

Innovations and networking in European Forestry



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The Multicriteria Decision Support System (MCDSS)

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Outline

- MCDSS Recap
- Mathematical Model
- Example Case Study Region Catalonia
- Results



Goals and characteristics:

- Develop a decision support system for stakeholders
- Find optimal assignment of management option to cells
- Planning horizon: 40 years (2020 2060)
- Consideration of user preferences / requirements
- Incorporate simulation data from representative stands of four case study regions (Estonia, Switzerland, Spain, Germany)



MCDSS - Recap

Initial	Species 1	Species 2		·
stand	share	share	share	
1	10	10		
2	10	10		
3	50	50		
	0	100		

Initial	Management	Indicators ≈ 20								
Stand option			1	2		8				
1	А	0	1	1		5				
1	В	1	0	1		0				
1	С	1	1	1		1				
1	D	1	2	0		0				
2	А									
2	В									
2	С									
2	D									
	А									
	В									
	C									
	D									



- A: low intensity
- B: business as usual
- C: climate adapted forestry
- D: intensified management

assign one management option to each of the

cells



MCDSS - Recap

Indicator List

- Standing timber
- Harvested timber (total + assortments)
- Periodic annual increment
- Quadratic mean diameter
- Height variability (mean + SD)
- Diameter variability (mean + SD)
- Deadwood
- Shannon index

- Carbon in stock
- Carbon sequestration
- Number of large trees
- Visual attractiveness
- Wood revenues
- Risk of total loss
- Risk of economic loss









Weighted Sum Approach

 $^{T} \cdot x + \beta \cdot c_{1}^{T} \cdot x$

...

s.t. $A \cdot x \leq B$,

 $x \ge 0$.





Weighted Sum Approach





Weighted Sum Approach



 $\max \alpha \cdot y_1^* + \beta \cdot y_2^*$ $\alpha + \beta = 1$



...

Indicators

timber

Standing

timber

Large trees

...

on



•••



Shannon Index

s.t.:

Mathematical Modelnot
linear!
$$v_{(shannon index),g} = -\sum_{t \in T} \sum_{c \in C_g} \sum_{m \in M} \sum_{s \in S} x_{c,m} \cdot F_{c,m,s,t} \cdot \ln(x_{c,m} \cdot F_{c,m,s,t})$$
 $\forall g \in G$ \Rightarrow Approximation through linearization necessary!
Assumption: Shannon index reaches the maximum if following statement applies: $\sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot F_{c,m,s,t} = \frac{1}{|S|}$ $\forall t \in T, s \in S$ ψ The area share of all species
should be as equal as
possible ψ The deviation to the
theoretical optimal share is
minimized
 $\forall s \in S, t \in T$ $u_{t,s} \leq s_{t,s}$ $\forall s \in S, t \in T$ $u_{t,s} \leq s_{t,s}$ $\forall s \in S, t \in T$ $0 \leq o_{t,s}, u_{t,s} \leq 1$ $\forall s \in S, t \in T$ $v_s \in \{0; 1\}$ $\forall s \in S, t \in T$



Selecting one management option for each cell

User constraints and goal programming possible, e.g.

•••

$$\sum_{c \in C_g} \sum_{m \in M} x_{c,m} \cdot B_{c,m,t}^{Trees} \stackrel{\leq}{\geq} Limit$$

 $\forall \ t \in T$

Maximize weighted sum objective:



Example -Case Study Region Catalonia



CSR Catalonia - Example



- 18 representative stands
 - Species code (Pinus sylvestris, Pinus nigra, Quercus ilex)
 - Site-quality index (high, low)
 - Stand age (young, based, mature)
- Simulation data for 19 indicators (each for the 18 stands and the planning horizon of 2020 -2060)
- 2693 cells
- 4 management options
 - A: Low intensity management / biodiversity
 - B: Protection function / Business as usual (BAU)
 - C: Climate-adapted forestry
 - D: Wood production



CSR Catalonia - Example

	10 1	IEForest									<u></u>	×
	Proje	ct About										0.1.1
	Cells Policies Objectives Constraints Optimization											
	Select Region: Pe WP3_MediterraneanForests_Spain >								Periods:	Read data		
10		stand	species1	species2	species3	species4	species5	species6	species7	species8	species9	species10 ^
	•	21_HIGH_MEDI	Crataegus spp	Pinus sylvestris	Crataegus mon	Pinus uncinata	Pinus pinea	Pinus halepensis	Quercus humilis	Pinus nigra	Fraxinus excelsi	Ulmus glab
stands		21_HIGH_YOUNG	Pinus sylvestris	Crataegus mon	Pinus uncinata	Quercus humilis	Pinus nigra	Juniperus com	Quercus petraea	Quercus faginea	Quercus ilex	Acer opalu:
		21_HIGH_MATU	Pyrus spp	Pinus sylvestris	Crataegus mon	Pinus uncinata	Pinus pinea	Quercus humilis	Pinus nigra	Pinus pinaster	Betula alba	Abies alba
		25_HIGH_MEDI	Crataegus spp	Pinus sylvestris	Crataegus mon	Pinus pinea	Pinus halepensis	Quercus humilis	Pinus nigra	Pinus pinaster	Juniperus com	Juniperus p
		25_HIGH_YOUNG	Pinus sylvestris	Pinus pinea	Juniperus oxyc	Pinus halepensis	Quercus humilis	Pinus nigra	Acer monspess	Juniperus com	Quercus faginea	Quercus ile
		25_HIGH_MATU	Pinus sylvestris	Pinus halepensis	Quercus humilis	Pinus nigra	Sorbus aucuparia	Quercus <mark>i</mark> lex	Acer opalus			
	<											>
			Size					Nam	e			
			JILC					1 turin				
		Add cell		Remove cell lo	oad CSS / CSR cells		Add group		Remo	ove group		
				Remove cell lo	oad CSS / CSR cells		Add group		Remo	ove group		
[]			size	Remove cell la	oad CSS / CSR cells]	Add group		Remo	ve group		^
2693 cells	•	cell	size 162,3113757	stand 21_LOW_YOUNG	oad CSS / CSR cells	1	Add group		Remo	we group		^
2693 cells	•	cell 1 2	size 162,3113757 143,1009052	stand 21_LOW_YOUNG 21_LOW_MATURE	oad CSS / CSR cells	1	Add group		Remo	ove group		^
2693 cells with	•	cell 1 2 3	size 162,3113757 143,1009052 143,1009052	Remove cell In stand 21_LOW_YOUNG 21_LOW_MATURE 21_HIGH_MEDIUM	oad CSS / CSR cells]	Add group		Remo	we group		^
2693 cells with		cell 1 2 3 4	size 162,3113757 143,1009052 143,1009052 143,1009052	stand 21_LOW_YOUNG 21_LOW_MATURE 21_HIGH_MEDIUN 21_HIGH_YOUNG	oad CSS / CSR cells	1	Add group		Remo	we group		^
2693 cells with correspondin		cell 2 3 4 5 6	size 162,3113757 143,1009052 143,1009052 143,1009052 143,1009052 143,1009052	stand 21_LOW_YOUNG 21_LOW_MATURE 21_HIGH_MEDIUM 21_HIGH_YOUNG 21_HIGH_MEDIUM 21_HIGH_MEDIUM	oad CSS / CSR cells	:	Add group		Remo	vve group		^
2693 cells with correspondin g stand and		cell 2 3 4 5 6 7	size 162,3113757 143,1009052 143,1009052 143,1009052 143,1009052 162,3113757 143,1009052	stand 21_LOW_YOUNG 21_LOW_MATURE 21_HIGH_MEDIUM 21_HIGH_YOUNG 21_HIGH_MEDIUM 21_LOW_MEDIUM	oad CSS / CSR cells		Add group		Remo	vve group		^
2693 cells with correspondin g stand and		cell 2 3 4 5 6 7 8	size 162,3113757 143,1009052 143,1009052 143,1009052 143,1009052 162,3113757 143,1009052 143,1009052 143,1009052	stand 21_LOW_YOUNG 21_LOW_MATURE 21_HIGH_MEDIUM 21_HIGH_YOUNG 21_HIGH_MEDIUM 21_HIGH_MEDIUM 21_HIGH_MEDIUM 21_HIGH_MEDIUM 21_HIGH_MEDIUM 21_HIGH_MEDIUM 21_HIGH_MEDIUM	oad CSS / CSR cells		Add group		Remo	vve group		^
2693 cells with correspondin g stand and size		cell 2 3 4 5 6 7 8 9	size 162,3113757 143,1009052 143,1009052 143,1009052 143,1009052 162,3113757 143,1009052 143,1009052 143,1009052	stand stand 21_LOW_YOUNG 21_LOW_MATURE 21_HIGH_MEDIUM 21_HIGH_YOUNG 21_HIGH_MEDIUM 21_LOW_MEDIUM 21_HIGH_MEDIUM 21_HIGH_MEDIUM 21_LOW_MEDIUM 21_LOW_MEDIUM 21_HIGH_MEDIUM	oad CSS / CSR cells		Add group		Remo	vve group		^



CSR Catalonia - Example

Image: Constraints Other Protection and green transition Scenario I Scenario II Scenario II Scenario III Scenario III	INN	OVAForONE	indicato	rs are				
Project About Standing Scenario I Scienty under voluntary green transition Scenario I Scenario I Scienty under voluntary green transition Scenario II Climate change Scenario II Climate change adaption and green transition Standing timber 5 10 10 Scenario II- Scenario III- Climate change recreation-oriented forest management forest management growing bioeconcy Protection and recreation-oriented forest management Scenario II Scenario II Scenario II Climate change 000 10 10 MD (harvested species) 5 3 000 20 20 5 3 000 10	. ON	EForest			<u> </u>		predefined	a tor tour
Cells Pelicitie Objectives Constraints Optimization Scenario I - Society under voluntary green transition Scenario II - Climate change adaption and green transition Scenario II - Climate change adaption and green transition Scenario II - Protection and recreation-oriented forest management Scenario II - Protection and recreation-oriented forest management Scenario II - Terrotexted fumber total 50 30 10 20 Periodic annual increment 5 5 5 5 5 5 QMD (harvested species) 5 3 QMD (standing species) 2 5 QMD (standing species) 2 5 10 10 QMD (standing stand) 2 5 5 5 Diameter variability (SD) 5 5 5 5 Diameter variability (SD) 5 5 5 5 Diameter variability (GD) 5 10 10 10 Carbon in stock aboveground 5 15 10 10 Number of large trees 5 5 20 10 10 Number of large trees 5 5 20 10	Projec	t About				0.1.1	scena	rios
Scenario I - Society under voluntary green transition Scenario II Sc	Cells	Policies Objectives Constraints Optimization					(THRO /	'SLU)
Scenario II - Climate change adaption and green transitionScenario III - Protection and recreation-oriented forest managementScenario III - IIII - Periodic annual incrementScenario III - IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII		Scenario I - Society under voluntary green transition			Scenario I	Scenario II	Scenario III	Scenario IV
Scenario III - Protection and recreation-oriented forest managementScenario IV - Climate change mitigation in a slow-growing bioeconomyStanding timber55301020MD (harvested species)533		Scenario II - Climate change adaption and green transition			Society under voluntary green transition	Climate change adaption and green transition	Protection and recreation-oriented forest management	Climate change mitigation in a slow- growing bioeconomy
Scenario III - Protection and recreation-oriented forest managementHarvested timber total50301020Scenario IV - Climate change mitigation in a slow-growing bioeconomyQMD (harvested species)533				Standing timber		5	10	10
Periodic annual increment555QMD (harvested species)53		Scenario III -		Harvested timber total	50	30	10	20
Scenario IV - Climate change mitigation in a slow-growing bioeconomyQMD (harvested species)53QMD (harvested stand)103QMD (standing species)25QMD (standing stand)25Peight variability (SD)5Diameter variability (mean)5Deadwood with decomposition10Carbon in stock aboveground5Carbon sequestration5Number of large trees52010Nisk of economic loss5Shanon index52010Wood revenues202010		Protection and recreation-oriented forest management		Periodic annual increment	5	5	5	5
QMD (harvested stand) 10 3 QMD (standing species) 2 5 QMD (standing stand) 2 5 Person 5 5 Diameter variability (SD) 5 5 Deadwood with decomposition 10 10 Carbon in stock aboveground 5 5 Carbon sequestration 5 10 Number of large trees 5 20 10 Visual attractiveness 5 20 10 Risk of economic loss 5 15 10 Wood revenues 20 10 10		Scopprin IV	\backslash	QMD (harvested species)	5	3		
QMD (standing species)25QMD (standing stand)25QMD (standing stand)25Height variability (SD)5Diameter variability (mean)5Deadwood with decomposition10Carbon in stock aboveground5Carbon in stock aboveground5Carbon sequestration5Number of large trees52010Visual attractiveness5Shannon index5Shannon index52010		Climate change mitigation in a slow-growing bioeconomy	\backslash	QMD (harvested stand)	10	3		
QMD (standing stand)25Height variability (SD)55Diameter variability (mean)510Deadwood with decomposition1010Carbon in stock aboveground55Carbon sequestration51510Number of large trees52010Visual attractiveness52010Risk of economic loss5510Wood revenues201010				QMD (standing species)		2	5	
Load Policy5Diameter variability (mean)5Deadwood with decomposition10Carbon in stock aboveground5Carbon sequestration5Number of large trees52010Visual attractiveness5Shannon index551510Wood revenues2010			\backslash	QMD (standing stand)		2	5	
Diameter variability (mean)5Deadwood with decomposition1010Carbon in stock aboveground55Carbon sequestration51510Number of large trees52010Visual attractiveness52010Risk of economic loss5510Shannon index5510Wood revenues201010				Height variablity (SD)				5
Deadwood with decomposition1010Carbon in stock aboveground55Carbon sequestration51510Number of large trees52010Visual attractiveness52010Risk of economic loss5515Shannon index551510Wood revenues201010		Load Policy		Diameter variability (mean)				5
Carbon in stock aboveground55Carbon sequestration51510Number of large trees52010Visual attractiveness52010Risk of economic loss5515Shannon index551510Wood revenues201010				Deadwood with decomposition			10	10
Carbon sequestration51510Number of large trees52010Visual attractiveness52010Risk of economic loss5510Shannon index551510Wood revenues201010				Carbon in stock aboveground		5		5
Number of large trees52010Visual attractiveness52010Risk of economic loss555Shannon index551510Wood revenues20105				Carbon sequestration	5	15		10
Visual attractiveness52010Risk of economic loss551510Shannon index551510Wood revenues20101010				Number of large trees		5	20	10
Risk of economic loss5Shannon index5510Wood revenues2010				Visual attractiveness		5	20	10
Shannon index551510Wood revenues2010				Risk of economic loss		5		
Wood revenues 20 10				Shannon index	5	5	15	10
				Wood revenues	20	10		

Weights for



CSR Catalonia - Example

	I ONEForest	—	×
	Project About		0.1.1
	Cells Policies Objectives Constraints Optim	ization	
Weighted sum objective based on the predefined weights (here: Scenario I)	- Global - Harvested Timber (total) - Periodic Annual Increment - QMD Harvested Species - QMD Harvested Stand - Shannon Index - Wood Revenues - Carbon Sequestration - Standing Timber - QMD Standing Species - QMD Standing Species - QMD Standing Stand - Height Variability (SD) - Diameter Variability (Mean) - Deadwood - Carbon in Stock (Aboveground) - Number of Large Trees - Visual Attractiveness - Risk of Total Loss RCP 4.5	First period: 0 Last period: 8 Indicator: Harvested Timber (total) Group: Global Weight (in group): 0	
	Create new objective Remove objective Objective = Save policy	1 * (0,5 * Harvested Timber (total) + 0,05 * Periodic Annual Increment + 0,05 * QMD Harvested Species + 0,1 * QMD Harvested Stand + 0,05 * Shann Index + 0,2 * Wood Revenues + 0,05 * Carbon Sequestration + 0 * Standing Timber + 0 * QMD Standing Species + 0 * QMD Standing Stand + 0 * He Variability (SD) + 0 * Diameter Variability (Mean) + 0 * Deadwood + 0 * Carbon in Stock (Aboveground) + 0 * Number of Large Trees + 0 * Visual Attractiveness + 0 * Risk of Total Loss RCP 4.5)	on ^ .ght v



CSR Catalonia - Example

		ONEForest		- 🗆	×
		Project About			0.1.1
		Cells Policies Objectives Constraints Optimization			
	1	Output folder path: Method: Weighted_Sum v	G	Solver: Surobi	~
Solve mathematical		Use heuristic Gen	erate		
model		approach?	r chart?	Go!	
		Extended log?			
		[Start] Create Objective Computation Time: 0,0475666			^
		[End] Create Objective [Start] Optimize Model using objective QMD Standing Species_Global			
		Computation Time: 1,9232245 [End] Optimize Model			
		Computation Time: 0,0021714 [End] Create Objective			
		[Start] Optimize Model using objective QMD Standing Stand_Global Computation Time: 2,0451042			
		[End] Optimize Model [Start] Create Objective			
		[End] Create Objective [End] Create Model using objective Height Variability (SD). Global			
		Computation Time: 2,0318279 [End] Optimize Model			
		[Start] Create Objective Computation Time: 0,0023281			
		[End] Create Objective [Start] Optimize Model using objective Diameter Variability (Mean)_Global			
		[End] Optimize Model			
		Computation Time: 0,0041477 [End] Create Objective			
		[Start] Optimize Model using objective Deadwood_Global			
					~



Results



Results

1	A	В	С	D	E	F	G	Н	1	J	К	L	м	
1	Objective	0,8486												
2	Computation Time	66,2785221												
3	MIP Gap	NaN												
4														
5	group	obj	lb	ub	objValue									
6	Global	Harvested Timber (total)	95315007,3	199037400	195423886,4									
7	Global	Periodic Annual Increment	6938792,489	9185256,94	7787285,573									
8	Global	QMD Harvested Species	4311958,507	7177996,16	6366197,087									
9	Global	QMD Harvested Stand	385582,6796	595479,403	536418,7324									
10	Global	Shannon Index	11,73378668	11,9944512	11,96166066									
11	Global	Wood Revenues	4377103291	9030269783	8788521103									
12	Global	Carbon Sequestration	84182291,67	126889810	89259010,78									
13	Global	Standing Timber	516956634,7	616348774	532825785,4									
14	Global	QMD Standing Species	12295500,71	13808342,7	13471288,78									
15	Global	QMD Standing Stand	474853,1271	535983,823	501174,3526									
16	Global	Height Variability (SD)	29888,5675	38739,7614	33859,16661									
17	Global	Diameter Variability (Mean)	449260,8015	516046,606	478892,9411									
18	Global	Deadwood	10831349,04	13061463,9	12323388,7									
19	Global	Carbon in Stock (Aboveground)	1004450633	1175770764	1025566546									
20	Global	Number of Large Trees	2852834,009	7695385,11	4808010,226									
21	Global	Visual Attractiveness	15226,6713	16312,8882	15683,64655									
22	Global	Economic Loss RCP 4.5	-658178,1021	7447,5058	-456730,3702									
23														
24	stand	cell	mgmt opt	id										
25	21_LOW_YOUNG	1	D	80004										
26	21_LOW_MATURE	2	С	80006										
27	21_HIGH_MEDIUM	3	D	80012										
28	21_HIGH_YOUNG	4	D	80014										
29	21_HIGH_MEDIUM	5	D	80015										
30	21_LOW_MEDIUM	6	D	80019										
31	21_HIGH_MEDIUM	7	D	80020										
32	21_HIGH_MEDIUM	8	D	80021										
33	21_LOW_MEDIUM	9	D	80022										
34	21_LOW_MEDIUM	10	D	80024										
35	21_LOW_MEDIUM	11	D	80025										
	Summa	ry Harvested Timber (Bhd) Ha	arvested Timber (total) Perio	odic Annual Increm	ent	QMD Harvest	ted Species	QMD Ha	arvested Stand	Wc	. 🕀 :	4	

- Detailed numerical output
- Value for all indicators and value range (lower bound / upper bound)
- Optimal assignment of management options to cells



Results - Scenario I







Results - Scenario II







Restuls - Scenario III













- The MCDSS helps stakeholders make informed, number-based decisions
- The simulation data from the case study regions serve as input for a mathematical model based on the weighted sum approach
- The results should be understood as suggestions for further analyses
- There is not ONE optimal solution because the results depend heavily on the weightings applied









This project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement N° 101000406.

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