FOREST MANAGEMENT OF COMMON LAND CLUSTERS USING MODISPINASTER AND OPTIMIZATION MODELS

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GOAL

Developing Forest Management models for a group of common land using ModisPinaster and Optimization Models

Evaluate alternative management models:

- global management models (G) and
- individual management models (I).

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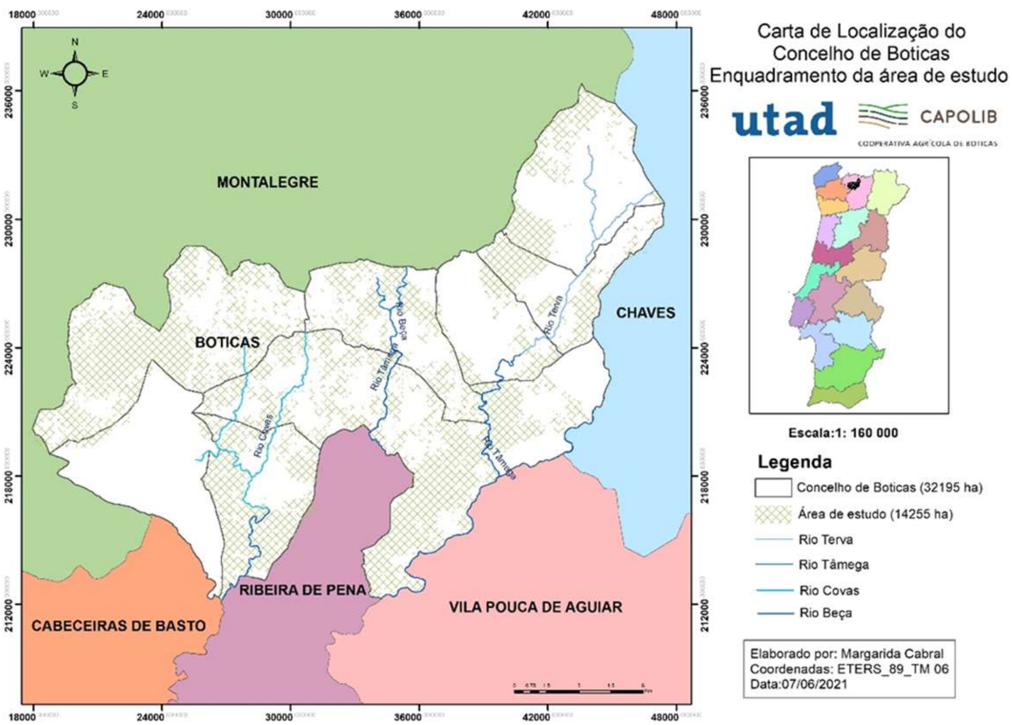
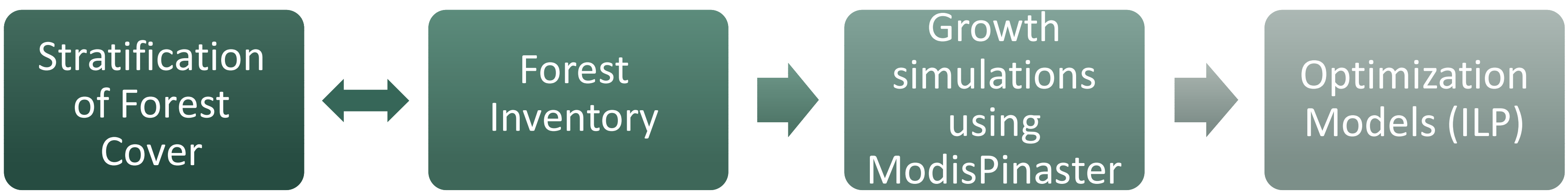
STUDY AREA



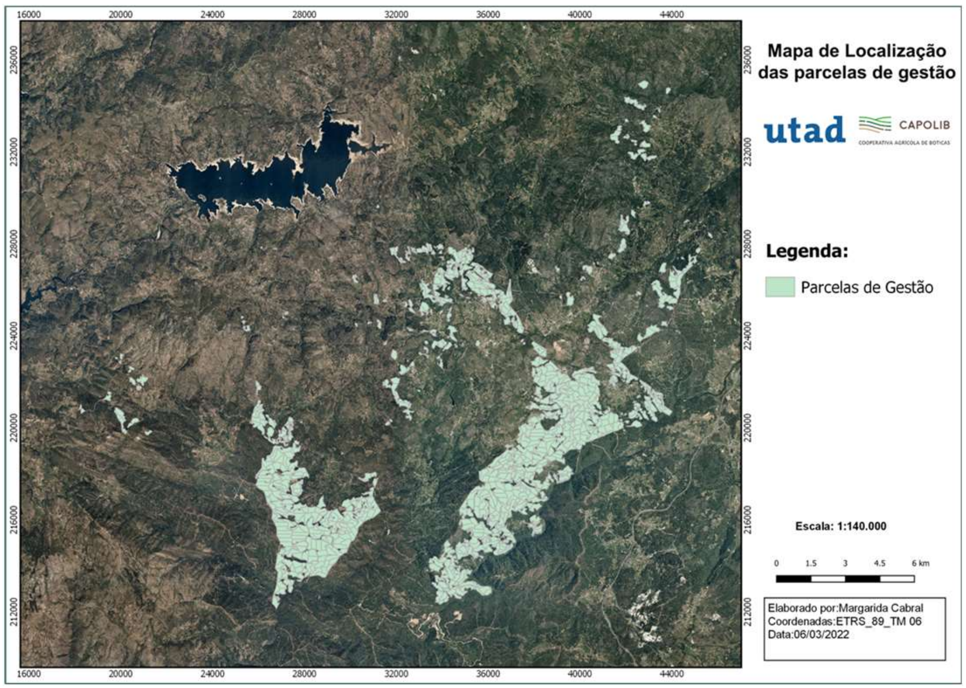
Geographical location of the study area, in the northern part of Portugal (CAOP, 2019)

- Boticas (Vila Real county)
- Group of communal areas in the municipal of Boticas (AdB Boticas)
  - CIFAP an CAPOLIB partnership protocol
  - 22 common lands, *baldios*, (14 255 ha)
- *Pinus pinaster* stands (5 014 ha)
  - Predominant species

METHODOLOGY



STRATIFICATION OF THE STUDY AREA



Orthophotomap of the management plots

892 Management Units (5 014 ha)

- 22 Common lands, *Baldios*
- $0.004 \leq$ area ≤ 10.41 ha

FOREST INVENTORY

Land ocupation map

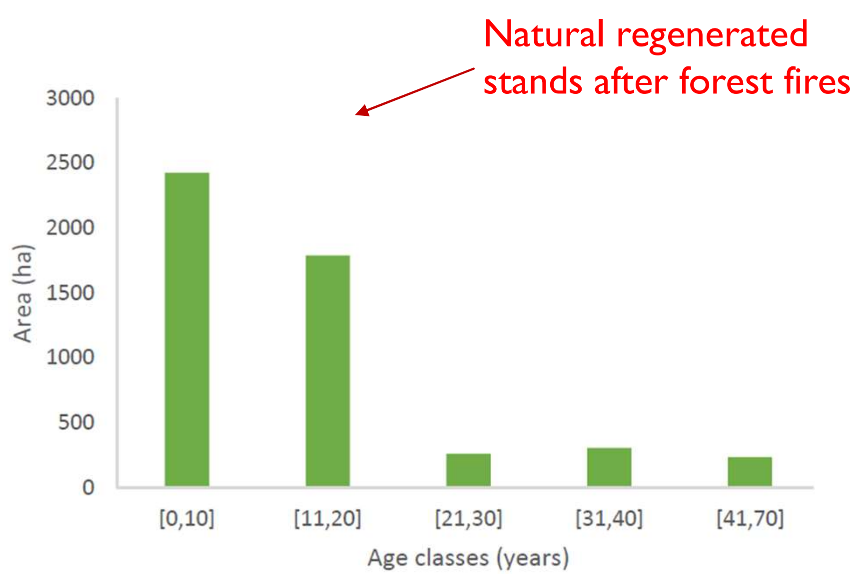
- Stand age (6 categories)
- Density (5 categories)
- 45 sampling plots (Stratified random sampling)

Study area- Natural regeneration

Density/Age	Saplings (0–5 yr)	Young-1 (6–12 yr)	Young-2 (13–20 yr)	Adult-1 (21–30 yr)	Adult-2 (31–40 yr)	Mature (>40 yr)
Low (≤500 trees ha^{-1})	-	+	+	+	+	+
Medium (501–1500 trees ha^{-1})	+	+	+	+	+	+
High (1501–3000 trees ha^{-1})	+	+	+	+	+	+
Very high (3001–10,000 trees ha^{-1})	+	+	+	+	-	-
Extremely high (>10,000 trees ha^{-1})	-	-	+	+	-	-

STUDY AREA

Initial characterization, 1st year of the planning horizon (2021)



Forest area of maritime by age class in 2021.

Variable	Min	Mean	Max	sd
t (yr)	4	22.5	65	15.4
N (trees ha^{-1})	300	2736	15350	3799
G ($m^2 ha^{-1}$)	0.2	17.6	42.4	10
SI_{35} (m)	12.5	16.9	23.6	2.67
dg (cm)	1.2	12.6	42.4	10.6
d_{dom} (cm)	1.7	18.7	46.9	12.1
h_{dom} (m)	1.4	10	26.3	6.5
hg/dg	42.2	88.7	337.5	60.8
CBD	0.04	0.13	0.32	0.07

Legend: t—stand age (yr); N—number of trees per hectare (trees ha−1); G—basal area per hectare (m2.ha−1); SI35 —Site index, defined as the stand dominant height at reference age of 35 years (m); dg—quadratic mean diameter at the height level of 1.30 m (cm); ddom—dominant diameter (cm); hdom—dominant height (m); hg/dg-stability coefficient; CBD-canopy bulk density (km/ kgm-3); Min—data minimum; Mean—data average; Max—data maximum; and sd—data standard devia-tion.

OPTIMIZATION MODEL

Goal: **Maximize the volume of wood harvested during the planning horizon,** 30 years (2021 to 2051);

Constraints:

- Silvicultural
- Operational
- Green-up
- Sustainability

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Integer Linear Programming (ILP) Model

OPTIMIZATION MODEL

Sets

- $T = \{1, \cdots, nt\}$ set of one-year periods,
- $S = \{1, \cdots, ns\}$ set of stands in the study area,
- $B = \{1, \cdots, nb\}$ set of common lands constrained to have incomes on tv periods,
- $T_1, \cdots, T_{\frac{nt}{5}} \subset T$ partition of set *T* in 5-years periods,
- $C_a \subset T$ subset of periods to impose constraints on age class area,
- $Tt_j \subset T$ set of periods to perform a thinning at stand *j*, with $j \in S$,
- $SB_i \subset S$ set of stands in common land *i*, with $i \in B$,
- $K = \{1, \cdots, nk\}$ the set of age classes $Y_k = [L_k, U_k]$ for each $k \in K$

OPTIMIZATION MODEL

Parameters

- A_j area of stand j (ha), $j \in S$,
- I_{0j} age (years) of stand j in the first year of the planning horizon, $j \in S$,
- C_j^t, D_j^t timber volume obtained by clear-cutting and by thinning stand j in period t (m^3), $j \in S$,
- HD_j^t be the quotient between the dominant height hg_j^t and dominant diameter dg_j^t, $HD_j^t = \frac{hg_j^t}{dg_j^t}$,

ModisPinaster simulations

- tA the target area, in ha, to each class of age,
- A_{max} the maximum area of a clear-cut (A_{max} =10 ha),
- tv maximum number of years without incomes for a given set of common lands, BV,
- tol years tolerance to perform a clear cut if stand has HD_j^t greater than 80,
- M big constant,
- Δ, θ allowed margin for removed volume and area class age target, respectively.

OPTIMIZATION MODEL

Decision variables

For each stand $j \in S$, period $t \in T$ and *baldio* $i \in B$

- **clear cut variables**

$$x_j^t = \begin{cases} 1 & \text{if a clear cutting is performed in stand } j \text{ ate period } t \\ 0 & \text{otherwise} \end{cases}$$

- **age variables**

$$\gamma_j^t = \text{age, in years, of stand } j \text{ in period } t$$

- **age class variables**

$$w_{jk}^t = \begin{cases} 1 & \text{if stand } j \text{ belongs to age class } k \text{ in period } t \text{ (with } k \in K) \\ 0 & \text{otherwise} \end{cases}$$

- **intervention variables**

$$y_i^t = \begin{cases} 1 & \text{if an intervention is performed in } baldio\ i \text{ in period } t \\ 0 & \text{otherwise} \end{cases}$$

OPTIMIZATION MODEL

$$\text{Max} \sum_{j\in S}\sum_{t\in T} x_j^t\left(C_j^t + \sum_{t_1=1}^{t} D_j^{t_1}\right) \qquad (1)$$

Subject to:

$$x_j^1 = 1 \quad \forall j \in S:\ I0_j \geq 70 \qquad (2)$$

$$\sum_{t\in T: I0_j+t-1<35} x_j^t = 0 \quad \forall j \in S \qquad (3)$$

$$\sum_{t\in T} x_j^t \leq 1 \quad \forall j \in S \qquad (4)$$

$$\sum_{t_1=t}^{min(t+4,nt)} x_j^t = 0 \quad \forall j \in S, t \in Tt_j \qquad (5)$$

$$\sum_{i=t}^{t+2}\sum_{j\in R} x_j^t \leq |R| - 1 \quad \forall R \in \Re^l, t \in T \qquad (6)$$

$$\sum_{l=1}^{min(t+tol,nt)} x_j^l = 1 \quad \forall j \in S,\ t \in T: I_{0j} + t - 1 \geq 35 \text{ and } HD_j^t > 80 \qquad (7)$$

$$y_i^t \leq \sum_{j\in SB_i} x_j^t + \sum_{j\in SB_i: t\in Tt_j}\left(1 - \sum_{l=1}^{t} x_j^l\right) \leq \text{M} \cdot y_i^t \quad \forall t \in T,\ i \in B \qquad (8)$$

$$\sum_{l=t}^{t+tv} y_i^l \geq 1 \cdot \quad \forall t \in \{1, \cdots, nT - tv\},\ i \in B \qquad (9)$$

$$(1-\Delta)VolumeP_{i-1} \leq VolumeP_i \leq (1+\Delta)VolumeP_{i-1},\ i = 1, \cdots, \frac{nt}{5} \qquad (10)$$

$$VolumeP_i = \sum_{j\in S}\sum_{t\in T_i} x_j^t\left(C_j^t + \sum_{t_1=1}^{t} D_j^{t_1}\right), \quad i = 1, \cdots, \frac{nt}{5} \qquad (11)$$

$$\gamma_j^t = I_{0j} + t - 1 - \sum_{l=1}^{t} x_j^t (I_{0j} + l - 1), \quad \forall j \in S, t \in \text{T} \qquad (12)$$

$$\sum_{k\in K} L_k w_{jk}^t \leq \gamma_j^t \leq \sum_{k\in K} U_k w_{jk}^t, \quad \forall j \in S, t \in T \qquad (13)$$

$$\sum_{k\in K} w_{jk}^t = 1, \quad \forall j \in S, t \in T \qquad (14)$$

$$(1-\theta)\, tA \leq \sum_{j\in S} w_{jk}^t A_j \leq (1+\theta)\, tA, \quad \forall k \in K, t \in Ca \qquad (15)$$

$$x_j^t, y_i^t \in \{0,1\}, \gamma_j^t \in Z_0^+ \quad \forall j \in S, t \in T \qquad (16)$$

$$w_{ji}^t \in \{0,1\} \ \forall j \in S, t \in T, i \in K \qquad (17)$$

OPTIMIZATION MODEL

Model FMPb, (1) – (6),(16)

- Bound on the area of clearings with an exclusion period
- Harvesting according to the age of the stand limits

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Model FMP, (1) – (17)

- FMPb's constraints
- Forest stability
- Revenues per common land
- Balanced revenue of volume
- Area by classes of age regulation

Individual management:

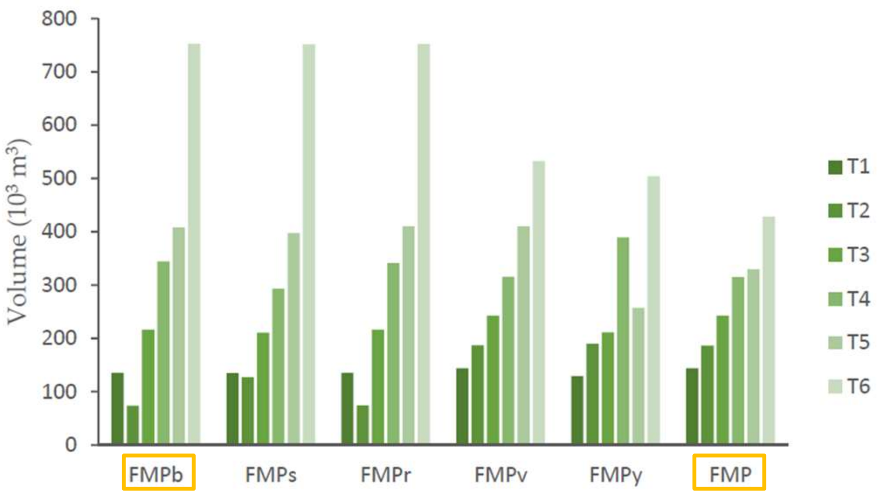
(1) – (5), (6'), (7), (8'),(9'), (10) – (16)

Global management:

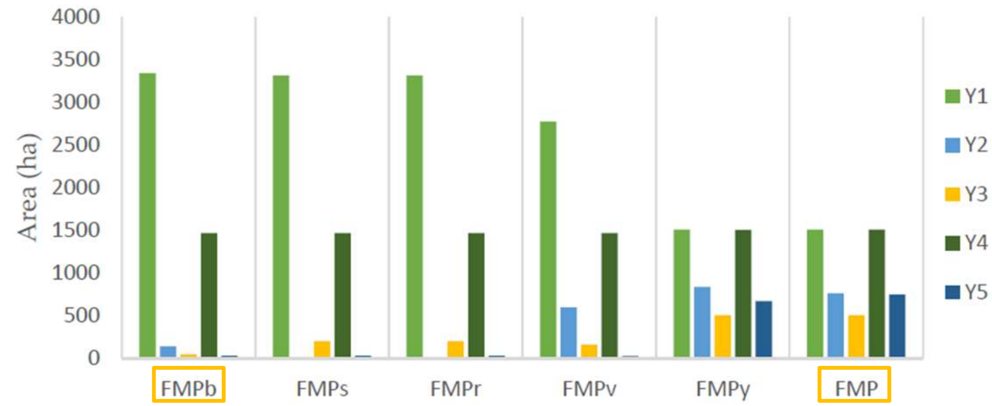
(1) – (17)

Model	Model size		Branch and Bound		Optimal value (m^3 x10^3)
	# var	# constr.	Time (s)	Gap (%)	
FMPb	187375	144101	13.4	0.0	1928.7
FMP	187855	146053	1072.3	0.0	1644.0

RESULTS ANALYSIS FMPb *versus* FMP



Removed timber volume (m^3) by each 5-years period during the planning horizon, T1=[1,5],T2=[6,10],T3=[11,15],T4=[16,20],T5=[21,25],T6=[26,30],



Area (ha) by age class, Y1=[0,10],Y2=[11,20],Y3=[21,30],Y4=[31,40],Y5=[41,70]

FMPb (base model), FMPs (model with stability constraints), FMPr (model with revenues per common land constraints), FMPv (model with balanced revenue of volume constraints), FMPy (model with area by classes of age regulation constraints) and FMP (all the constraints)

RESULTS ANALYSIS GLOBAL *versus* INDIVIDUAL

Global management (G)			Individual management (I)			100(G-I)/G	
Model	**Vol. (m^3)**	**$\bar{t}$ (yrs)**	**Model**	**Vol. (m^3)**	**$\bar{t}$ (yrs)**	**Vol. (m^3)**	**$\bar{t}$**
FMPb	1,901,081.9	10.09	**FMPb-IND**	1,905,323.9	10.04	−0.22	+0.5
FMP	1,626,701.4	21.00	**FM-IND**	1,766,397.0	20.44	−8.59	+2.67

In the FMP model, the three pillars of sustainability: environmental, economic and social are addressed.

Although the total volume of wood removed is lower with the FMP-global management model, this model presents a result more consistent with sustainable forest management.

RESULTS ANALYSIS

Optimal solution FMP (global management) *versus* FMP-IND (individual management) model

5-Years Period	FMP				FMP-IND			
	Cc		Th		Cc		Th	
	n	A (ha)	*n*	A (ha)	*n*	A (ha)	*n*	A (ha)
T_1	20	76.8	168	947.7	12	53.1	171	959.0
T_2	127	478.8	212	1195.9	39	147.6	272	1446.8
T_3	59	211.2	466	2964.4	0	0.0	499	3113.1
T_4	91	475.5	488	3125.2	3	17.5	647	3753.2
T_5	55	356.5	516	3101.0	70	470.0	479	2967.9
T_6	177	1147.5	244	1306.2	373	2007.7	202	1072.5

RESULTS ANALYSIS

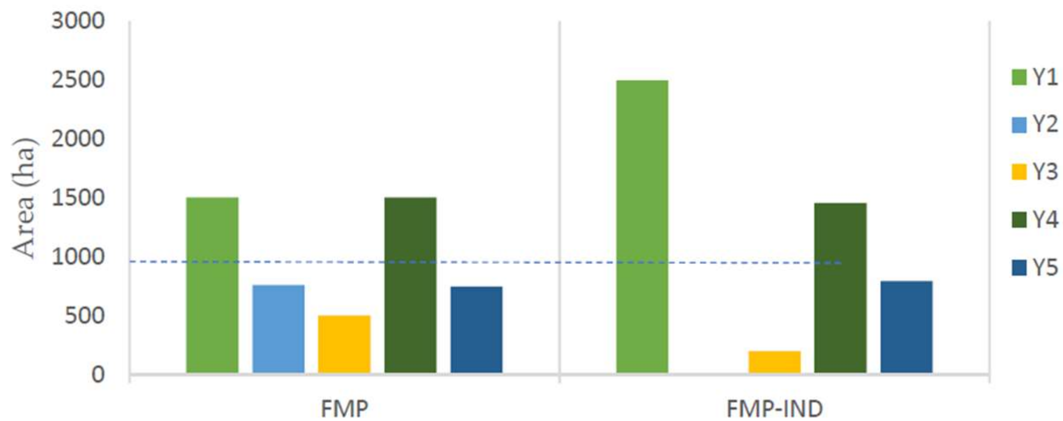
Trade-off

Individual management

Increase 8.6% in the removed volume with the individual management model.

Global Management

It guarantees a better balance of area per age class.



Area (ha) by age class, Y1=[0,10], Y2=[11,20], Y3=[21,30], Y4=[31,40], Y5=[41,70] in the last period of the planning horizon, according to the results of models FMP for the whole management (left) and for the independent management (right).

CONCLUSIONS

- The optimization model can be used or adapted to other regions, regardless of species, and to other groups of areas with multiple managing bodies, such as the ones occurring with implementation of associativism.
- Assessment of the impact of changing governance policies in the management of forest areas has never been accomplished for real cases of study involving common lands in Europe.
- The results highlight the importance of managing multi-stakeholder forest areas as a whole instead of being managed independently if the aim is to assure more sustainable management of forest resources in the mid and long terms.

Merci beaucoup!

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