Mapping berry yields with remote sensing and model development to forest planning

Inka Bohlin, Swedish university of Agricultural sciences

Nordic Wild Berry R & D Network Country Webinar, Sweden 18th of April 2024

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Predicting bilberry and cowberry yields using airborne laser scanning and other auxiliary data combined with National Forest Inventory field plot data

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heureka!

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Shrub Cover Models

Two models for estimating shrub cover percentage are available in Heureka.

Bilberry and lingonberry cover models by Bohlin

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The Finnish Society of Forest Science

Jari Miina[1], Inka Bohlin[2], Torgny Lind[2], Jonas Dahlgren[2], Kari Härkönen[3], Tuula Packalen[1,5] and Anne Tolvanen[4]

Lessons learned from assessing the cover and yield of bilberry and lingonberry using the national forest inventories in Finland and Sweden

SLU

Identifying potential locations for bilberry picking with remote sensing, in-situ field data and phone-application

Bohlin[1], A. Wahlberg[2], R. Uddstål[2], F. Nilbrink[2], E. Bergström[1], P. Axensten[1], M. Ekström[1], A-K. Karlsson[2] and K. Östergren[2]

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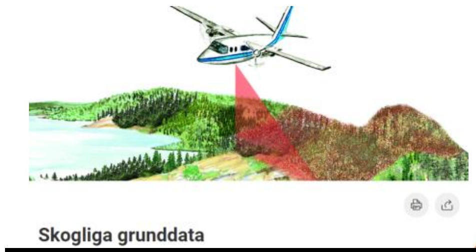
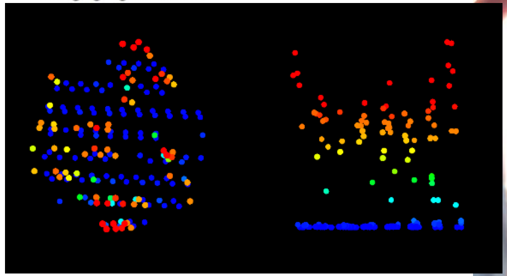
[2] Rise Research Institutes of Sweden

FAIRCHAIN SLU RISE

Mapping berry yields with remote sensing

- We want to eat berries, berries important for ecosystems!
- Mapping berry yields in forest landscape?
  - Where are the berries?
  - Can we use wall-to-wall remote sensing technology?





- Improved knowledge on potential berry locations?
  - Easier to find berries and plan berry picking
  - More berries utilized by both household and local berry industry
  - Combining different ecosystem services in forest management
  - Berries in ecosystem functioning

Study 1.

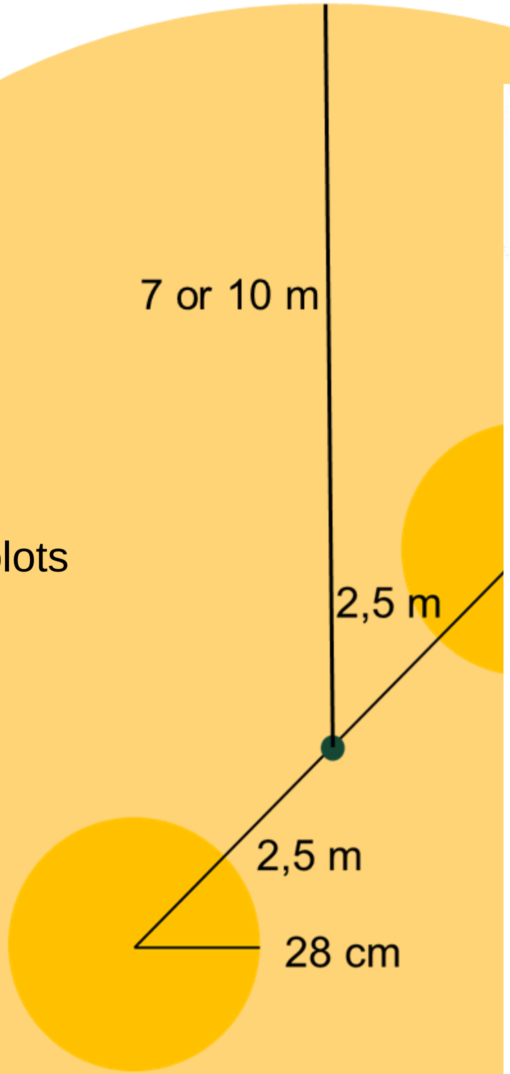
In this study we combined bilberry/cowberry data from Swedish NFI with nationwide ALS data to predict bilberry yields. The specific aims were

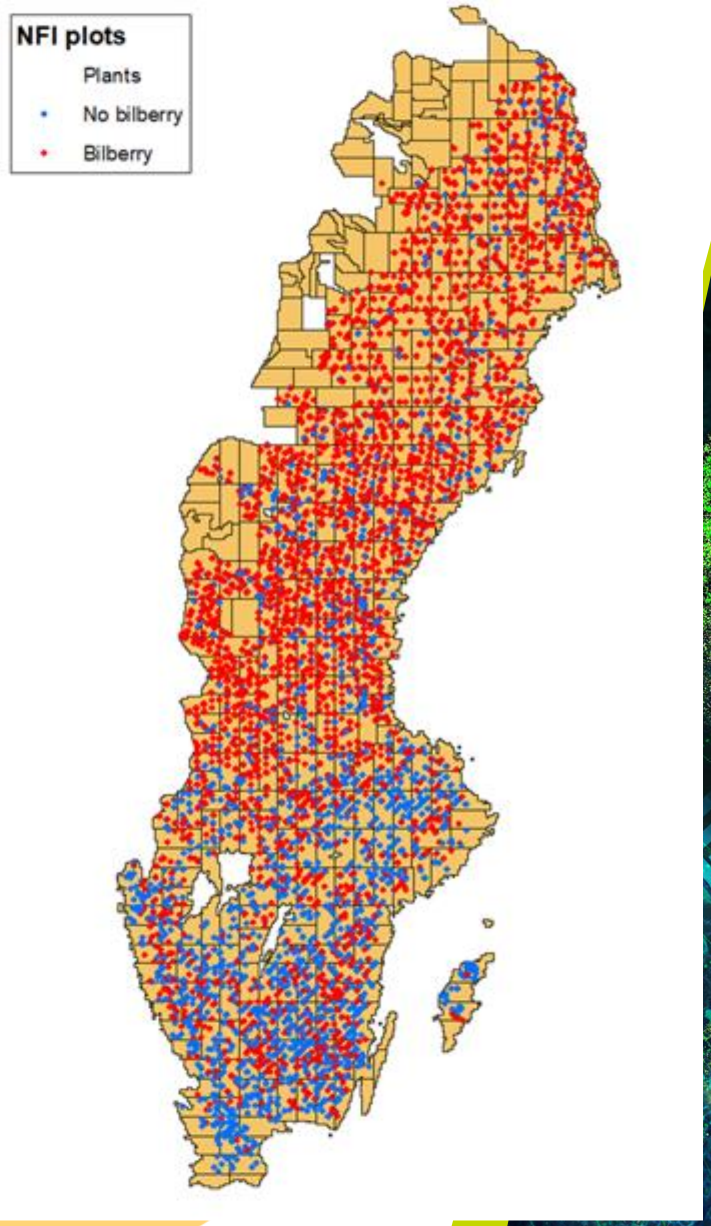
1) to develop general prediction model for berry yield based on ALS (airborne laser scanning) data and other existing wall-to-wall data and

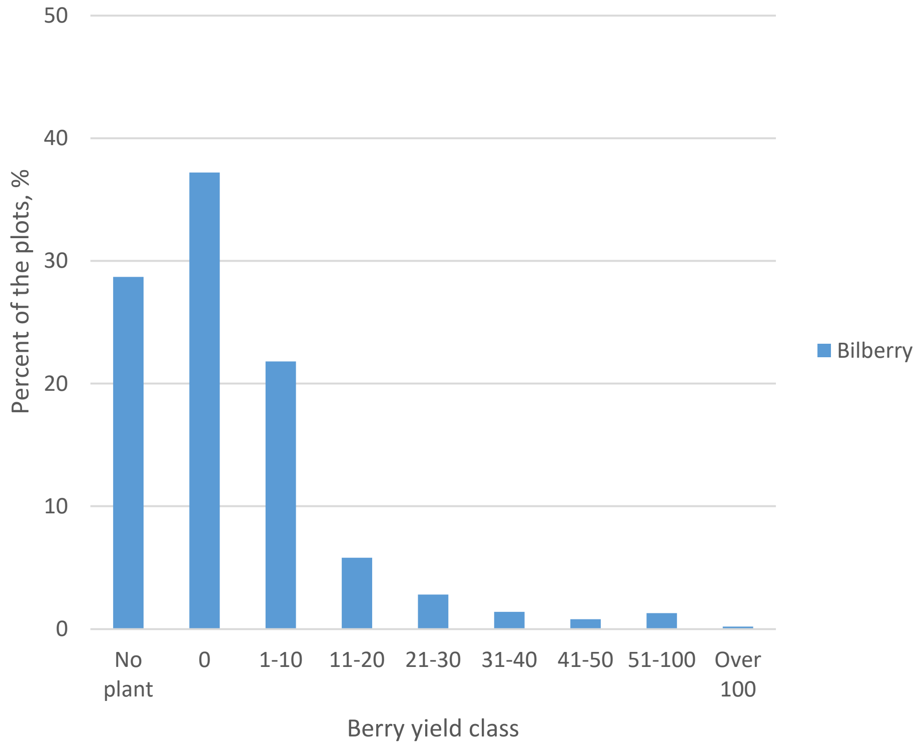
2) to identify laser based structural features of forest that can be linked to locations of the highest yield, highly interesting by the berry pickers

NFI data

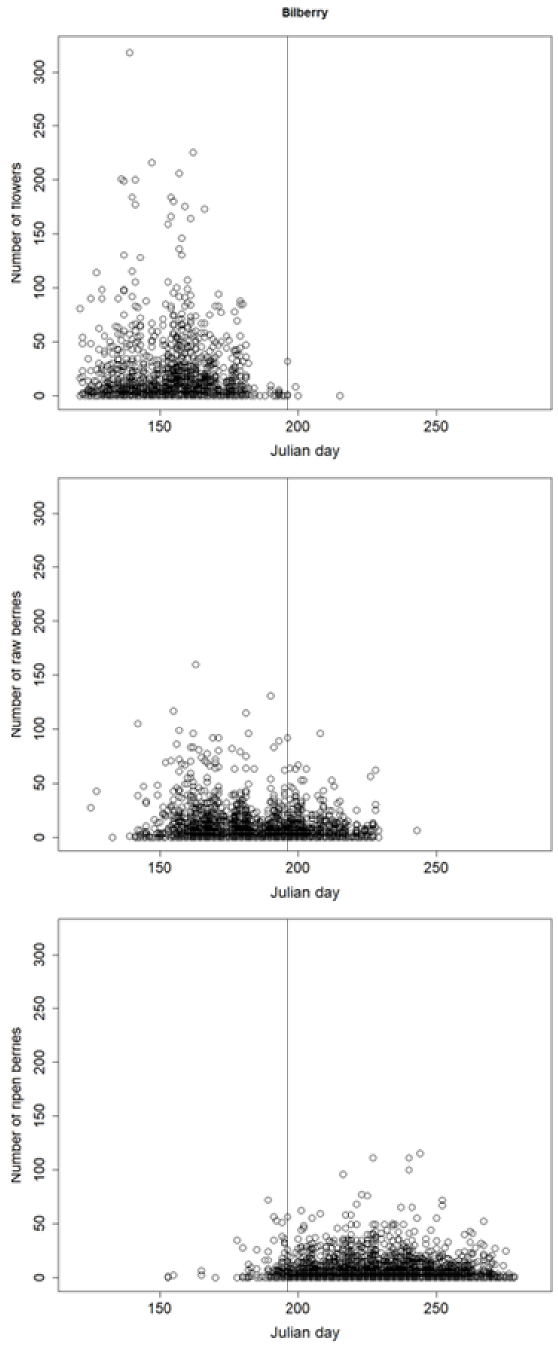
- NFI field plots 2007-2016 over 13 000 plots
- Sum of flowers/berries in two 0,25m2 berry plots inside NFI plots
- Only plots having bilberry/cowberry plants with development stage flower, raw and ripen berries and plots without bilberry plants were used in modelling
- Only plots within 3 year from ALS data acquisition







Percentages of plots in berry yield classes (sum of number of flowers, raw berries and ripe berries) in the bilberry data. No plant refers to data where no bilberry/cowberry plants were observed in the plots. Each plot represents sum of two 0.25m2 berry plots inside NFI plot.

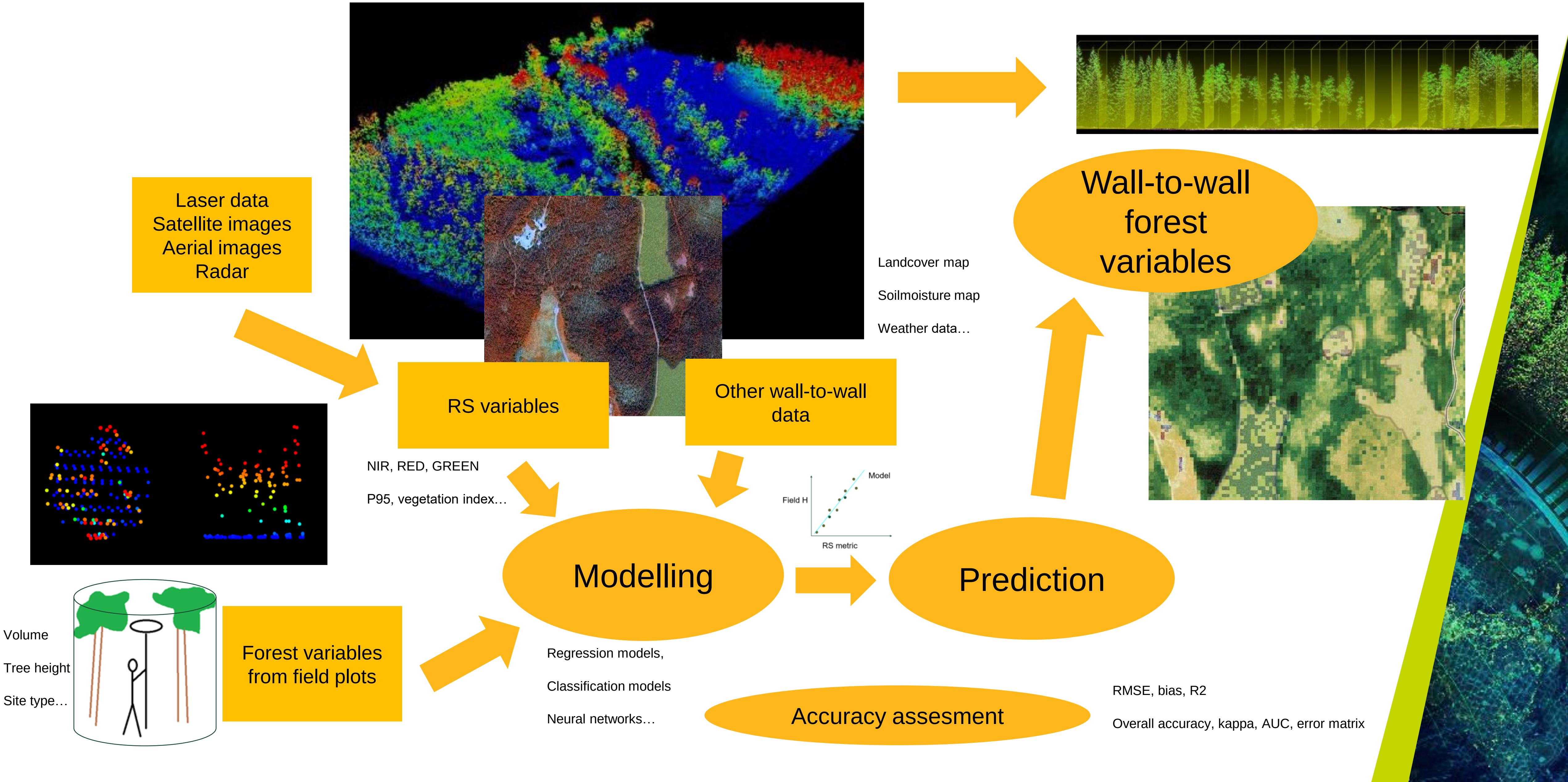


The number of flowers and berries is depended on the inventory day of the growing season

Time difference between the inventory day and the Julian day when the berries expected to be ripen (mid_July) was used as one variable in the models

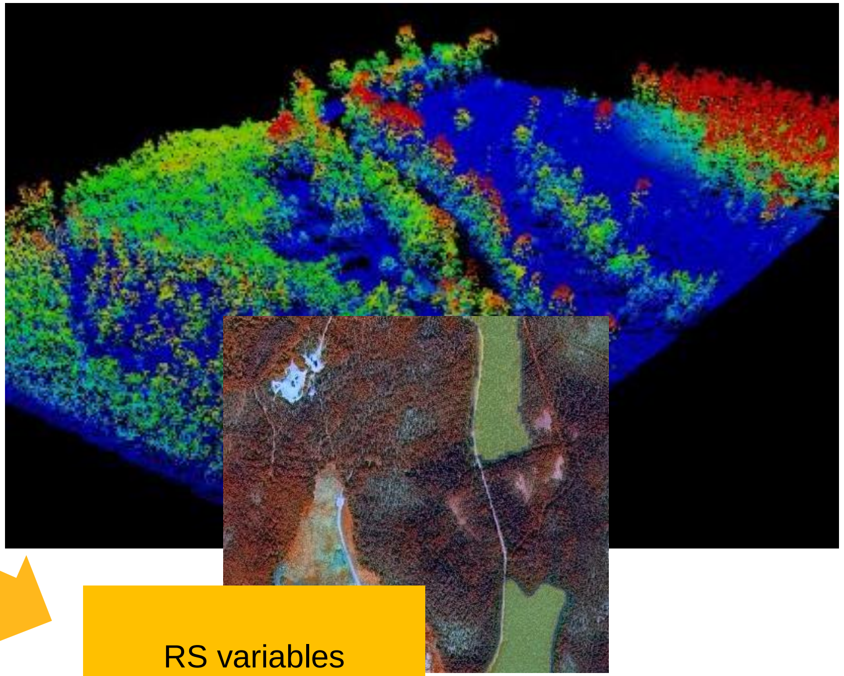
-> change in berry amount (%) during the season

Remote sensing based forest inventory; Area-based approach



Remote sensing based forest inventory; Area-based approach

Laser data
Satellite images
Aerial images
Radar

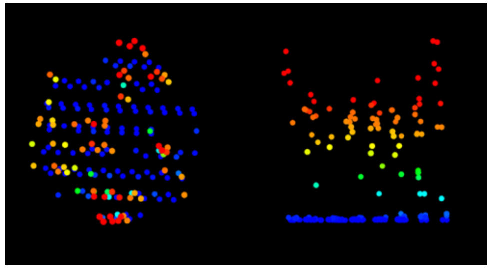


RS variables

NIR, RED, GREEN

P95, vegetation index…

Remote sensing based forest inventory; Area-based approach



RS variables

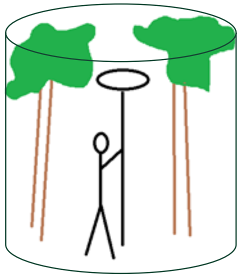
NIR, RED, GREEN

P95, vegetation index…

Volume

Tree height

Site type…



Forest variables from field plots

Remote sensing based forest inventory; Area-based approach

Landcover map

Soilmoisture map

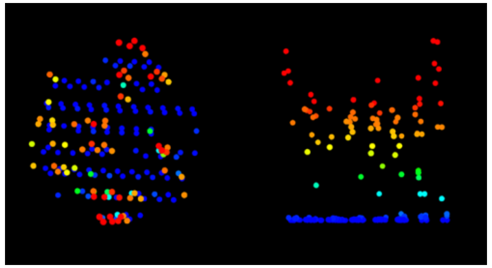
Weather data…

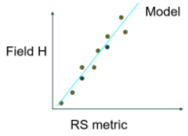
RS variables

Other wall-to-wall data

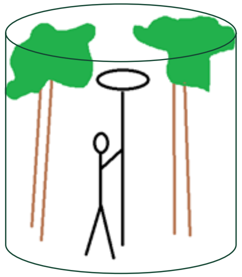
NIR, RED, GREEN

P95, vegetation index…





Modelling



Volume

Tree height

Site type…

Forest variables from field plots

Regression models,

Classification models

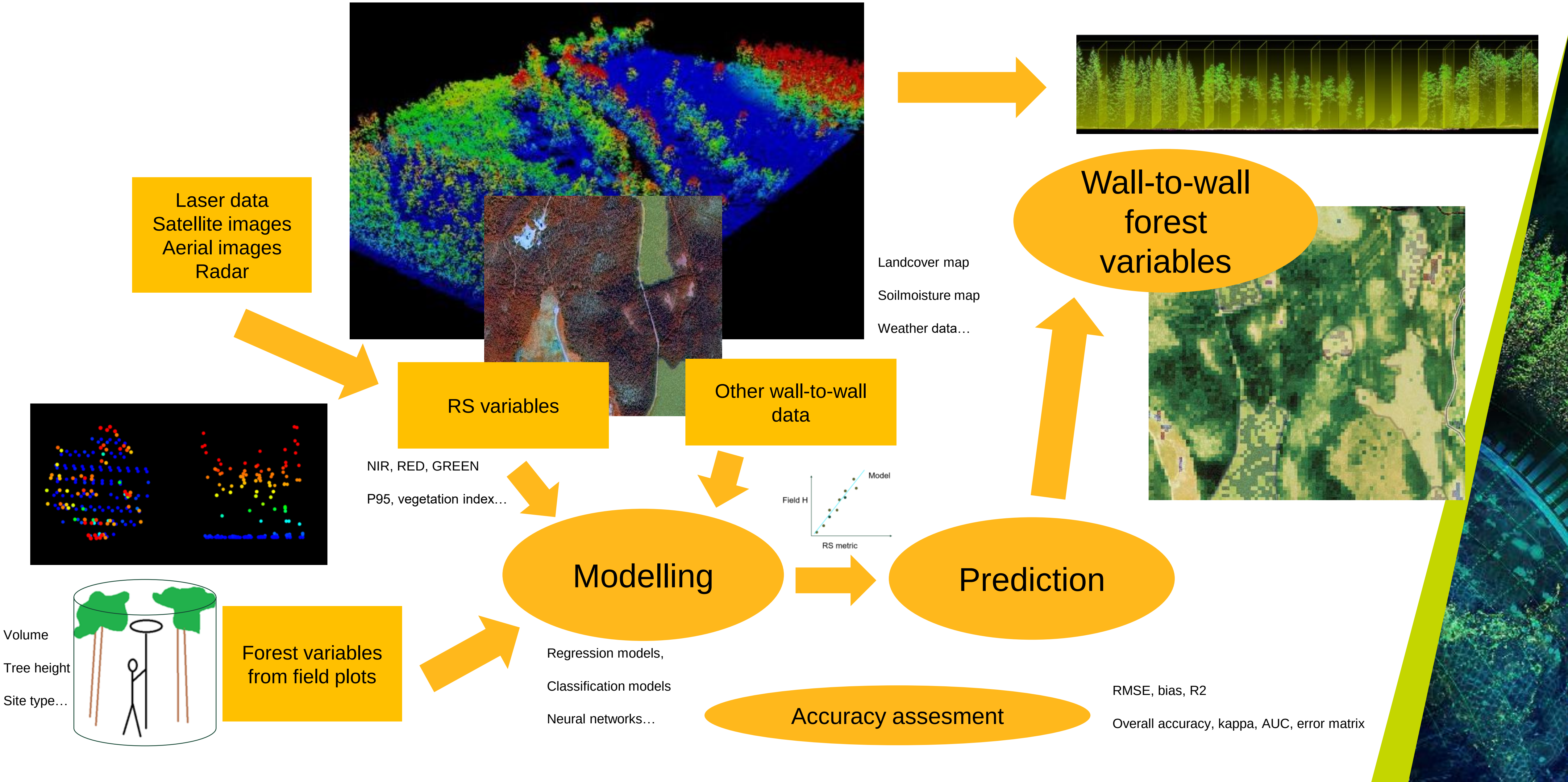
Neural networks…

Accuracy assesment

RMSE, bias, R2

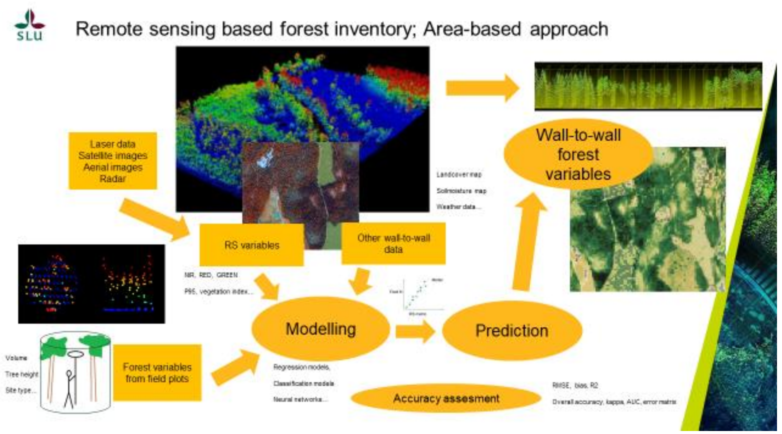
Overall accuracy, kappa, AUC, error matrix

Remote sensing based forest inventory; Area-based approach



Method

- Modelling the relationship between field measured berry yields and **forest structural variables** based on ALS data (and other wall-to-wall variables),
  - direct measurements of berry yields using ALS data impossible!
- Calculating the ALS and other metrics from NFI plots with 7m radius
  - Berry plots too small to measure forest structure
- Finding best modelling method for the data



RS datasets used in modelling:

- ALS based structural metrics
- ALS based surface metrics from DEM (2x2m)
- Bioclimatic variables (1x1km)
- Soil type and soil depth (Geographical survey of Sweden) (10x10m)
- Landover map (Swedish environmental protection agency) (25x25m), 2000
- SLU forest map (25x25m), 2010 (species)
- The time difference between Julian day of field data collection and middle of July (bilberries ready for picking)

Generalized linear mixed effect model

$$y_{ijk} \sim Poisson(\pi_{ijk})$$

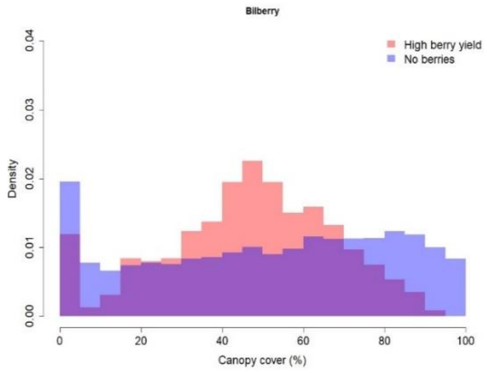
$$ln(\pi_{ijk}) = \boldsymbol{x}'_{ijk}\beta + u_i + u_{ij} + u_{ijk}$$

Poisson for count data

where y is the sum of flowers and berries in two 0.25m^2 circular plots inside the NFI plot; Poisson distribution with mean π_{ijk} is the conditional distribution of y_{ijk} given the random effects u_i, u_{ij} and u_{ijk}; $ln(\pi)$ is a log-link function and $\boldsymbol{x}'_{ijk}$ are the fixed predictor variables with corresponding coefficients vector β. Subscripts i, j and k refers to nested cluster, laser block and county levels and u_i, u_{ij} and u_{ijk} are normally distributed random effects with mean of zero and constant variances.

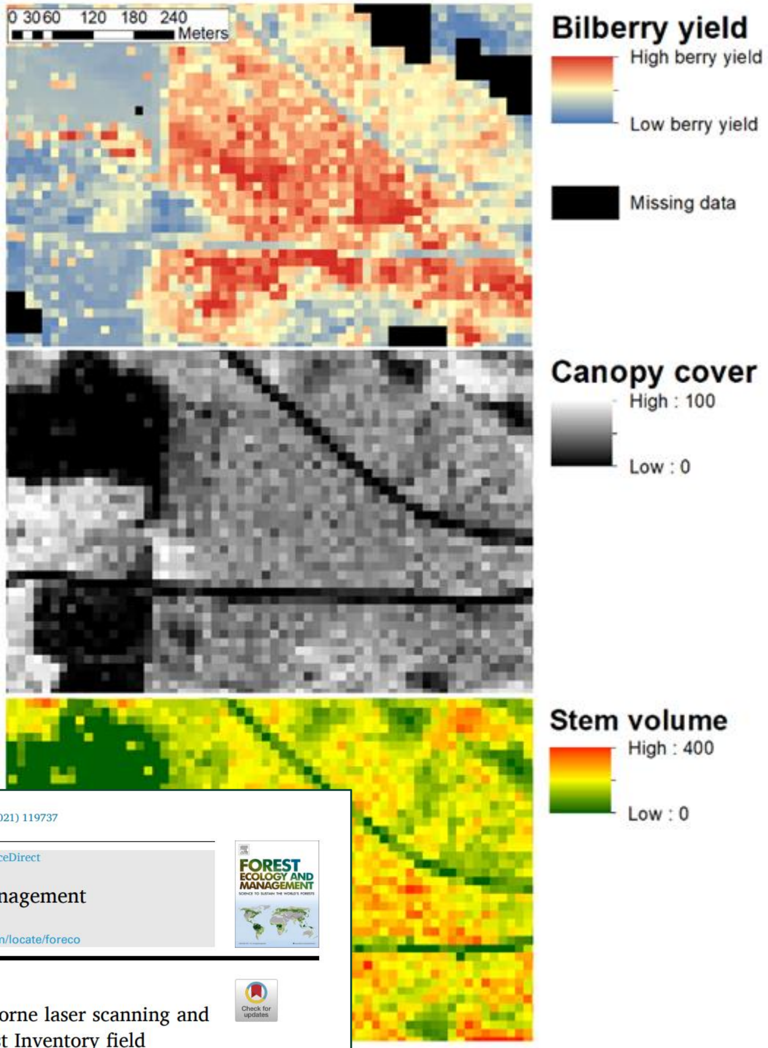
Results/conclusions

- Combination of different variables needed
  - Forest and terrain structure (ALS)
  - Climate
  - Tree species, land cover (satellite images)
- 1,5 % decrease in bilberries per day over the season
- Calculated optimal canopy cover 48 % for bilberry
- Pine dominated, mature forest, relative open canopy for bilberry!
- R2: 0.4 (full model), 0.08 (fixed part)
  - Difficult -> variables in the model can describe only the small part of the variation of the berry production
  - model should not be used to predict exact yield but as an effective tool for predicting the most potential locations for the berry yields



First national berry yield models based on ALS data!

	Estimate	Std.Error	t-value	p-value	Scaled estimate
Intercept	-3.6588	0.3265	-11.21	<0.001	0.9969
Continuous variables					
Mid_July	-0.0145	0.0006	-22.29	<0.001	-0.5847
Temperature seasonality	0.0005	0	15.65	<0.001	0.4306
CCLeaf	-0.0106	0.0017	-6.38	<0.001	-0.3876
Canopy cover^{2*}	-0.0004	0	-16.22	<0.001	-0.3206
Elev.variance	0.0136	0.0012			
DEM_mean	0.0018	0.0002			
DecidPro (%)	-0.0191	0.0027			
PineVolume (m^3ha^{-1})	0.0031	0.0004			
SpruceVolume (m^3ha^{-1})	-0.0025	0.0004			
Slope_mean	0.0192	0.0037			
Shrub cover	-0.8380	0.2242			
Precipitation seasonality^2	-0.0007	0.0001			
SW_mean	0.0086	0.0023			
Canopy cover*	0.0409	0.0033			
Categorical variables					
Year (ref. 2007)					
2008	0.1473	0.1571			
2009	0.0750	0.1561			
2010	0.3379	0.1490			
2011	-0.2977	0.1330			
2012	0.2066	0.1161			
2013	0.3402	0.1306			
2014	-0.1358	0.1384			
2015	0.5667	0.1389			
2016	0.2987	0.1574			
Leaf-on/off (ref. leaf off)					
Leaf-on	-0.2892	0.0839			
Land use (ref. others)					
Deciduous forest	0.1447	0.1992			
Conifer forest with lichen	0.2340	0.1918			
Conifer forest 7-15 m	0.3005	0.1871			
Conifer forest > 15 m	0.4138	0.1871			
Conifer forest in mire	-0.2105	0.2218			
Conifer forest in mountain	0.1749	0.2155			

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[b] University of Eastern Finland, School of Forest Sciences, P.O. Box 111, Joensuu, Finland
[c] Natural Resources Institute Finland, Yliopistokatu 6, 80100 Joensuu, Finland

EU-funded project (2021-2024) testing innovations to build sustainable intermediate food value chains

Swedish case study:

DEVELOPING WILD BERRY BUSINESS TO BOOST LOCAL ECONOMY AND SOCIAL COHESION

This project has received funding from the European Union's funding programme H2020 research and innovation programme under grant agreement 101000723.

Study 2.

AIM: Develop a practical method for identifying potential locations for bilberry picking in forest landscape with help of remote sensing, local field data and phone-application for supporting the development of the local berry value chain

Research questions:

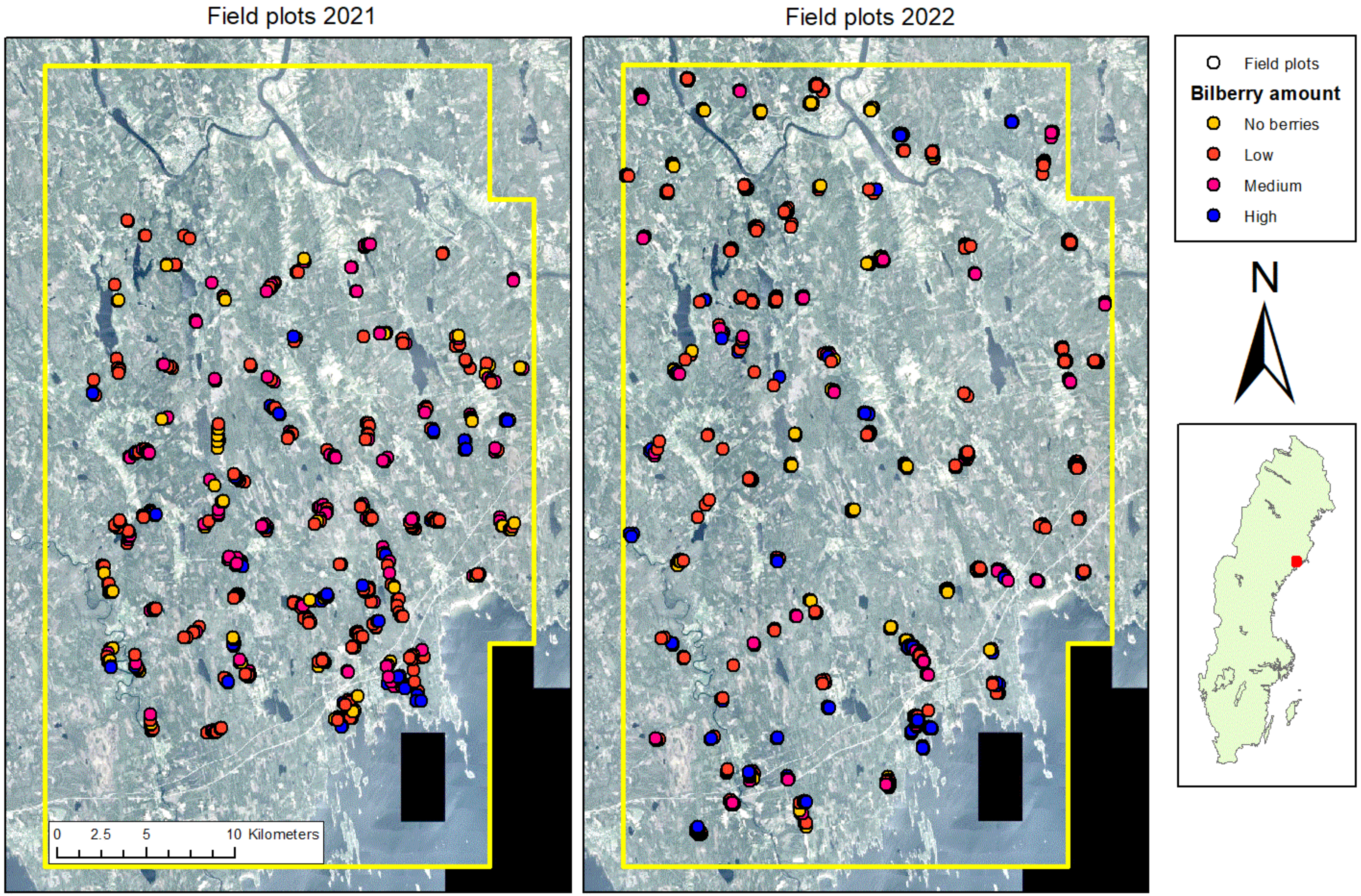
- Can we map local berry yields by combining remote sensing and in-sity field data and how accurately ?
- Which variables are most importat?
- Can we improve predictions with annual calibration?

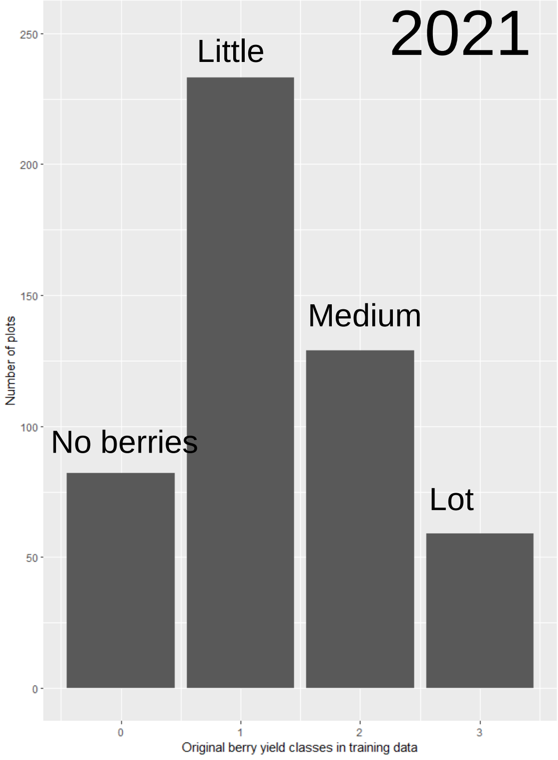
Swedish Case study:

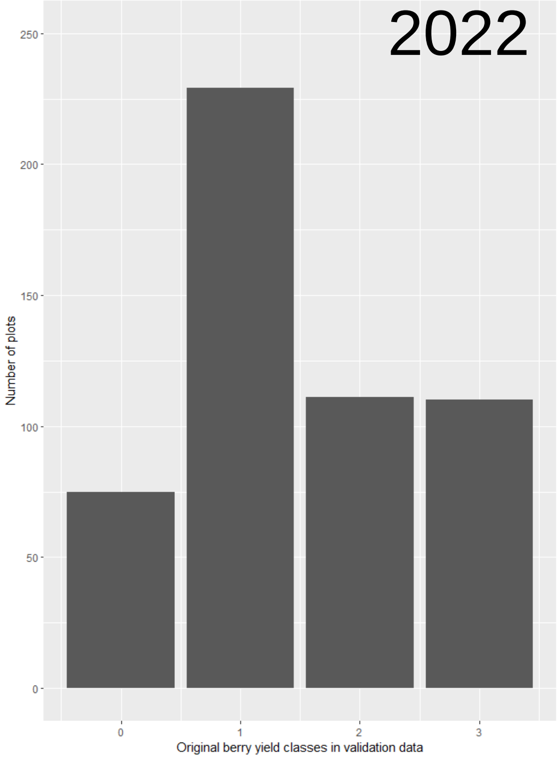
- **Development of an innovative application to identify areas with high berry yields, encouraging local picking, and demonstrating its effectiveness in real conditions**
- Test implementation by creating a system demonstrator called "Bär i bygden" (eng. Berries in the region) together with local stakeholders in the Bjurholm municipality
- Organisation of a social berry festival to promote local berry products and engage the community in the municipality of Bjurholm
- Conducting workshops with stakeholders from across the value chain to co-create ideas for testing and implementing the app tool and business model
- Contribution to the establishment of a Nordic research conference, an international food hack and a regional homepage dedicated to berries, fostering knowledge sharing and collaboration
- Contribution to the formation of two new organisations that will test new components of an intermediate value chain. These organisations will serve as a demonstration or proof-of-concept to validate the feasibility and effectiveness of the desired new intermediate value chain

Field data

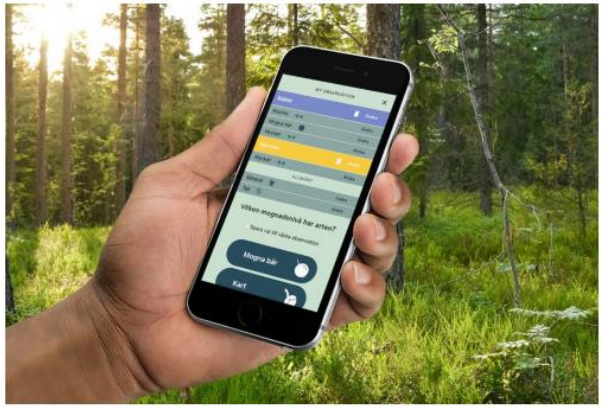
- Local forest landscape 25x45 km in Västerbotten, Sweden
- Training data: 503 plots in 2021
- Validation/calibration data: 525 plots in 2022
- Different forest types (density, height, tree species…)







- Potential for berry picking observed by four shrub cover and berry yield classes (all raw berries)
- Plots were placed inside the forest representing the berry potential of the surrounding forest
- Data collection and GPS positioning via specially developed phone-application



https://www.fairchain-h2020.eu/case-study-update-the-fairchain-project-is-looking-for-berries/

Counting raw berries in 1 m^2 square plot

	flower	raw	ripen
Bilberry little	0-90	0-50	0-30
Bilberry medium	91-170	51-100	31-60
Bilberry lot	Over 170	Over 101	Over 61

Berry yield classes

WALL-TO-WALL REMOTE SENSING DATA

- Sentinel 2 image from 2021 -> spectral metrics (new data source)
- National airborne laser scanning (ALS) data from 2020 -> structural forest and terrain metrics (1–2 pulse/m2)
- SLU-forest map of tree species (improved data source)
- National forest attribute map Site-index (new data source) and soil moisture map (improved data source)
- Land use classification map (based on satellite data)

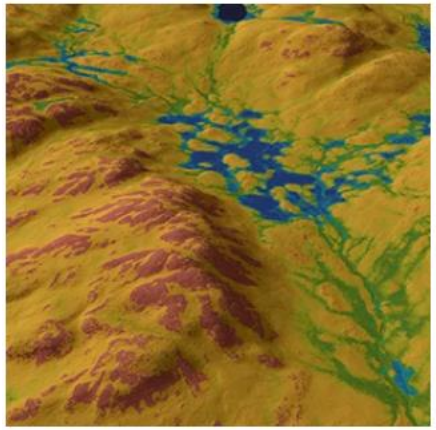
All metrics were extracted from the 10 m radius circular buffer around the field plots

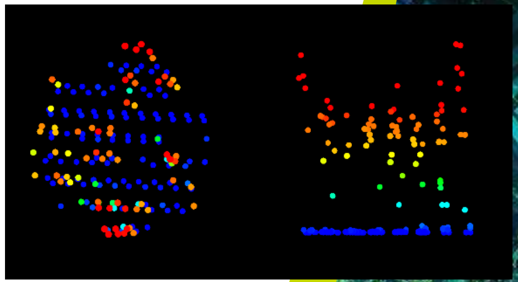
Skogliga grunddata

SKOGSSTYRELSEN

LANTMÄTERIET

SLU

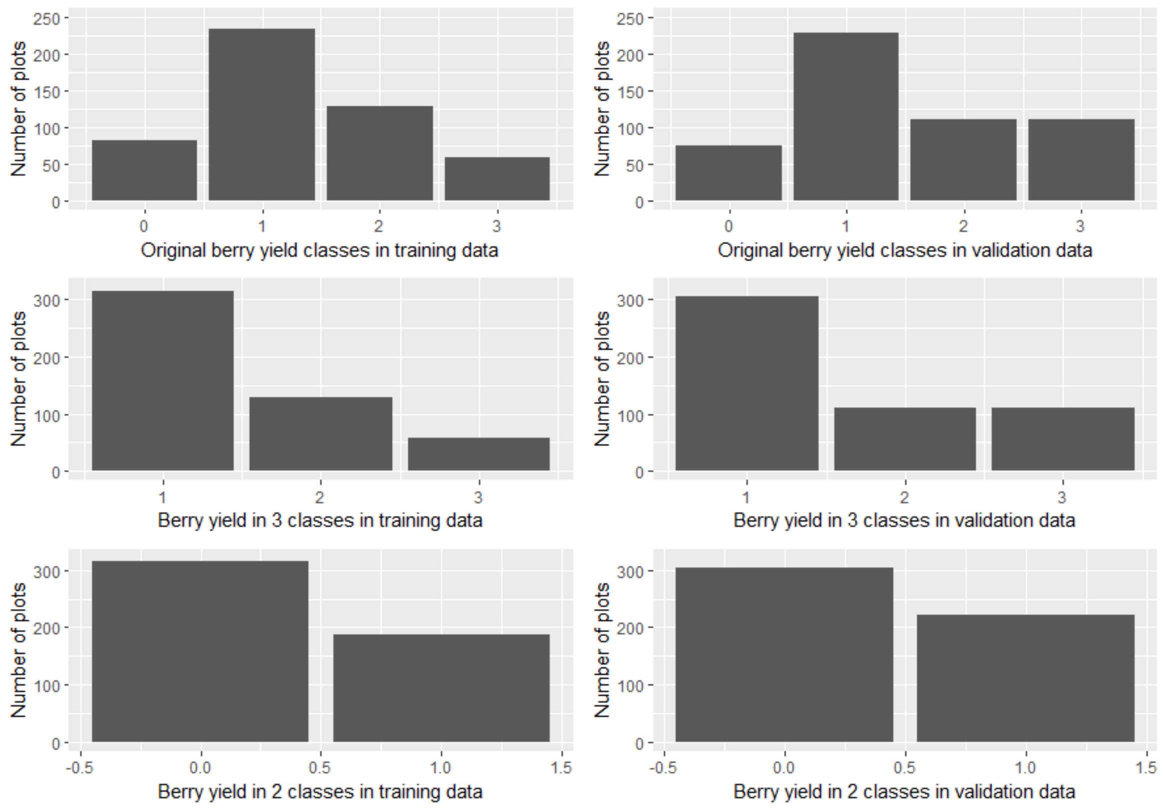




https://www.slu.se/en/departments/forest-ecology-management/forskning/soil-moisture-maps/about-soil-moisture-maps/

Modelling

- Modelling the relationship between remote sensing metrics (forest characteristics) and shrub cover and berry yield classes using 2021 data
- Logistic and ordinal regression model for bilberry shrub and yield classes (4,3 and 2 classes were tested)
- Model validation and annual calibration was done using 2022 data

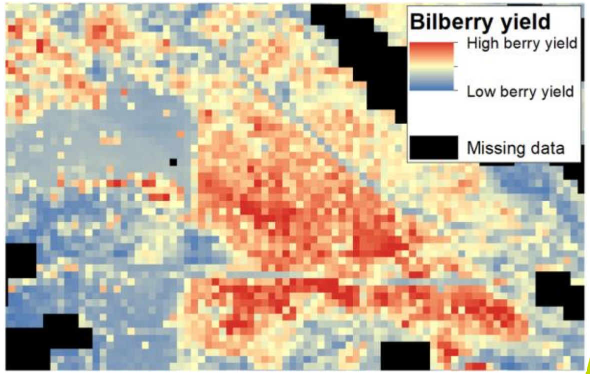


-4 classes: 0=no berry, 1= low berry, 2=medium berry amount and 3=high berry

-3 classes: 1= no or low berry, 2=medium berry amount and 3=high berry

-2 classes: 0=no or low berry/shrub cover and 1= medium or high berry/shrub cover

RESULT: best models from training data



	OA	KAPPA	AUC	Predictor variables
Yield 4 class	0.57	0.34	0.69	b3b4 + mean_gel + rootmean2_1ret_gel + PineVolume + Site_index_spruce + LandUse
Yield 3 class	0.71	0.41	0.75	b3b4 + L3_gel + PineVolume + b5b11 + Site_index_pine
Yield 2 class	0.78	0.51	0.75	Pine_volumeSM + b3b4 + L3_gel + p30_gel
Shrub 4 class	0.60	0.32	0.55	PineVolume + p30_gel + I((prop_gel_of_all_20)^2) + prop_gel_of_all_20
Shrub 3 class	0.70	0.35	0.59	p30_gel + prop_1ret_gel_of_1ret_20 + mean2_1ret_gel
Shrub 2 class	0.83	0.51	0.73	p30_gel + rootmean3_1ret_gel + b3b4 + soilmoisture

Wall-to-wall prediction with yellow models

Spectral metrics
Structural Laser metrics
Other raster metrics

For example:

L3_gel = skevness of laser point distribution

p30_gel = height of the laser points when
30 % of the laser points had been accumulated

B3/b3 = band3 divided by band4

PineVolume = volume of pine in Laser based
National forest attribute map

Site_index_pine = height of trees in this site
in age of 100 years (based on bitemporal laserdata)

Results

Model	A. Training, 2021			B. Validation, 2022			C. Annual calibration, 2022		
	OA	kappa	AUC	OA	kappa	AUC	OA	kappa	AUC
Yield 2 class	0.78	0.51	0.75	0.70 (0.74)	0.40 (0.46)	0.70 (0.73)	0.71	0.40	0.70
Shrub 2 class	0.83	0.51	0.73	0.68 (0.68)	0.23 (0.24)	0.60 (0.61)	0.71	0.36	0.67

Prediction accuracies (overall accuracy, kappa and AUC values) of the best classification models A) in 2021 training data, B) in 2022 validation data, C) in 2022 data using annual calibration -> **moderate accuracies**

Values in round brackets () show the plot level accuracies based on raster cells in wall-to-wall prediction

Annual calibration (2022) only slightly improved the prediction in validation data

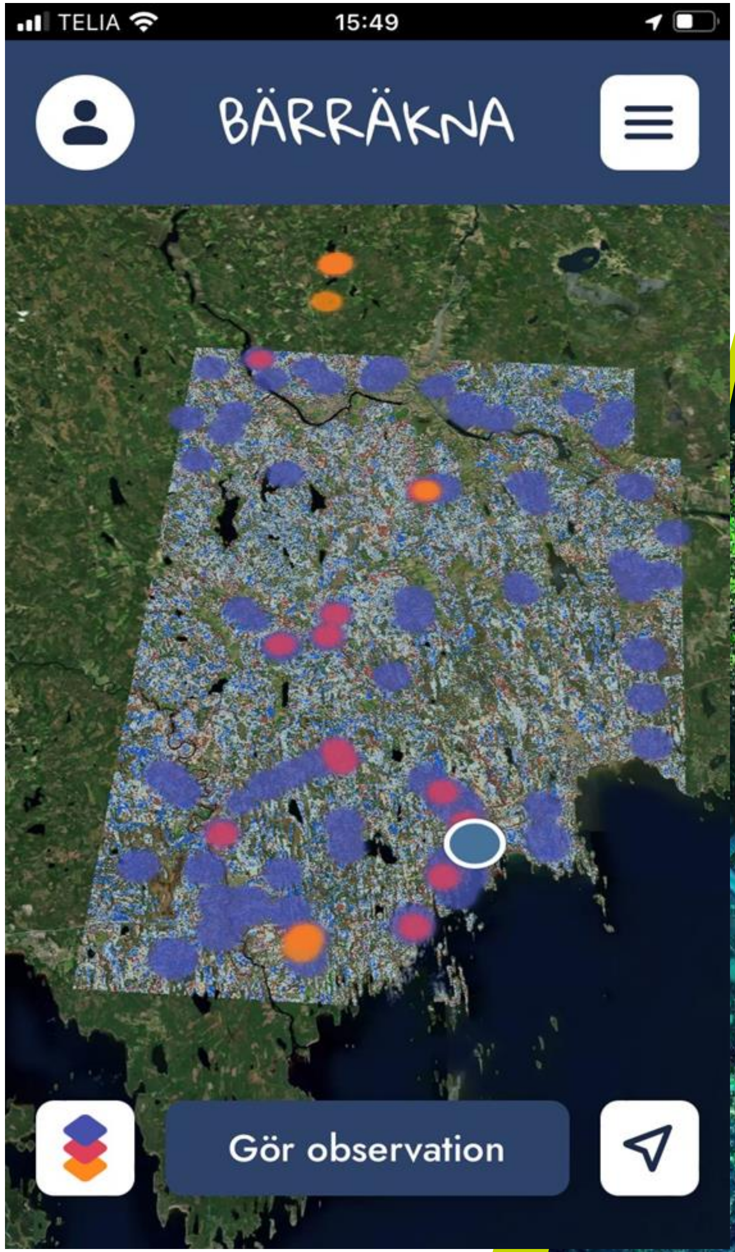
Discussion

Practical method for locating potential berry locations was demonstrated
-> berry pickers can easier find the berries
-> development of the local berry value chain

- Still, prediction of berry yields complicated (weather, picking/eating, local spatial variation) but possible
- Still, best results with combination of different kind of predictor variables, new variables
- More years would be needed to see if the annual variation in berry yields in local area can be measured with remote sensing! (maybe weather and local stage of plant physiology has higher impact?)
- To receive higher prediction accuracies would demand more accurate information on the spatial and temporal variation of berry yields, e.g. annual weather data

Future recommendations

- Calibration of the model after each season or new observation (inventory or berry pickers) -> improved general model
- Wall-to-wall predictions with annually calibrated data improved by weather data?
- Collect practical experience of the usefulness of the map and phone-application



Field measured berry locations and the best model for potential locations for bilberry picking was demonstrated in dedicated phone application

Case 3 forest planning

First shrub cover models to heureka!

- **Bohlin: bilberry and cowberry (permanent NFI plots 2011-2016)**

  Bilberry -> $R2 = 0.41$ and 0.57
  - **Pine dominated**: Vegetation type, temperature sum, soil moisture, basal area, stand age, site index class, time since thinning
  - **Spruce dominated:** Vegetation type class, temperature sum, basal area, stand age, site index class, time since thinning

  Cowberry -> $R2 = 0.42$
  - Vegetation type, temperature sum, basal area, basal area for pine, stand age, site index, time since thinning and time since clearcut

- **Hedvall: bilberry, cowberry and heather**
  - Shrub cover 10 years before
  - Ratio of carbon and nitrogen in top-soil
  - Age, basal area and proportion of basal area of spruce and deciduos trees

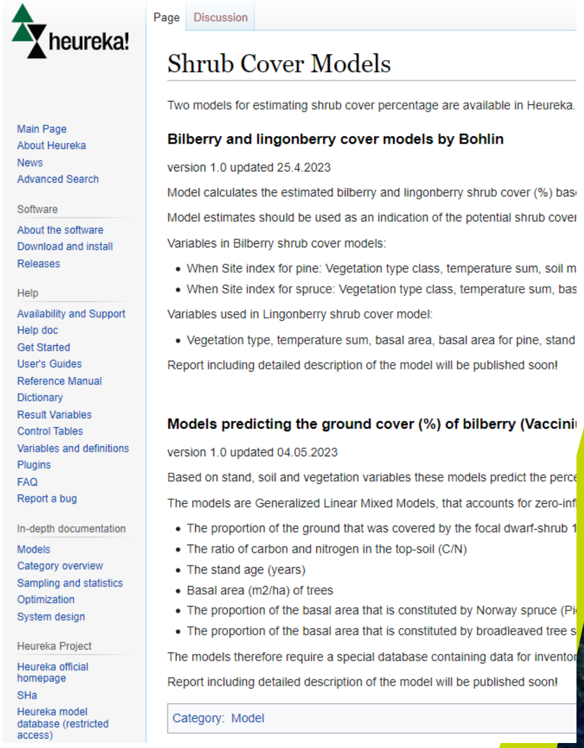
$$\text{General Model (Equation 1)} = -3.903858 - 0.000825\left(\frac{T^2}{1000}\right) + \sum_{i=1}^{16} a_i F_i + \sum_{j=1}^{3} b_j M_j + 0.013928A - 0.090987\left(\frac{A^2}{100}\right) + 0.023883B - 0.090987\left(\frac{B^2}{100}\right) + \sum_{k=1}^{7} c_k S_k + \sum_{l=1}^{2} d_l T_l \quad (1)$$

$$\text{Norway Spruce Model} = 100\times\left(1+\exp\left(-1\times\left(\text{Model (Equation 1)} + 0.5\times\left(0.1382452^2 + 0.5141306^2\right)\right)\right)\right)^{-} \quad (2)$$

$$\text{Scots Pine Model} = 100\times\left(1+\exp\left(-1\times\left(\text{Model (Equation 1)} + 0.5\times\left(0.06597713^2 + 0.4079041^2\right)\right)\right)\right)^{-1} \quad (3)$$

Where:

Variable	Explanation
T	Temperature sum (°C)
F1 - F16	Field Layer Vegetation
M1, M2, M3	Soil Moisture (Class 1-3)
A	Stand Age (Years)
B	Basal Area (m^2/ha)
S1 - S7	Site Index Classes
T1, T2	Time Since Thinning (Years)


heureka!

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Shrub Cover Models

Two models for estimating shrub cover percentage are available in Heureka.

Bilberry and lingonberry cover models by Bohlin

version 1.0 updated 25.4.2023

Model calculates the estimated bilberry and lingonberry shrub cover (%) bas

Model estimates should be used as an indication of the potential shrub cover

Variables in Bilberry shrub cover models:

- When Site index for pine: Vegetation type class, temperature sum, soil m
- When Site index for spruce: Vegetation type class, temperature sum, bas

Variables used in Lingonberry shrub cover model:

- Vegetation type, temperature sum, basal area, basal area for pine, stand

Report including detailed description of the model will be published soon!

Models predicting the ground cover (%) of bilberry (Vaccini

version 1.0 updated 04.05.2023

Based on stand, soil and vegetation variables these models predict the perc

The models are Generalized Linear Mixed Models, that accounts for zero-inf

- The proportion of the ground that was covered by the focal dwarf-shrub 1
- The ratio of carbon and nitrogen in the top-soil (C/N)
- The stand age (years)
- Basal area (m2/ha) of trees
- The proportion of the basal area that is constituted by Norway spruce (Pi
- The proportion of the basal area that is constituted by broadleaved tree s

The models therefore require a special database containing data for inventor

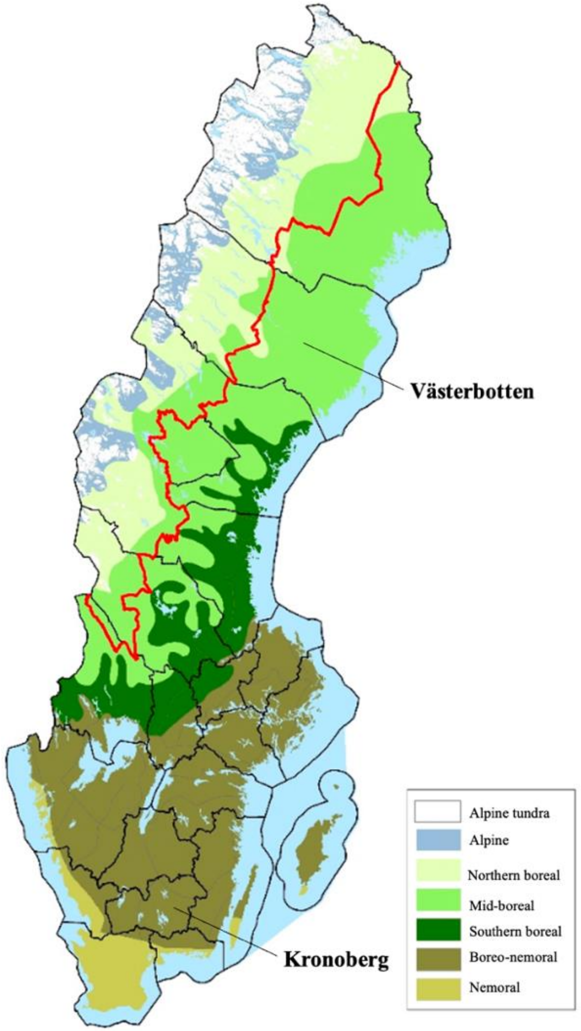
Report including detailed description of the model will be published soon!

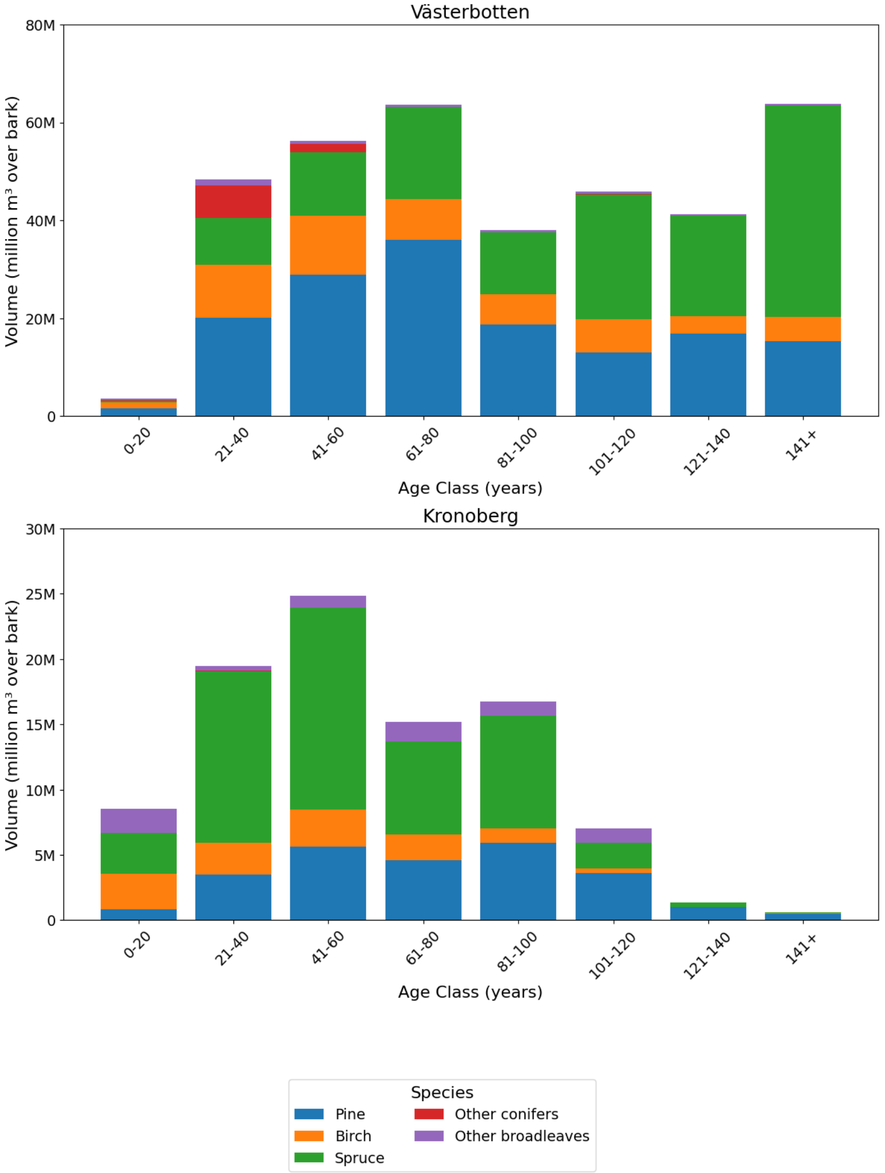
Category: Model

Master thesis: Bilberry cover and its relationship to silvicultural strategies by Jens Bergenheim, SLU

- The interplay between silvicultural strategies and bilberry (Vaccinium myrtillus) cover in Sweden's boreal forests
- 2017-2018 NFI data from Västerbotten and Kronoberg counties
- Heureka decission suppport system
- Testing of different management strategies and their effects on bilberry cover and forest economic outputs (trade-off when maximizing net present value (NPV) and bilberry cover)

Tree Species Volume per Age Class





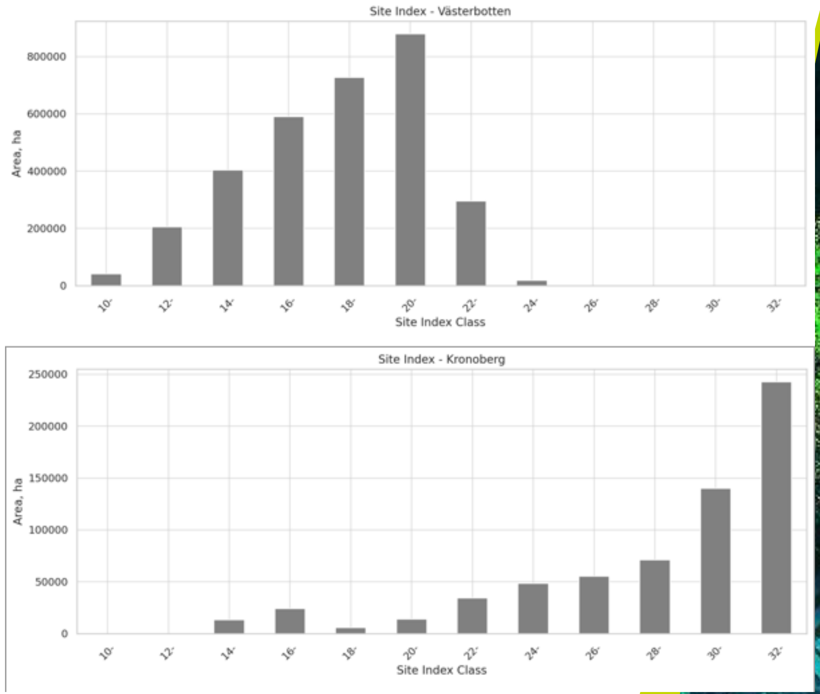
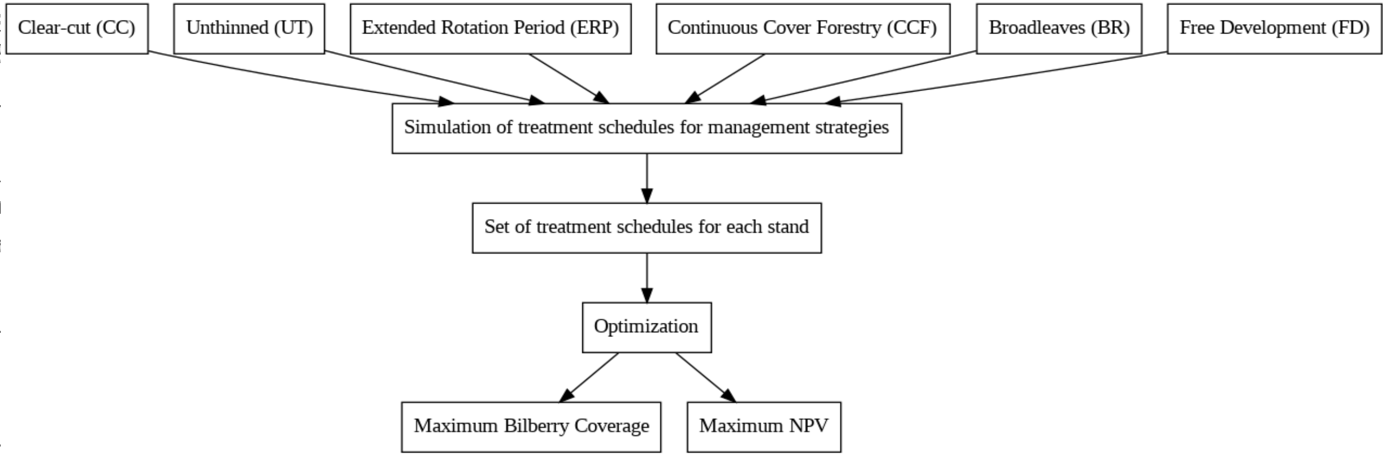


Table 2: Management strategies

Management practices	CC	CCF	ERP	UT	BR	FD
Regeneration method	Planting	Natural	Spruce; planting Pine; natural, seed trees retained	Planting	Spruce:planting Pine; natural	-
Soil scarification	Yes	-	Yes	Ye		
Broadleaf after cleaning	20%	-	20%	20		
Broadleaf after thinning	20%	50%	20%	-		
Delay in final felling after minimal felling age	Max 30 years	-	35-60 years	Ma yea		
Number of single retention trees per ha	10	10	20	10		
Number of high stumps per ha	3	-	6	3	6	-

Optimization of NPV and bilberry cover

- optimal combination of treatments during 100 year



CC=clear cut

CCF= contineus cover forestry

ERP=extended rotation lenght

UT= unthinned

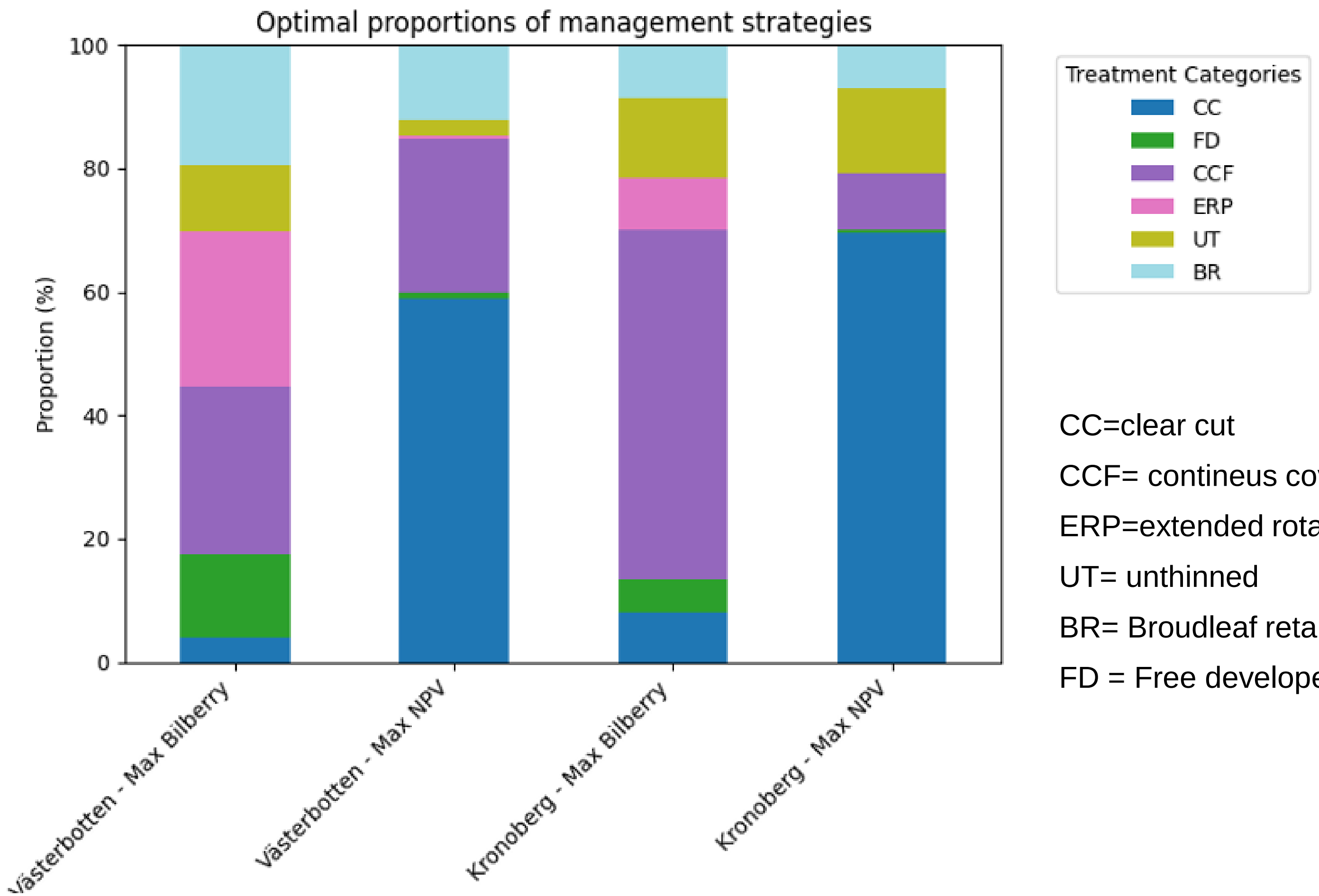
BR= Broudleaf retantion

FD = Free developent

Table 1: Indicators and their definitions studied in the simulations.

Indicator	Definition	Unit
NPV per ha	Net Present Value per hectare	SEK/ha
Mean Age	The average age of trees in a stand	years
Average Final Felling Age	The average age at which trees are harvested in final felling	years
Bilberry Cover	The ground area covered by bilberry plants	% cover
Total m3 under bark Volume	Total cubic meters of wood under bark volume harvested	m3 under bark
Basal Area	The sum of all cross-sectional areas of tree trunks at breast height (1.3 m)	m2/ha

Some results: combination of strategies



CC=clear cut

CCF= contineus cover forestry

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FD = Free developent

- **The best solution, regardless of goal, always includes different management strategies**
- **Maximum net present value – more aligned to current practices and CC**
- **Maximum bilberry – more diverse proportion off strategies**
- **Large differences between counties**
- **ERP strong alternative for Västerbotten, no change in CCF**
- **Kronoberg CCF dominates, increased ERP**

Development of bilberry cover when maximising bilberry or NPV

Västerbotten from 24 % increase to 17 % decrease

Kronoberg from 42% increase To 32% decrease

CC=clear cut

CCF= contineus cover forestry

ERP=extended rotation lenght

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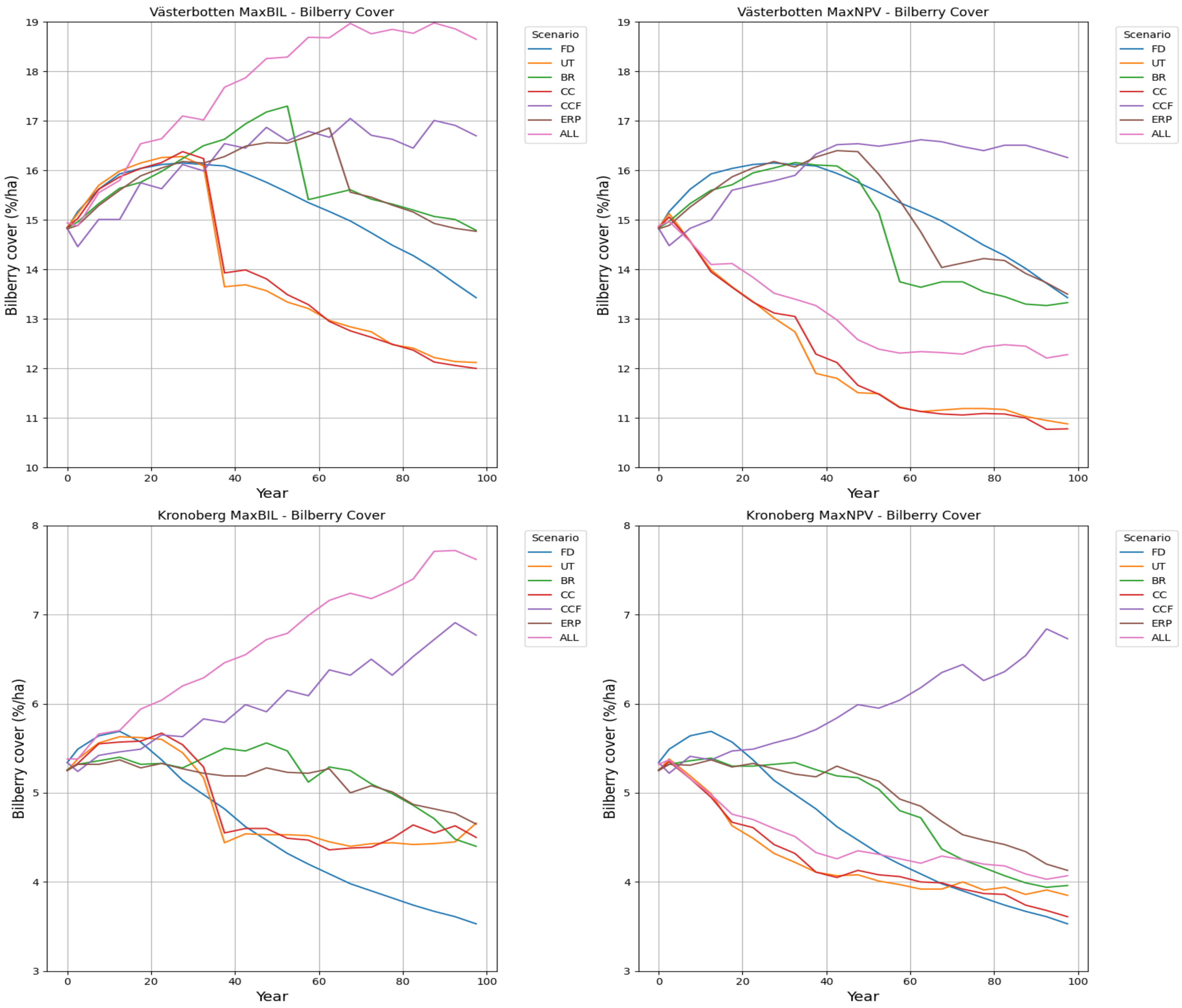

Future research interest

- Improving berry yield mapping and modelling with better remote sensing data and new modelling methods
- Including annual data like weather into models (annual calibrated models)
- Adding and improving berry yield models to forest planning system
- Trade-off between different forest management goals including berry yields
- Better utilization of berry yield data from Swedish NFI

Thank you for your attention

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