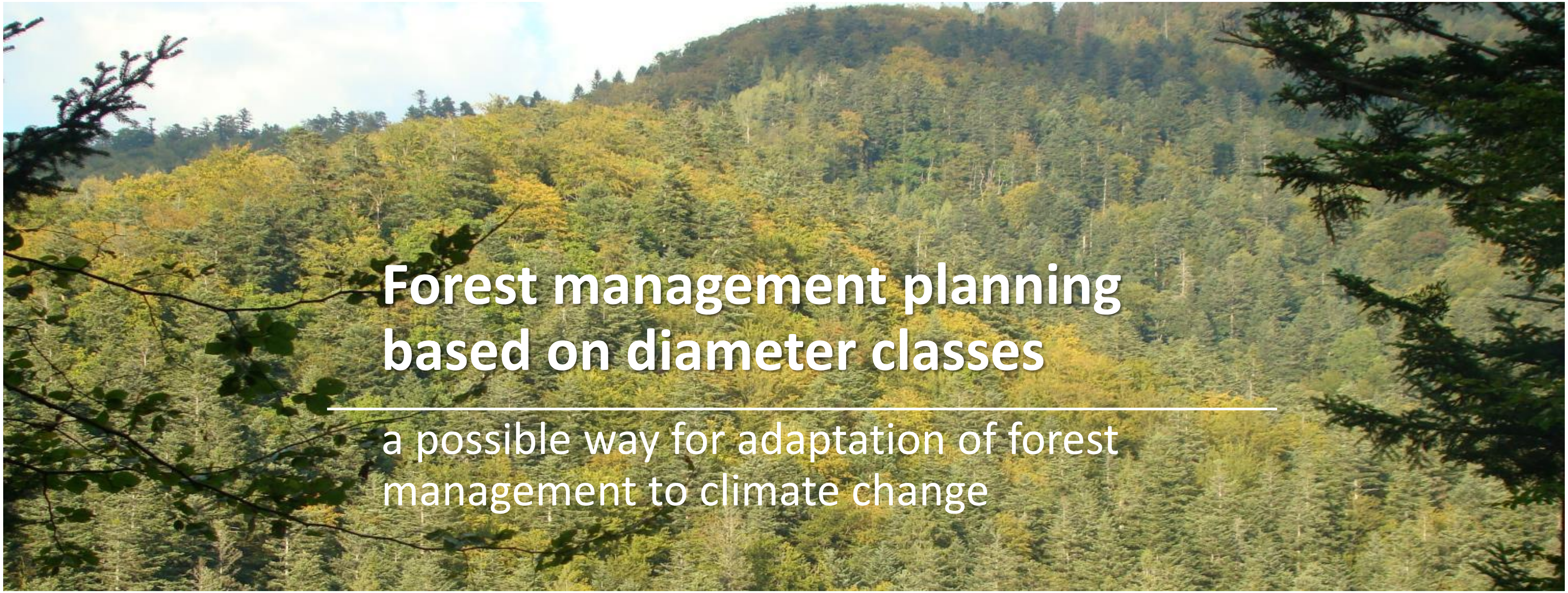


# Forest management planning based on diameter classes

## a possible way for adaptation of forest management to climate change

Ladislav Kulla

National Forest Centre – Forest Research Institute Zvolen

Zvolen, 20.09.2019

# Content

1. Introduction
    - Two ways of forestry
    - Forests and climate change
2. Possible innovations for uneven-aged forest management
    - Remote sensing in forest inventory and mapping
    - Advanced matrix modelling in yield control and harvest regulation
    - Optimized rules for selection of trees for harvest
3. Summary and outlook

# 1.
# Introduction

- Two ways of forestry
- Uneven-aged forests and climate change

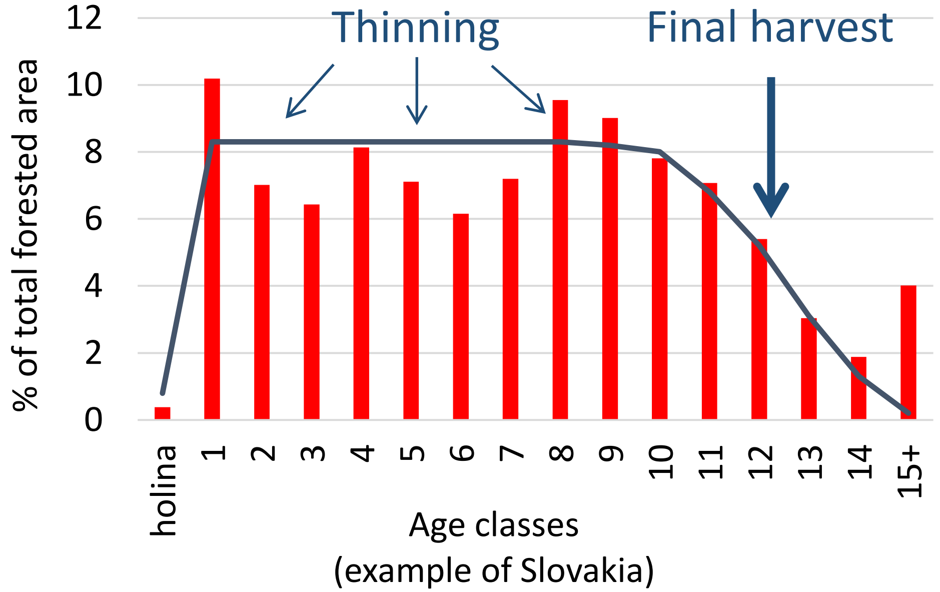
# Introduction: two ways of forestry

| Rotation forest management (RFM) | Continuous cover forestry (CCF) |
| --- | --- |
| • Thinning and cyclic final harvest with subsequent reforestation<br>• More or less uniform even-aged **forests of age classes** | • Permanent selective cutting and natural regeneration<br>• Differentiated uneven-aged **forests of diameter classes** |

# Introduction: two ways of forestry

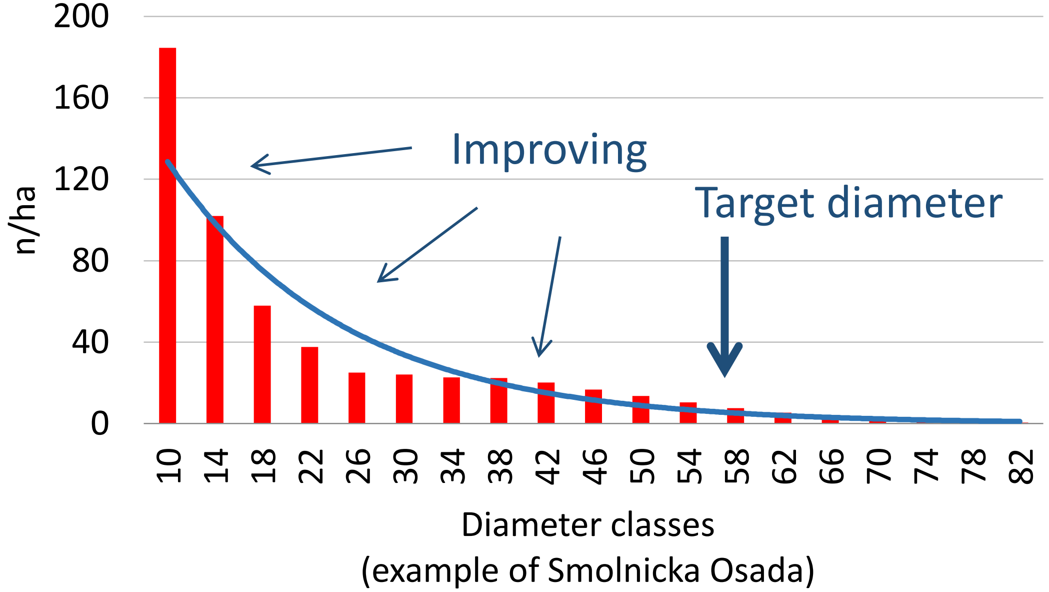
## RFM

- **Inventory:** mensuration based on yield tables
- **Yield control:** balanced area of age classes
- **Harvest:** at culmination targeted effect (NPV)




## CCF

- **Inventory:** full callipering or statistic inventory
- **Yield control:** decreasing frequency curve
- **Harvest:** improving structure, target diameters



# Introduction: two ways of forestry

## RFM

**Advantages:**

- Long tradition, simple practical application
- Low costs of inventories and planning

**Disadvantages:**

- Lower resistence and extensive disturbances in forests

**Possible improvements:**

- Establishing mixed forest stands
- Utilizing shelterwood systems
- Reducing cuttings area
- Prolonging regeneration periods

➢ Conversion to CCF systems

## CCF

**Advantages:**

- Better resistance and resilience of forests
- Better provision of ecosystem services

**Disadvantages:**

- Much higher costs of forest inventories
- Open questions of optimality and yield control
- Lacking practical experience

**Possible improvements:**

... are the subject of this presentation

# Introduction: two ways of forestry

## CCF in Europe:

**<u>Close-to-nature forest management (CTNF) promoted by ProSilva Europe:</u>**

- Tree species composition adapted to site conditions
- Avoidance of clear felling
- Focus on tree and stand stability
- Use of natural regeneration
- Natural stem numbers reduction (biological automation)
- Emphasis on dvelopment of individual trees
- Result: mixed and uneven-aged forests

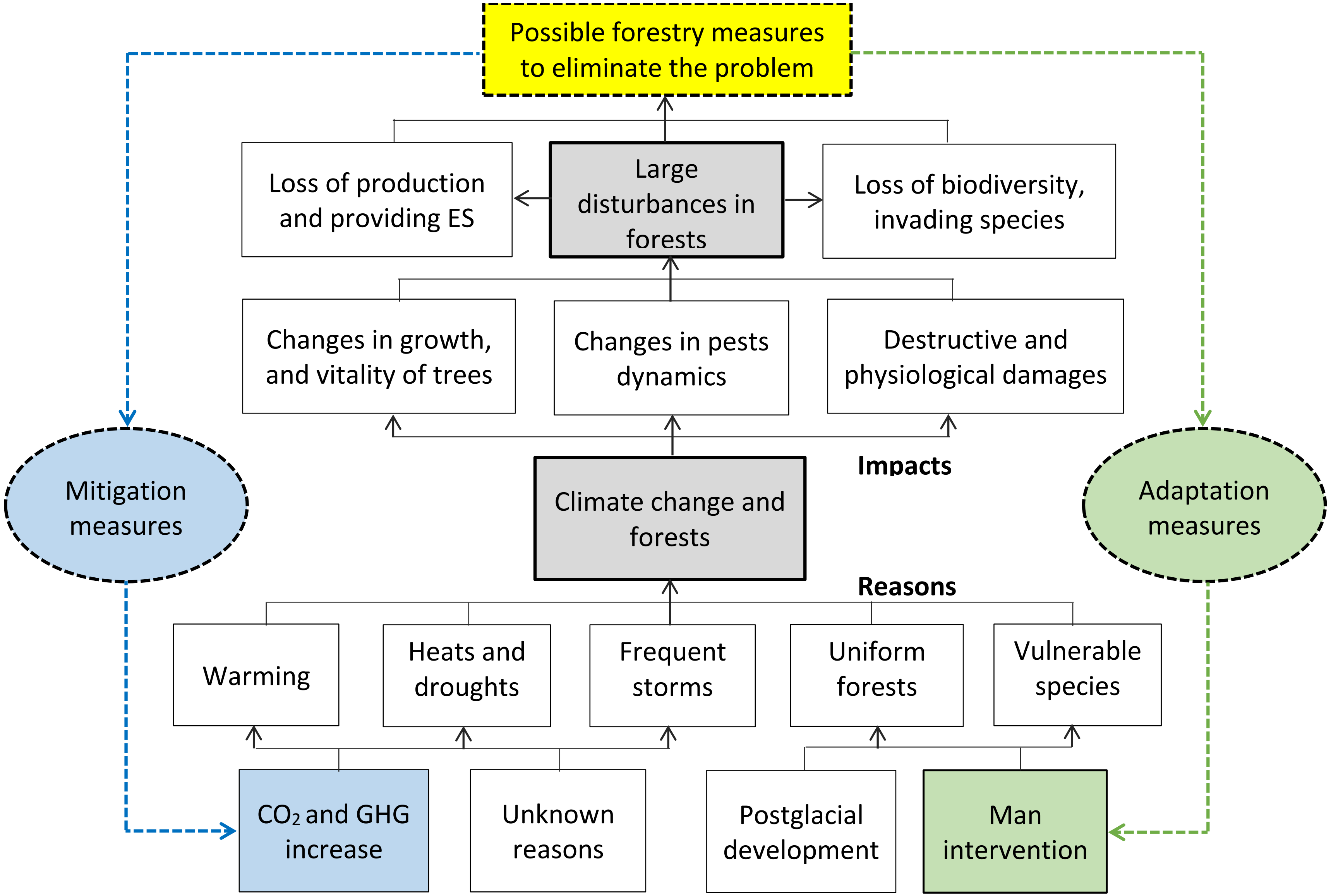
In most EU countries CTNF is considerd as an adaptation measure to climate change

# Introduction: two ways of forestry

**Preliminary results of unformal survey on CTNF practices (NFC 2019)**

| Country | Member of ProSilva Europe | Compliance with Pro Silva principles | Proportion of CTNF from forested area | CTNF considered an adaptation measure to climate change |
|---|---|---|---|---|
| **Austria** | * | yes | 10 % | yes |
| **Croatia** | * | yes | < 60 % | yes |
| **Czech Republic** | * | yes | 3 % | yes |
| **Finland** | - | no | n.a. | yes |
| **France** | * | yes | 60 % | yes |
| **Hungary** | * | yes | 50 % (?) | yes |
| **Low Saxony (D)** | * | yes | 35 % | yes |
| **Poland** | - | partially | < 5% | yes |
| **Slovakia** | * | yes | 3 % | yes |
| **Slovenia** | * | yes | 100 % | yes |
| **Spain** | * | yes | 1 % | no |
| **Sweden** | * | yes | < 5 % | yes |
| **Switzerland** | - | yes | n.a. | yes |

# Introduction: uneven-aged forests and climate change



# Introduction: uneven-aged forests and climate change

## Mitigation measures

**<u>Maintain and increase carbone storage in wood:</u>**

- Afforestation of non-forest land
- Application of forest management alternatives more accumulating stock (CTNF, CCF)

**<u>Replace carbon from fosil fuels:</u>**

- Establishment of energy plantation
- Complex utilisation of wood

**<u>Store carbon in long live wood products:</u>**

- ...

## Adaptation measures

**<u>Increase of biodiversity, resistance and resilience:</u>**

- Close-to-nature forest management (CTNF, CCF)
- Assisted migration of species and genotypes

**<u>Adaptive forest management:</u>**

- Permanent forest inventories and flexible yield models (CTNF, CCF)

Uneven aged forestry is a robust measure contributing to both: mitigation and adaptation to climate change

## CCF in Slovakia:

**<u>According to current amendment of legislation in Slovakia, CTNF means:</u>**

- Selective forests
- Permanently multiple-layered forests
- Mosaic forests with groups of different ages up to 0.2 ha
- Shelterwoods in cableway terrains with strips´ width to one stand height, area to 1.5 ha and regeneration period longer than 50 years
- All stands being converted to CTNF

Conversion of even aged forests to CTNF will be main task in Slovakia for next decades

**Conversion alternatives**

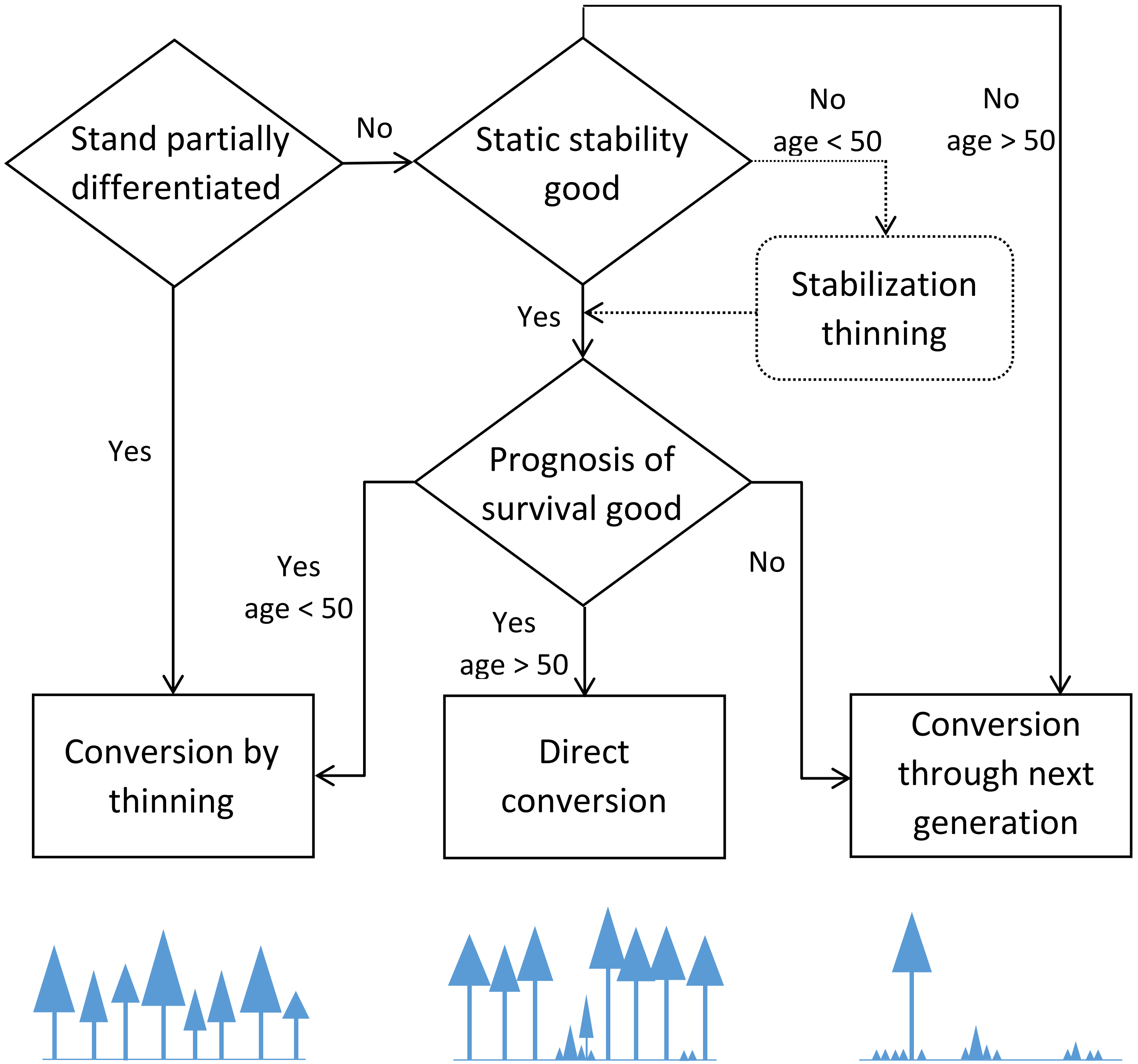
(adapted from Shütz 1989)

It is possible to start conversion **in any time**, and any initial state of the forest stand.

**In the beginning** of conversion, adapted mensuration and planning methods for forests of age classes might be applied

**BUT**

**Since „the conversion half time“** the inventory and planning methods valid for forests of diameter classes have to be introduced



# 2.
# Possible innovations for uneven-aged forest management

- Fundamental principles, inventory and spatial arrangement
- Remote sensing in forest inventory and mapping
- Advanced matrix modelling in the yield control

# Fundamental principles, inventory and spatial arrangement

## 1. Replacement of age classes by diameter classes

❖ *Suggested adaptation of diameter classes*

| Single diameter class (D) | Diameter range in cm | Agregated diameter class (DC) | Harvest class (HC) |
|---|---|---|---|
| 10 | 8 - 12 | Thin poles | Pre-comercial thinning |
| 14, 18 | 12 - 20 | Thick poles | |
| 22, 26, 30 | 20 - 32 | Thin stems | Commercial thinning |
| 34, 38, 42, 46, 50 | 32 - 52 | Thick stems | Final harvest |
| 54 + | 52 a viac | Very thick stems | |

# Fundamental principles, inventory and spatial arrangement

**<u>Main problem of forest inventory in uneven-aged forests:</u>**

- **High costs of data colection**

| No | Product / Service | Total area of inventory | Price unit | Price in EUR without VAT |
|---|---|---|---|---|
| 1 | Detail measurements of all dendrometric parameters of trees including coordinates (MARTELOSCOP) | x | 1 ha | 4000.- |
| 2 | Standard callipering of all trees without coordinates and additional informations | x | 1 ha | 200.- |
| 2 | Statistical forest inventory with accuracy of stock estimation ± 10% (price depends on total area) | 10 ha | 1 ha | 200.- |
| | | 100 ha | 1 ha | 50.- |
| | | 1000 ha | 1 ha | 25.- |

(Price list NFC, 2019)

# Fundamental principles, inventory and spatial arangement

## 2. Making the inventory more efficient

$$n = 4\left(\frac{\sigma_Y\%}{E_Y\%}\right)^2 \rightarrow \Delta_Y\% = 2\frac{s_Y\%}{\sqrt{n}}$$

Dependence of number of inventory plots (sample size - *n*) on:

a) variability of given parameter in statistic file ( $s_Y\%$, direct proportion)

b) required accuracy ( $\Delta_Y\%$, inverse proportion)

**<u>Suggested solution:</u>**

- Optimize IP design and minimize set of measured parameters
- Design of larger spatial inventory units with sufficient internal homogenity →

WITH HELP OF REMOTE SENSING

# Fundamental principles, inventory and spatial arangement

## ❖ *Optimized design of inventory plots for Smolnicka Osada*

- Circles with variable radius with flexibly adjusted step 0.5 m for measurement at least 20 (in optimal case 20 – 30) trees with diameter 8 cm and higher
- Regular square grid 250 x 250 m
- Measured parameters:
  - ✓ Polar coordinates (azimuth, distance from center)
  - ✓ Tree species
  - ✓ Diameter at breast height (dbh)
  - ✓ Tree height
  - ✓ Crown lenght
  - ✓ Stem quality

→ IMPORTANT FOR YIELD CONTROL

# Fundamental principles, inventory and spatial arrangement

## 3. Three levels of spatial units for different purposes

- <u>**Forest development type (FDT)**</u>

**Hierarcically higher spatial unit** combining main site and tree component parameters of forests (represents group of existing forest stands)

➢ Utilised for yield modelling by matrix model

- <u>**Stand development type (SDP)**</u>

**Hierarcically middle spatial unit** combining FDT with actual stock level determined by remote sensing (rerpresents group of existing forest stands)

➢ Utilised for summarizing results of inventory and for harvest planning

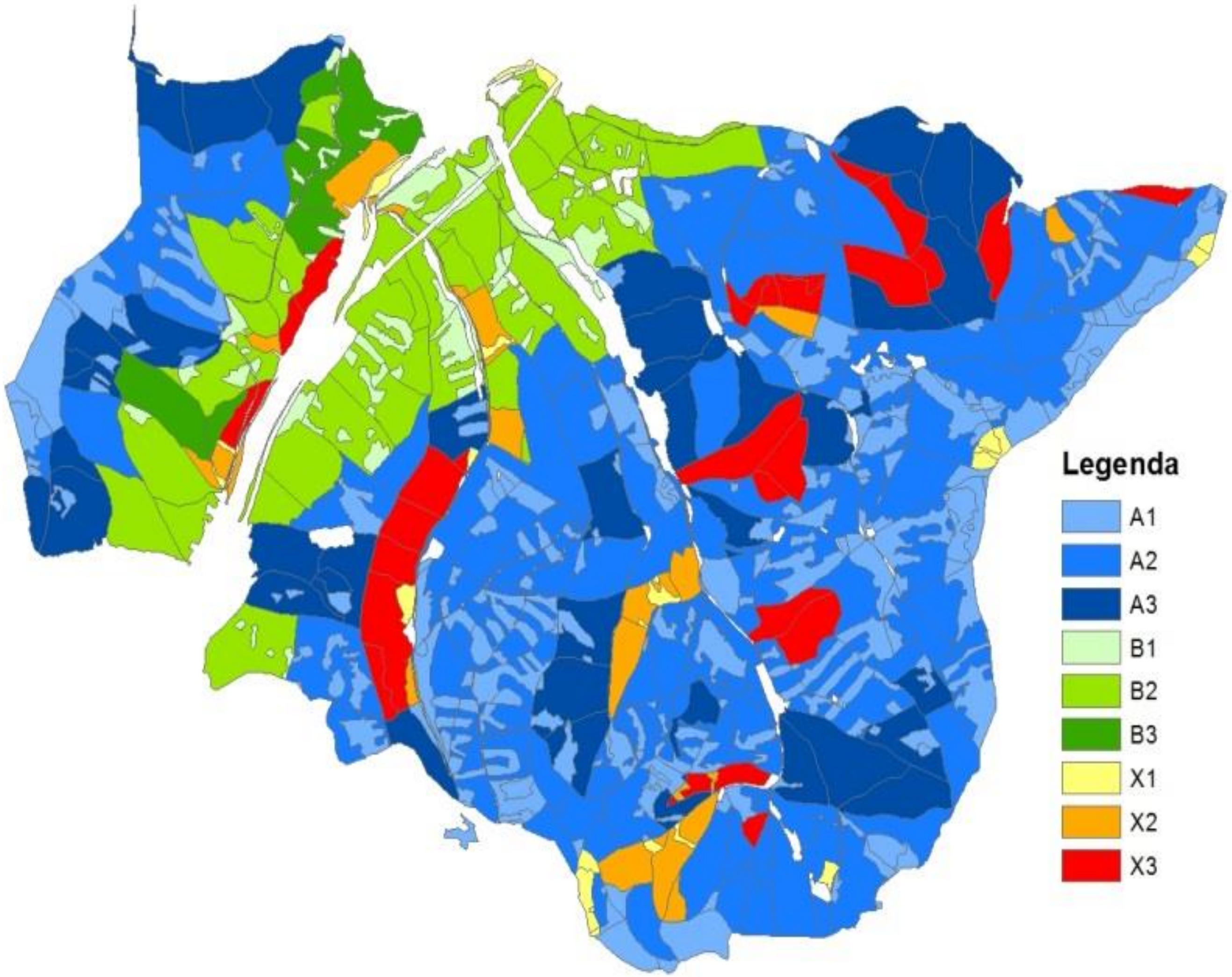
- <u>**Forest stand**</u>

**Existing basal spatial unit** for orientation, management control and keeping of management records

➢ Utilised for indicative spatial distribution of harvest with the help of remote sensing and GIS tools

# Fundamental principles, inventory and spatial arrangement

❖ *Example of spatial units in Smolnicka Osada*




| | Forest development type (FDT) | Stand development type (SDT) |
|---|---|---|
| **A** | Fertile Spruce-Fir-Beech forest in mountain zone | 1 – low stock |
| | | 2 – medium stock |
| | | 3 – high stock |
| **B** | Poor Fir-Spruce forest with Pine and Beech in sub-mountain zone | 1 – low stock |
| | | 2 – medium stock |
| | | 3 – high stock |
| **X** | Exposed protective forest | 1 – low stock |
| | | 2 – medium stock |
| | | 3 – high stock |

# Fundamental principles, inventory and spatial arrangement

❖ *Example of inventory results for Smolnicka Osada*

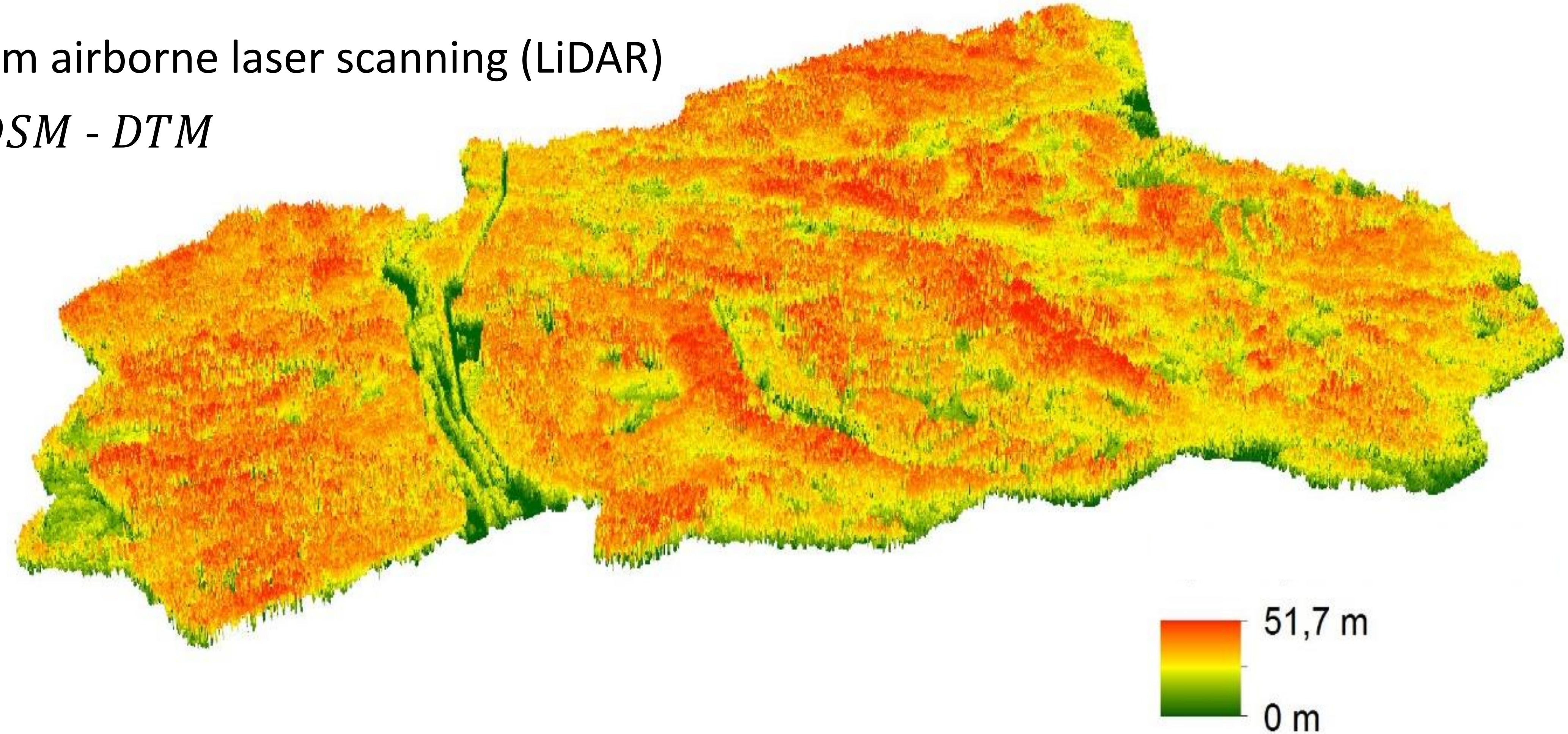
| Forest devel. type (FDT) | Stand devel. type (SDT) | Area (ha) | Number of IP (n) | Number of trees (N/ha) | Basal area ($m^2$/ha) | Stock ($m^3$/ha) | Error of stock estimation ($\Delta_Y$%) |
|---|---|---|---|---|---|---|---|
| A | A1 | 345 | 54 | 1034 ± 170 | 23,3 ± 2,9 | 193 ± 35 | ±18 |
| | A2 | 770 | 131 | 535 ± 63 | 32,3 ± 2,1 | 403 ± 33 | ±8 |
| | A3 | 376 | 54 | 473 ± 59 | 41 ± 3,6 | 556 ± 56 | ±10 |
| A total | | 1491 | 239 | 634 ± 60 | 32,2 ± 1,7 | 390 ± 28 | ±7 |
| B | B1 | 61 | 11 | 1317 ± 507 | 20,5 ± 5,8 | 134 ± 48 | ±36 |
| | B2 | 300 | 49 | 581 ± 99 | 34,7 ± 3,1 | 412 ± 42 | ±10 |
| | B3 | 54 | 9 | 499 ± 158 | 39,9 ± 15,8 | 511 ± 219 | ±43 |
| B total | | 415 | 69 | 688 ± 125 | 33,1 ± 3,3 | 381 ± 49 | ±13 |
| X total | | 226 | 36 | 494 ± 89 | 29,9 ± 3,8 | 367 ± 58 | ±16 |
| Smolnicka Osada | | 2132 | 344 | 630 ± 50 | 32,2 ± 1,4 | 386 ± 23 | ±6 |

# Remote sensing in the forest inventory and mapping

## 1. Digital forest height model (*nDSM*)

- Derived from airborne laser scanning (LiDAR)

  $nDSM = DSM - DTM$



# Remote sensing in the forest inventory and mapping

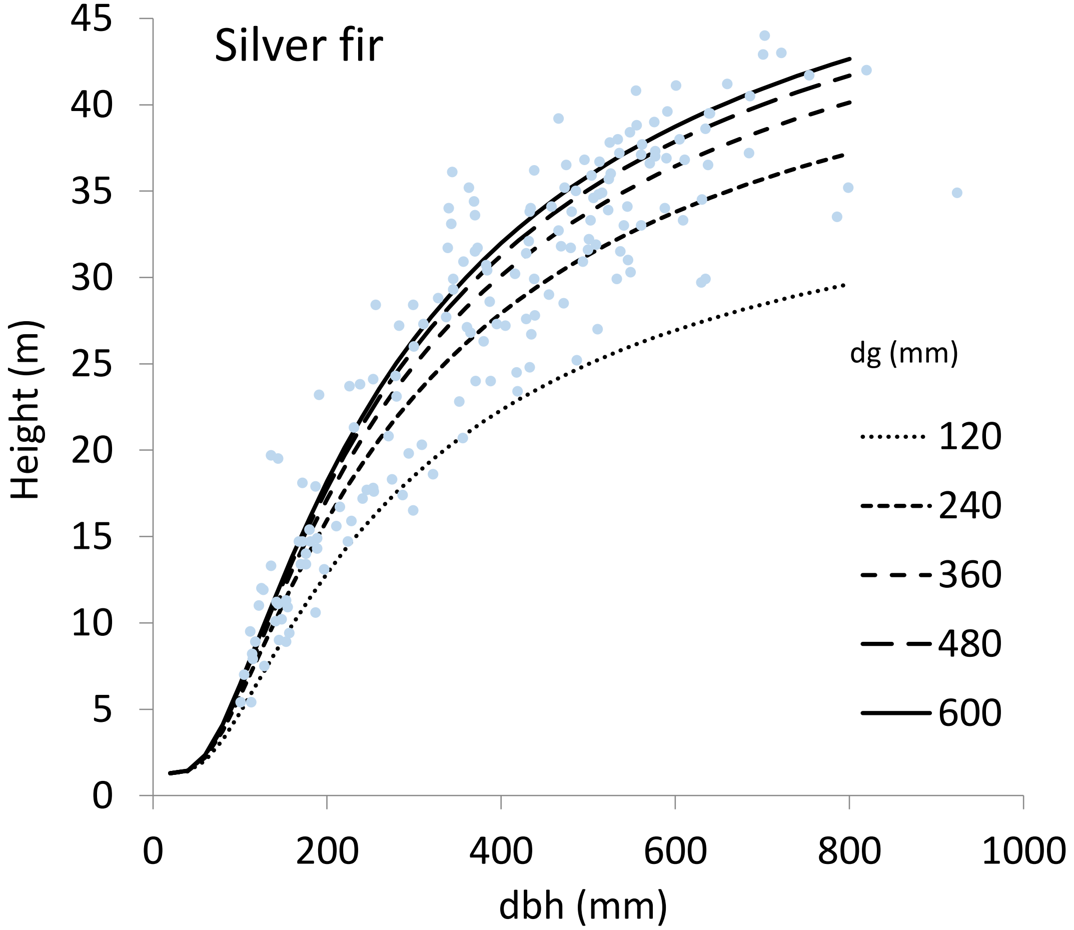
## 2. Transforming of *nDSM* to spatial diameter distribution model *(SDDM)*

**1. Height curve:** dependence **of *h*** *(height)* on *dbh* and *dg* (mean diameter from inventory)

$$h = 1{,}3 + a.e^{(-b/dbh + c/d_g)}$$

**2. Inverse curve:** dependence **of *dbh*** on *h (height)* and *dg* (mean diameter from inventory)

$$dbh = b/(LN\left(\frac{h-1.3}{a}\right) - \frac{c}{dg})$$



# Remote sensing in the forest inventory and mapping

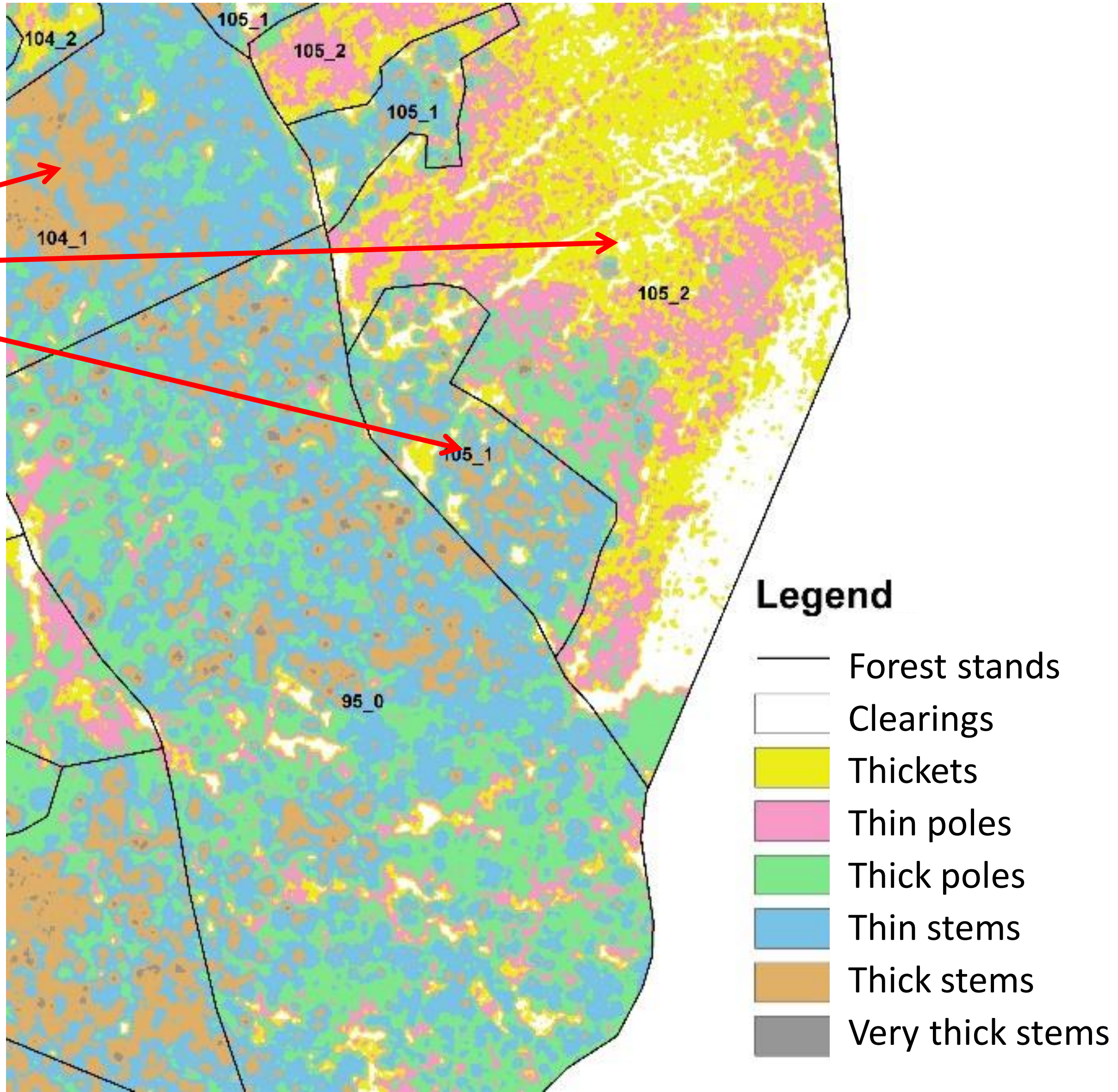
## 3. Using of *SDDM*

1) Stratification of forest stands according to stock level to stand development types (SDT)

High
Low
Medium

2) Detailed spatial mapping of distribution of diameter classes (DC)

❖ ***Design of stand map prototype for forest of diameter classes***



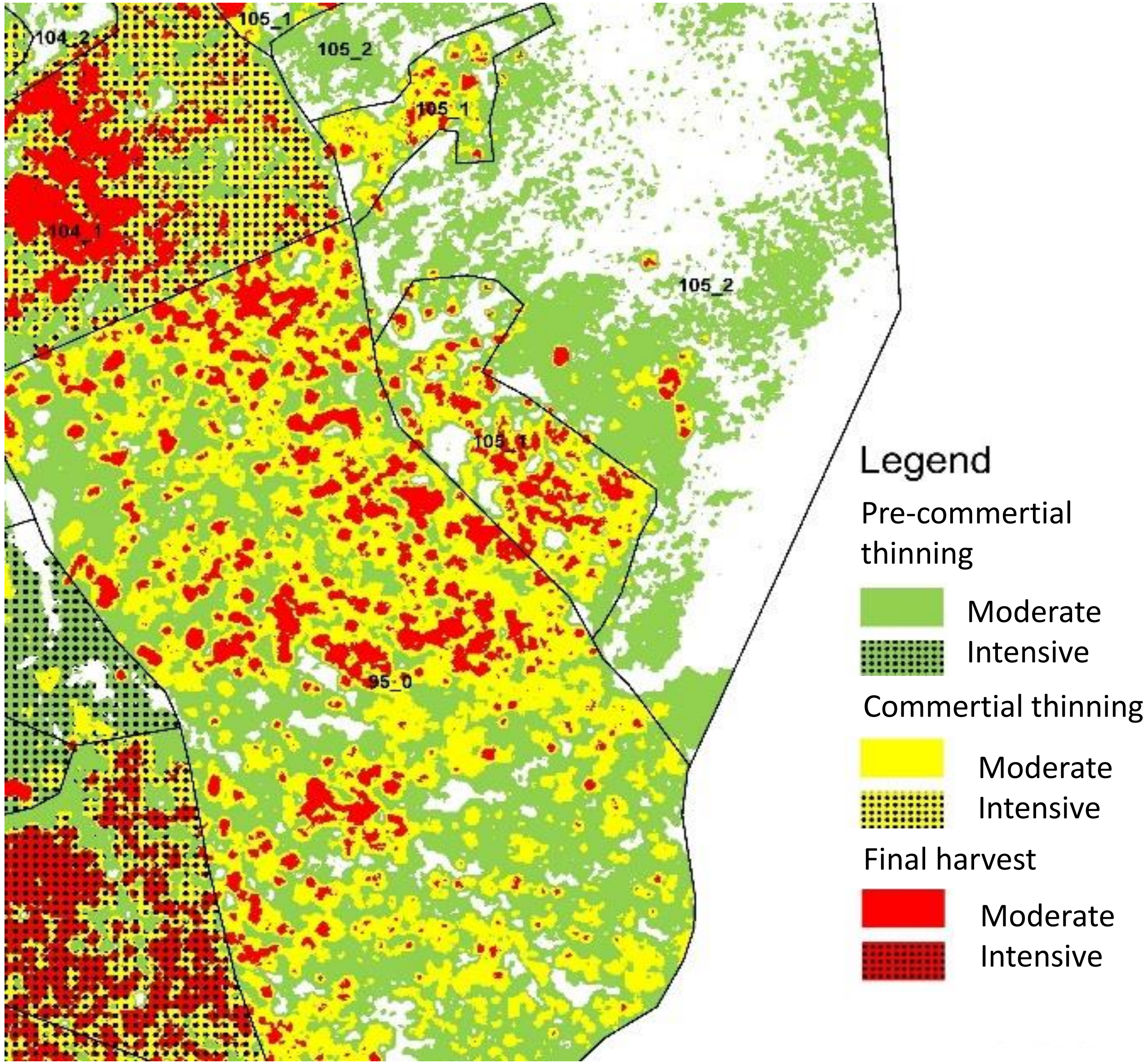
# Remote sensing in the forest inventory and mapping

## 3. Using of *SDDM*

3)

Distribution of harvest derived for stand development types (SDT) to the forest stands according to area proportion of harvest classes (HC)

- ***Design of harvest map prototype for forest of diameter classes***



# Advanced matrix modelling in the yield control

- **Optimal (target) state of uneven-aged forest is steady state with continuous ingrowth and maximal wood increment**

**Target steady state is determined by:**

1) Target tree species composition
2) Target wood stock (basal area)
3) Target diameter distribution
4) Target harvest

# Advanced matrix modelling in yield control

## 1. Original matrix model with integrated optimizer

➢ Developed for detection of target steady state

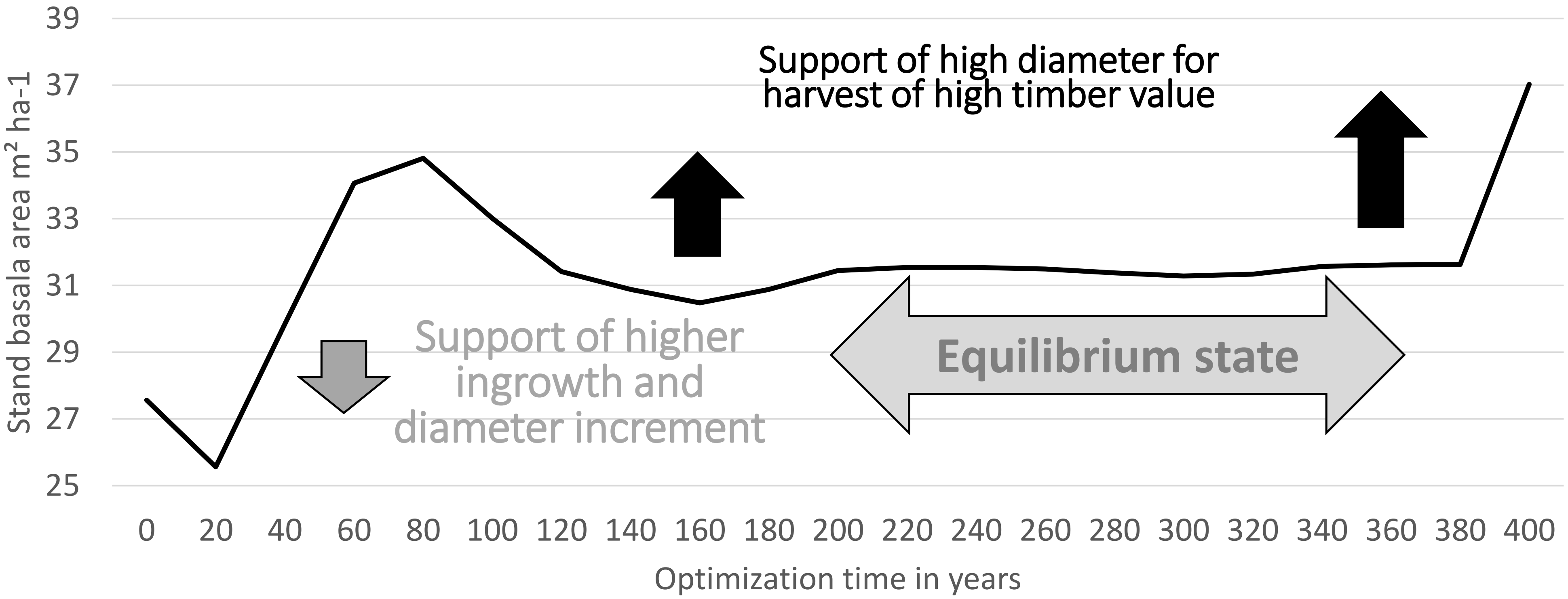
**Matrix model**

**Ecological part:**
- Simulates ingrowth
- Simulates increment
- Simulates mortality

**Economical part:**
- Considers wood price
- Considers harvest costs
- Considers interest rate

**Optimizer**

# Advanced matrix modelling in the yield control



# Advanced matrix modelling in the yield control

*J. Roessiger et al.*

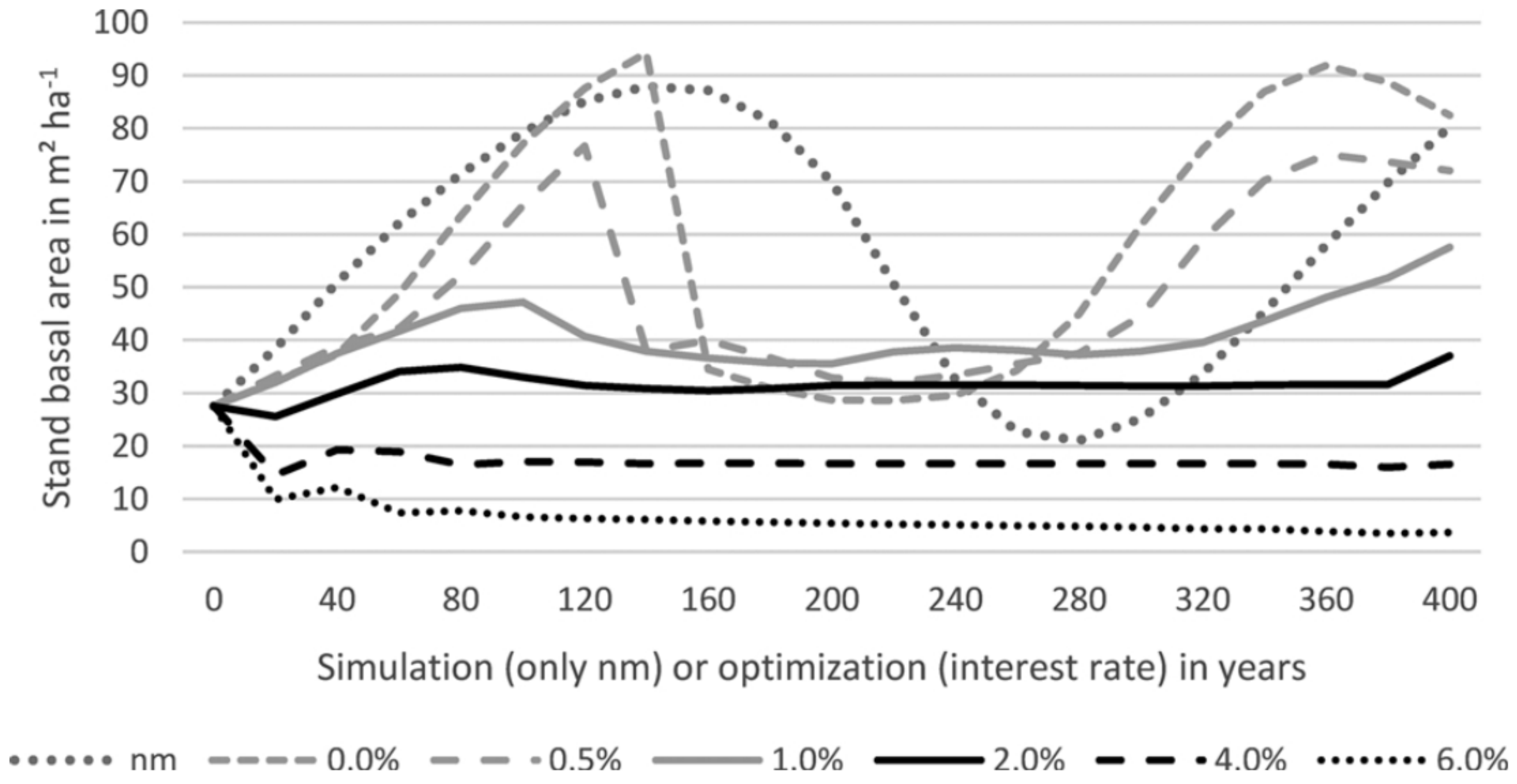
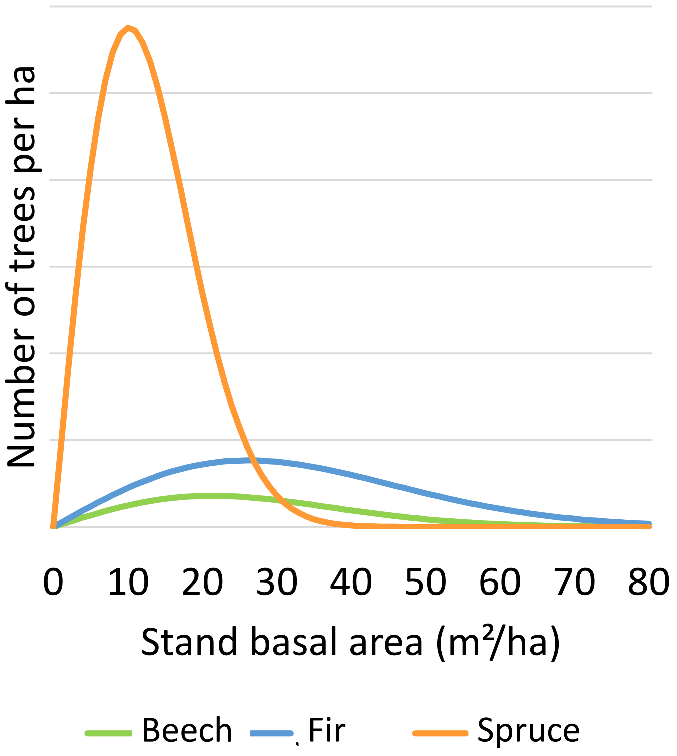


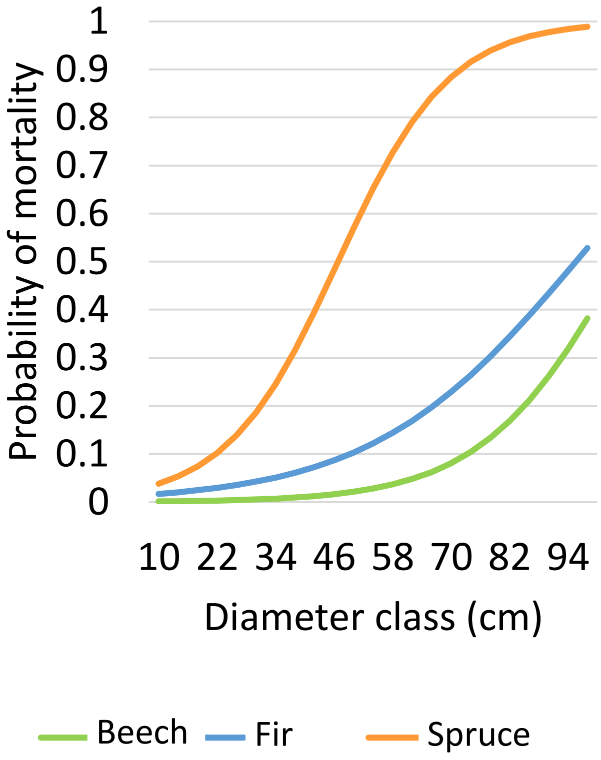

**Fig. 3.** *Ba* standing before harvest in a single period dependent on interest rate and simulation year.

# Advanced matrix modelling in the yield control

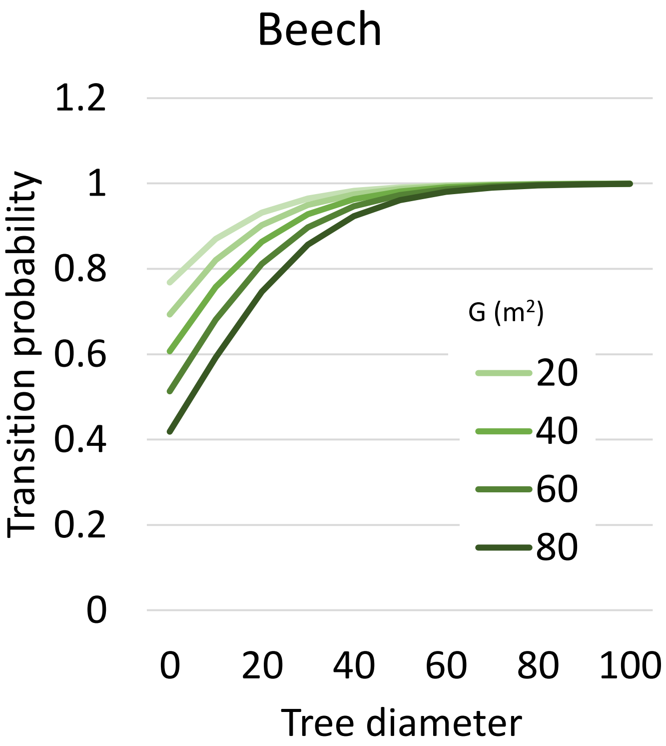
## How matrix model works – ecological part




Submodel of Ingrowth



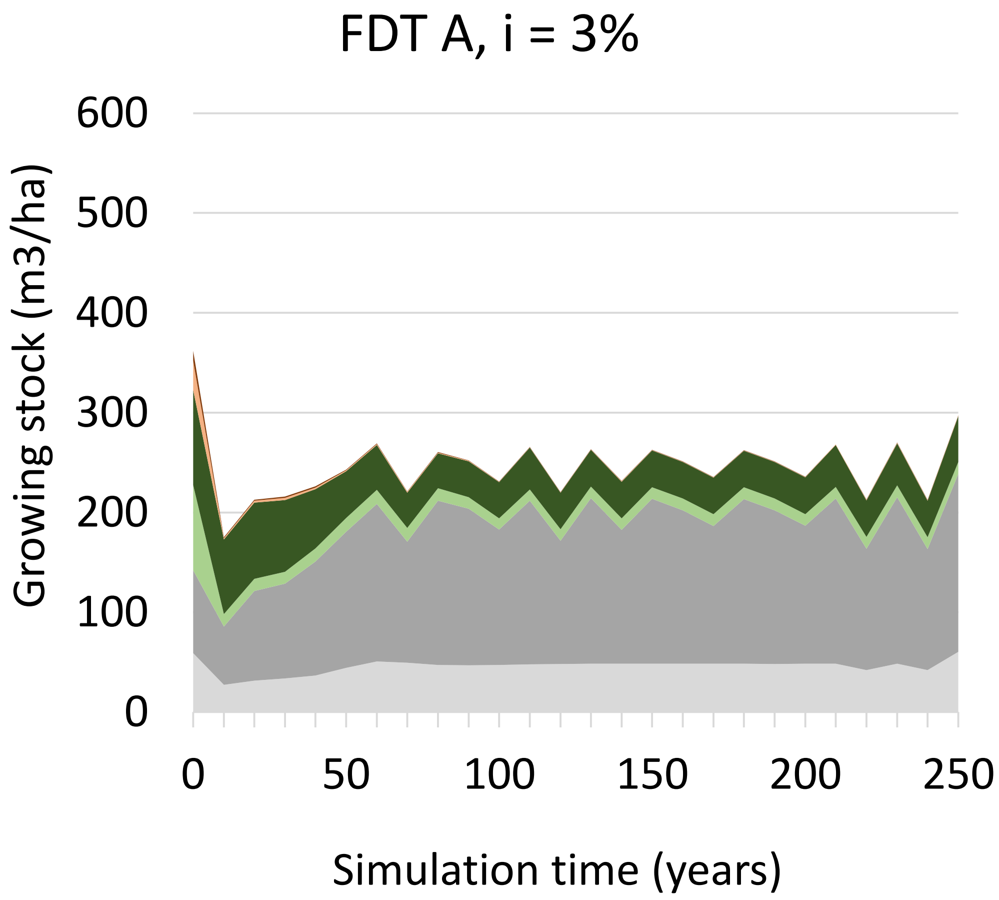

Submodel of mortality

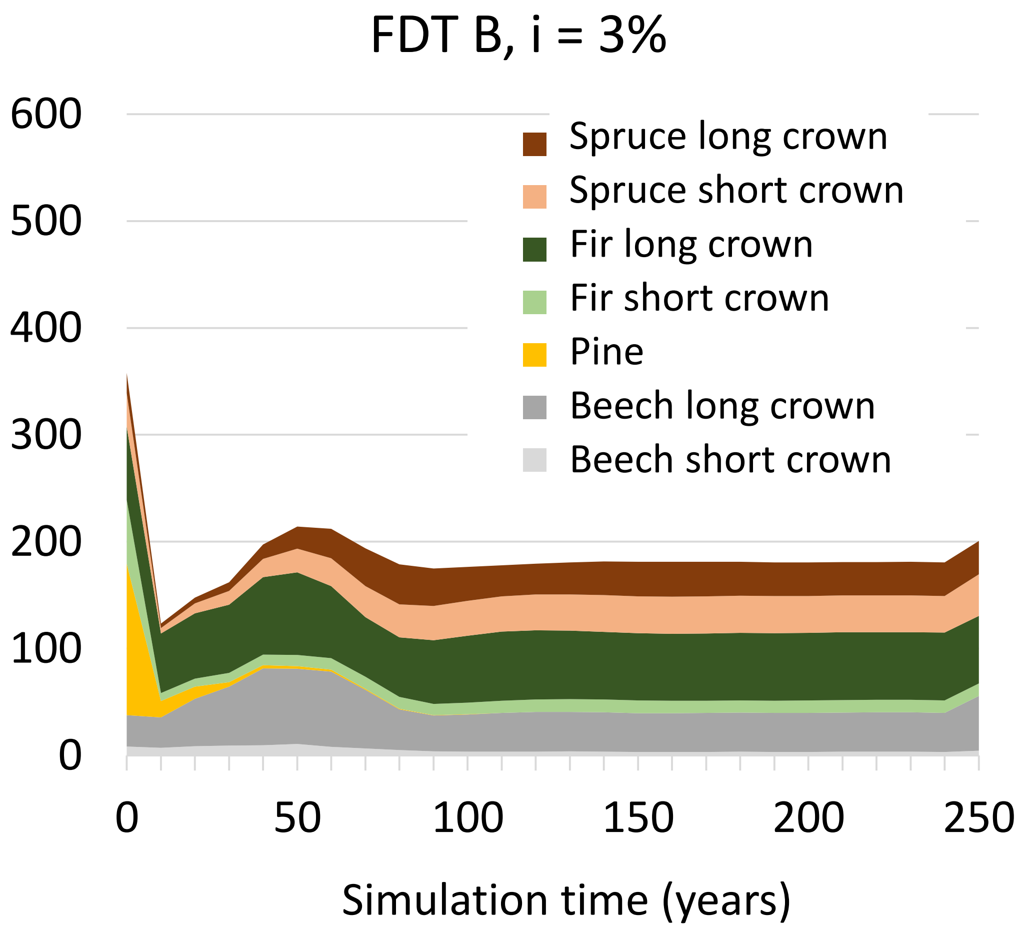



Submodel of transition

# Advanced matrix modelling the in yield control

- *Examples of steady states for Smolnicka Osada*



# Advanced matrix modelling in the yield control

❖ *Examples of target tree species composition for Smolnicka Osada*

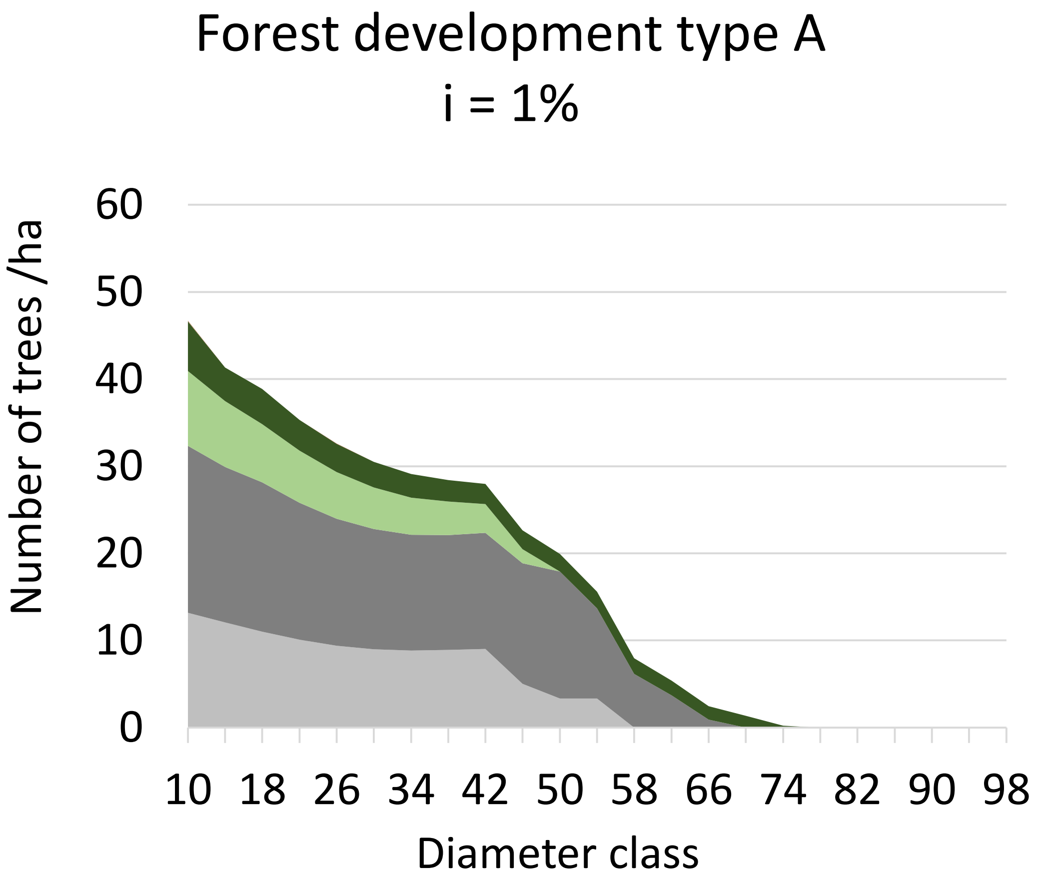
| Forest devel. type | i = 1% | | | i = 1,5% | | | i = 2% | | | i = 3% | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BK | JD | SM | BK | JD | SM | BK | JD | SM | BK | JD | SM |
| A | 78% | 22% | - | 78% | 22% | - | 78% | 22% | - | 80% | 20% | - |
| B | 44% | 54% | 2% | 41% | 52% | 7% | 37% | 49% | 14% | 22% | 41% | 37% |

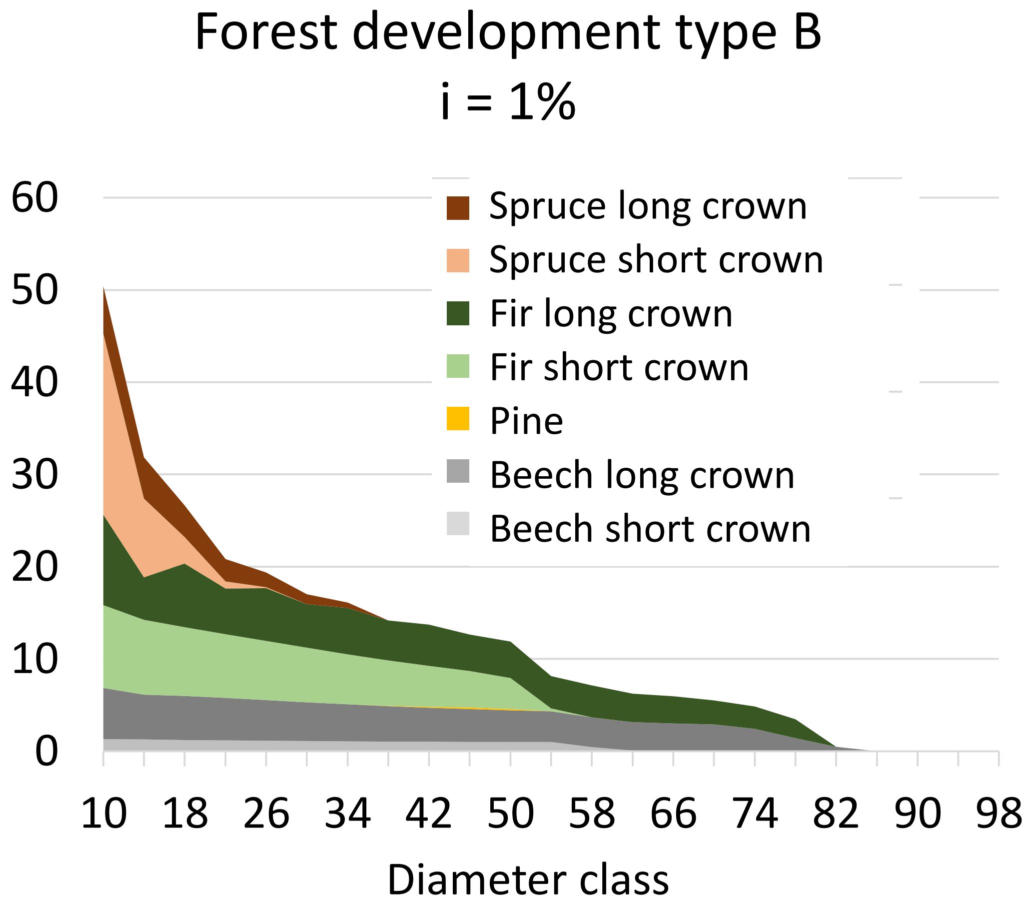
❖ *Examples of target growing stock for Smolnicka Osada*

| Forest devel. type | i = 1% | i = 1,5% | i = 2% | i = 3% |
|---|---|---|---|---|
| A | 430 | 408 | 355 | 244 |
| B | 375 | 315 | 260 | 181 |

# Advanced matrix modelling in yield control

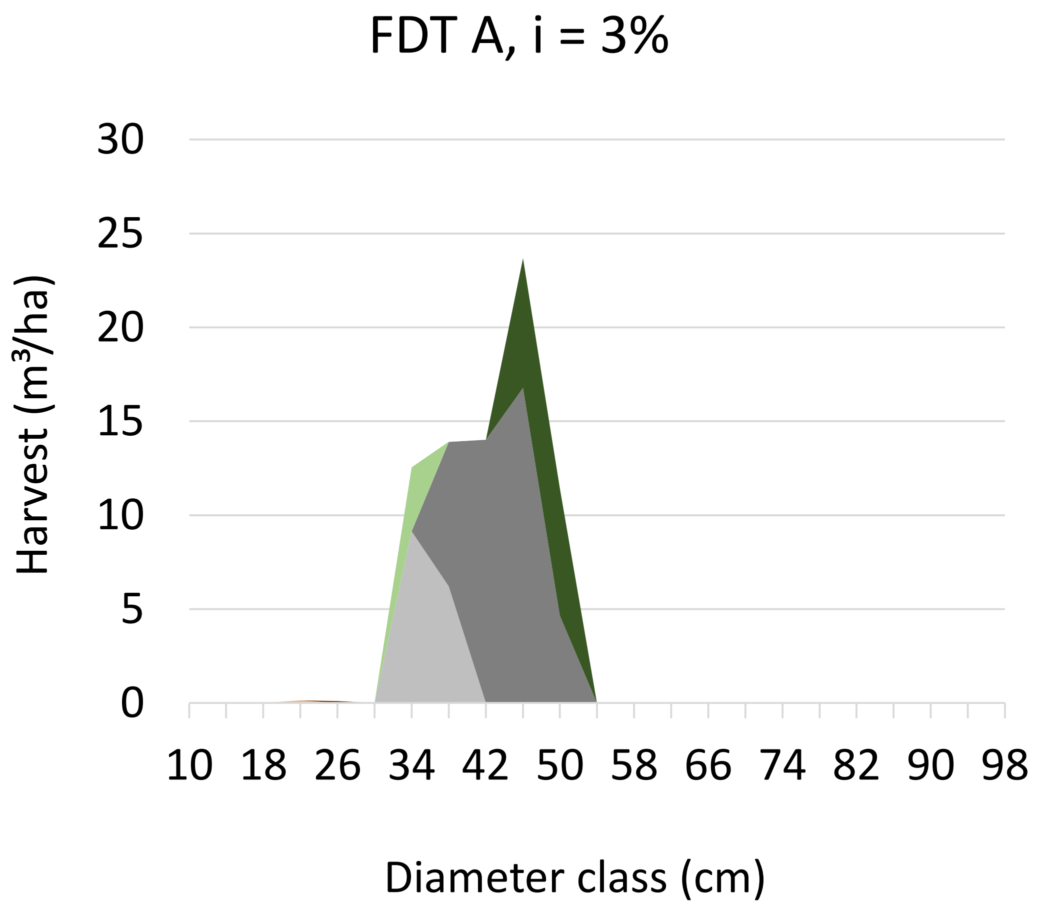
❖ *Examples of target diameter distribution for Smolnicka Osada*

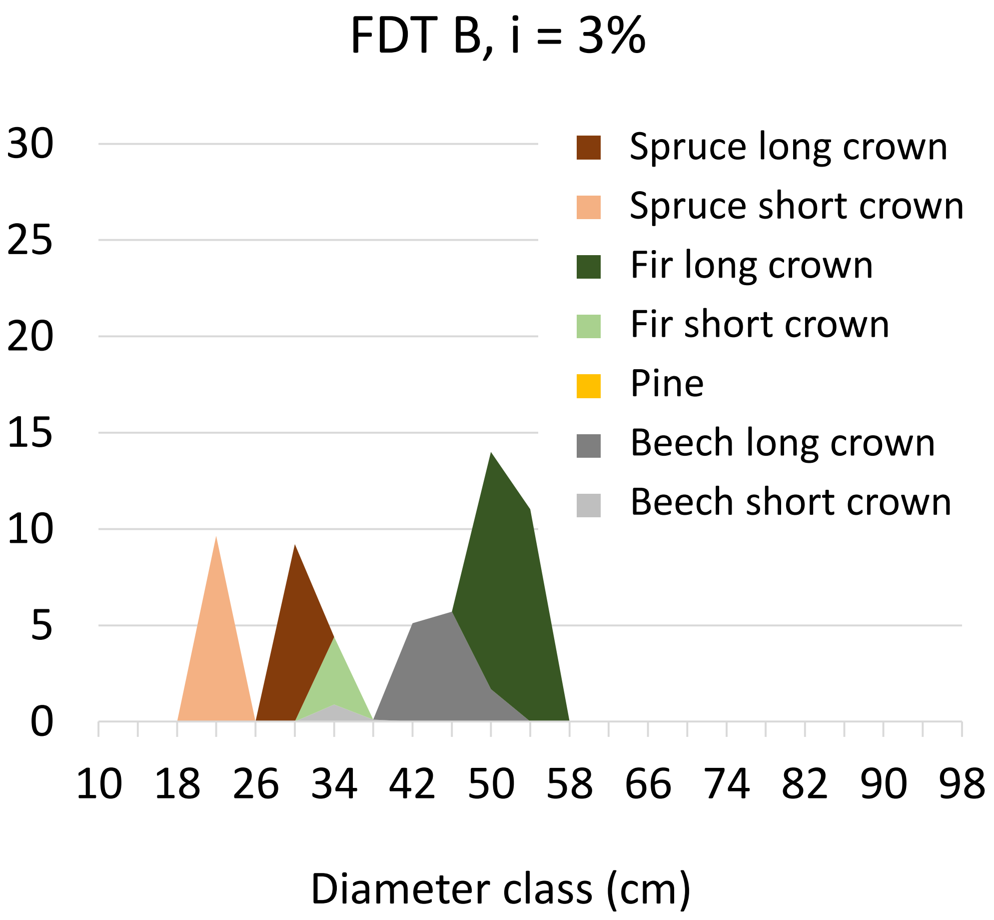


# Advanced matrix modelling in yield control

❖ *Examples of target harvest for Smolnicka Osada*



# Advanced matrix modelling in yield control

**<u>Determination of harvest for development stand type:</u>**

Growing stock from inventory is confronted with optimal target growing stock detedcted by matrix model (by tree species and diameter classes)

a) The growing stock by inventory (plus expected increment) is **<u>higher than optimal</u>**:

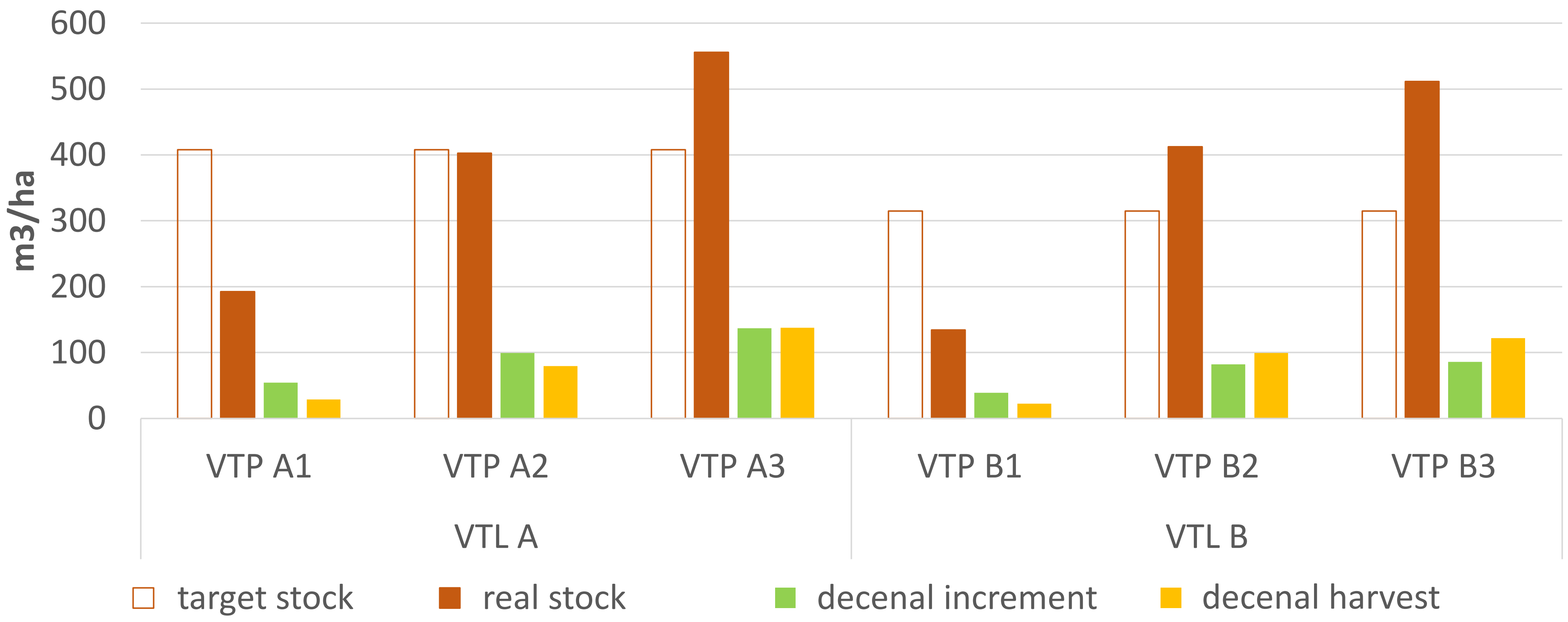
- a part of the surplus dependent on predefined transition period is suggested for harvest

b) The growing stock by inventory (plus expected increment) is **<u>lower than optimal:</u>**

- a proportional part of increment dependent on predefined transition period is suggested for harvest

# Advanced matrix modelling in yield control

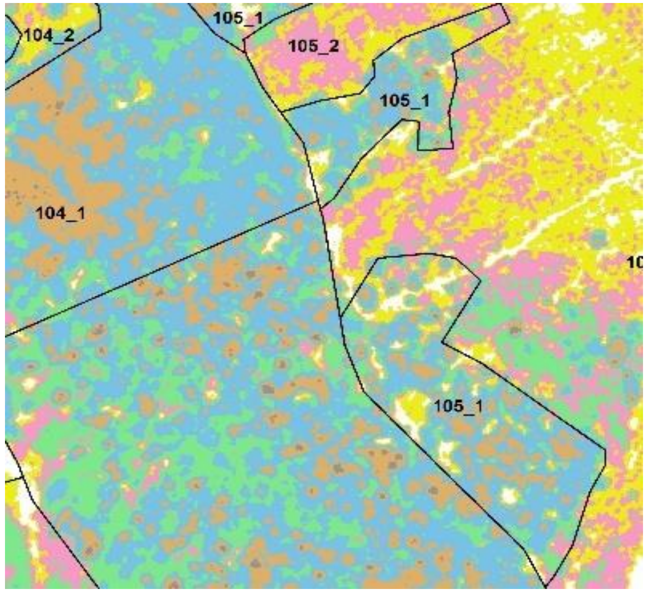
❖ *Comparison of target growing stock, real growing stock, increment and suggested harvest for Smolnicka Osada*

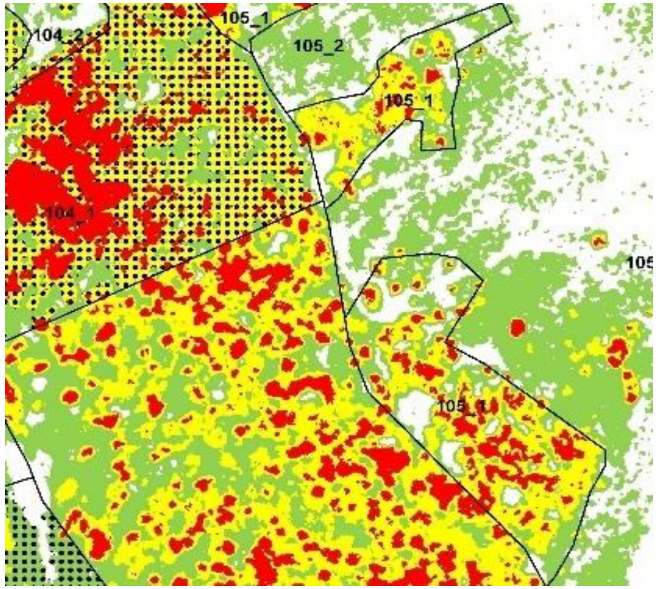


# Advanced matrix modelling in yield control

## **Determination of harvest for forest stands:**

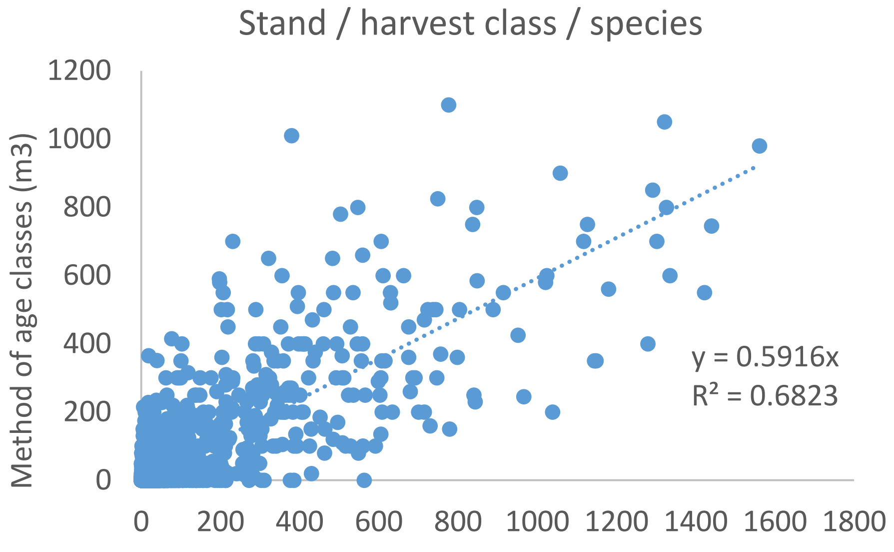
1. Harvest volume derived for stand development type is splited to harvest classes (HC)
2. Splited harvest is spatially allocated within forest development type according to known distribution of diameter classes *(SDDM)* using methods of map algebra (harvest map is created)
3. Estimated harvest for forest stand is obtained by overlapping raster layer of harvest map with vector layer of forest stands and is tranfered to Foret Management Plan:

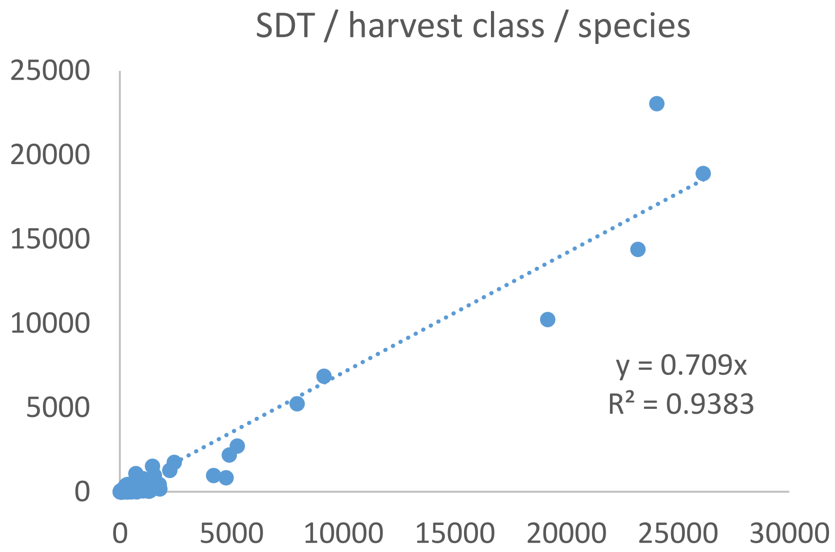


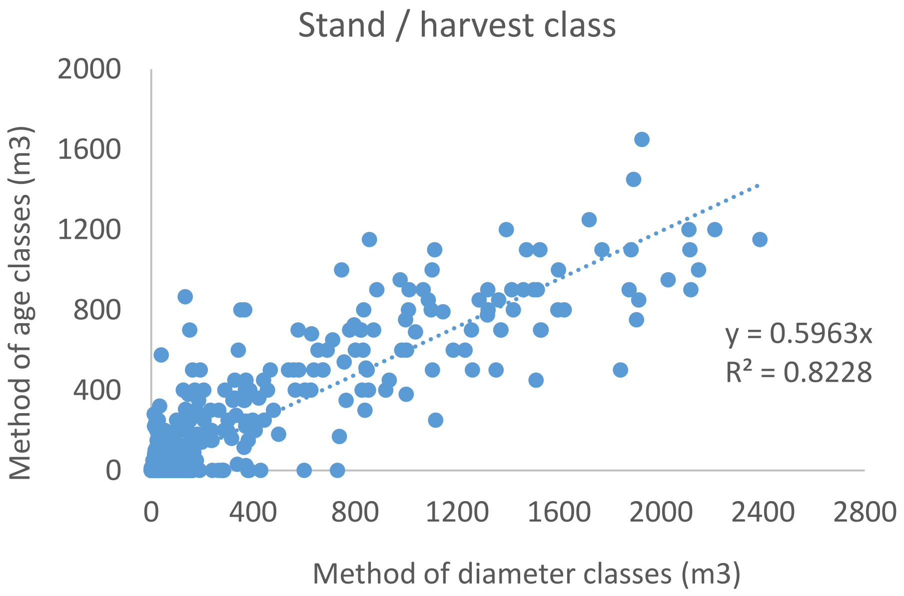



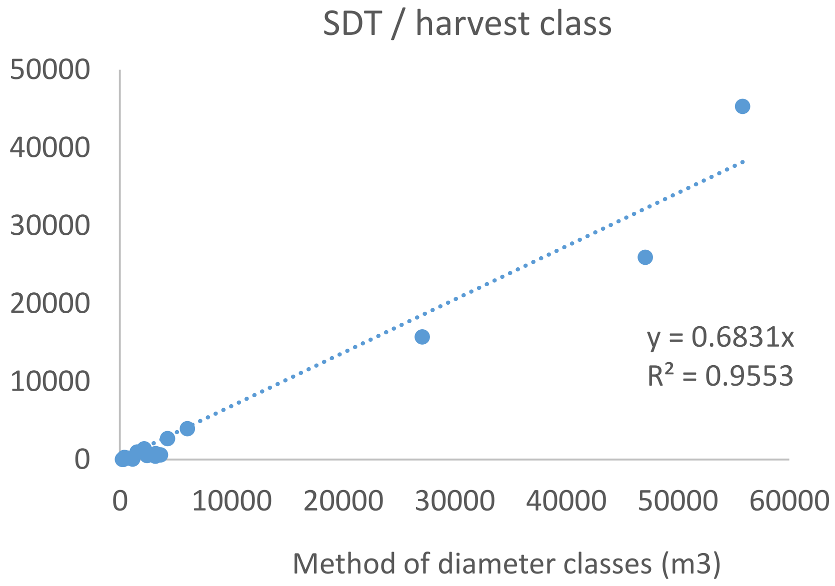

| Stand | Species | Harvest class | Stock | Harvest | ... |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

# ❖ *Planned harvest: method of diameter classes versus method of age classes*



# 3.
# Summary and outlook

- In particular, three innovative approaches to the management of uneven-aged forests were presented:
    1. Matrix optimisation for finding the target steady state
    2. Estimation of spatial diameter distribution using LiDAR
    3. Spatial allocation of harvest to single stands after deriving harvest for higher spatial unit
- Results are not generally valid, but represent a promising way for precising and streamlining forest management planning in uneven-aged forests in the future

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# Finding equilibrium in continuous-cover forest management sensitive to interest rates using an advanced matrix transition model

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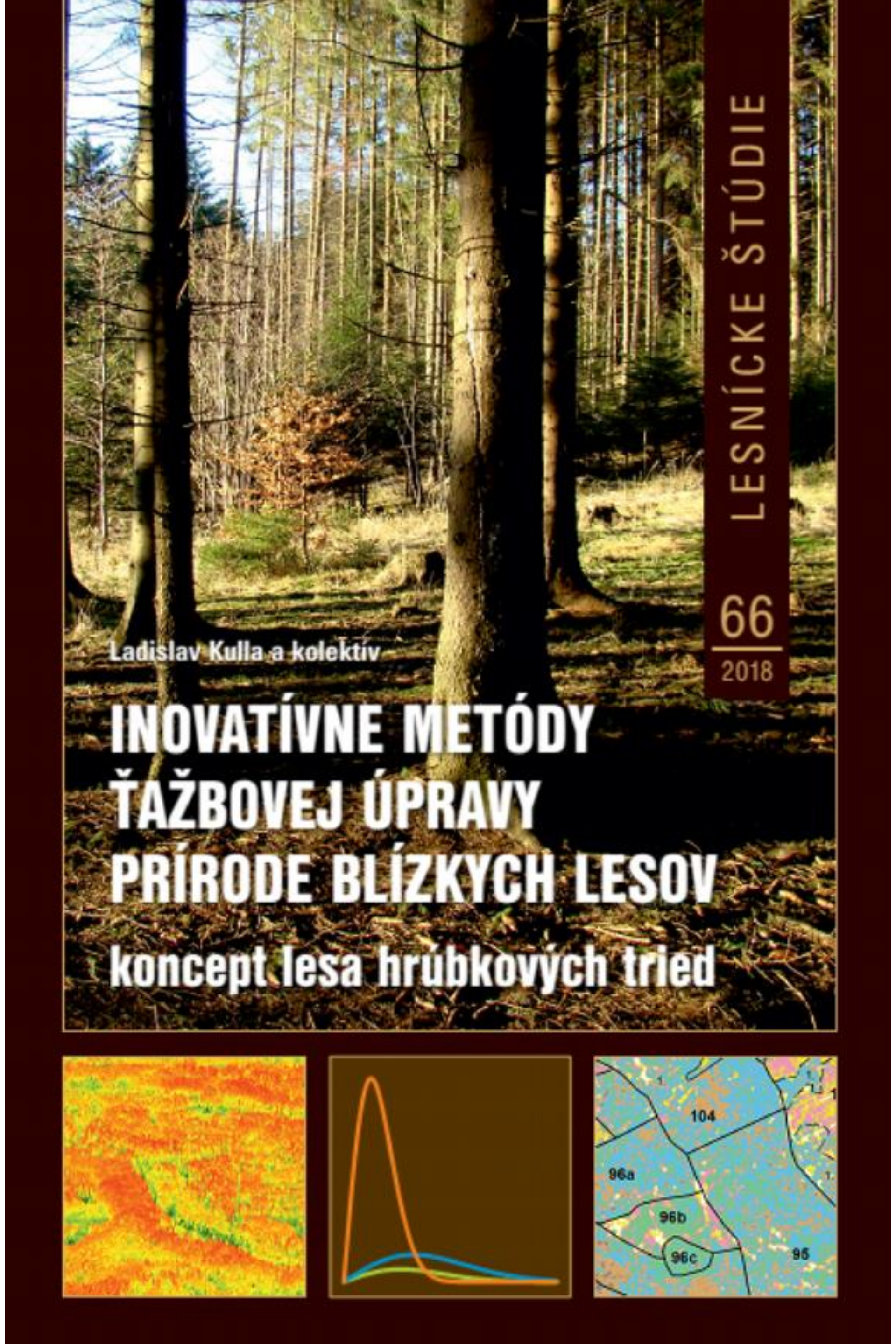
Simultaneous nonlinear optimisation

ABSTRACT

Continuous-cover forestry is a management alternative that seeks to provide more diverse forests for continual multi-purpose benefits. Whether there is an economically-optimal equilibrium of uneven-aged forest can be tested deterministically by varying interest rate *i*. To answer this question, optimisation focused on maximising

http://www.nlcsk.sk/images/pdf/Kulla_web.pdf



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