HOW TREE SELECTION AFFECTS ECOSYSTEM SERVICE TRADE-OFFS AND SYNERGIES IN BOREAL FOREST THINNING?

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INTRODUCTION

- Thinning is the selective removal of trees → more growth resources to remaining trees.
  - In boreal forests, the harvester operator typically makes the selection of harvested/retained trees based on his/her experience.
- Thinning affects several ecosystem services, including forest structure and productivity, carbon sinks, biodiversity, and scenery → **multi-criteria decision making** is required.

Thinned vs. unthinned forests. Photo: Mikko Niemi

- Improved quality and availability of individual tree-level data enables pre-optimized tree selection by considering multiple ecosystem services. Also, within stand variation of soil and tree attributes can be considered in the optimization → **Precision forestry**.

RESEARCH QUESTIONS

1. **How the selection of harvested/retained trees affects following indicators of forest stand structure and ecosystem services?**
    1. The immediate harvest value
    2. Relative value growth for the next 10 years (growth models of Pukkala et al. 2021)
    3. Soil expected value (SEV) (Ruotsalainen et al. 2021)
    4. Tree size diversity (Gini coefficient) (e.g., Valbuena et al. 2012)
    5. Stand spatial ordering (Clark & Evans 1954) (CEI)
    6. Species mixture (by applying Bettinger & Tang 2015)
    7. Tree retention index (for plot-level using tree-level conservation values of Lehtomäki et al. 2015)
    8. Landscape amenity (Silvennoinen et al. 2001)
2. **Analyze trade-offs between different objectives**
3. **Demonstrate multi-objective optimization for tree selection**

MATERIAL AND METHODS

- Tree maps of thinning-stage stands (N=35), measured by the Finnish Forest Centre.
- **Inventoried attributes** (mean values):
  - Average plot area 0.13 ha, DBH 21.2 cm, basal area 27.3 m^2 ha^{-1}, volume 247 m^3 ha^{-1}
- **Derived attributes** (mean values):
  - Harvest value: 7 700 € ha^{-1}
  - Relative value growth: 6.0%
  - Soil expected value (SEV): 11 900 € ha^{-1}
  - Gini coefficient (GC): 0.36
  - Clark-Evans index (CEI): 1.30
  - Species mixture index: 0.37
  - Tree retention value: 12.8
  - Landscape amenity: 0.51

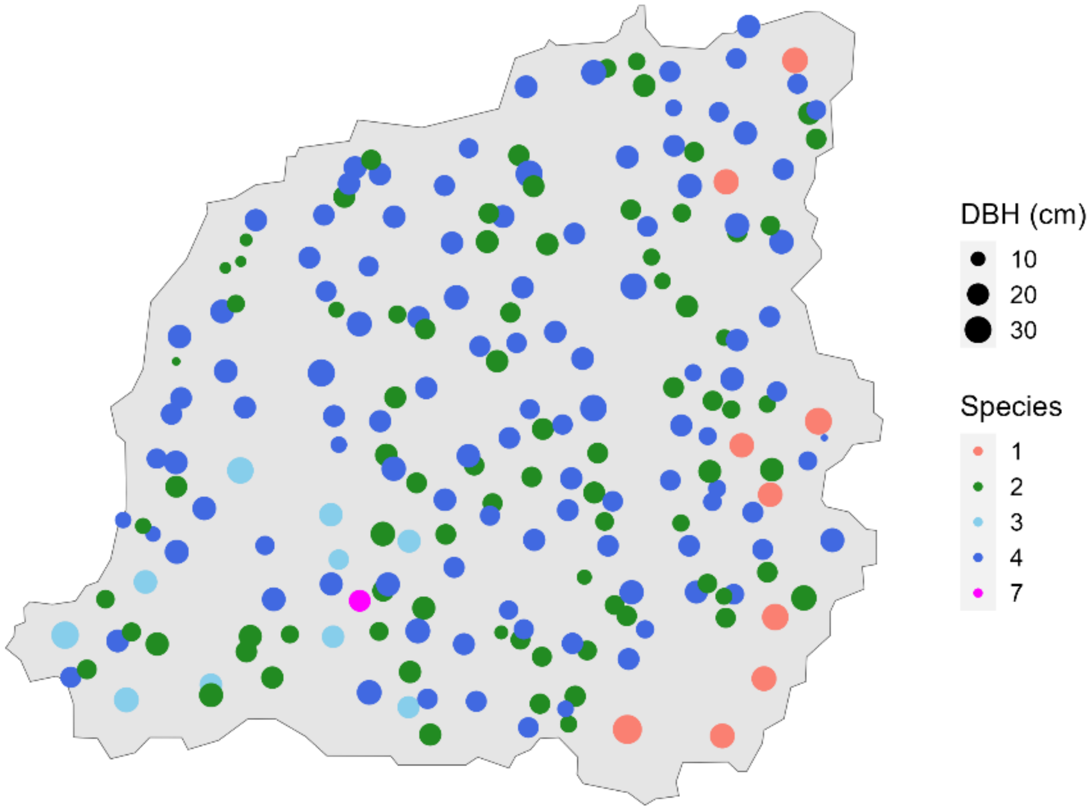


Figure 1. *Example of the individual tree-level data from plot ID 3752. Mesic heath forest. Stem count 1060* ha^{-1}*,* D_g *20,5 cm, basal area 28,7* m^2/ha*. Species codes: 1 = pine, 2 = spruce, 3 = silver birch, 4 = downy birch, 7 = European (common) alder.*

SINGLE-OBJECTIVE OPTIMIZATION

maximize/minimize y_i

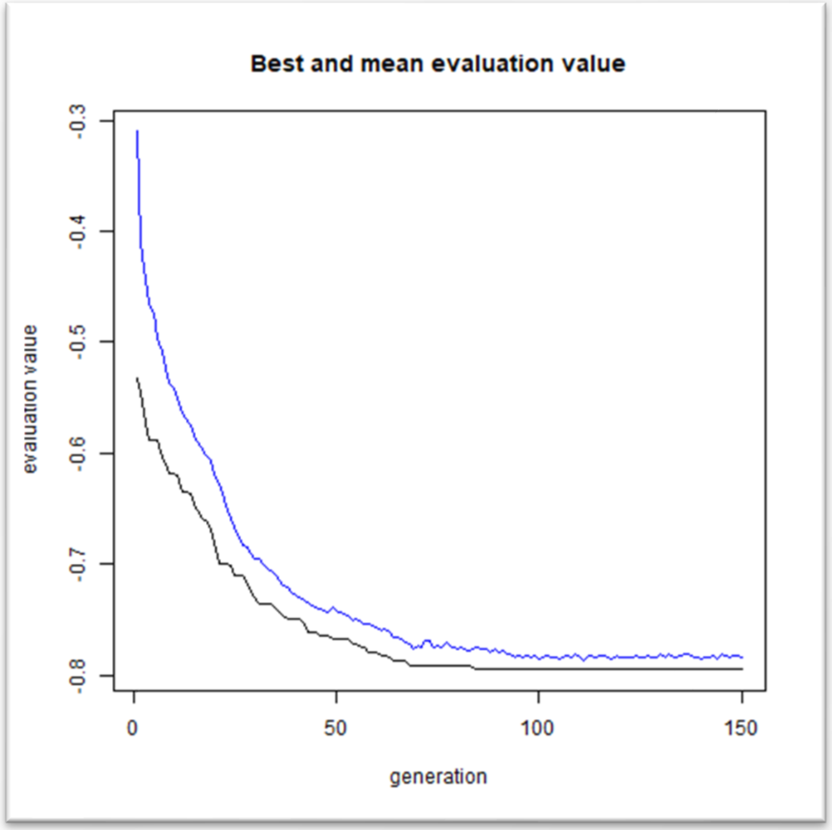
- y_i = value of optimized objective. All objectives (economic indicators, GC, CEI, species mixture, tree retention index, landscape amenity) were maximized, and GC was also minimized.

$$y_i = f(x_1, x_2, \ldots, x_n)$$

- x_1, x_2,.. = decisions to harvest/retain individual trees.
- Solutions constrained by basal area target derived from Finnish forest management recommendations:

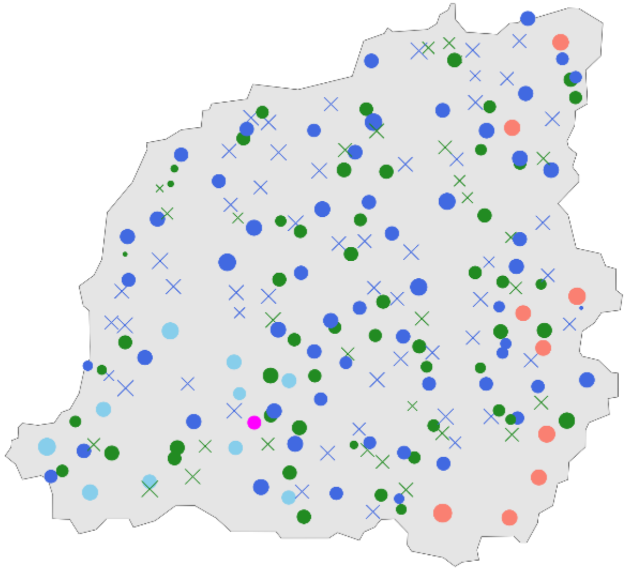
$$|BA(x_1, x_2, \ldots, x_n) - BA_{constraint}| \leq 0.5$$

- $BA(x_1, x_2, \ldots, x_n)$ = basal area of retained trees
- Solved by the Genetic Algorithm →

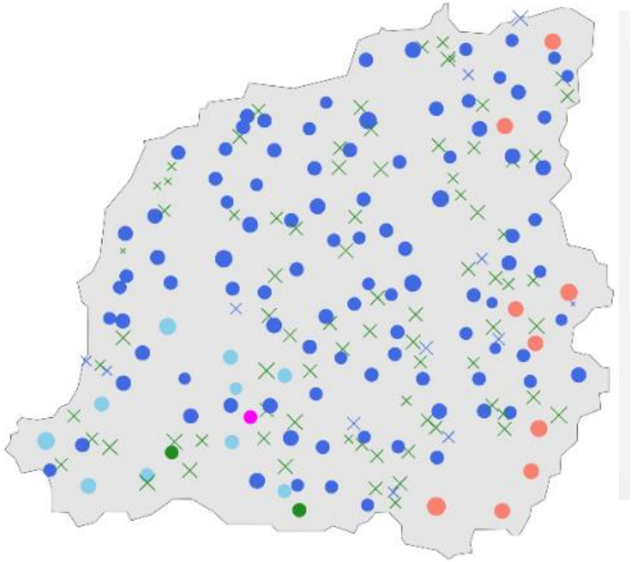


TREE SELECTIONS BY SINGLE-OBJECTIVE OPTIMIZATIONS

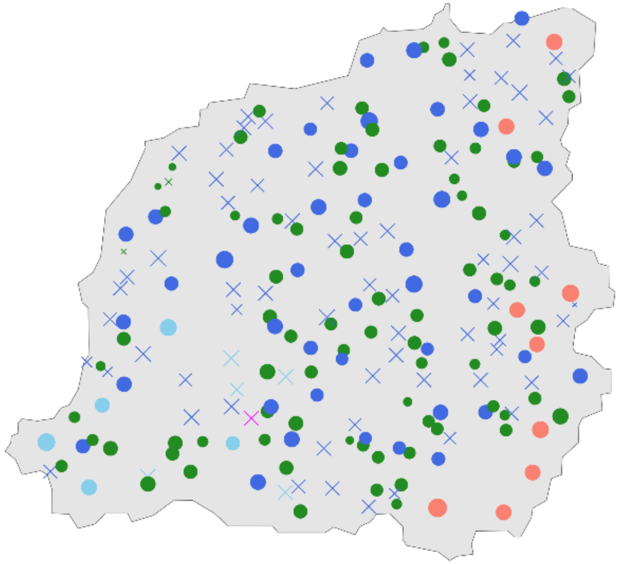
Maximize species mixture



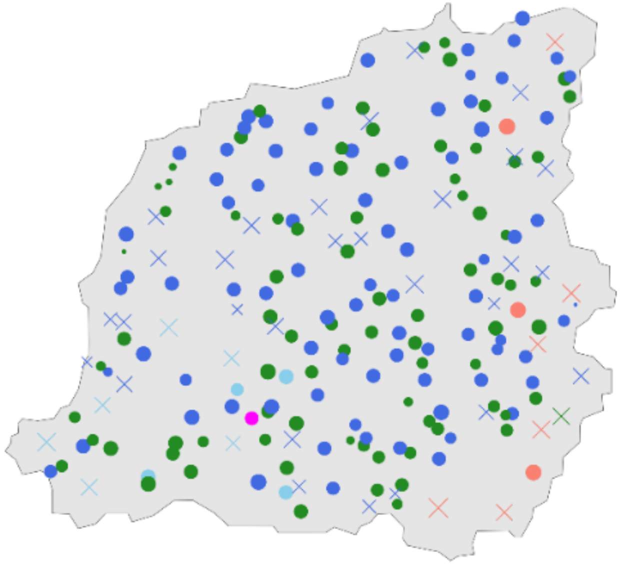
Maximize landscape amenity



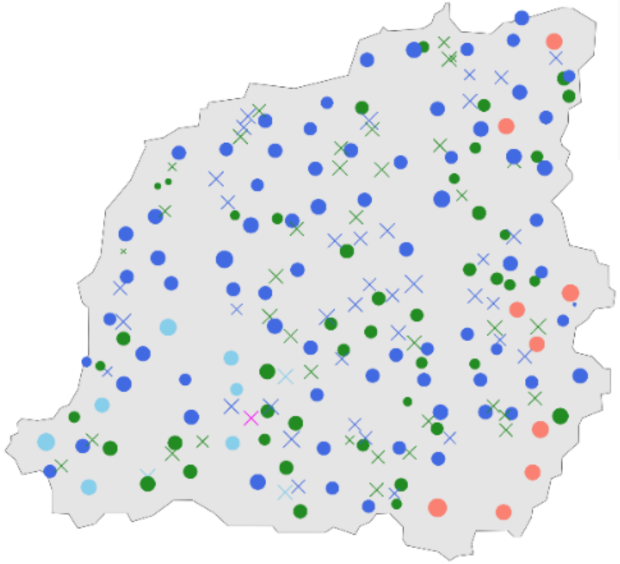
Maximize soil expected value (SEV)



Maximize relative value growth



Maximize spatial ordering (CEI)

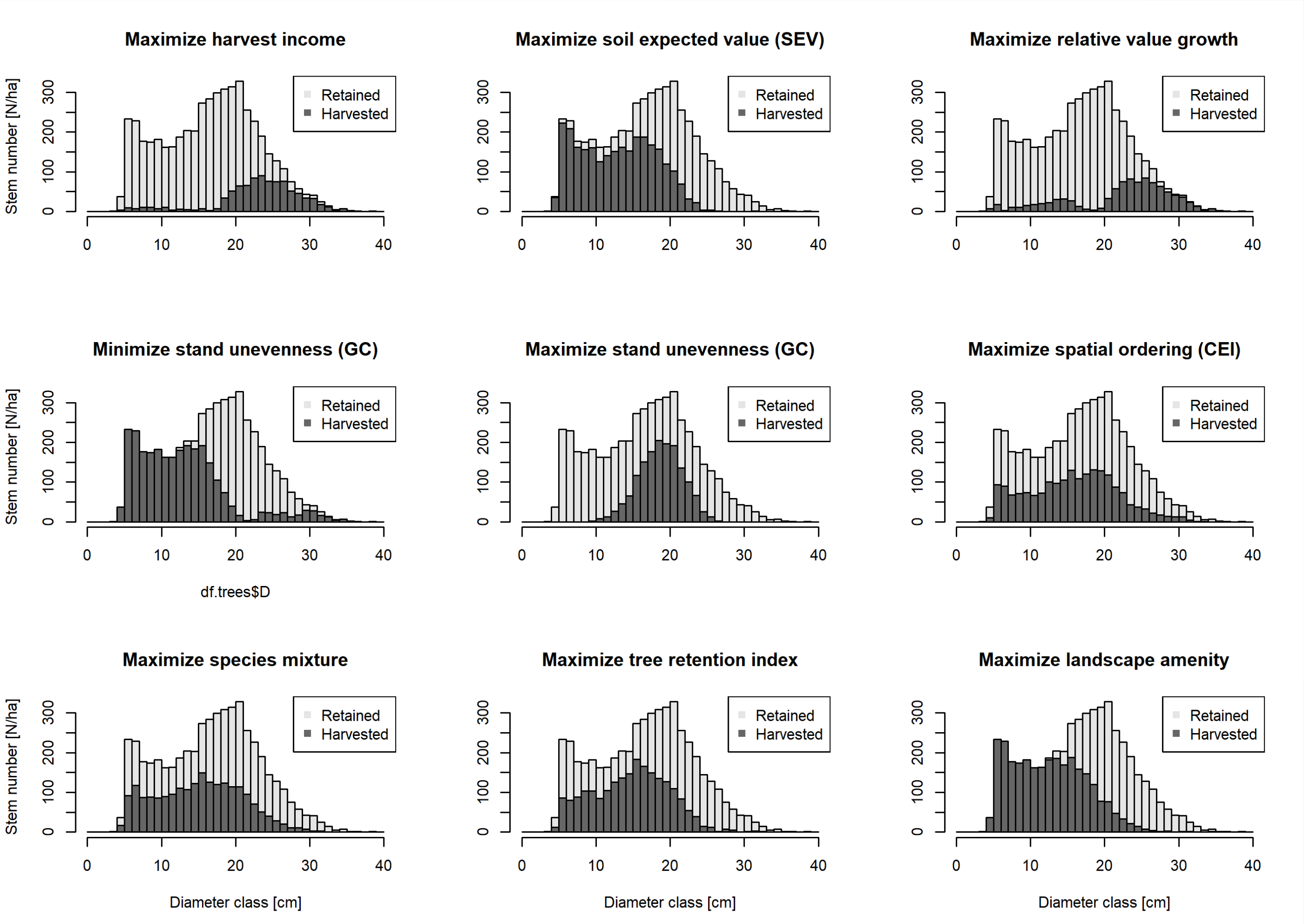


Species 1 2 3 4 7

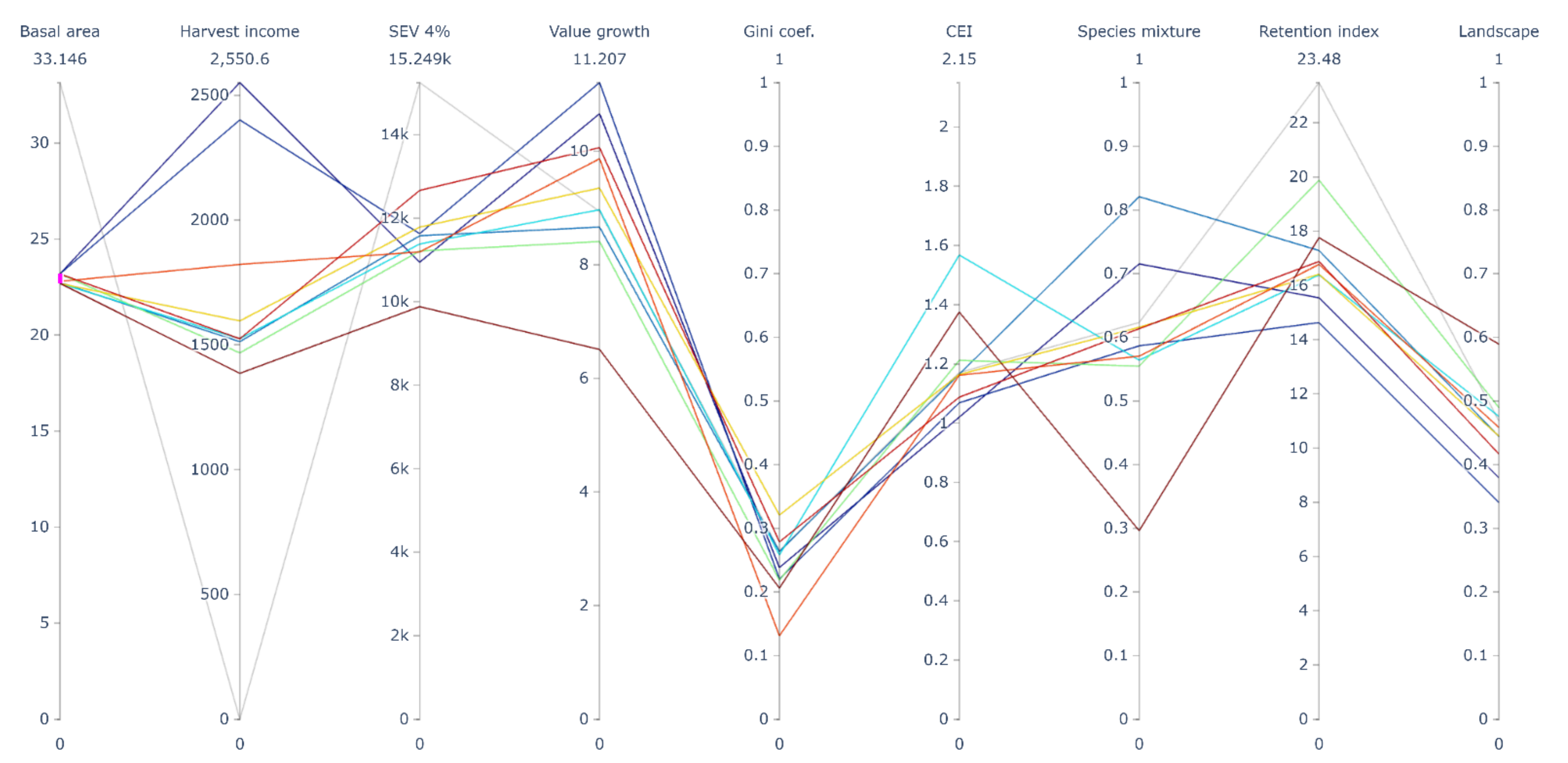
1 = pine, 2 = spruce, 3 = silver birch, 4 = downy birch,
7 = European (common) alder

HARVESTED / RETAINED TREES BY DBH

- Depending on the objective function, harvesting was focused on different-sized trees.
- Harvesting was focused more on conifers, when harvest income or tree retention index were maximized.
- Harvesting was focused more on deciduous trees, when soil expected value was maximized.



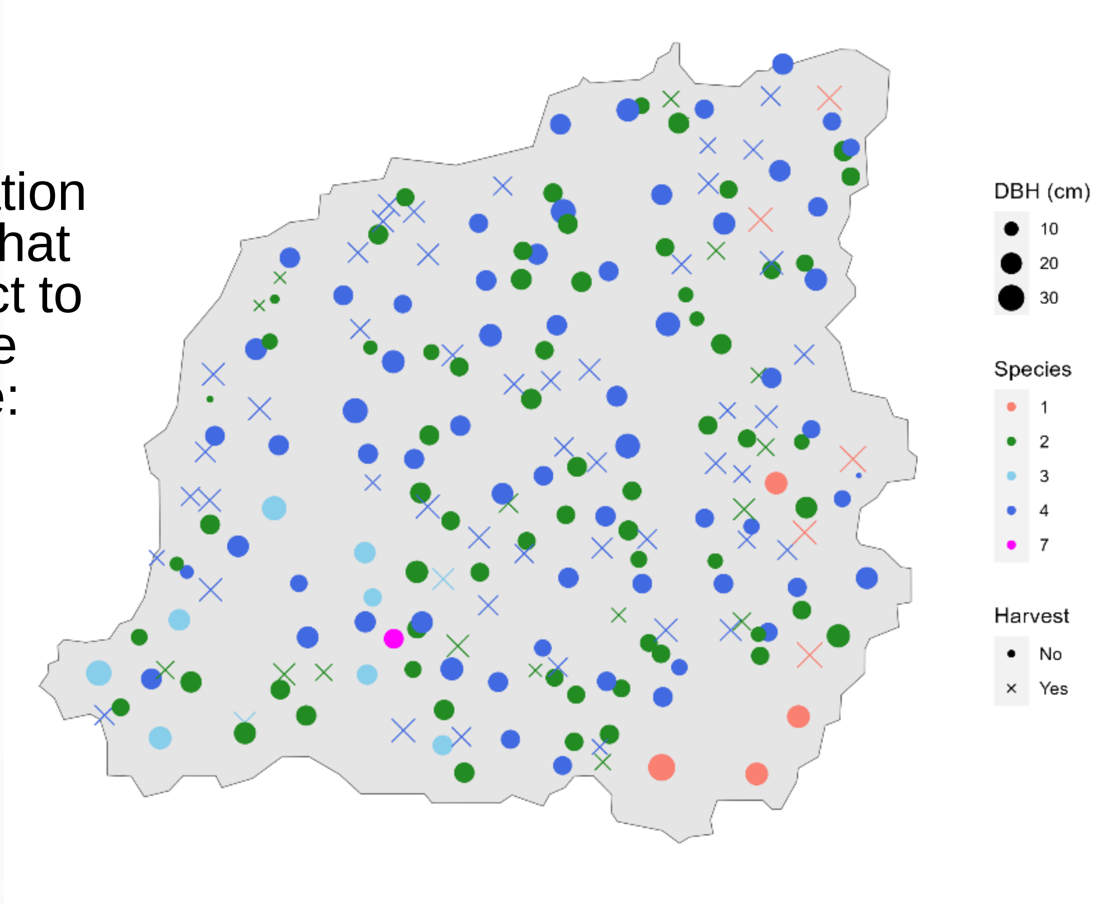
TRADE-OFF ANALYSIS



MULTI-OBJECTIVE OPTIMIZATION

- Trade-off examination gave information about possible ranges of all criteria.
- Multi-objective optimization needs input information on the decision hierarchy of single objectives. That can be done by weighting all criteria with respect to their importance to decision maker(s), and some criteria can be given as constraints, for example:

- $\max \left(0.6 * \frac{value\_gr}{value\_gr_{max}}\right) + (0.4 * sp\_mix)$
  - $CEI \geq 1.30$
  - $|BA(x_1, x_2, \ldots, x_n) - BA_{constraint}| \leq 0.5$



CONCLUSIONS

- Tree selection in forest thinning has long-lasting effects to forest structure and ecosystem services.
- Single-objective optimization improved our understanding of feasible solutions, although multi-criteria objective functions are required for reasonable suggestions.
- Further study questions:
  - How to optimize stand-level decisions?
    - Equal or varying objective functions for different clusters?
    - How to consider logging trails in the optimization?
    - Where retention trees should be left?
  - How to work with more uncertain inventory data?
  - What kind of information benefits the harvester operator?

Ponsse Cobra -harvester. Photo: Jori Uusitalo

THANK YOU FOR YOUR ATTENTION!

And please check out the article
Trade-off analysis for multi-objective boreal forest thinning
when it is published…

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