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# Regulating agro-forest areas for a sustainable cork harvest

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# Introduction

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.





## Study area

- Located in a Mediterranean region of Portugal.
- An agro-forestry management unit of cork oak partial affected by fire was considered.

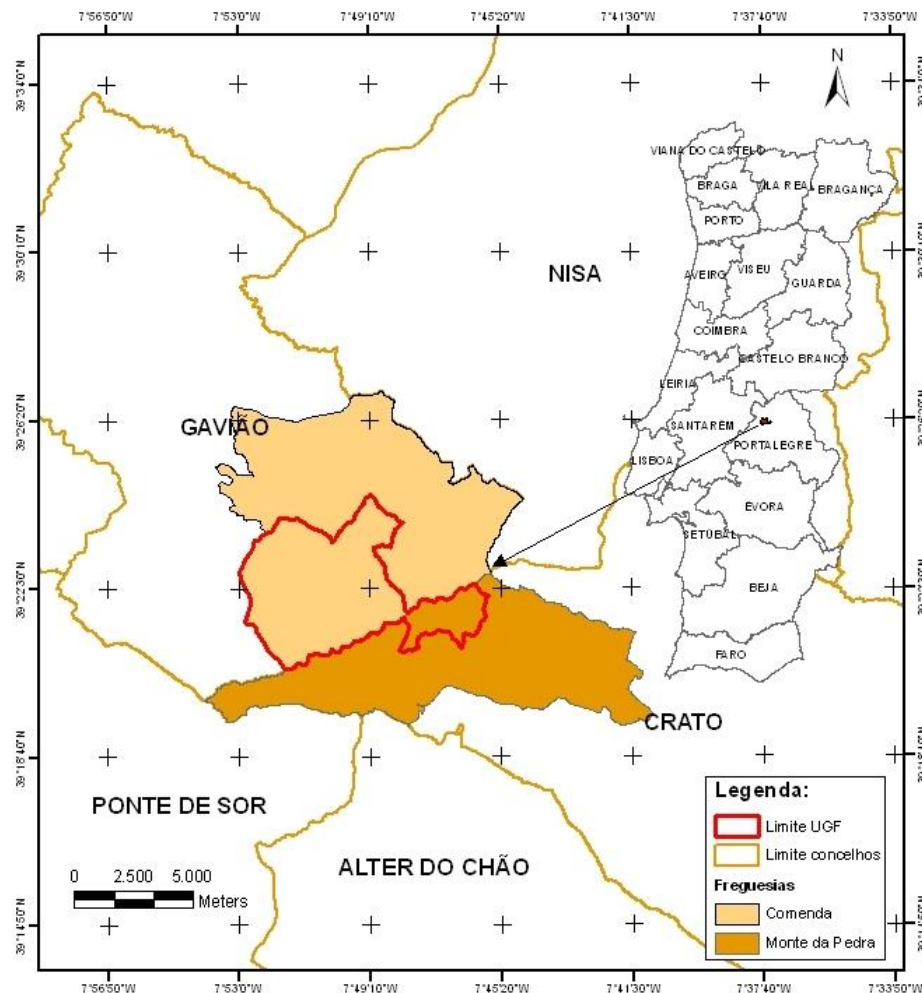


Fig. 1 Geographic location of the study area



- 2003 – Fire
- 2005/06 – plantation (burnt areas were forested with cork oak)

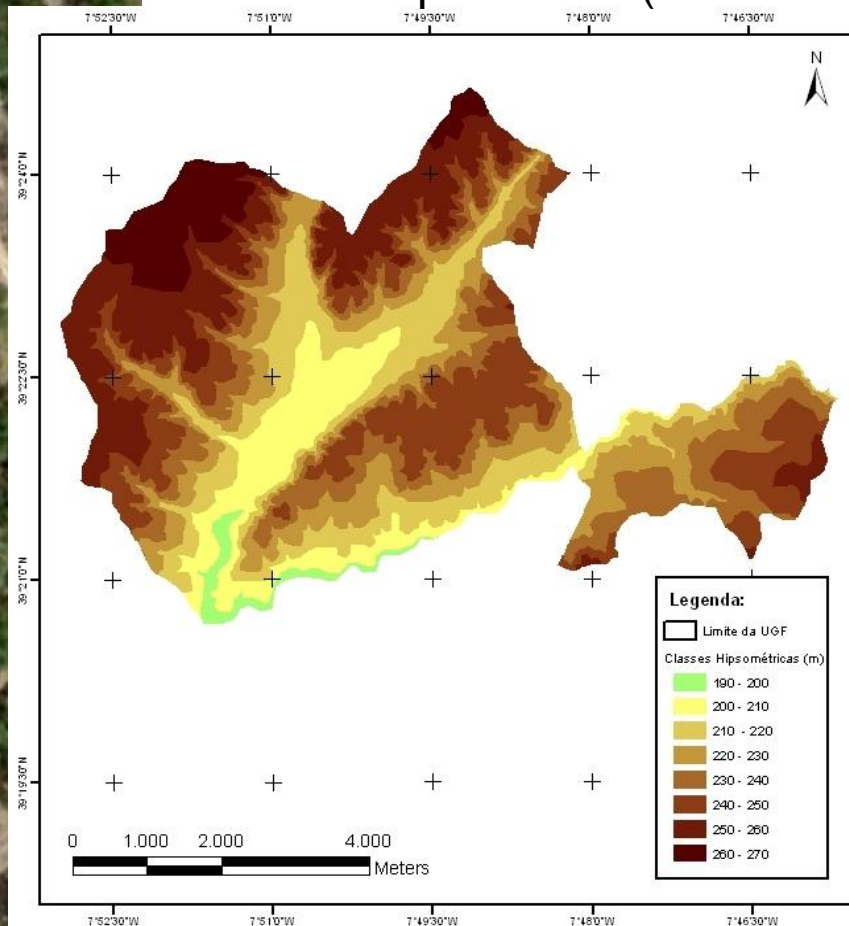


Fig. 2 Elevation (DEM)

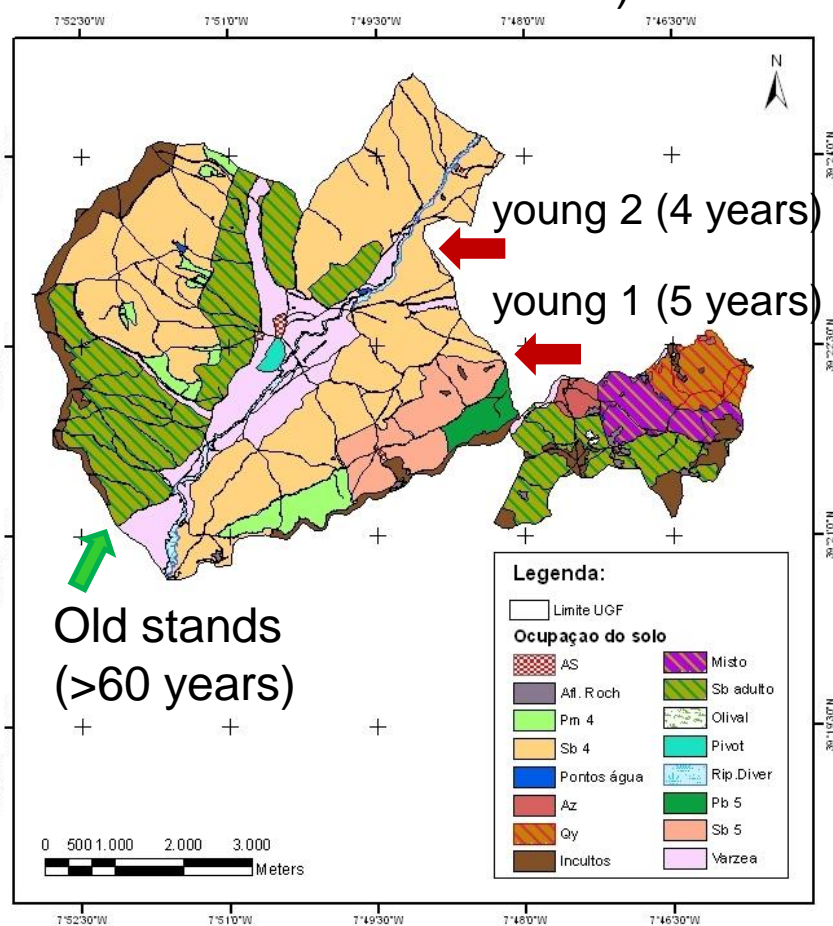


Fig. 3 Land cover area



## Field measurements

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

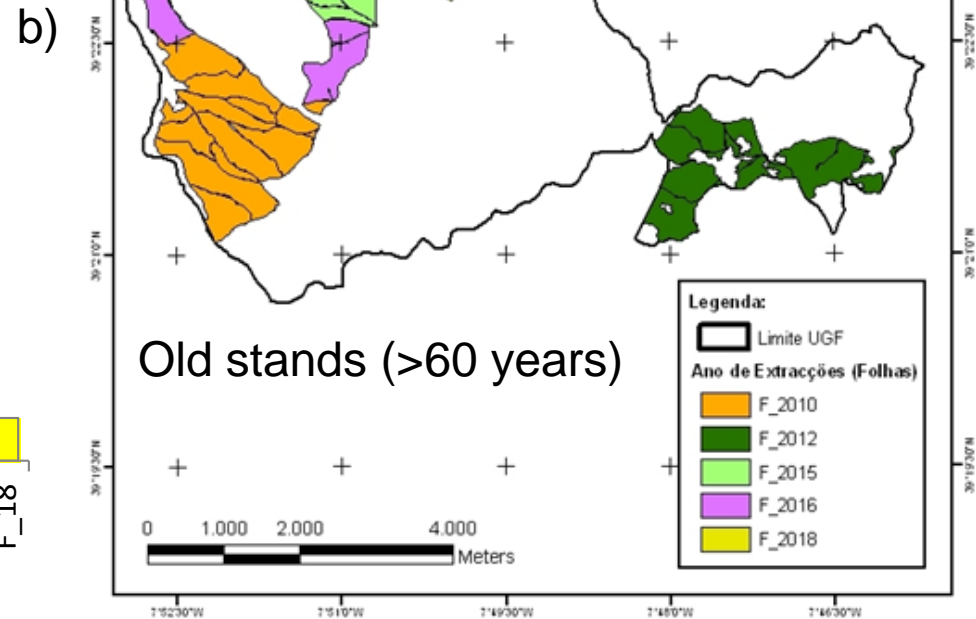
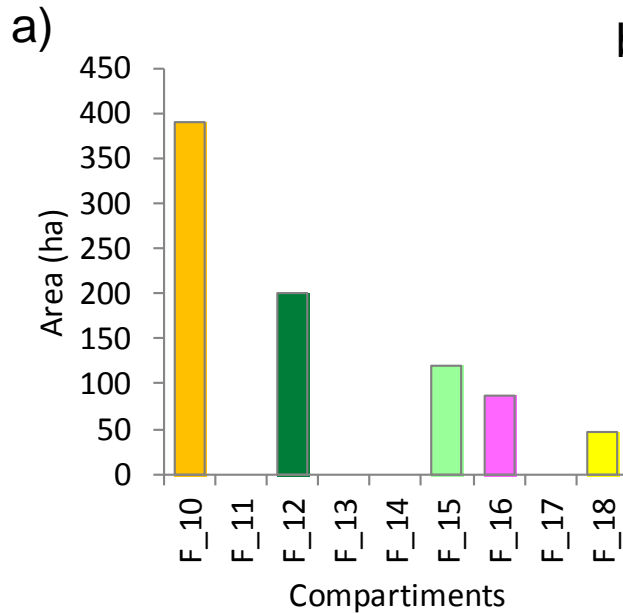


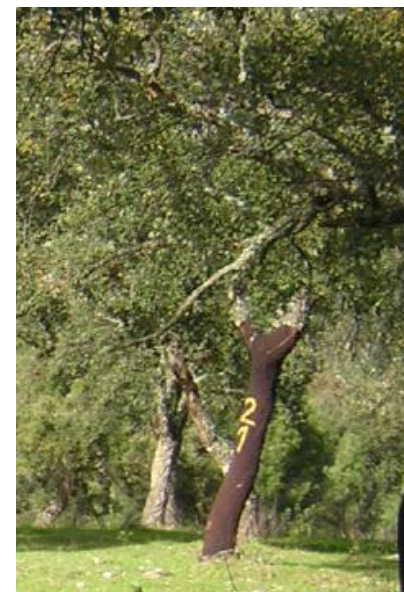
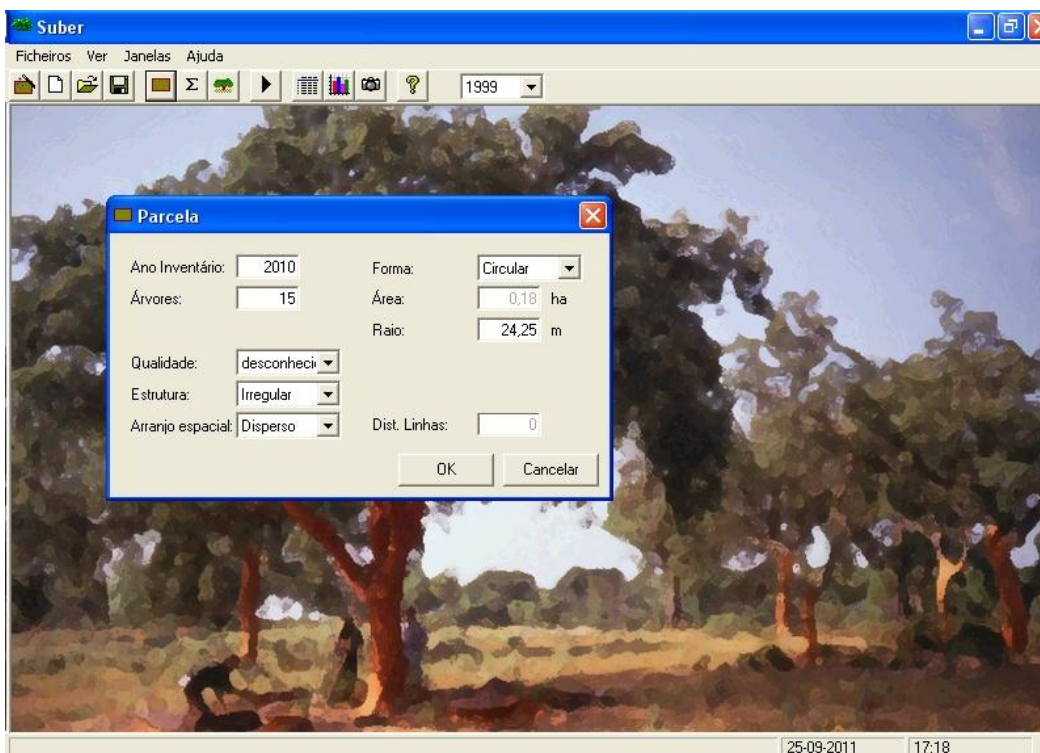
Fig. 4 Current compartments (old stands): a) harvest years and areas; b) sample plots (n=12)



## Cork yield simulation

Individual tree growth and yield model Suber v3.0

Cork extraction cycle – nine years



Simulation

along 27 years:

- 1<sup>st</sup> cycle: 2010-2018
- 2<sup>nd</sup> cycle: 2019-2027
- 3<sup>rd</sup> 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 1 Old and young stands

Cork stands	Areas (ha)
Old	845.82
Young 1	207.08
Young 2	1523.00
Total	2575.90

- 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.

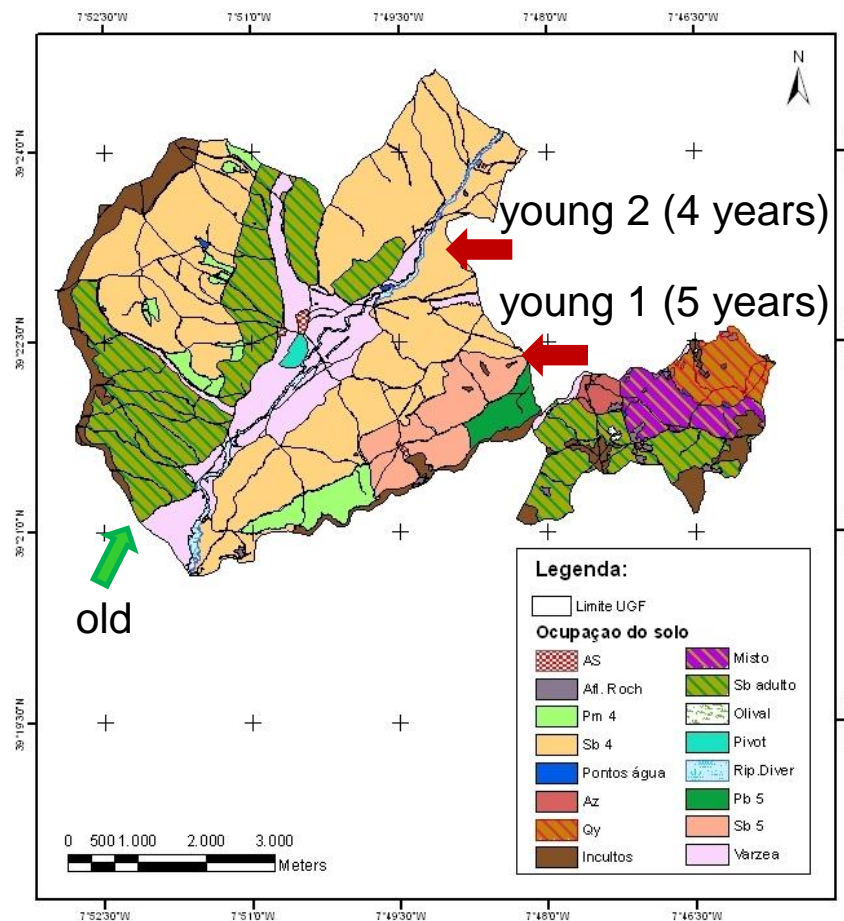


Fig. 6 Compartments - 2010



- Silvicultural prescription (Louro et al. 2000)

Age 110-135 years: final cut

	2010-2018	2019-2027	2028-2036	2037-2045
Current	1 <sup>st</sup> cycle	2 <sup>nd</sup> cycle	3 <sup>rd</sup> cycle	4 <sup>th</sup> cycle
Old stands (>60 years)	>69 years	>78 years	>87 years	>96 years
Young stands (4-5 years)	14 years	23 years	32 years	41 years

Age 25-35 years: 1<sup>st</sup> 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 1<sup>st</sup> extracting cycle and draw up a tentative budget for the 2<sup>nd</sup> cycle.
5. Extract the cork, compare the **results** to the **expectations**, and when the 1<sup>st</sup> cycle ends, start the analysis all over again (Davis & Johnson 1986).





## Area control method

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

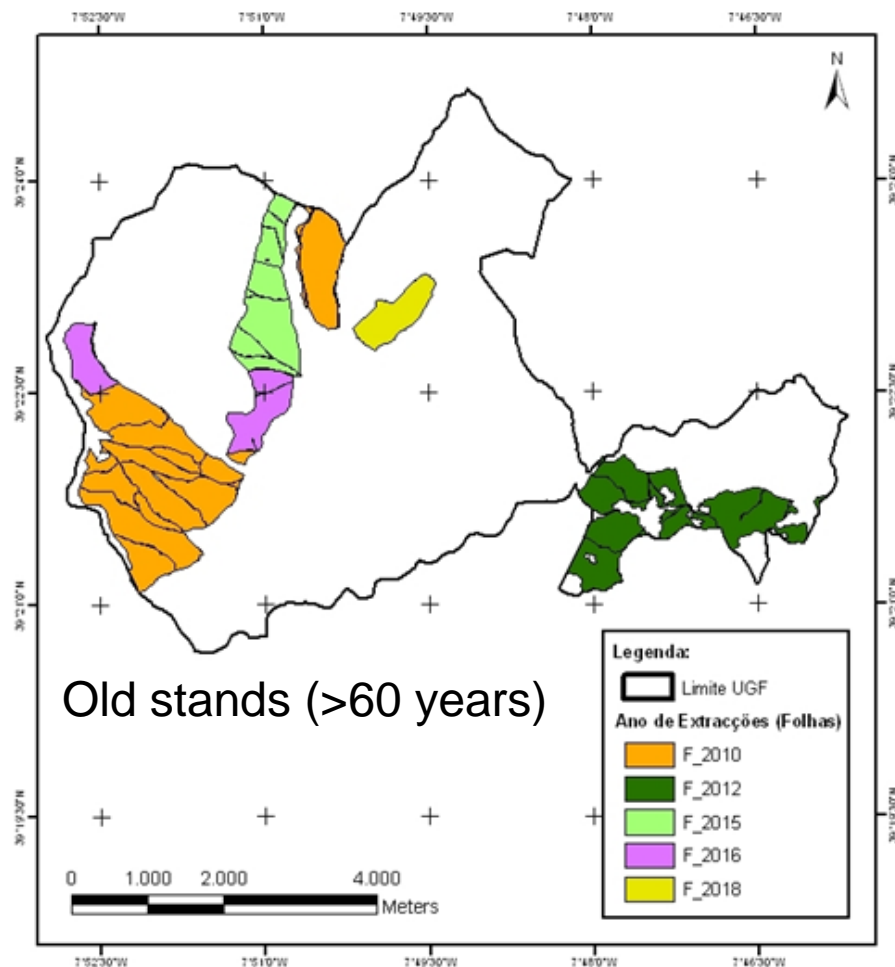
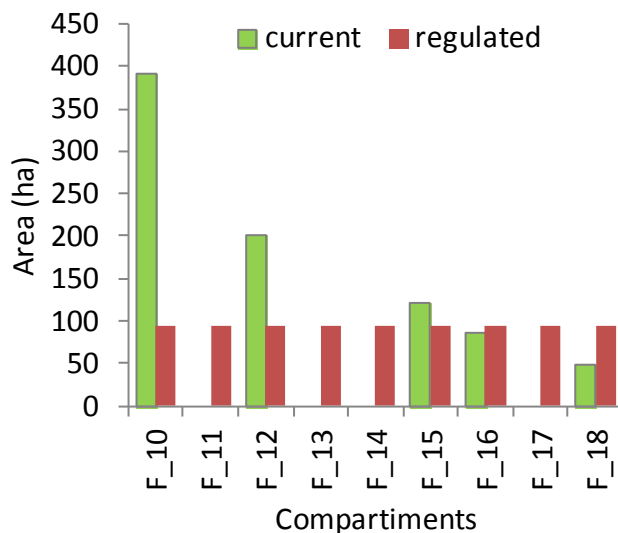


Fig. 7 Current compartments (old stands): harvest years and areas



1<sup>st</sup> cycle - old stands (2010-2018)

S= 845.82 ha

R=9 years

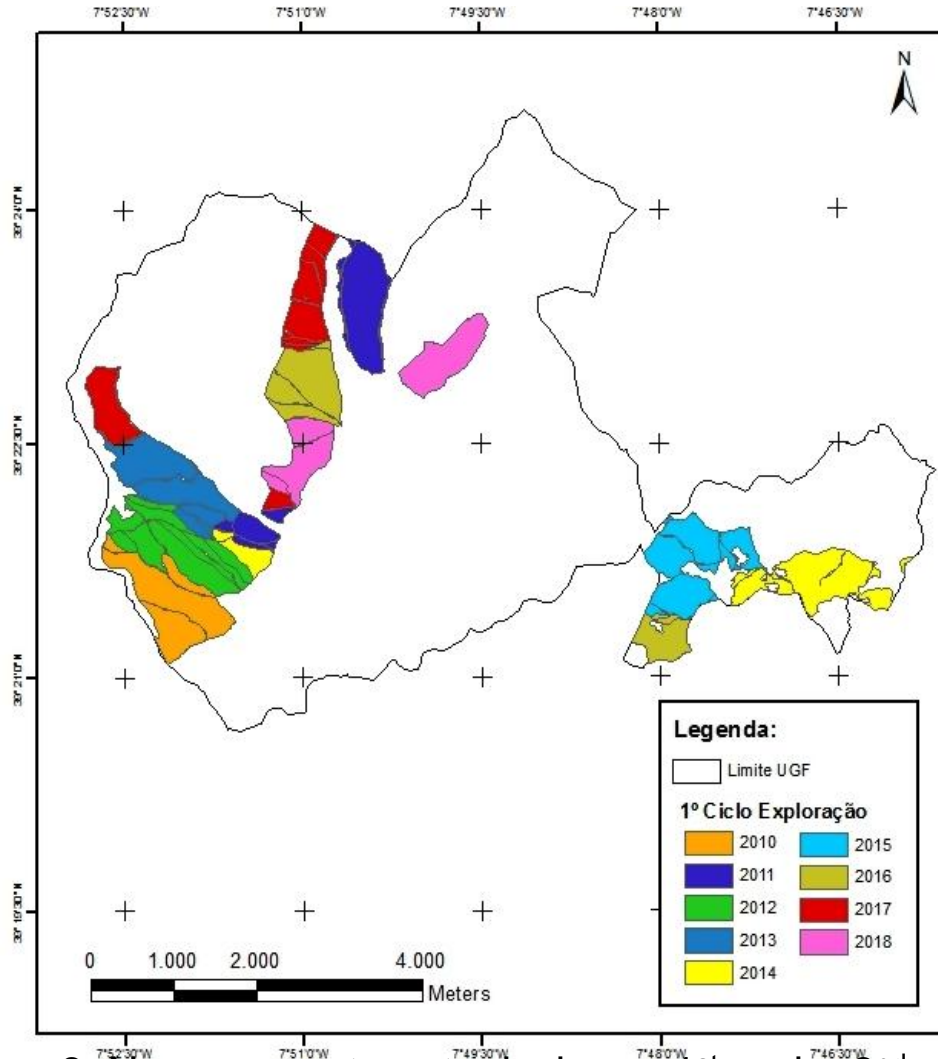
Annual harvest area s= 93.98 ha

Table 2 New compartments area – 1<sup>st</sup> cycle (old stands)

		N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_9
		F_10_1	F_10_2	F_10_2	F_10_3	F_10_4/F_12_1	F_12_1	F_12_2/F_15_1	F_15_2/F_16_1	F_16_2/F_18_1
Compartments	Area (ha)	2010	2011	2012	2013	2014	2015	2016	2017	2018
F_10	390.15	93.98	93.98	93.98	93.98	14.23				
F_12	201.88					79.75	93.98	28.15		
F_15	120.52							65.83	54.69	
F_16	85.91								39.29	46.62
F_18	47.36									47.36
<b>Total</b>	<b>845.82</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>

Sacrifices - extract cork later than 9 years

In order to achieve regulation



N_1
N_2
N_3
N_4
N_5
N_6
N_7
N_8
N_9

27 years

1<sup>st</sup> cycle: 2010-2018

2<sup>nd</sup> cycle: 2018-2027

3<sup>rd</sup> cycle: 2028-2036

Figure 8. New compartments design – 1<sup>st</sup> cycle, 2<sup>nd</sup> cycle and 3<sup>rd</sup> cycle  
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4<sup>th</sup> cycle - old stands plus young stands (2045-2045)

- **Old stands annual harvest area**  $s_1=93.98$  ha  
Age > 87 years

Young stands  $S=1730.08$  ha  
Age around 32 years – ready for the 1<sup>st</sup> cork extraction

Cork extraction cycle  $R=9$  years

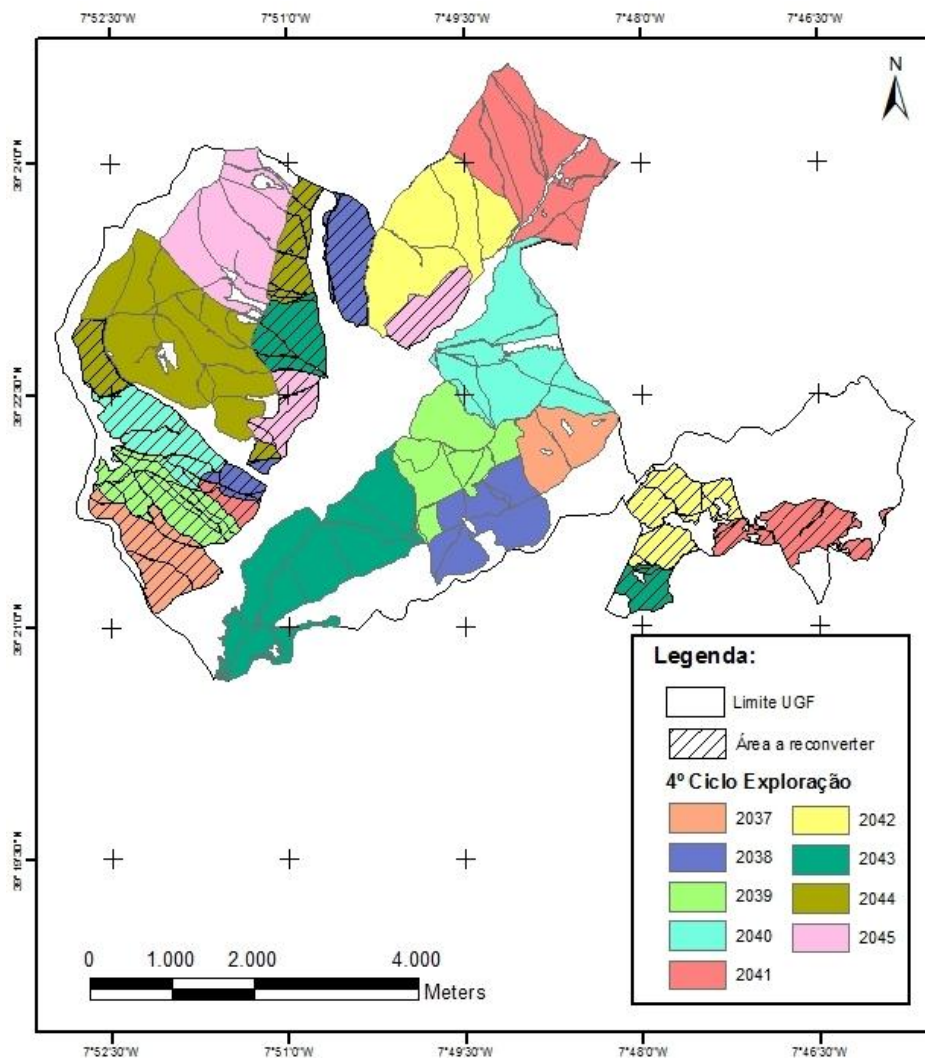
- **Young stands annual harvest area**  $s_2=192.23$  ha
- **Total annual harvest area**  $s=s_1+s_2=286.21$  ha





Table 3 Compartments old and young stands - 4<sup>th</sup> cycle

Compartments	Area (ha)	2037	2038	2039	2040	2041	2042	2043	2044	2045
N_1	93.98	93.98								
N_2	93.98		93.98							
N_3	93.98			93.98						
N_4	93.98				93.98					
N_5	93.98					93.98				
N_6	93.98						93.98			
N_7	93.98							93.98		
N_8	93.98								93.98	
N_9	93.98									93.98
<b>Old</b>	<b>845.82</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>	<b>93.98</b>
<b>Compartments</b>		<b>Y1</b>	<b>Y2</b>	<b>Y3</b>	<b>Y4</b>	<b>Y5</b>	<b>Y6</b>	<b>Y7</b>	<b>Y8</b>	<b>Y9</b>
Y1	207.00	192.23	14.77							
Y2	1523.04		177.46	192.23	192.23	192.23	192.23	192.23	192.23	192.23
<b>Young</b>	<b>1730.08</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>	<b>192.23</b>
<b>Total</b>	<b>2575.90</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>	<b>286.21</b>



N_1
N_2
N_3
N_4
N_5
N_6
N_7
N_8
N_9

Y_1
Y_2
Y_3
Y_4
Y_5
Y_6
Y_7
Y_8
Y_9

Figure 9. Compartments (old and young stands) – 4<sup>th</sup> cycle  
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## Area control and volume control combined

### Cork yield

Table 4 Annual cork harvest - 1<sup>st</sup> cycle

	2010	2011	2012	2013	2014	2015	2016	2017	2018
<b>Cork yield (ton ha<sup>-1</sup>)</b>									
F_10	2.28	2.28	2.31	2.44	2.51				
F_12					2.45	2.43	2.37		
F_15							2.23	2.24	
F_16								2.26	2.69
F_18									2.12
<b>Area (ha)</b>									
F_10	93.98	93.98	93.98	93.98	14.23				
F_12					79.75	93.98	28.15		
F_15							65.83	54.69	
F_16								39.29	46.62
F_18									47.36
<b>Total cork yield (ton)</b>									
	214.26	214.71	217.14	229.01	231.21	227.96	213.68	211.26	225.58



Annual cork harvest is quite stable in the 1<sup>st</sup> cycle.

In both 2<sup>nd</sup> cycle and 3<sup>rd</sup> cycle:

- increasing tendency
- more variability

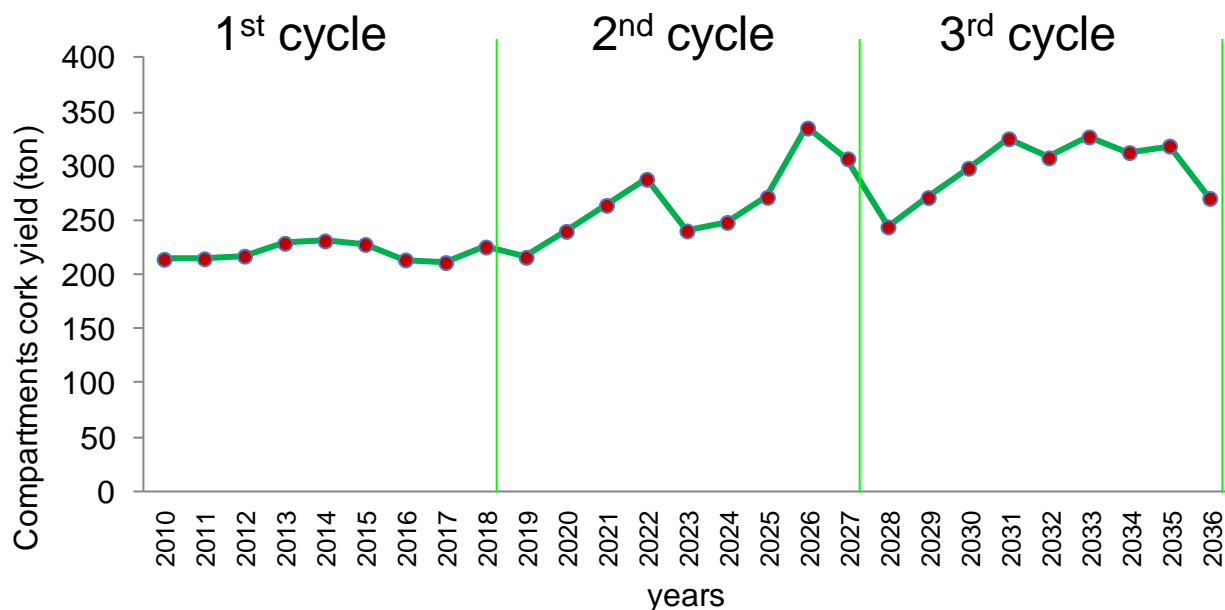


Fig. 10 Annual cork harvest



In the 4<sup>th</sup> 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 4<sup>th</sup> cycle – age >96 years

Table 5 Inventory data in 2010

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

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 1<sup>st</sup> 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 1<sup>st</sup> 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 4<sup>th</sup> 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.





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