SMARTForest

Semantic segmentation of forest stands using deep learning

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Forest stands - Definition

*A **forest stand** is a cohesive community of trees with **sufficient consistency** in attributes **to distinguish it from adjacent communities**. These attributes include species composition, structure, age, size class distribution, stocking level, spatial arrangement reflecting **historical and local silvicultural practices**, and site characteristics such as topography and site index (Baker, 1950; Husch et al., 1993; Smith, 1986).*

- Relatively homogenous area suited for a specific management regime.
- Stands serves as the fundamental units in inventory, for forest management, and financial analysis.
- Usually covers a minimum area; *typically, 0.2 ha according to Norwegian practices.*

Stand delineation

- Historically, stands were delineated using stereoscopic viewing of physical aerial images.
- Today, the process remains manual but now involves manual interpreting digital images, often with additional information from airborne laser scanning (ALS) to aid decision-making.
- Manually delineating stands is a time-consuming affair…
- Stand delineation is highly subjective:
  - Not all boundaries exist as distinct, crisp boundaries in the landscape.
  - Different interpreters may produce different results when evaluating the same area
  - The same interpreter can produce different results for the same area on different occasions

Efforts towards automation

Three different approaches in published research:

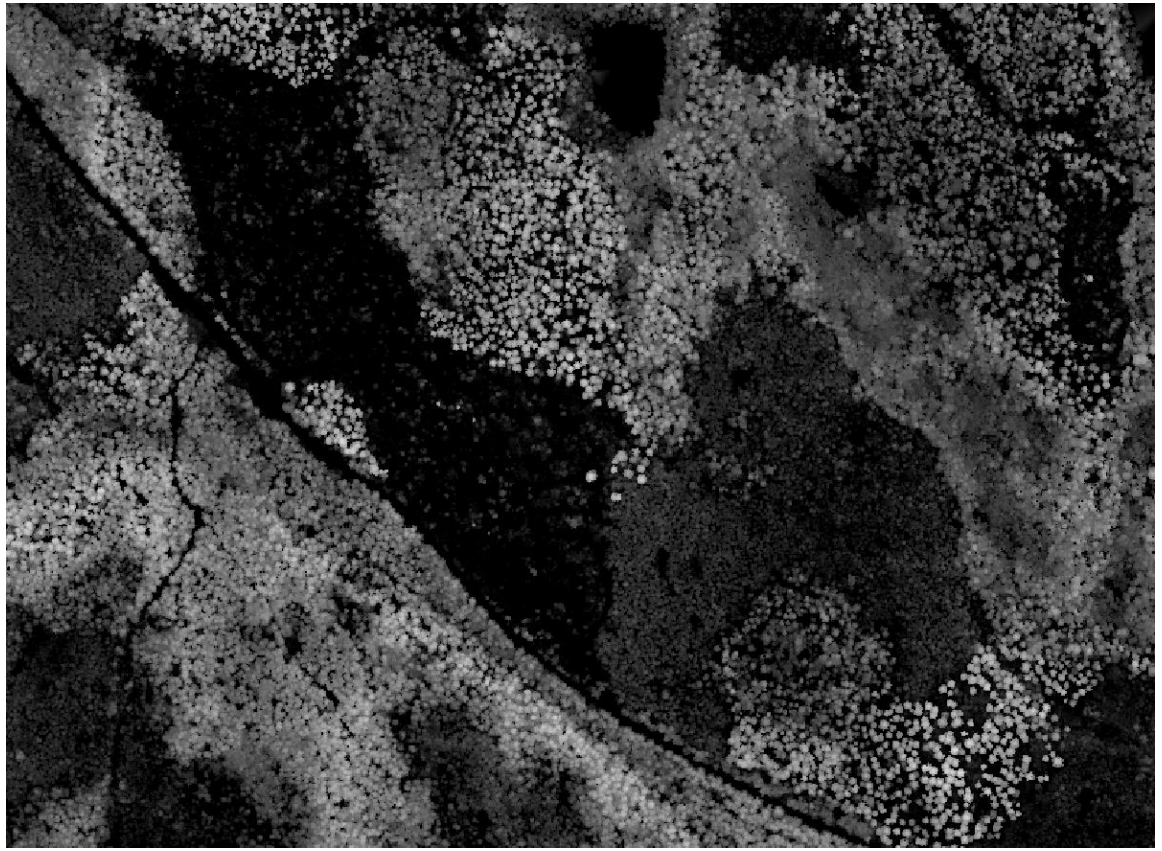
- Aerial images

Efforts towards automation

Three different approaches in published research:

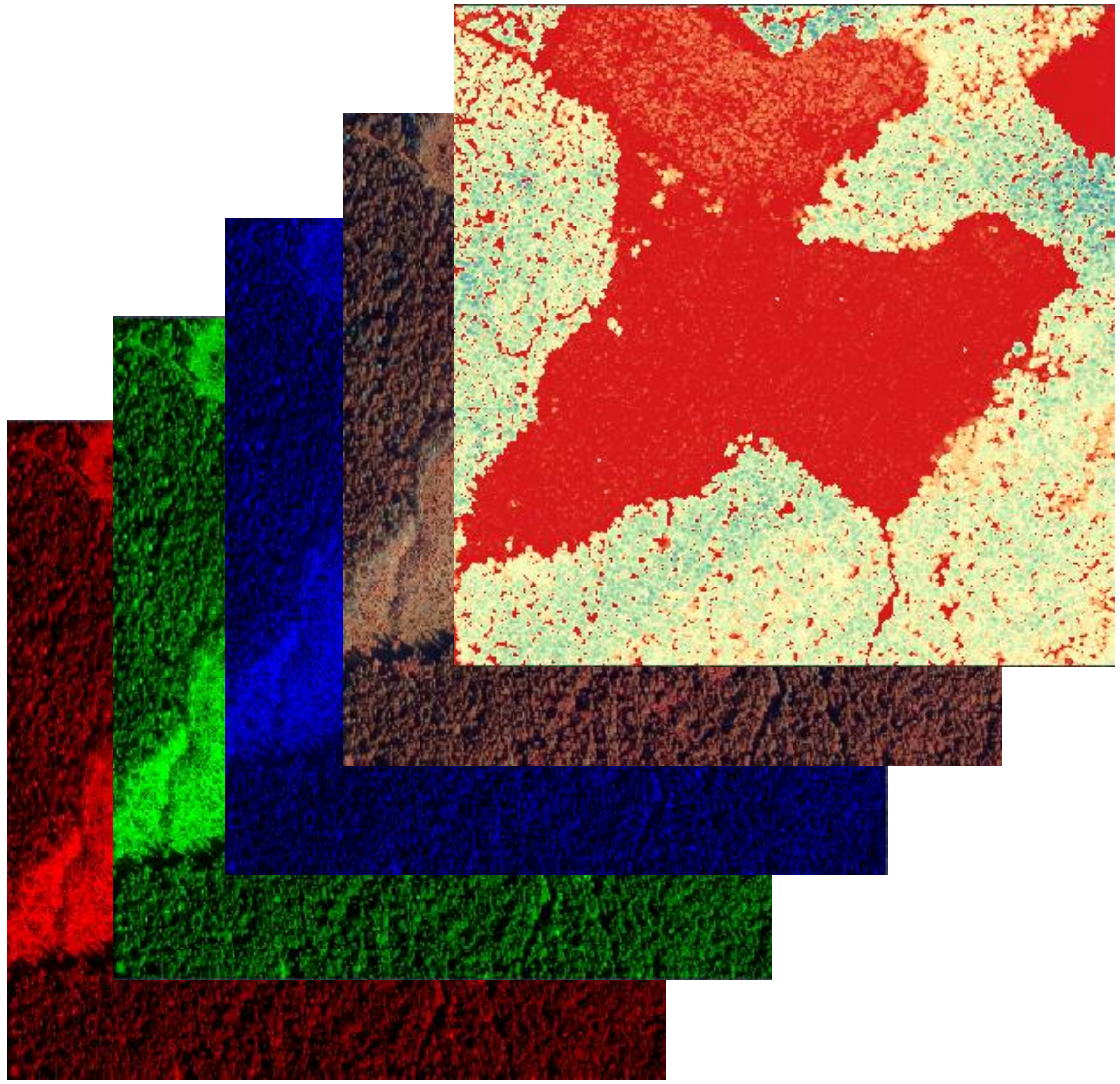
- Aerial images
- Canopy height model (CHM)
- Aerial image + CHM

Most studies focus on region growing algorithms



Input data

- RGBI + CHM
- 1×1 m resolution
- 8-bit radiometric resolution



Reference data

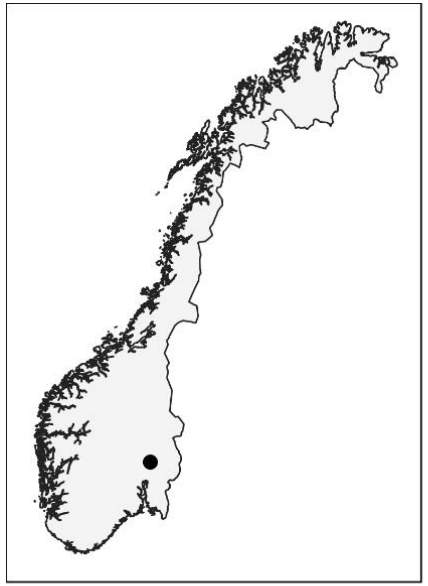
An existing stand map serves as the reference to which the model can learn from

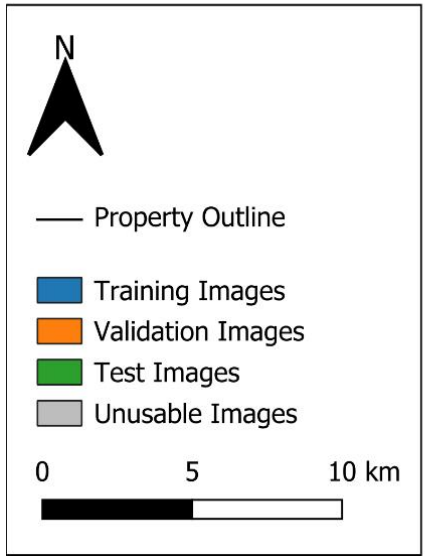
Class	Management
Non-forest (NF)	-
I - II	Regeneration/Pre-comercial thinning
III	Thinning
IV	Thinning
V	Harvest

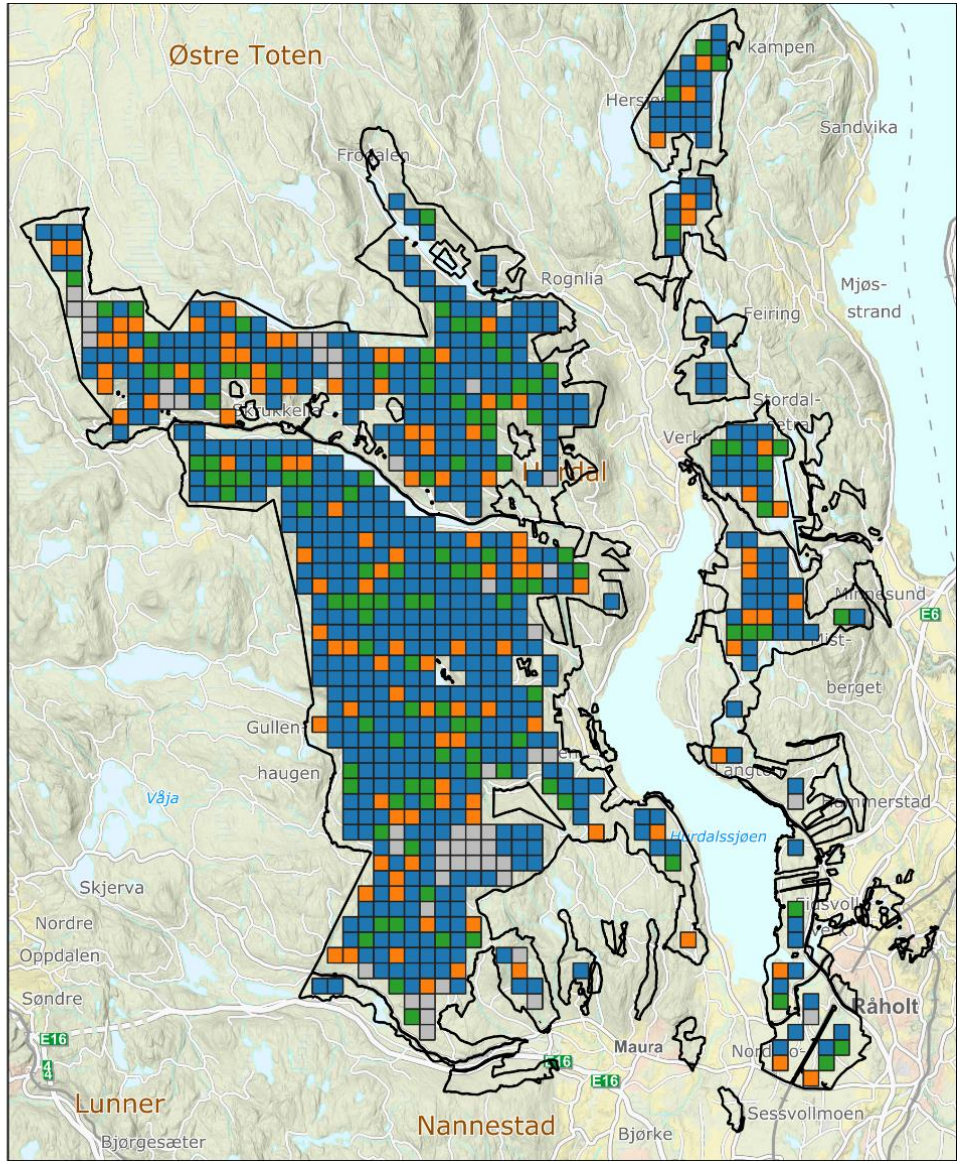
Study area

- Actively managed forest
- Low variability and good stand structure
- Relatively simple conditions for stand delineation

Stand map (2021)
ALS (2021)
Aerial images (2022)







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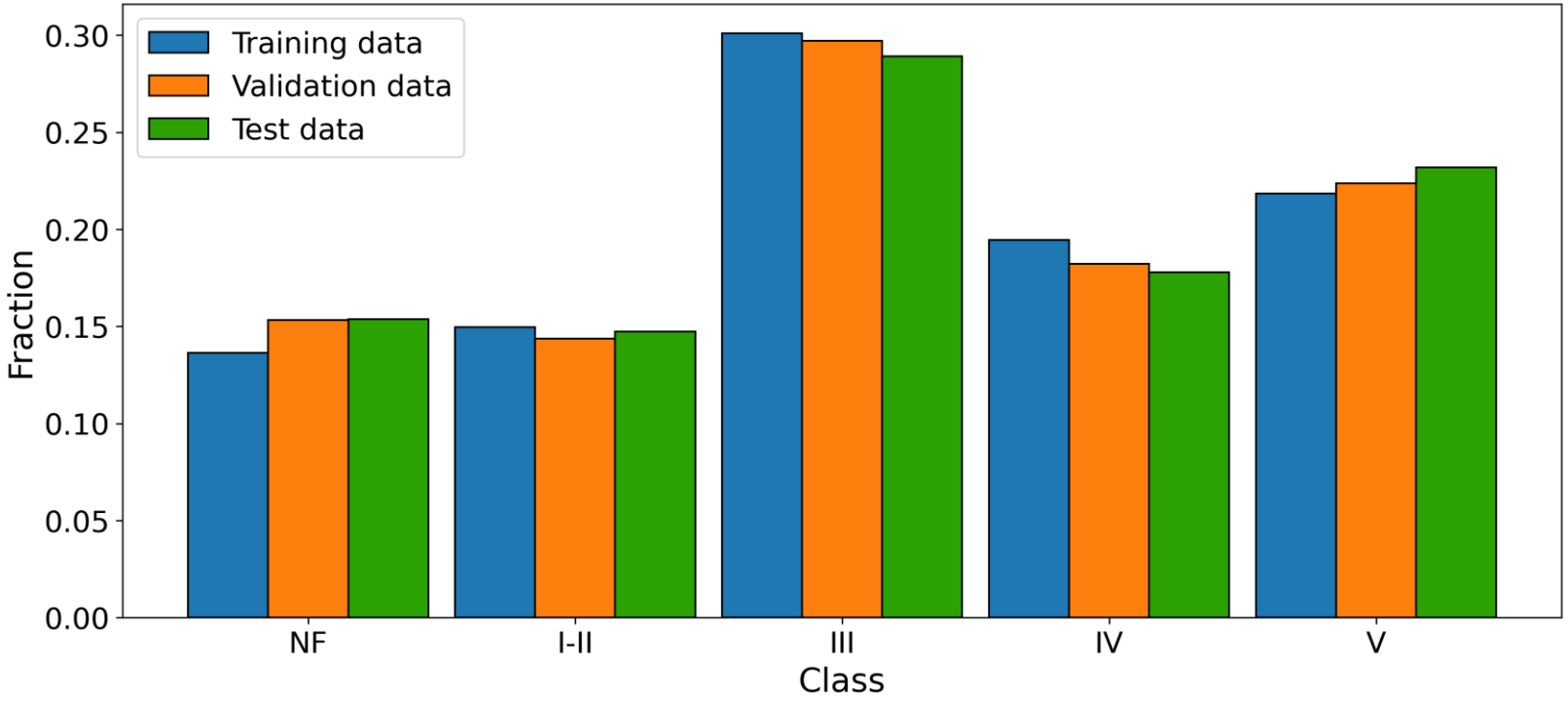
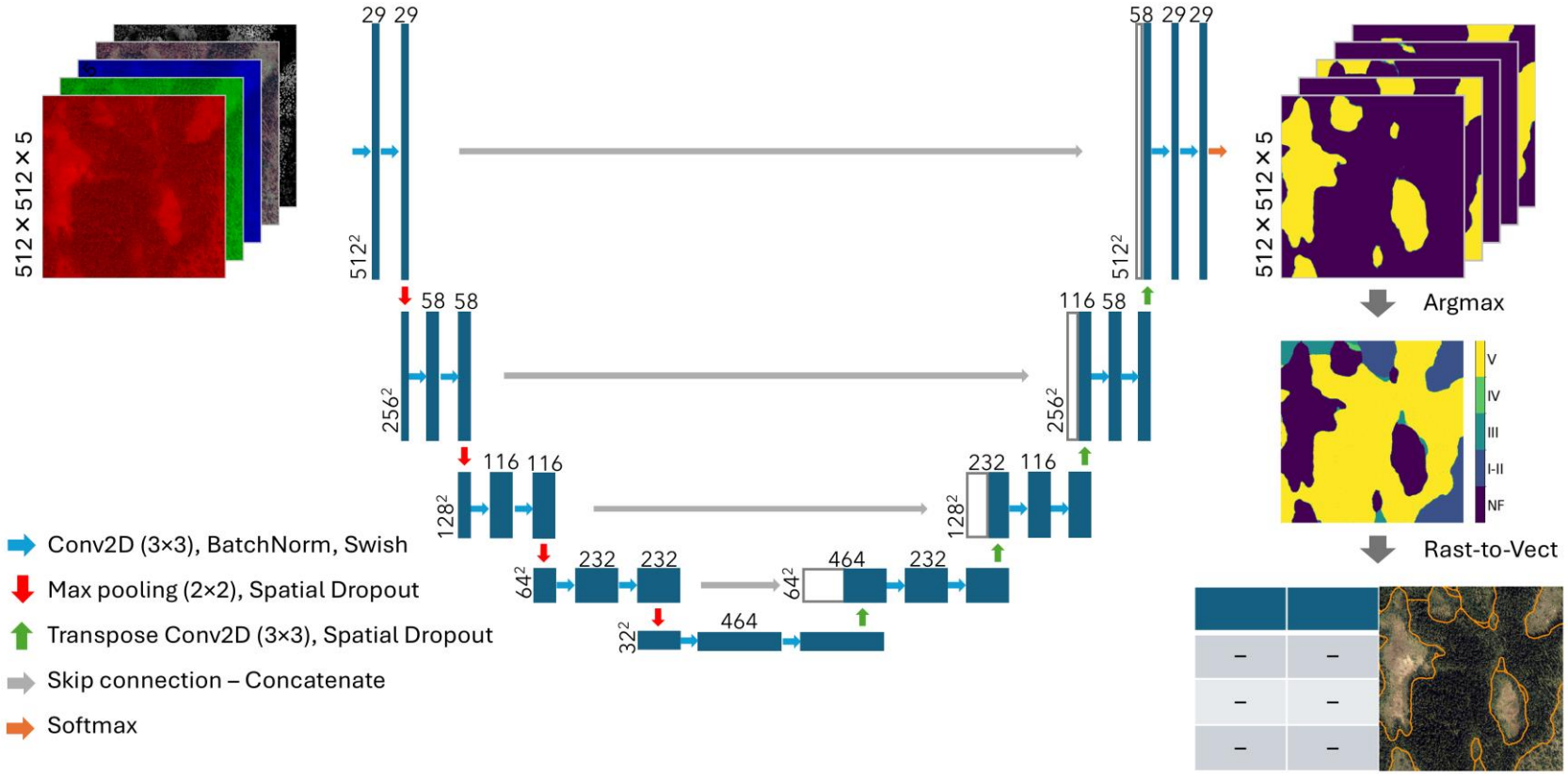
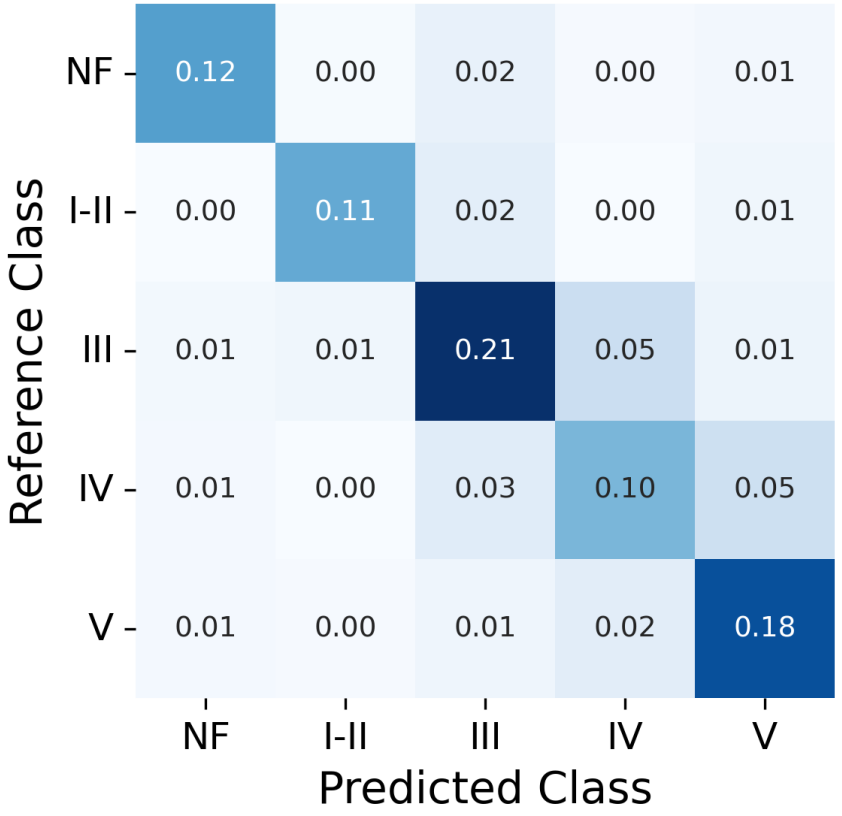

Training data
Validation data
Test data
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Fraction
NF
I-II
III
IV
V
Class

Model


512 × 512 × 5
29 29
512²
58 58
256²
116 116
128²
232 232
64²
464
32²
58 29 29
116 58
232 116
Argmax
V
IV
III
I-II
NF
Rast-to-Vect
Conv2D (3×3), BatchNorm, Swish
Max pooling (2×2), Spatial Dropout
Transpose Conv2D (3×3), Spatial Dropout
Skip connection – Concatenate
Softmax

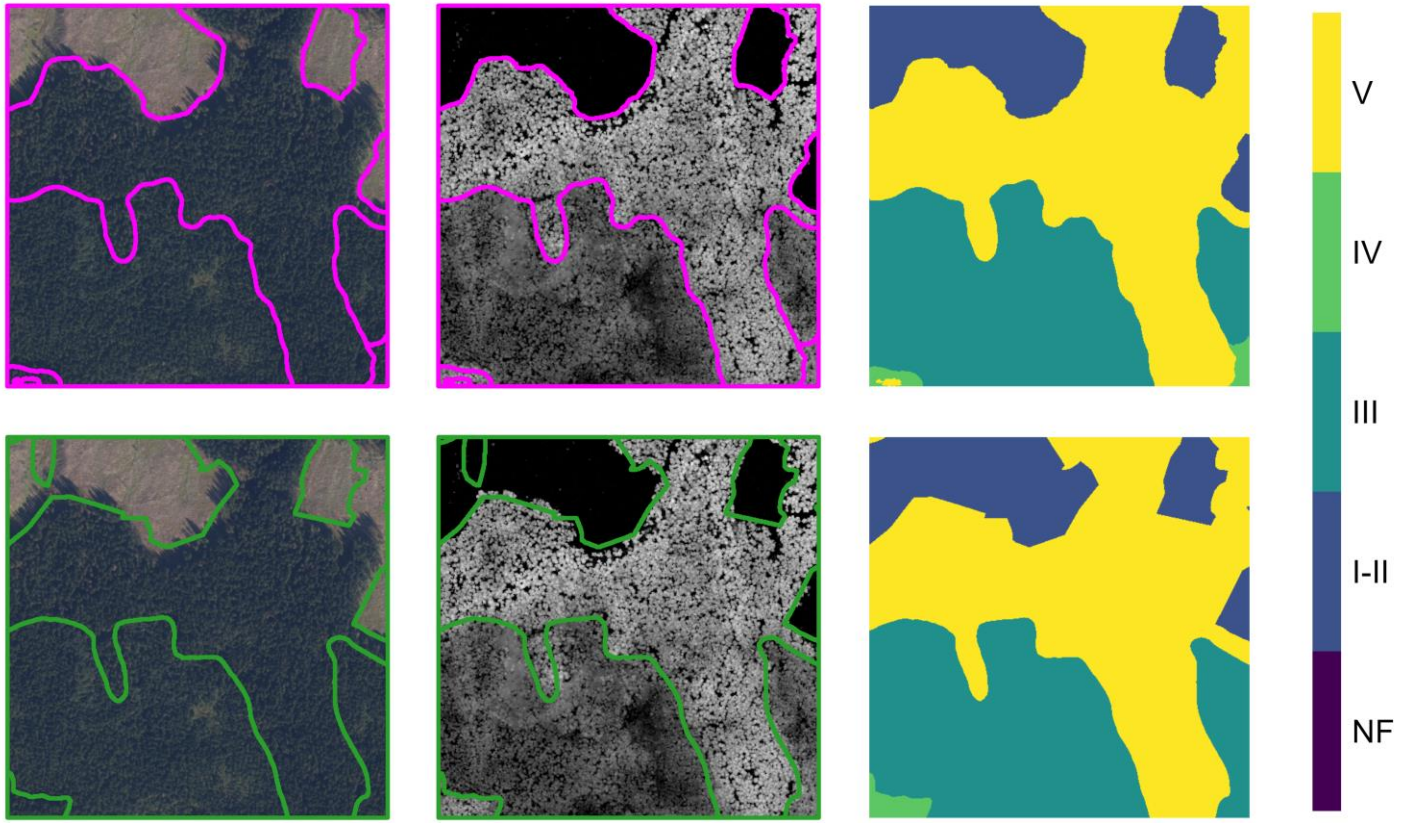
Results


Reference Class
NF
I-II
III
IV
V
0.12 0.00 0.02 0.00 0.01
0.00 0.11 0.02 0.00 0.01
0.01 0.01 0.21 0.05 0.01
0.01 0.00 0.03 0.10 0.05
0.01 0.00 0.01 0.02 0.18
NF
I-II
III
IV
V
Predicted Class

Results

Modell

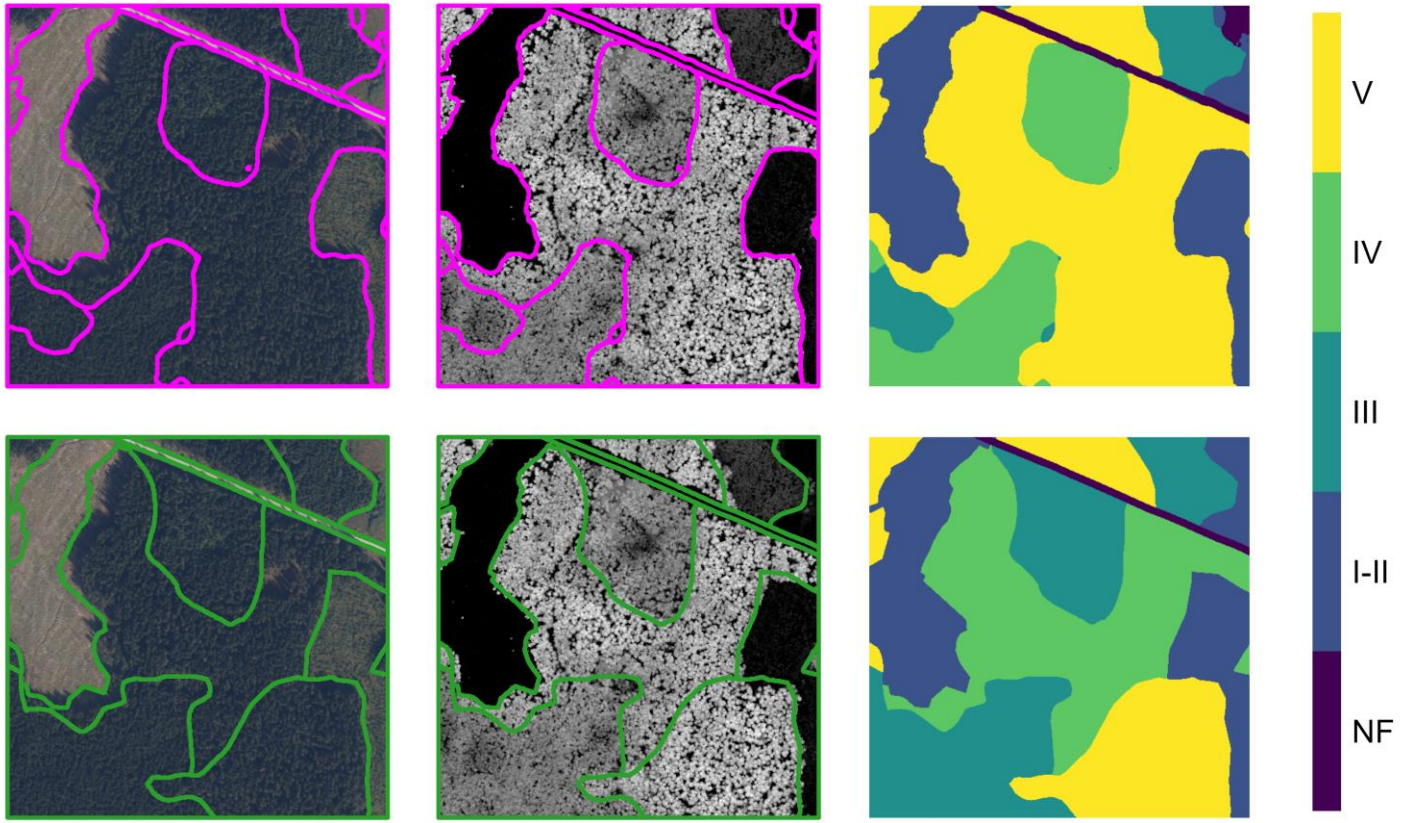
Reference



Results

Modell

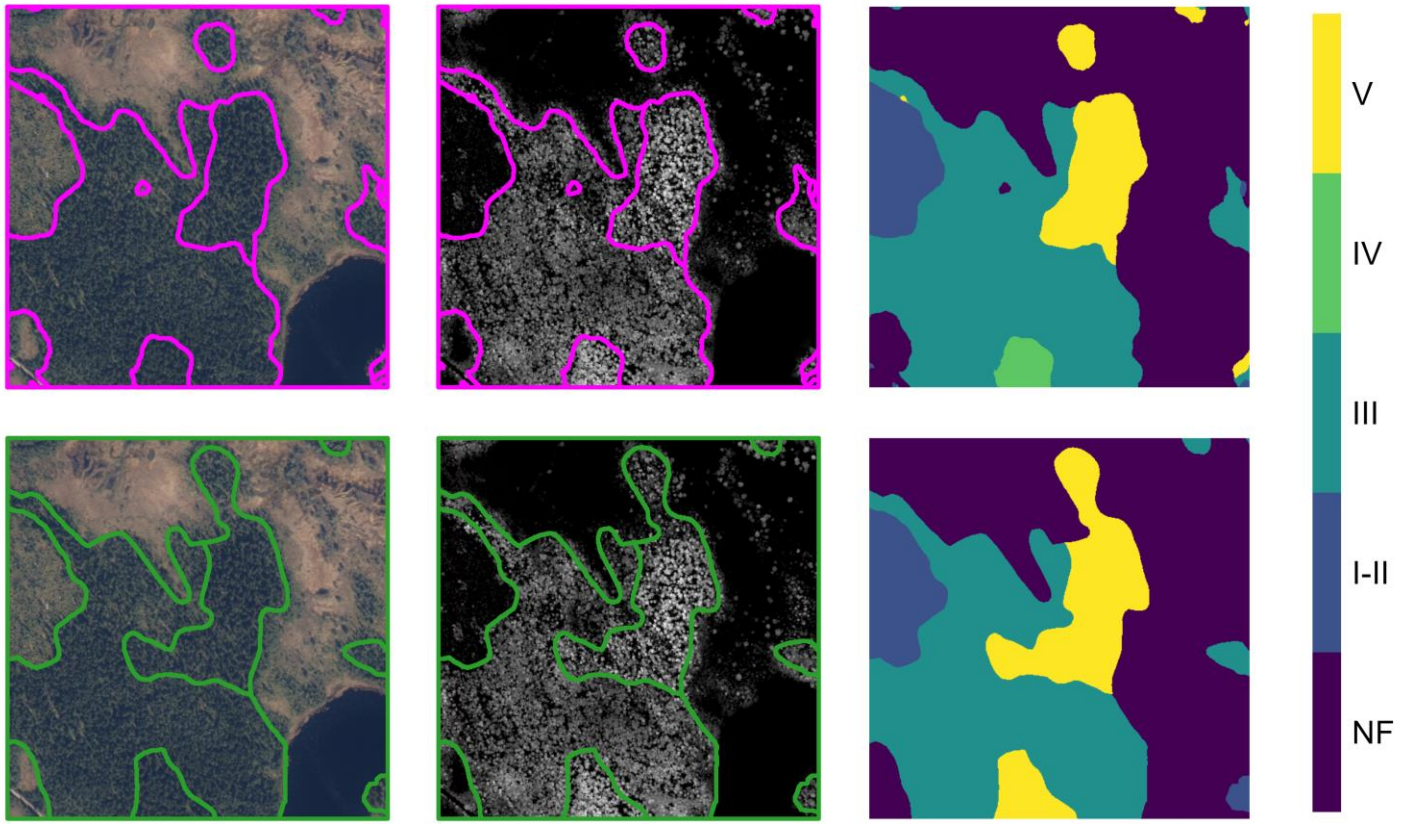
Reference



Results

Modell

Reference



Conclusion

- The study successfully demonstrated a proof of concept with promising initial results.
- The dataset should be expanded to include more diverse and realistic forest conditions.
- Temporal differences between the data acquisitions introduced limitations – alternative data sources should be explored.
- It is likely that key information is missing, enriching the input with additional data sources should be explored.

References

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https://arxiv.org/abs/2504.02471

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