Bundesforschungs- und Ausbildungszentrum
für Wald, Naturgefahren und Landschaft

für Wald und Mensch

Forschung - Monitoring - Bildung

EFDM

European Forestry Dynamics Model

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Aims of EFDM
European Forestry Dynamics Model

- Predict development of the forest
- Include management activities
- Simulate the effects of management decisions
- Simple and versatile model

Mathematical principle

Markov chain:

- Discrete time steps, new state depends only on last one
- State is a vector
- Transition is represented by matrices

  P ... transition probability matrix without management

  A ... activity matrix

$$x_{t+1} = A(t) \cdot P \cdot x_t$$

Calculation process

1. Initialization: description / formatting of data
2. Estimation of *P* (transitions without management)
3. Setting up the transitions conditional on activities and input of activity probabilities (*A*)
4. Building the total transition matrix
5. Input of the current state
6. Calculation of the next state
7. Repeat 3. – 6.

Activity matrix

- Can change between time steps
- Can be chosen manually
- Possible activites:
  - Thinning / selective felling
  - Clearcut
  - Shelter system / no harvest
  - Calamities (storms, parasites, …)
  - Ingrowth / afforestation

State vector

- Elements are units of land / plots
- Data divided according to factors (~stratified)
  - e.g. dominant species, sea level, age, owner, stemnumber/ha, stock (volume/ha) in classes
  - one element per combination of factor classes: number of plots that fall into this category
  - quickly a large number of elements

$$n = \prod_{i=1}^{k} n_i$$

n ... size of state vector

k ... number of factors

n_i ... number of classes in the i^{th} factor

Transition probability matrix

- Size n x n
- $p_{i,j}$ denotes the probability of the transition of an element in state j to state i
- Data of plots at two points of time
- To completely fill the matrix P, data for all n^2 combinations are needed (unrealistic)
  - $(10 * 15 * 3 * 3)^2 = 1{,}822{,}500$
- 2 remedies:
  - set some factors constant (e.g. sea level) to create blocks of zeros in P
  - use Bayesian estimator

The Bayesian estimator

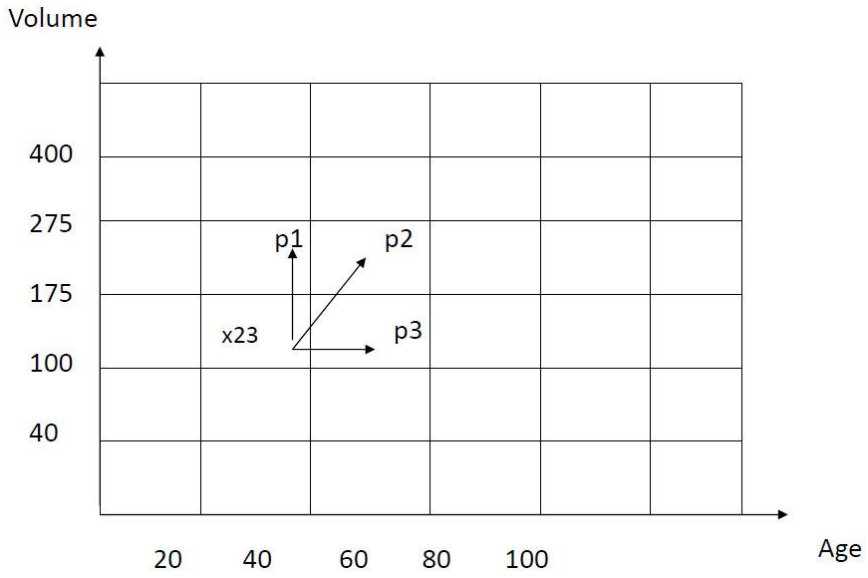
- Simple model
- Additional data can be included easily
- Very flexible R code, can adapt to specific needs of different countries
- Developed at METLA, Finland
- Open source, EUPL licence

The stepwise implementation

- pool data over all constant factors
- choose prior, e.g. identity matrix
- calculate *P* (=posterior)
- split data by one factor
- use posterior as new prior, calculate new posterior for every factor class
- repeat until no constant factors are left
- weighting possible at each step

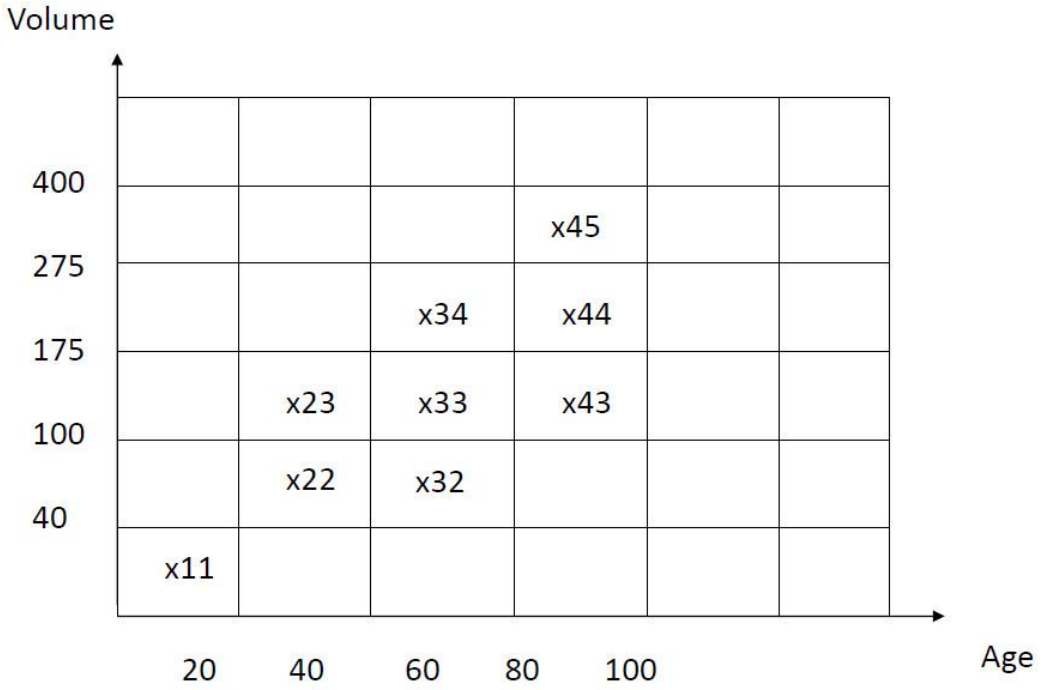
Implementation so far

- Only first international phase
- No activity matrix *A* yet in Austria
- Simplest model: state vector seen as age - volume matrix



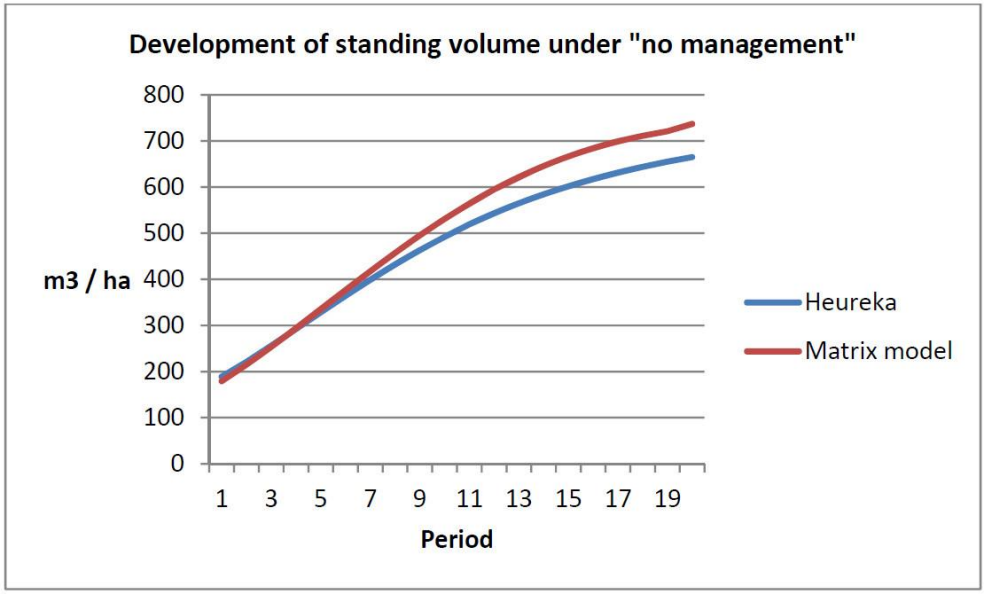
Sweden

- Age-volume model
- For demonstration purposes: one unit of land, see how it develops



Sweden

- Used NFI data and compared to currently used growth simulator to predict 100 year development



	Area (mill. ha)	Initial mean volume (m3/ha)	Avg. increment over 100 years (m3/ha,year)
Heureka	6.0	185	5.2
Matrix Model	5.6	179	5.6

Age-Volume

- Age often unknown, hard to estimate
- Requires even-aged stands
- "one-dimensional"
- Suitable for Scandinavian forests
- Austria: mostly uneven-aged stands
- Stem number instead of age

Data

- Plot data
- Two NFIs: 2000 – 2002 and 2007 – 2009

  → 7 year time steps in simulation
- "no harvest": no harvested trees between NFI periods, but still mostly managed forest

  → expect growth on the high side
- Two constant factors: sea level, dominant species
- Variable factors: stem number/ha, volume/ha

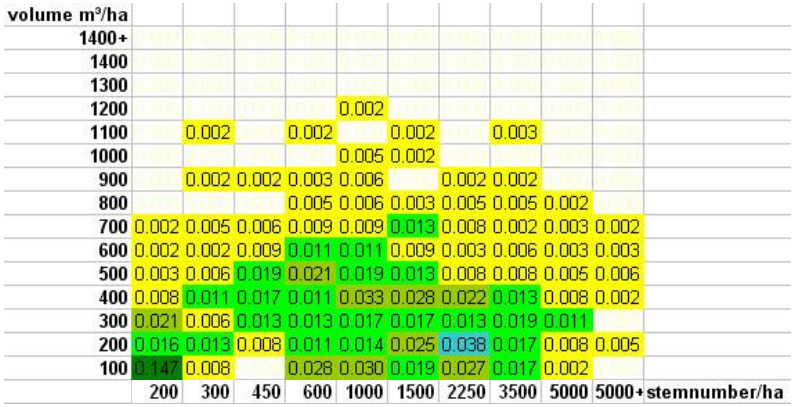
Stem number - Volume

- Stands/plots can 'move' in any direction
- In general from bottom right to top left
  (high stemnr, low volume to low stemnr, high volume)

volume m³/ha											
1400+	0	0	0	0	0	0	0	0	0	0	
1400	0	0	0	0	0	0	0	0	0	0	
1300	0	0	0	0	0	0	0	0	0	0	
1200	0	0	0	0	1	0	0	0	0	0	
1100	0	1	0	1	0	1	0	2	0	0	
1000	0	0	0	0	3	1	0	0	0	0	
900	0	1	1	2	4	0	1	1	0	0	
800	0	0	0	3	4	2	3	3	1	0	
700	1	3	4	6	6	8	5	1	2	1	
600	1	1	6	7	7	6	2	4	2	2	
500	2	4	12	13	12	8	5	5	3	4	
400	5	7	11	7	21	18	14	8	5	1	
300	13	4	8	8	11	11	8	12	7	0	
200	10	8	5	7	9	16	24	11	5	3	
100	93	5	0	18	19	12	17	11	1	0	
	200	300	450	600	1000	1500	2250	3500	5000	5000+	stemnumber/ha

factors: sea level: below 900m, dominant species: spruce
616 plots

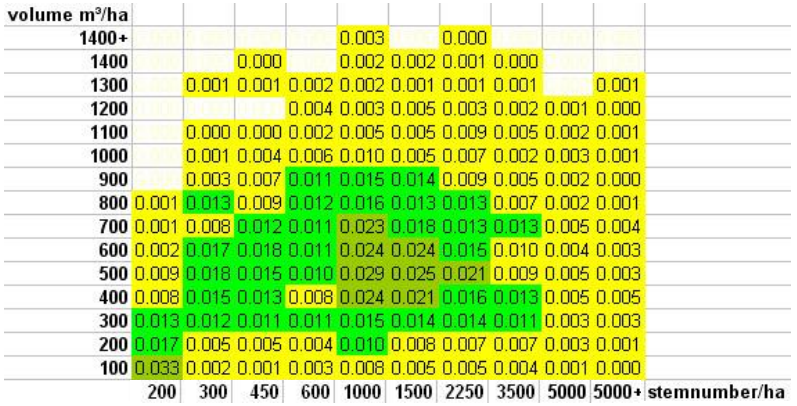
Stem number - Volume Simulation



volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+										
1400										
1300										
1200					0.002					
1100		0.002		0.002		0.002		0.003		
1000					0.005	0.002				
900		0.002	0.002	0.003	0.006		0.002	0.002		
800				0.005	0.006	0.003	0.005	0.005	0.002	
700	0.002	0.005	0.006	0.009	0.009	0.013	0.008	0.002	0.003	0.002
600	0.002	0.002	0.009	0.011	0.011	0.009	0.003	0.006	0.003	0.003
500	0.003	0.006	0.019	0.021	0.019	0.013	0.008	0.008	0.005	0.006
400	0.008	0.011	0.017	0.011	0.033	0.028	0.022	0.013	0.008	0.002
300	0.021	0.006	0.013	0.013	0.017	0.017	0.013	0.019	0.011	
200	0.016	0.013	0.008	0.011	0.014	0.025	0.038	0.017	0.008	0.005
100	0.147	0.008		0.028	0.030	0.019	0.027	0.017	0.002	

stemnumber/ha

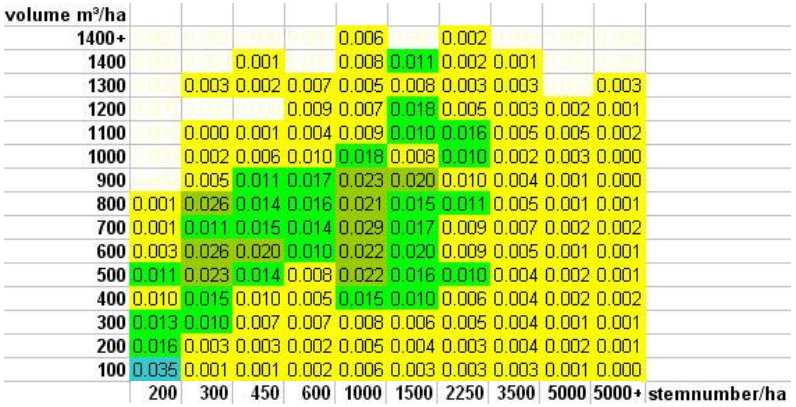
0 years, 1185 stems, 291 m³



volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+					0.003		0.000			
1400				0.000		0.002	0.002	0.001	0.000	
1300		0.001	0.001	0.002	0.002	0.001	0.001	0.001		0.001
1200				0.004	0.003	0.005	0.003	0.002	0.001	0.000
1100		0.000	0.000	0.002	0.005	0.005	0.009	0.005	0.002	0.001
1000		0.001	0.004	0.006	0.010	0.005	0.007	0.002	0.003	0.001
900		0.003	0.007	0.011	0.015	0.014	0.009	0.005	0.002	0.000
800	0.001	0.013	0.009	0.012	0.016	0.013	0.013	0.007	0.002	0.001
700	0.001	0.008	0.012	0.011	0.023	0.018	0.013	0.013	0.005	0.004
600	0.002	0.017	0.018	0.011	0.024	0.024	0.015	0.010	0.004	0.003
500	0.009	0.018	0.015	0.010	0.029	0.025	0.021	0.009	0.005	0.003
400	0.008	0.015	0.013	0.008	0.024	0.021	0.016	0.013	0.005	0.005
300	0.013	0.012	0.011	0.011	0.015	0.014	0.014	0.011	0.003	0.003
200	0.017	0.005	0.005	0.004	0.010	0.008	0.007	0.007	0.003	0.001
100	0.033	0.002	0.001	0.003	0.008	0.005	0.005	0.004	0.001	0.000

stemnumber/ha

35 years, 1270 stems, 522 m³



volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+					0.006		0.002			
1400			0.001		0.008	0.011	0.002	0.001		
1300		0.003	0.002	0.007	0.005	0.008	0.003	0.003		0.003
1200				0.009	0.007	0.018	0.005	0.003	0.002	0.001
1100		0.000	0.001	0.004	0.009	0.010	0.016	0.005	0.005	0.002
1000		0.002	0.006	0.010	0.018	0.008	0.010	0.002	0.003	0.000
900		0.005	0.011	0.017	0.023	0.020	0.010	0.004	0.001	0.000
800	0.001	0.026	0.014	0.016	0.021	0.015	0.011	0.005	0.001	0.001
700	0.001	0.011	0.015	0.014	0.029	0.017	0.009	0.007	0.002	0.002
600	0.003	0.026	0.020	0.010	0.022	0.020	0.009	0.005	0.001	0.001
500	0.011	0.023	0.014	0.008	0.022	0.016	0.010	0.004	0.002	0.001
400	0.010	0.015	0.010	0.005	0.015	0.010	0.006	0.004	0.002	0.002
300	0.013	0.010	0.007	0.007	0.008	0.006	0.005	0.004	0.001	0.001
200	0.016	0.003	0.003	0.002	0.005	0.004	0.003	0.004	0.002	0.001
100	0.035	0.001	0.001	0.002	0.006	0.003	0.003	0.003	0.001	0.000

stemnumber/ha

70 years, 1045 stems, 645 m³

volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+					0.000		0.000			
1400				0.017		0.138	0.532	0.000	0.051	
1300		0.073	0.000	0.133	0.000	0.000	0.000	0.000		0.015
1200					0.000	0.000	0.000	0.000	0.007	0.004
1100				0.000	0.000	0.000	0.000	0.000	0.024	0.007
1000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
900		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
700	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
400	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
300	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

stemnumber/ha

7000 years, 1302 stems, 1317 m³

Dynamics of the model

- "two-dimensional"
- Land units can "move in any direction"

volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+										
1400										
1300										
1200										
1100										
1000										
900										
800										
700										
600										
500										
400										
300			1.000							
200										
100										

stemnumber/ha

volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+										
1400										
1300										
1200										
1100										
1000										
900										
800			0.012			0.018				
700					0.006					
600				0.006						
500			0.024	0.012	0.048					
400		0.067	0.139	0.036	0.018	0.018				
300	0.012	0.176	0.285	0.055	0.012	0.006				
200		0.006	0.018							
100	0.024									

stemnumber/ha

volume m³/ha	200	300	450	600	1000	1500	2250	3500	5000	5000+
1400+					0.001	0.000				0.000
1400						0.000				
1300										
1200										
1100			0.000	0.000	0.000	0.001	0.001	0.001		
1000		0.000	0.001	0.001	0.002	0.001	0.000	0.000		
900			0.003	0.001	0.002	0.004	0.000	0.000		
800		0.002	0.008	0.004	0.007	0.011		0.001		
700	0.000	0.001	0.003	0.004	0.011	0.002	0.001	0.000		
600	0.001	0.005	0.020	0.017	0.019	0.006	0.000	0.001		
500	0.002	0.020	0.064	0.028	0.044	0.012	0.002	0.000		0.000
400	0.010	0.084	0.113	0.030	0.028	0.018	0.002	0.000		
300	0.035	0.122	0.100	0.034	0.012	0.008	0.001	0.000	0.000	
200	0.010	0.008	0.013	0.001	0.002	0.000	0.000	0.000	0.000	0.000
100	0.043	0.000	0.000	0.001	0.003	0.001	0.001	0.001	0.000	

stemnumber/ha

Properties of the model

- Markov Chain
- Positive semidefinite matrix
- Asymptotically converges to stable state, independently of initial state
- Eigenvector to the biggest Eigenvalue
- Converges very slowly: after 1000 simulated years still not close to stable state
- Based on one 7 year time step
- No long term reliability

Results

- Good (very plausible) short term results
- Overall average annual growth ~7m³/ha
- Without mortality and calamities ~9m³/ha
- Managed forest higher increment than unmanaged
- Sea level trend: lower growth at high elevation
- Compares well to NFI results
- Little data for high volume classes – reason for unrealistic long term results?

Other countries

- Finland similar to Sweden
- France simulated individual trees, used diameter classes
- Portugal: Eucalyptus plantations

  Two simulations:

  1. No management
  2. Management and fire

Future prospects

- Second phase will start soon
- Inclusion of more countries
- Inclusion of management activity matrix
- Already partly done for Sweden using 5 management groups
- Include forest products and services
  - biomass
  - harvested wood in terms of timber assortments
- Harmonization across Europe

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