td>32 years</td>
<td>41 years</td>
</tr>
</tbody>
</table>

Age 110-135 years: final cut

Age 25-35 years: 1\textsuperscript{st} cork extraction ($d>22.3$ cm)

- Harvest rules
  1. Rotation age is 9 years.
  2. Area regulation: extract and regenerate one compartment each year.
  3. Never harvest before reaching 9 years after previous cork extraction.
  4. Never harvest if tree legal dimension ($d>22.3$ cm) is not verified.
  5. Harvest older compartments first.
  6. Harvest, then grow.
Area control and volume control combined

1. Make an area control calculation for the forest to estimate the annual regeneration harvest area.

2. Calculate the average cork yield that would come off these hectares.

3. Decide what stands to explore over the next few periods.

4. Draw up a specific budget for the 1st extracting cycle and draw up a tentative budget for the 2nd cycle.

5. Extract the cork, compare the results to the expectations, and when the 1st cycle ends, start the analysis all over again (Davis & Johnson 1986).
Area control method

Current compartments don't allow a sustainable annual cork harvest.

Fig. 7 Current compartments (old stands): harvest years and areas
1st cycle - old stands (2010-2018)
S= 845.82 ha
R=9 years
Annual harvest area s= 93.98 ha

Table 2 New compartments area – 1st cycle (old stands)

<table>
<thead>
<tr>
<th>Compartments</th>
<th>Area (ha)</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_10</td>
<td>390.15</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>14.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_12</td>
<td>201.88</td>
<td></td>
<td>79.75</td>
<td>93.98</td>
<td>28.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_15</td>
<td>120.52</td>
<td></td>
<td></td>
<td></td>
<td>65.83</td>
<td>54.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_16</td>
<td>85.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39.29</td>
<td>46.62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_18</td>
<td>47.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47.36</td>
</tr>
<tr>
<td>Total</td>
<td>845.82</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
</tr>
</tbody>
</table>

Sacrifices - extract cork later than 9 years
In order to achieve regulation
Figure 8. New compartments design – 1<sup>st</sup> cycle, 2<sup>nd</sup> cycle and 3<sup>rd</sup> cycle

27 years

1<sup>st</sup> cycle: 2010-2018
2<sup>nd</sup> cycle: 2018-2027
3<sup>rd</sup> cycle: 2028-2036
4th cycle - old stands plus young stands (2045-2045)

- **Old stands annual harvest area**  
  Age>87 years

  Young stands S= 1730.08 ha  
  Age around 32 years – ready for the 1st cork extraction

  Cork extraction cycle R=9 years

- **Young stands annual harvest area**  
  s2=192.23 ha

- **Total annual harvest area**  
  s=s1+s2=286.21 ha
Table 3 Compartments old and young stands - 4th cycle

<table>
<thead>
<tr>
<th>Compartments</th>
<th>Area (ha)</th>
<th>2037</th>
<th>2038</th>
<th>2039</th>
<th>2040</th>
<th>2041</th>
<th>2042</th>
<th>2043</th>
<th>2044</th>
<th>2045</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_1</td>
<td>93.98</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_2</td>
<td>93.98</td>
<td></td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_3</td>
<td>93.98</td>
<td></td>
<td></td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_4</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_5</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_6</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_7</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N_8</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93.98</td>
<td></td>
</tr>
<tr>
<td>N_9</td>
<td>93.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93.98</td>
</tr>
<tr>
<td>Old</td>
<td>845.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compartments</th>
<th>Y1</th>
<th>Y2</th>
<th>Y3</th>
<th>Y4</th>
<th>Y5</th>
<th>Y6</th>
<th>Y7</th>
<th>Y8</th>
<th>Y9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1</td>
<td>207.00</td>
<td>192.23</td>
<td>14.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y2</td>
<td>1523.04</td>
<td>177.46</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
</tr>
<tr>
<td>Young</td>
<td>1730.08</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
<td>192.23</td>
</tr>
<tr>
<td>Total</td>
<td>2575.90</td>
<td>286.21</td>
<td>286.21</td>
<td>286.21</td>
<td>286.21</td>
<td>286.21</td>
<td>286.21</td>
<td>286.21</td>
<td>286.21</td>
</tr>
</tbody>
</table>
Figure 9. Compartments (old and young stands) – 4th cycle
Area control and volume control combined

Cork yield

Table 4 Annual cork harvest - 1st cycle

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cork yield (ton ha⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_10</td>
<td>2.28</td>
<td>2.28</td>
<td>2.31</td>
<td>2.44</td>
<td>2.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_12</td>
<td></td>
<td></td>
<td></td>
<td>2.45</td>
<td>2.43</td>
<td>2.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.23</td>
<td>2.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.26</td>
<td>2.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_10</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>93.98</td>
<td>14.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_12</td>
<td>79.75</td>
<td></td>
<td>93.98</td>
<td>28.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_15</td>
<td>65.83</td>
<td>54.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_16</td>
<td></td>
<td>39.29</td>
<td>46.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cork yield (ton)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>214.26</td>
<td>214.71</td>
<td>217.14</td>
<td>229.01</td>
<td>231.21</td>
<td>227.96</td>
<td>213.68</td>
<td>211.26</td>
<td>225.58</td>
<td></td>
</tr>
</tbody>
</table>
Annual cork harvest is quite stable in the 1\textsuperscript{st} cycle.

In both 2\textsuperscript{nd} cycle and 3\textsuperscript{rd} cycle:
- increasing tendency
- more variability

Fig. 10 Annual cork harvest
In the 4th cycle - an increase in annual cork harvest is expected old stands + young stands

It makes possible planning old stands regeneration/renovation without great loss of previous annual cork production.

Old stands in the end of the 4th cycle – age >96 years

<table>
<thead>
<tr>
<th>Compartments</th>
<th>N (trees.ha⁻¹)</th>
<th>Crown area (%)</th>
<th>Average diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_10</td>
<td>75</td>
<td>37</td>
<td>31.6</td>
</tr>
<tr>
<td>F_12</td>
<td>47</td>
<td>28</td>
<td>47.3</td>
</tr>
<tr>
<td>F_15</td>
<td>70</td>
<td>49</td>
<td>36.2</td>
</tr>
<tr>
<td>F_16</td>
<td>105</td>
<td>52</td>
<td>33.7</td>
</tr>
<tr>
<td>F_18</td>
<td>45</td>
<td>20</td>
<td>44.0</td>
</tr>
</tbody>
</table>

Old stands:
- very low stand densities
- problems of tree vitality
- near final cut age (100-135 years)

• Restore density around 100-150 trees per hectare in order to obtain a crown occupation between 40-60% (Louro et al. 2000).
• The area control method was applied to fully regulate the existing old cork stands.

• New compartments for old stands were designed in a GIS.

• These new compartments will fulfill this goal for the next 27 years.

• Annual cork harvest was quite stable in the 1st cycle.

• More reliable cork yield simulation for the next two following cycles is expected to be achieved with updated inventory data after each cycle.

• Young stands inventory should also be promoted.

• Planning must be re-evaluated with the updated inventory data.

• Simulated cork yield and cork selling prices should also be considered in forest regulation analysis.
• After the 27 years, it is expected that young cork stands will be ready for the 1st cork extraction.

• The area control method was again applied to fully regulate the young cork stands.

• New compartments for young stands were added in a GIS.

• In the 4th cycle both old and young stands will be in production.

• Good opportunity for planning old stands regeneration/renovation without great loss of previous annual cork production.

• This strategy will make possible to achieve cork oak areas sustainability while regenerating/renovating old stands.

• The area control method and volume control method combined was also essayed and an increasing yield was obtained.
Our participation was supported by