Combining multiple criteria techniques and optimisation for longterm multi-objective forest management planning under climate change

SilviStrat
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1. Background

Forests are a key resource serving a multitude of functions such as providing income to forest owners, supplying industries with timber, protecting water resources, providing habitat for wildlife and maintaining biodiversity. Recently much attention has been paid to the role of forests in the global carbon cycle and their management for increased carbon sequestration is seen as a possible mitigation option against climate change.

Forest resource managers are challenged by the task to balance multiple and often conflicting interests while at the same time meeting economic requirements. It has long been acknowledged that long-term forest planning includes a high degree of risk and uncertainty. This is particularly true with regard to uncontrollable external variables such as climate.

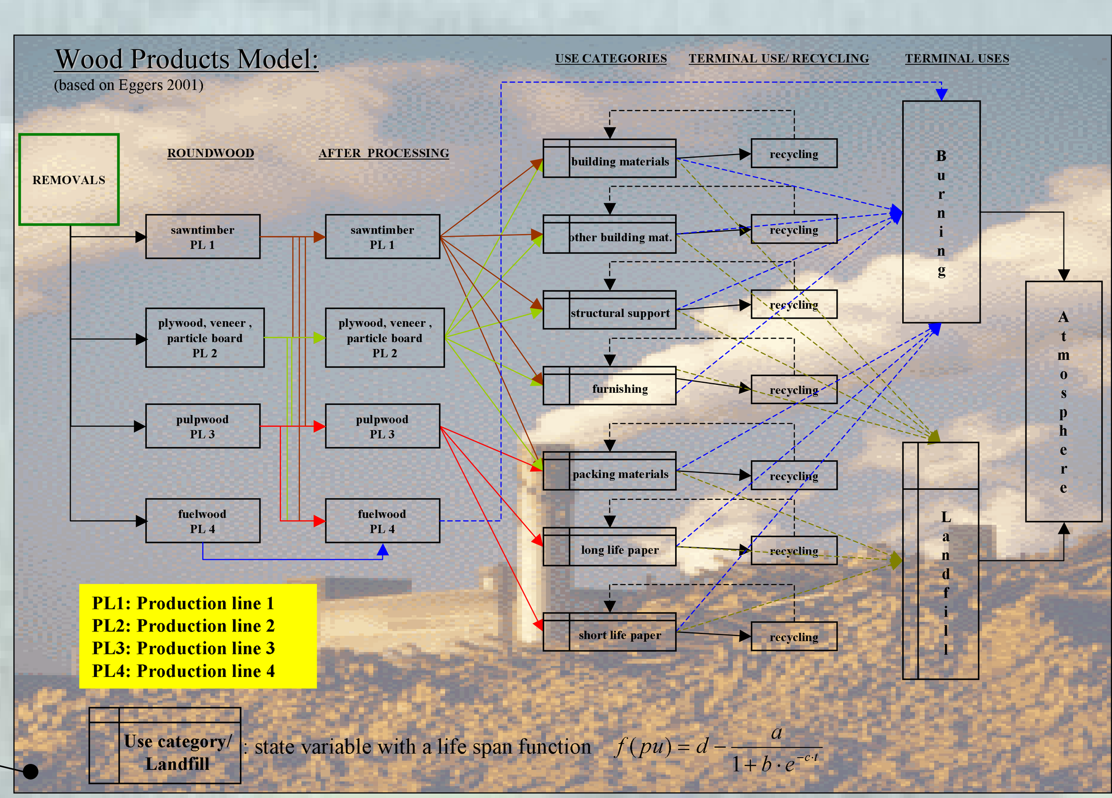
2. Objectives

There are numerous examples of the integration of risk in forest planning. However, few studies exist of long-term forest management planning at forest level which include multiple objectives and uncertainty due to a possible climate change.

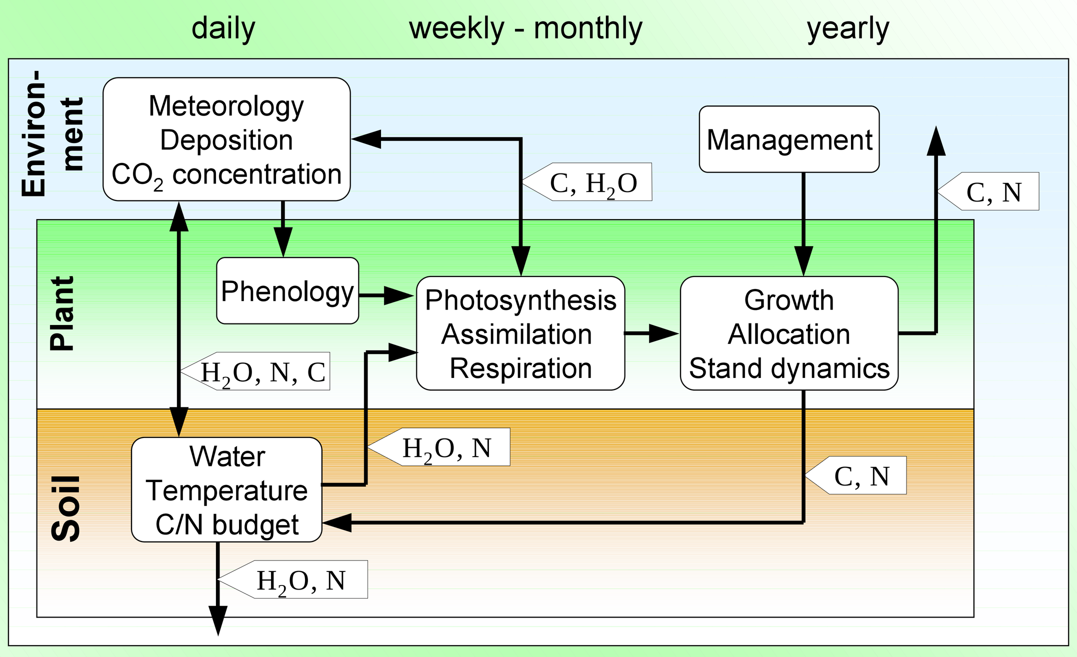
In a case study we combine

- process based forest simulation modeling
- multi-criteria appraisal methods
- optimisation

to design management plans for multiple objectives (timber production, carbon sequestration, groundwater recharge, biodiversity) under climate change conditions for a 900 ha management unit in the state of Brandenburg, Germany.

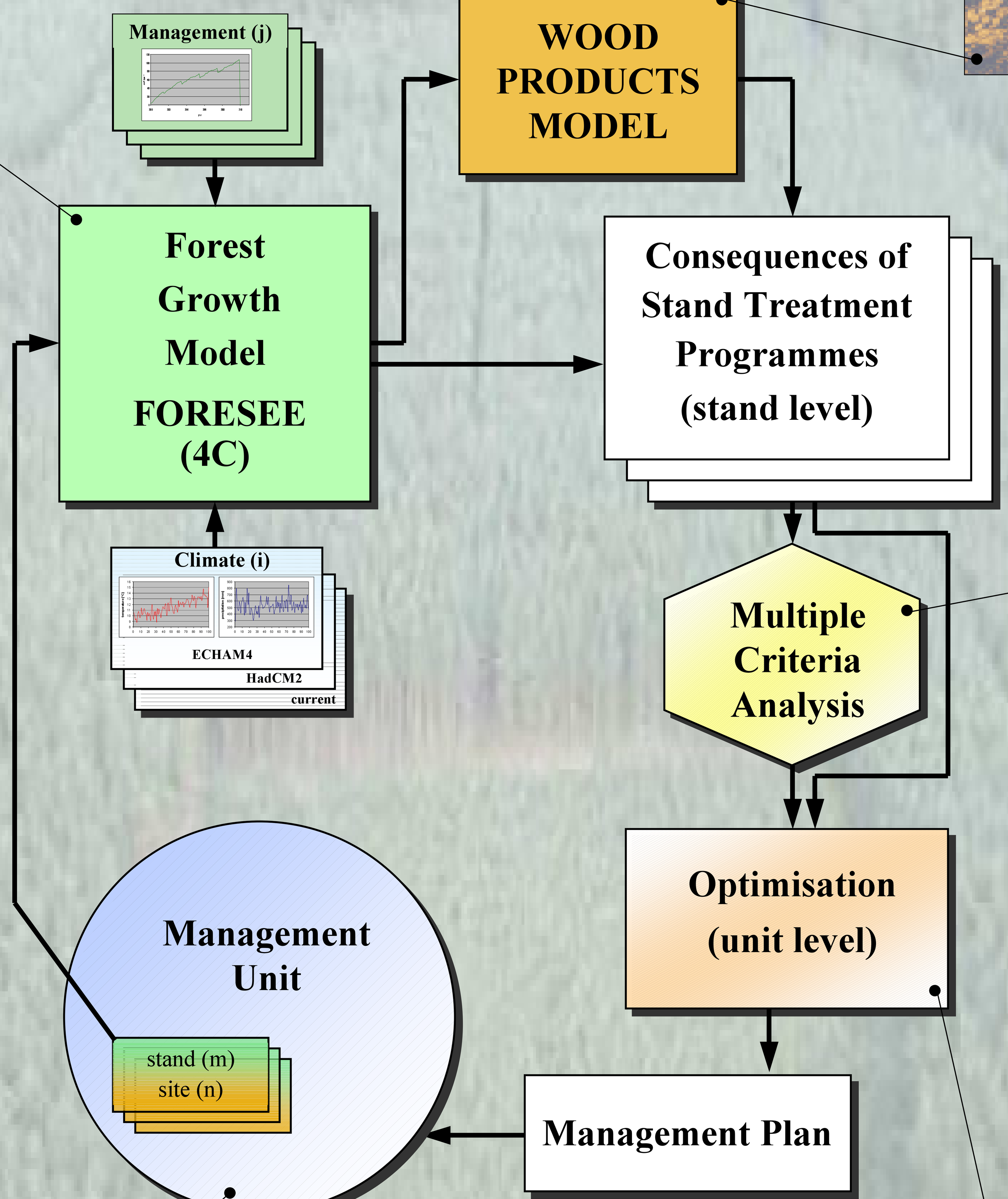


Model of forest gap dynamics, 4C
FOREStt Ecosystems in a changing Environment

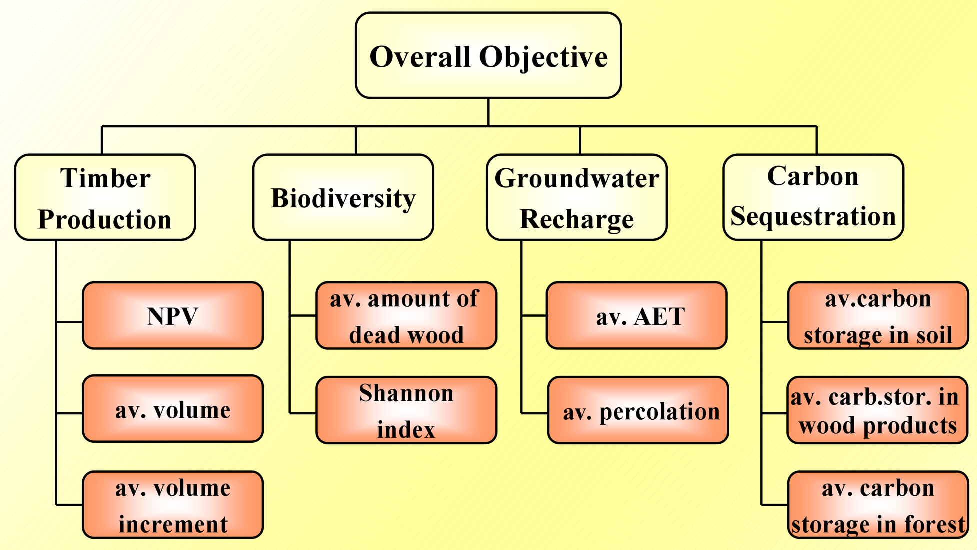


Characterisation of 4C (Lasch et al. 2002):

- physiologically based model of gap dynamics
- describes explicitly establishment, growth and mortality of tree cohorts
- three discrete time steps:
  - a) *daily* for soil dynamics and phenology
  - b) *one to two weeks* for net primary productivity (NPP)
  - c) *annual* for tree growth (allocation) and population dynamics
- explicit simulation of net photosynthetic production by the canopy and allocation of assimilates
- soil water balance, C/N turnover and soil temperature is calculated for a layered soil
- mortality is based on carbon balance and an age-dependent mortality is included
- simulation of management treatment programs:
  - a) harvesting systems: shelterwood and clear cut
  - b) regeneration: pure pine and oak, mixtures between pine and oak
  - c) rotation period length and thinning intensity



Timber production, maintenance of biodiversity, groundwater recharge and carbon sequestration are identified as relevant management objectives at stand level. These management objectives are decomposed into measurable decision criteria.



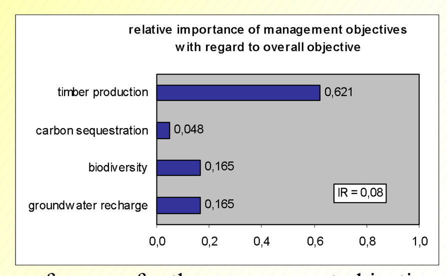
decision hierarchy at stand level

The expected utility from choosing a stand treatment programme under each of the climate scenarios with regard to the stand level objectives is calculated in a bottom up approach with an additively weighted utility model (Lexer, 2000). As an example the utility function at the level of the management objectives is given:

$$U_{overall} = a_1 \cdot U_{TP} + a_2 \cdot U_{BD} + a_3 \cdot U_{GWR} + a_4 \cdot U_{CS}$$

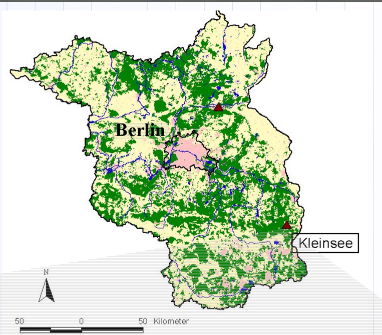
$$\sum a_x = 1$$

The parameter values (stakeholder´s preferences) of the utility functions are estimated with Saaty´s eigenvalue method (pairwise comparison of objectives / criteria).

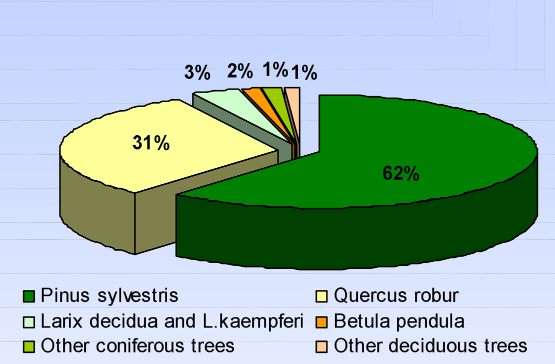


preferences for the management objectives

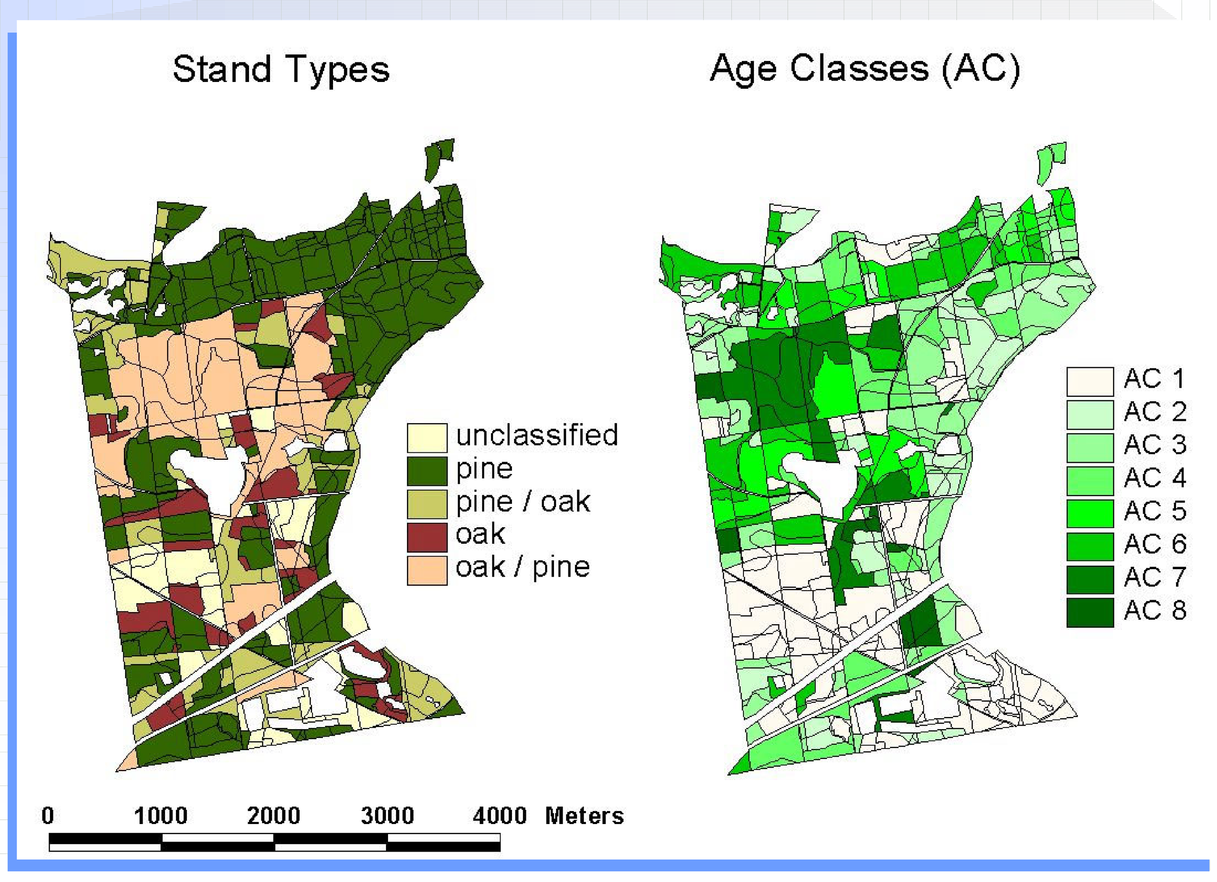
Forest district Kleinsee, Brandenburg, Germany



- 917 ha
- species composition:



- stand classification:



- mostly poor sandy soils
- current climate:
  - annual mean temperature 8,7°C
  - mean annual precipitation 550 mm
- harvest systems:
  - clearcut
  - shelterwood

The purpose of the optimisation heuristic is to find a combination of stand treatment programmes (STPs) which maximises the expected utility for the hole management unit.

Maximum utility at stand level from choosing optimal stand treatment programmes has to be traded off for either (a) satisfying decision constraints at unit level (e.g., sustainable harvesting level) or (b) optimising target variables for the whole unit (e.g., maximum carbon sequestration).

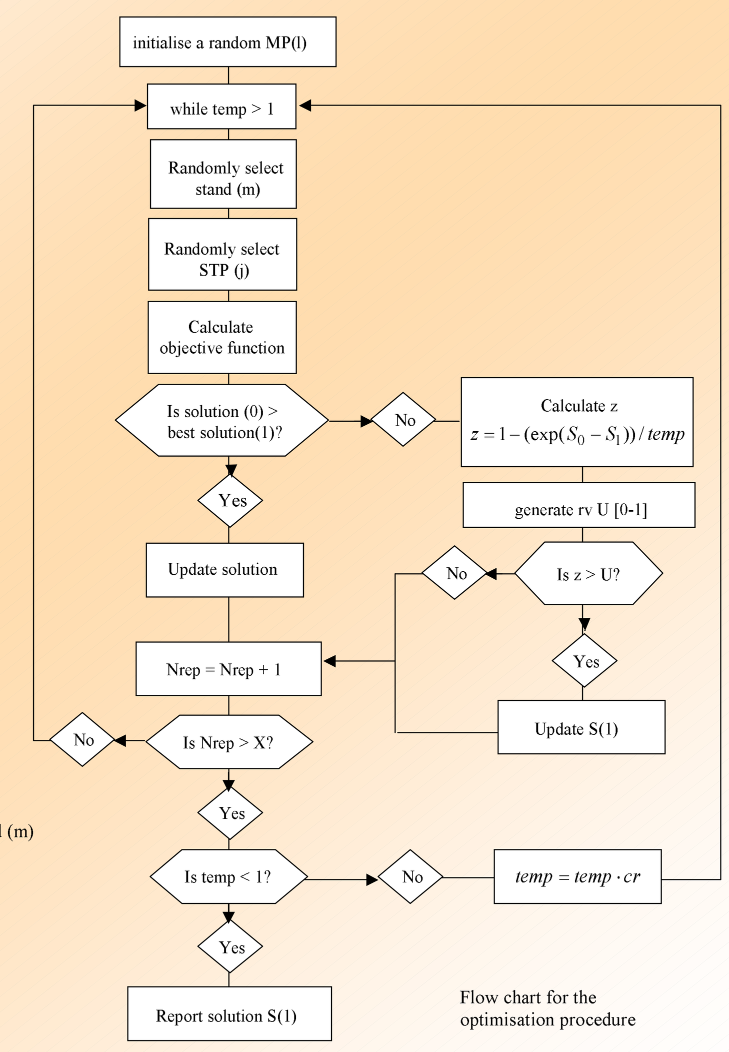
objective function:

$$U = w_{ul} \cdot \sum_{o=1}^{z} a_o \cdot \left[b_{o1} \cdot A_{o1} + b_{o2} \cdot R(A_o)\right] + w_{sl} \cdot \sum_{m=1}^{s} relA_m \cdot \sum_{k=1}^{u} d_k \cdot P_k \cdot (X_{kijm})$$

$$R(A_o) = f\left[\max\left((A_{o1} - A_{o2}), (A_{o1} - A_{o3})\right)\right] \quad \text{if: } A_{o1} > A_{oi}$$

legend:

- $relA_m$ = relative area of stand (m)
- $P_k(X_{kijm})$ = priority index regarding criterion X_k under climate scenario (i) for STP (j) in stand (m)
- A_{oi} = achievement value regarding target variable (o) under climate scenario (i)
- $R(A_o)$ = regret component for target variable (o) under a changing climate
- w_{sl} = importance of optimum stand level utility
- w_{ul} = importance of unit level achievements



Flow chart for the optimisation procedure

3. Methodological approach

For each stand type of the management unit a number of possible stand treatment programmes over 100 years are simulated with the process-based growth model 4C under the current climate and under the climate change scenarios (based on output from ECHAM4 and HadCM2). The purpose of forest management planning is to find a combination of stand treatment programmes which maximises the expected utility for the whole forest. In our analysis the principal hierarchical planning levels are the stand level and the forest level. At each level priorities for the management objectives are explicitly defined. At the management-unit level forest strata with differing priorities for the management objectives can be specified (e.g., productive vs. unproductive sites). At the stand level management objectives are decomposed into measurable decision criteria. The expected utility from choosing a stand treatment programme under each of the climate scenarios with regard to the stand-level objectives is calculated from additive sub-utility functions.

At forest level achievement functions account for deviations from specified target levels of objective variables. The robustness of a particular management plan towards an eventual climate change is included by considering the eventual loss under a changing climate.

Parameter values of the utility functions at stand level as well as for the achievement functions at forest level are estimated with Saaty´s eigenvalue method. An optimisation heuristic is employed to search the decision space for optimised management plans.

4. Expectations and limitations of the approach

It is shown how different priorities of management objectives as well as attitude towards risk due to uncertain future climatic conditions influence the selection of a forest level management plan. However, uncertainty in climate is poorly represented by just two GCM scenarios. Due to a fixed climate trajectory and fixed stand treatment programmes over 100 years the approach does not consider the potential cost of choosing an inappropriate stand treatment regarding the actual climate development.

References

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Acknowledgements

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