# Modelling annual basal area increment of Scots pine stands using tree ring cores and multisource remote sensing data

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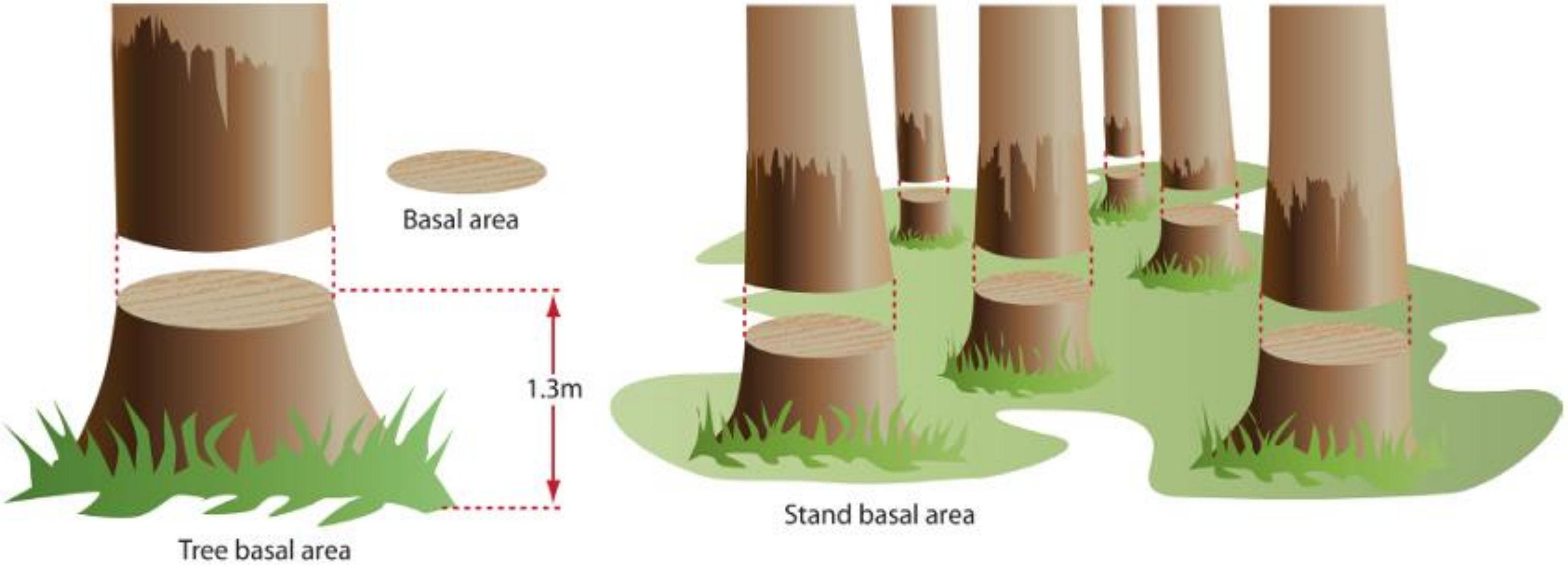
# Motivation

- importance of basal area (BA) for forest management and wildlife
- previous studies used limited data
- identification of features that can be derived from RS data and used for stand-level predicion of BAI
- identification of stands that may suffer growth inhibition during drought conditions

# Basal area

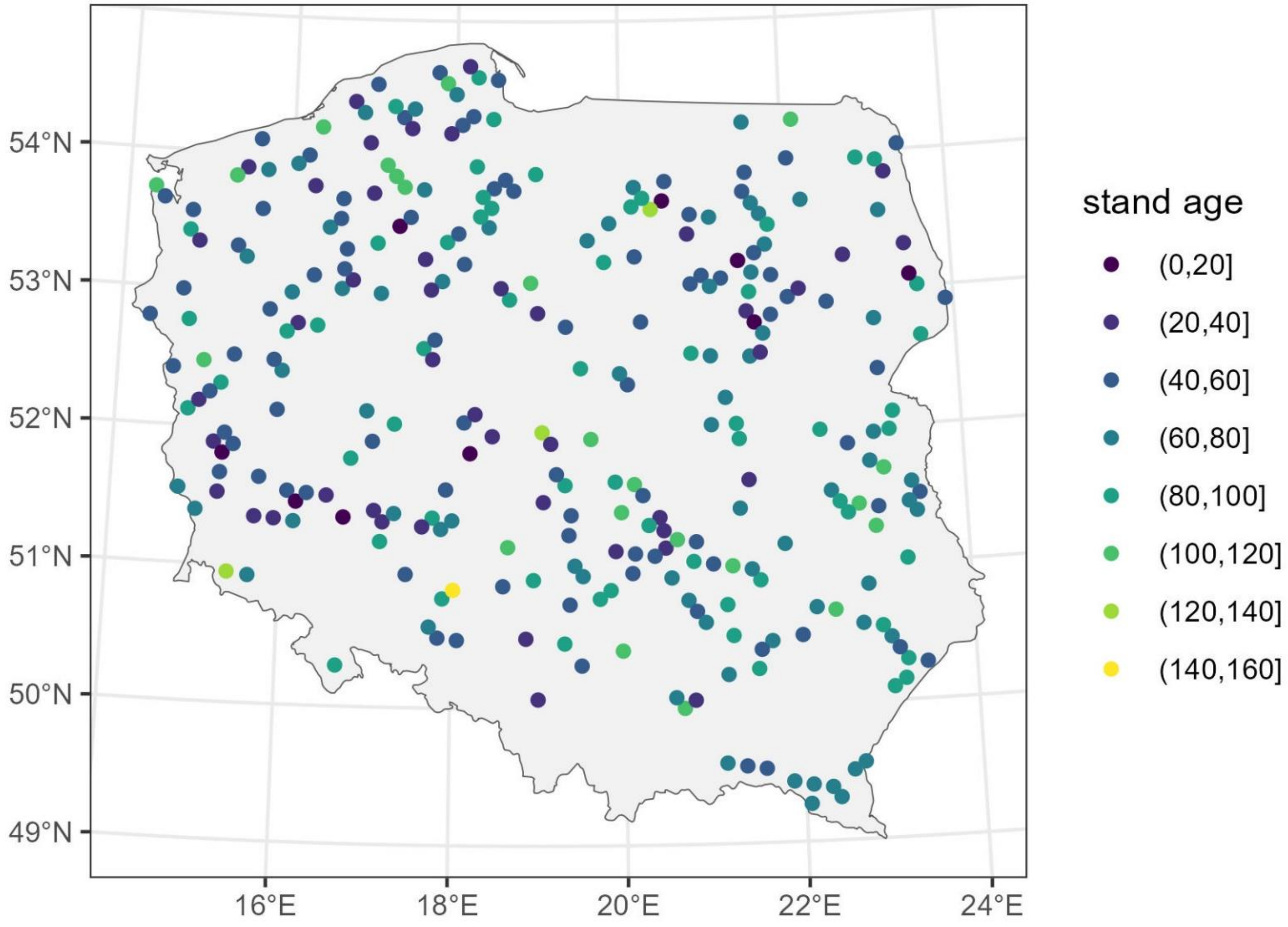
- describes the average amount of an area occupied by tree stems
- defined as the total cross-sectional area of all stems in a stand measured at breast height (1.3 m), and expressed as per unit of land area ($m^2$/ha)
- it is usually calculated for stand based on measurements of DBH made for single trees at sample plots




Source of graphic: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/pnf/130035standbasalarea.pdf

# Study area

- Scots pine stands
- stratification based on age and site classes
- 300 circular plots
- varying plot size (0.01 – 0.3 ha)



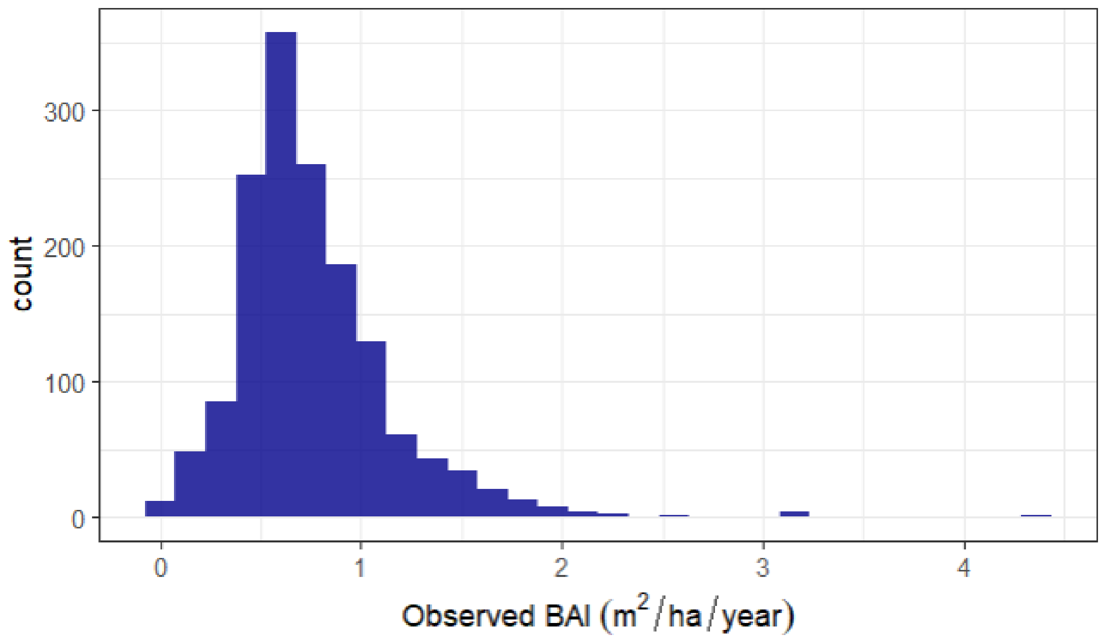

Data collected under the project: „Models of stand volume increment for main forest forming tree species in Poland" financed by State Forests – National Forest Holding in Poland

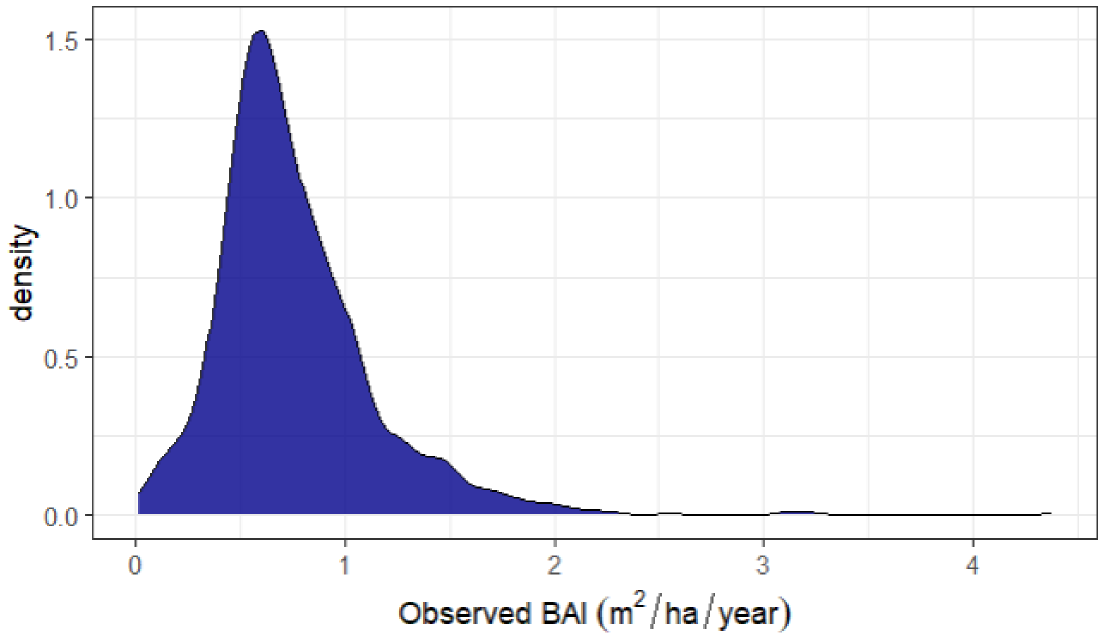
# Field data collection

- field campaign 2022/2023
- minimum 30 trees per plot
- DBH
- height
- crown lenght
- species
- distance and azimuth
- minimum 10 years of annual tree ring width (TRW)
- TRW data collected from 9 665 trees

# Calculation of annual BAI

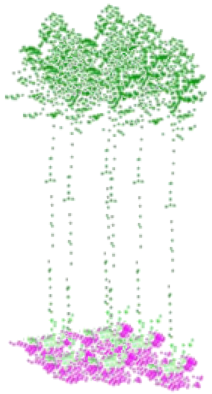
- DBH of each tree updated based on TRW
- bark correction factor (1.115)
- annual basal area for each tree
- annual BA for plot
- BAI as difference of plot BA from subsequent years



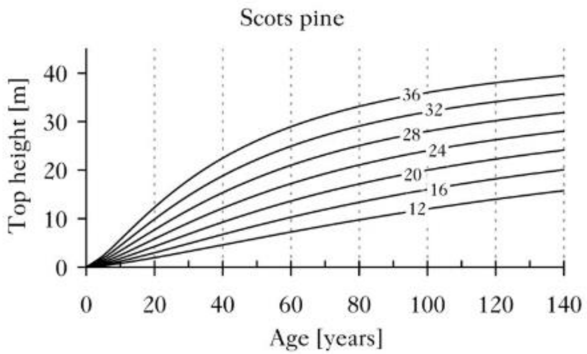
# Datasources for explanatory variables

- airborne laser scaning (ALS)
- Sentinel-2 satellite images
- MODIS  (Moderate Resolution Imaging Spectroradiometer)
- TerraClimate



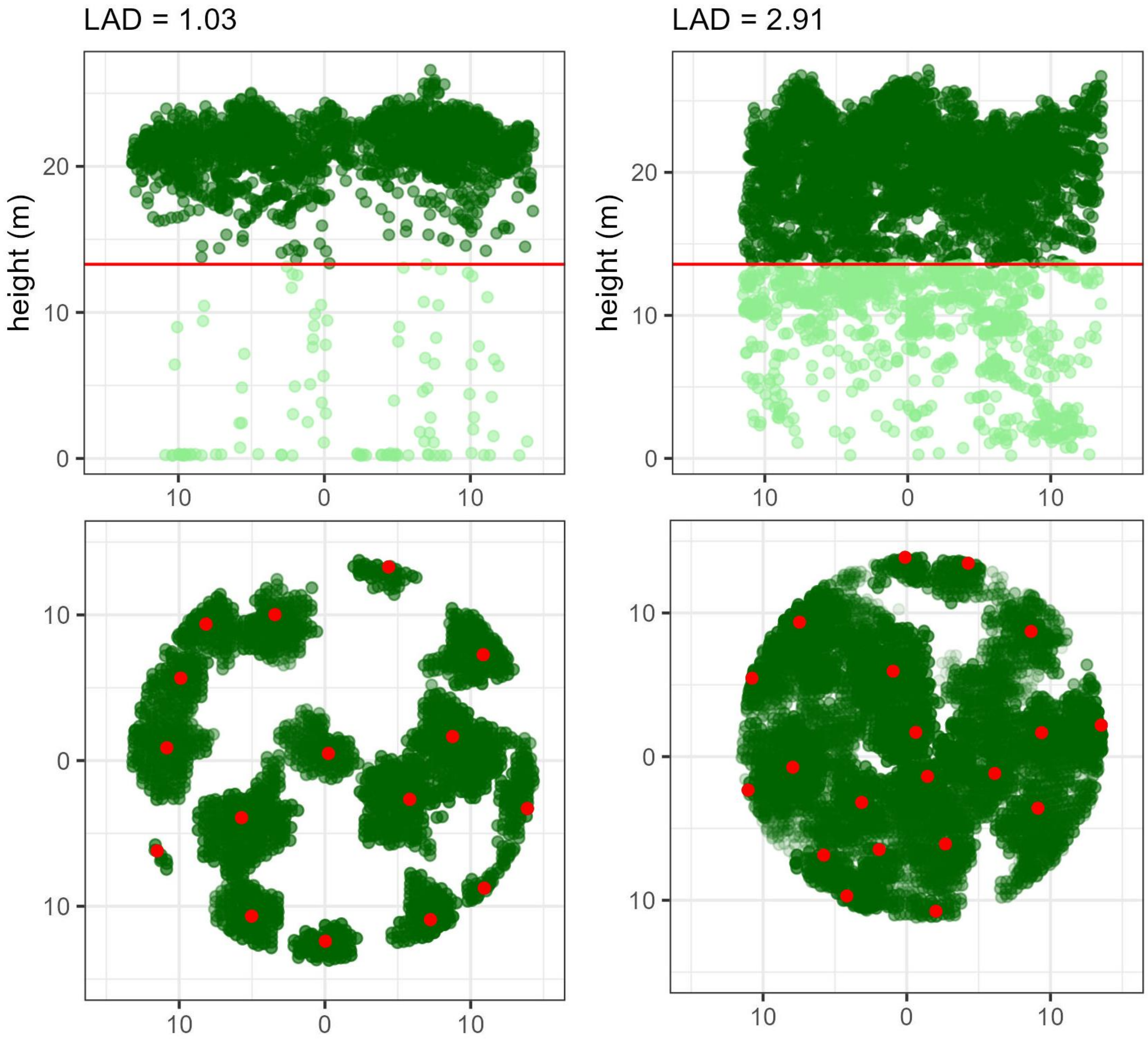
# ALS

- lidR package for R
- mean height of ttops
- leaf area density (LAD)
- top height
- site index $H_2 = H_1 \frac{T_2^{b_1}(T_1^{b_1} \cdot R + b_2)}{T_1^{b_1}(T_2^{b_1} \cdot R + b_2)}$

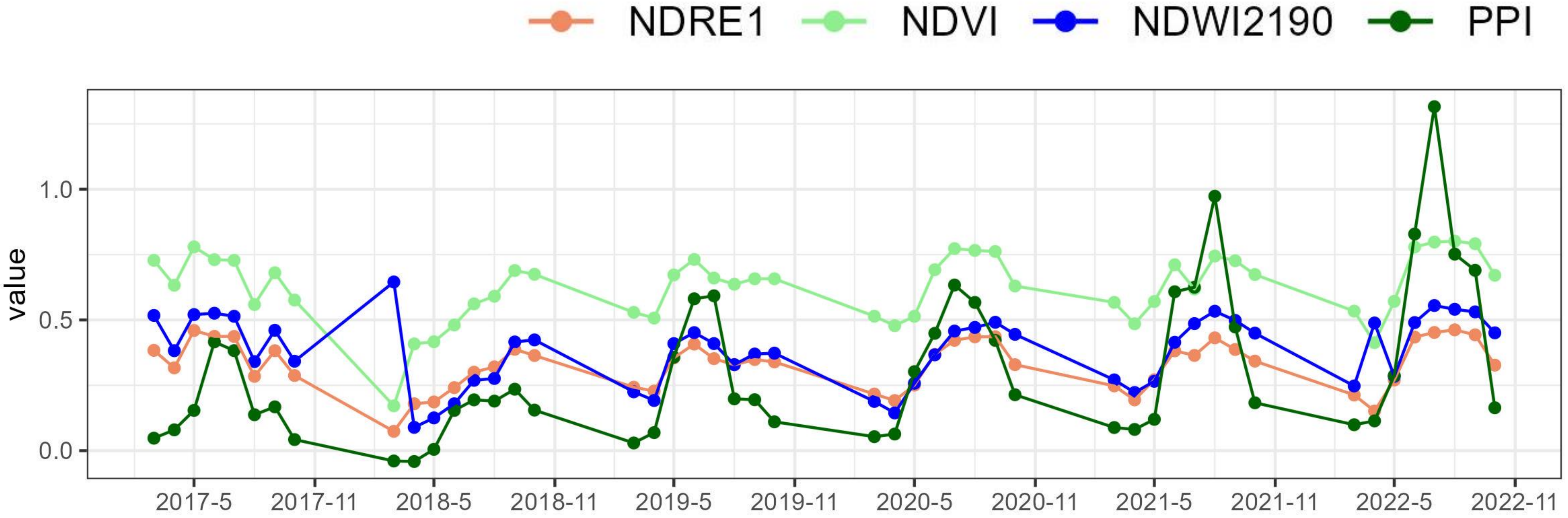



- relative spacing index (RSI)

$$RSI = \frac{AS}{TH} \times 100 = \frac{10^4 \times \sqrt{\frac{2}{N \times \sqrt{3}}}}{TH}$$



# Sentinel-2

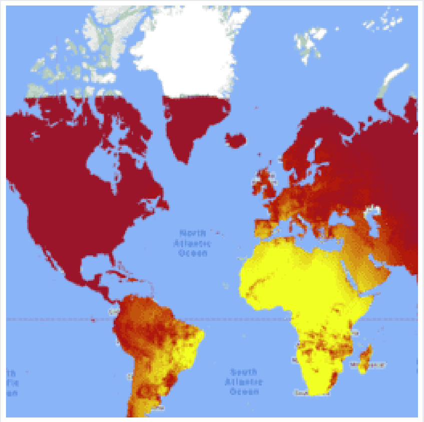



- Google Earth Engine
- mean montlhy values form all available cloud-free pixels
- vegetation indices based on different wavelengths

# MODIS

Earth Engine Data Catalog

## MCD18C2.061 Photosynthetically Active Radiation Daily 3-Hour



**Dataset Availability**

2002-02-24T00:00:00Z–2024-04-01T00:00:00Z

**Dataset Provider**

NASA LP DAAC at the USGS EROS Center

**Earth Engine Snippet**

```
ee.ImageCollection("MODIS/061/MCD18C2")
```

**Tags**

par radiation

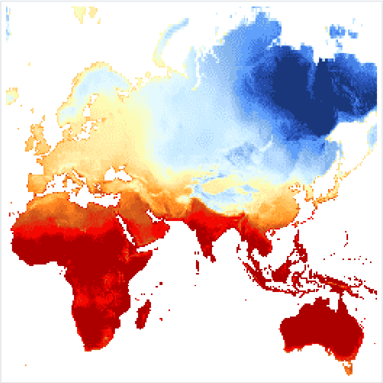
Description | Bands | Terms of Use | Citations | DOIs

**Resolution**
500 meters

- mean values per day
- averaged for months

# TerraClimate

Earth Engine Data Catalog



**Dataset Availability**

1958-01-01T00:00:00Z–2023-12-01T00:00:00Z

**Dataset Provider**

University of California Merced

**Earth Engine Snippet**

`ee.ImageCollection("IDAHO_EPSCOR/TERRACLI`

**Tags**

**Resolution**

4638.3 meters

**Bands**

| Name | Units | Min | Max | Scale | Description |
|---|---|---|---|---|---|
| aet | mm | 0* | 3140* | 0.1 | Actual evapotranspiration, derived using a one-dimensional soil water balance model |
| def | mm | 0* | 4548* | 0.1 | Climate water deficit, derived using a one-dimensional soil water balance model |
| pdsi | | -4317* | 3418* | 0.01 | Palmer Drought Severity Index |
| pet | mm | 0* | 4548* | 0.1 | Reference evapotranspiration (ASCE Penman-Montieth) |
| pr | mm | 0* | 7245* | | Precipitation accumulation |
| ro | mm | 0* | 12560* | | Runoff, derived using a one-dimensional soil water balance model |
| soil | mm | 0* | 8882* | 0.1 | Soil moisture, derived using a one-dimensional soil water balance model |
| srad | W/m^2 | 0* | 5477* | 0.1 | Downward surface shortwave radiation |
| swe | mm | 0* | 32767* | | Snow water equivalent, derived using a one-dimensional soil water balance model |
| tmmn | °C | -770* | 387* | 0.1 | Minimum temperature |
| tmmx | °C | -670* | 576* | 0.1 | Maximum temperature |
| vap | kPa | 0* | 14749* | 0.001 | Vapor pressure |
| vpd | kPa | 0* | 1113* | 0.01 | Vapor pressure deficit |
| vs | m/s | 0* | 2923* | 0.01 | Wind-speed at 10m |

* estimated min or max value

# Generalized Additive Models (GAM)

$$y = \beta_0 + f_1(x_1) + f_2(x_2) + \cdots + f_p(x_p) + \epsilon$$

- 80/20 train vs. test proportion of sample plots
- training on years 2017-2020
- validation on years 2021-2022
- four models: stand, ALS, climate, spectral (spectral = full model)

# Results – selected predictors

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
```

| Group | Term | edf | Ref.df | F | p-value | |
|---|---|---|---|---|---|---|
| stand | s(BA) | 6.048229 | 9 | 92.229 | < 2e-16 | *** |
| stand | s(age) | 5.782944 | 9 | 6.600 | < 2e-16 | *** |
| ALS | s(rsi) | 2.580188 | 3 | 14.862 | < 2e-16 | *** |
| ALS | s(lad) | 0.638997 | 9 | 0.197 | 0.089223 | . |
| ALS | s(SI) | 1.675895 | 9 | 0.908 | 0.002695 | ** |
| climate | s(pdsi_10) | 0.893444 | 9 | 0.186 | 0.071284 | . |
| climate | s(tmmx_3) | 1.963607 | 9 | 1.309 | 0.000266 | *** |
| climate | s(pr_4,pr_6,pr_10) | 5.175798 | 109 | 0.140 | 0.001200 | ** |
| climate | s(PAR_4,PAR_9) | 0.000263 | 29 | 0.000 | 0.394512 | |
| spectral | s(NDVI_4,NDVI_6,NDVI_8) | 12.373157 | 109 | 0.393 | < 2e-16 | *** |
| spectral | s(NDWI1610_4,NDWI1610_6,NDWI1610_8) | 4.375990 | 109 | 0.114 | 0.001040 | ** |
| spectral | s(PPI_4,PPI_9) | 6.936955 | 29 | 0.587 | 0.002698 | ** |
| spectral | s(NDRE_4,NDRE_9) | 6.353330 | 29 | 0.602 | 0.000393 | *** |

```
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.768   Deviance explained = 78.2%
-REML = -165.53  Scale est. = 0.034848  n = 916
```
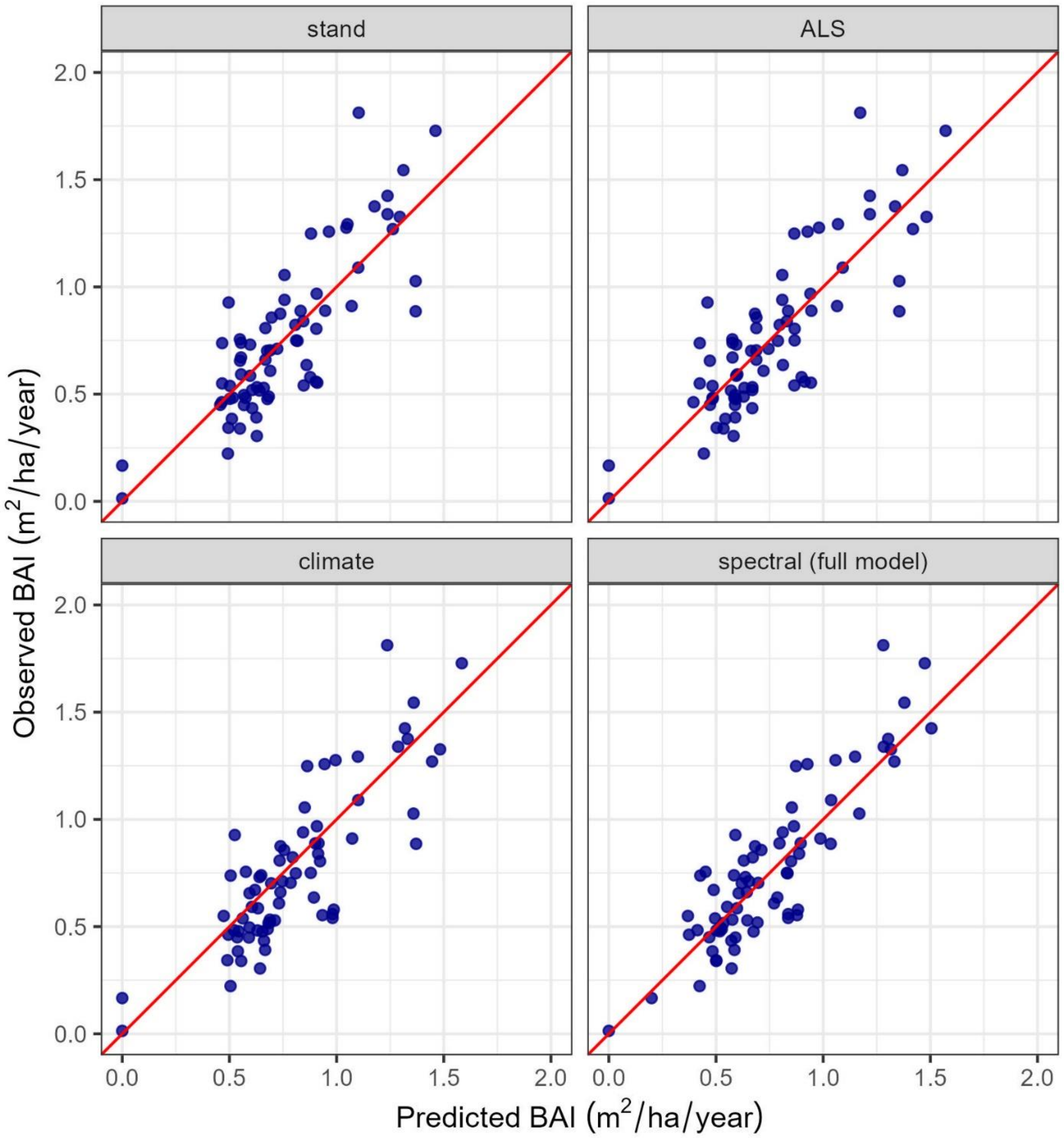
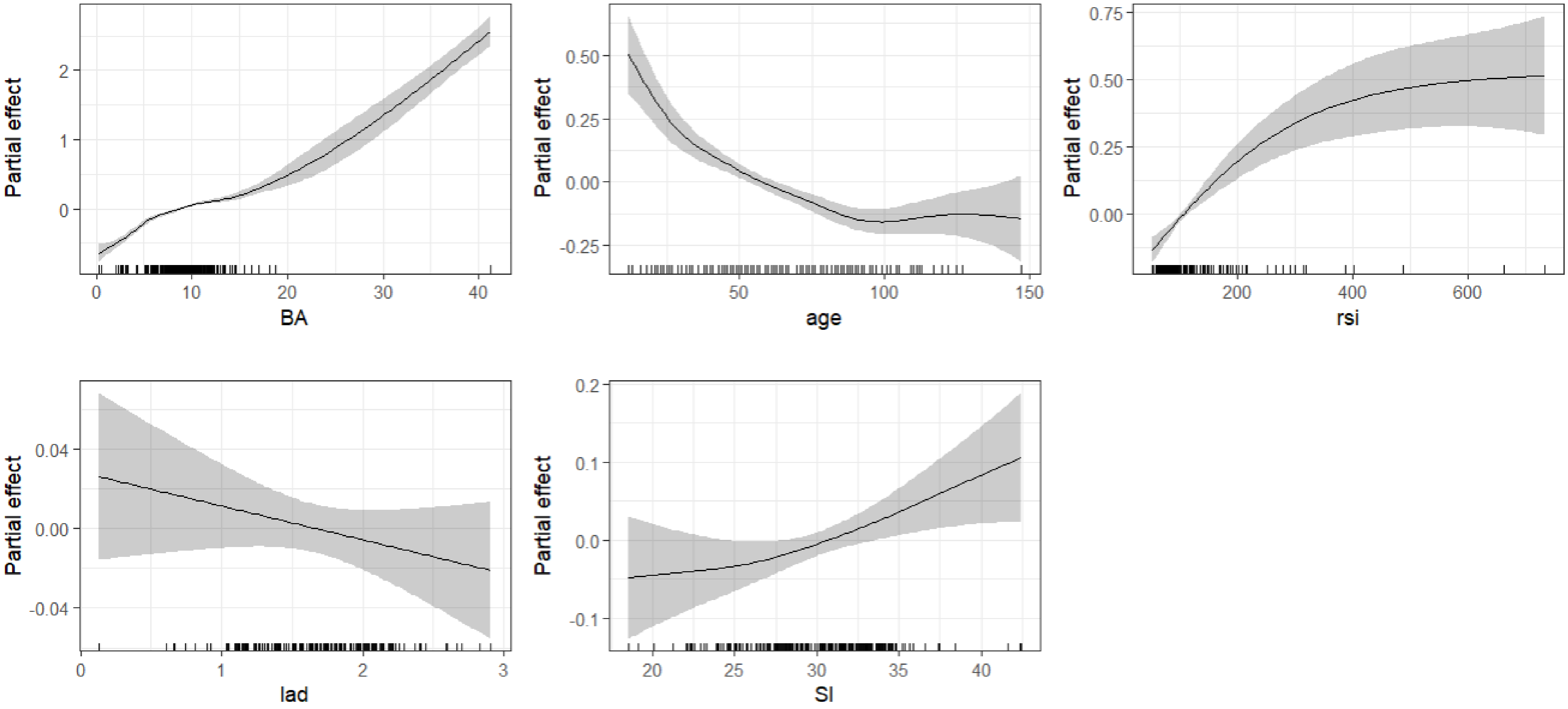

# Results – model validation

- 62 plots,
- 72 observations (10 from 2022)

| | stand | ALS | climate | spectral |
|---|---|---|---|---|
| RMSE | **0,206** | 0.203 | 0.206 | **0.173** |
| RMSE% | **27.0** | 26.6 | 27.2 | **22.7** |
| MAE | **0.158** | 0.158 | 0.162 | **0.136** |
| MAE% | **20.8** | 20.8 | 21.4 | **17.9** |
| $R^2$ | **0.68** | 0.69 | 0.69 | **0.78** |



# Results – partial effect plots



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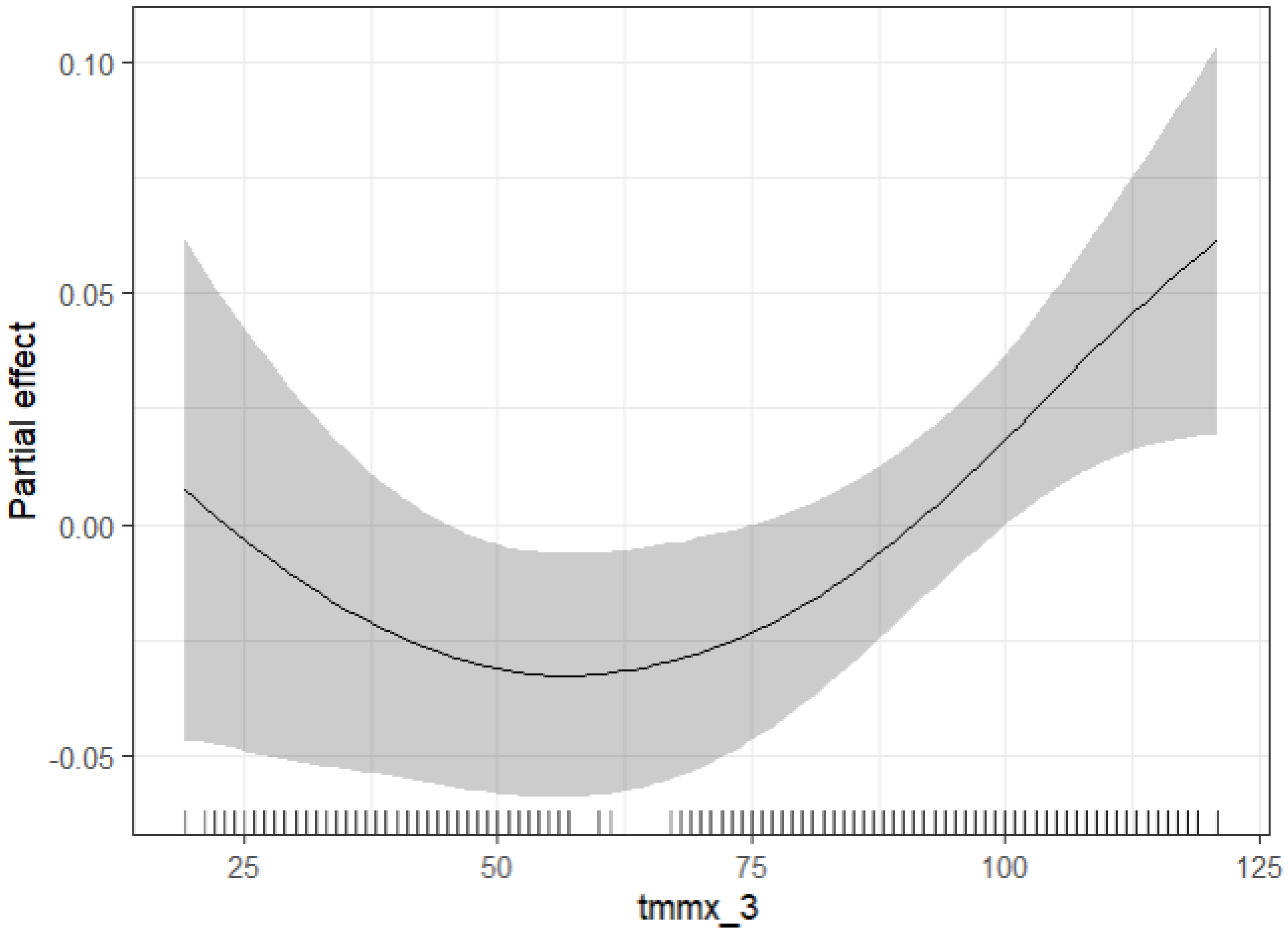


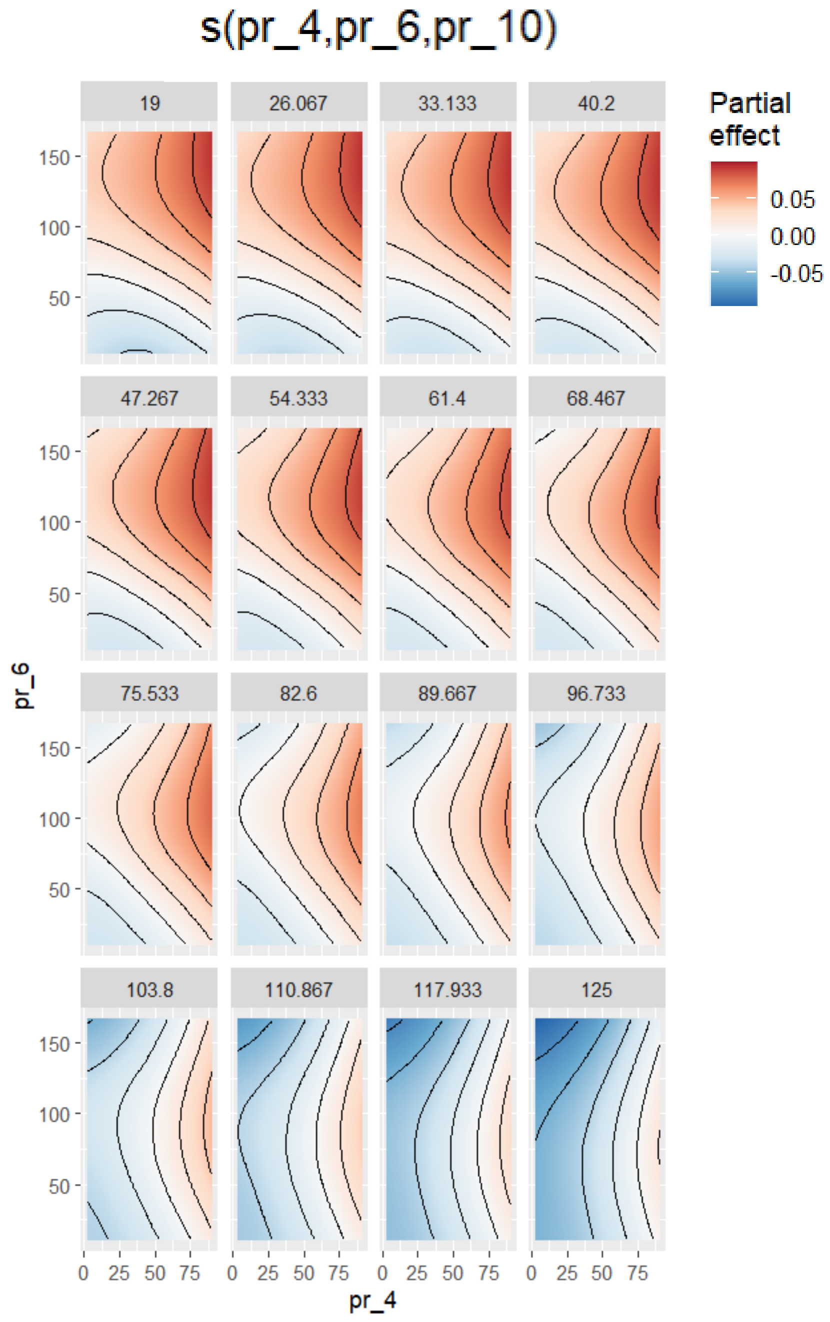

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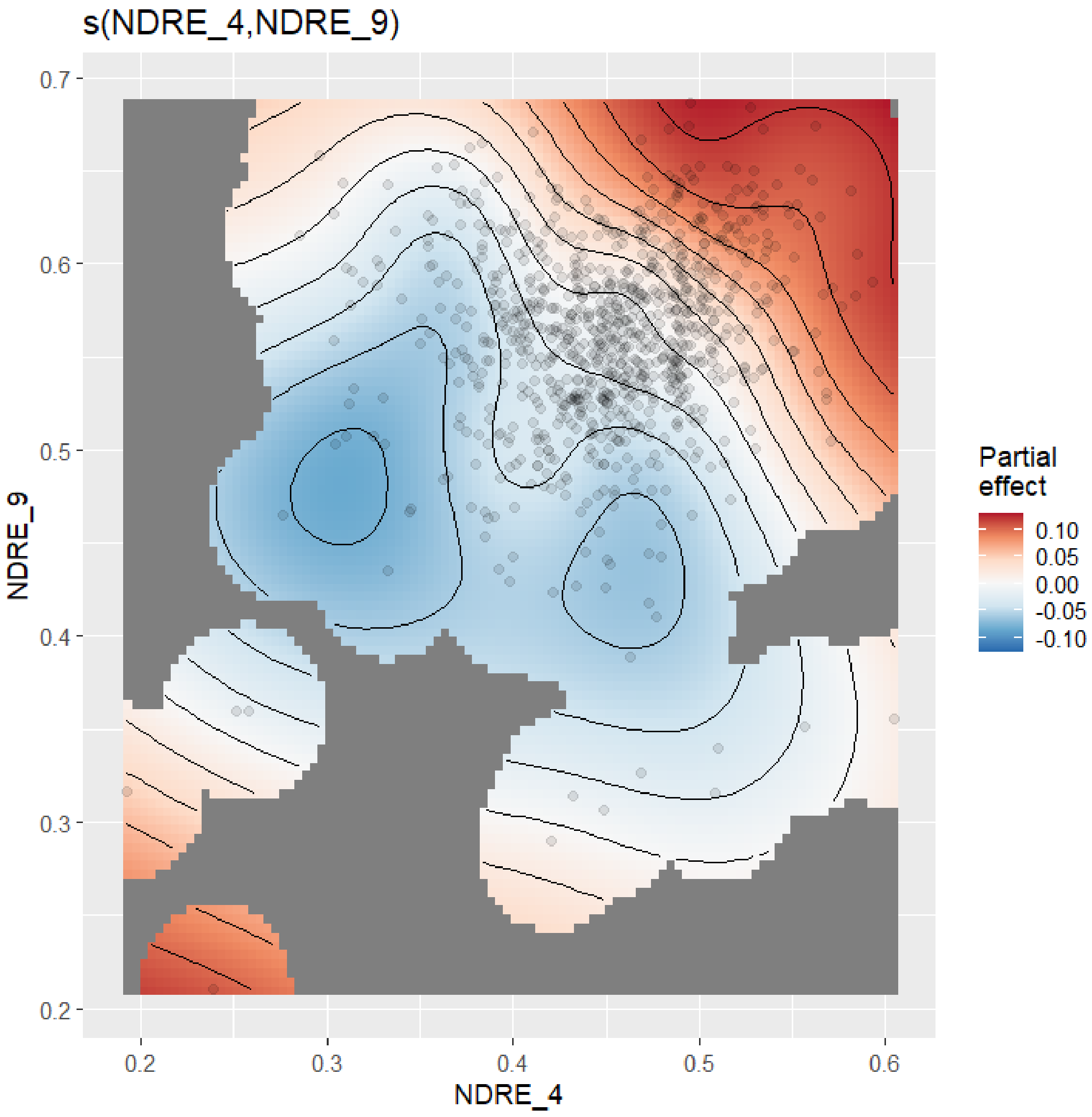
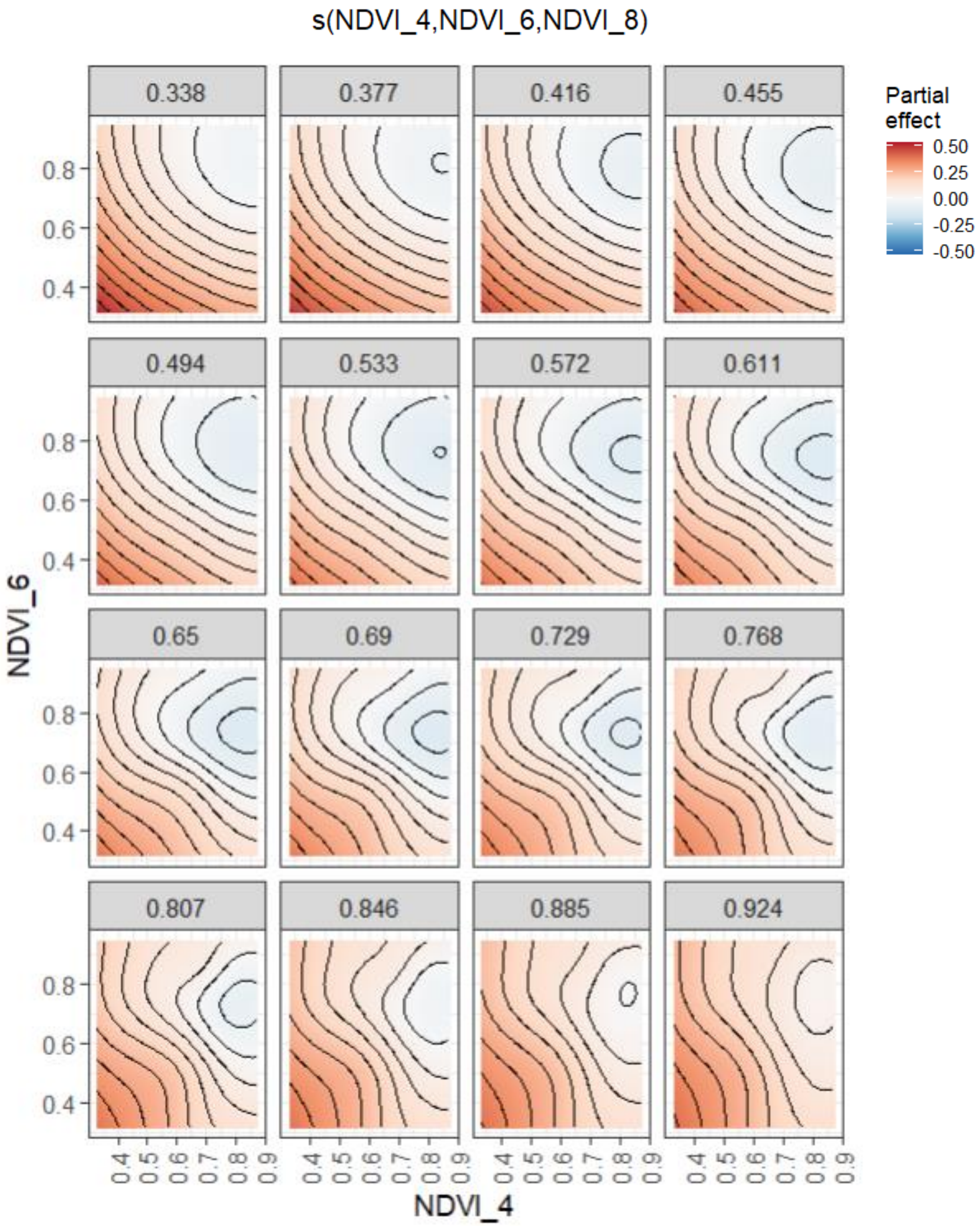
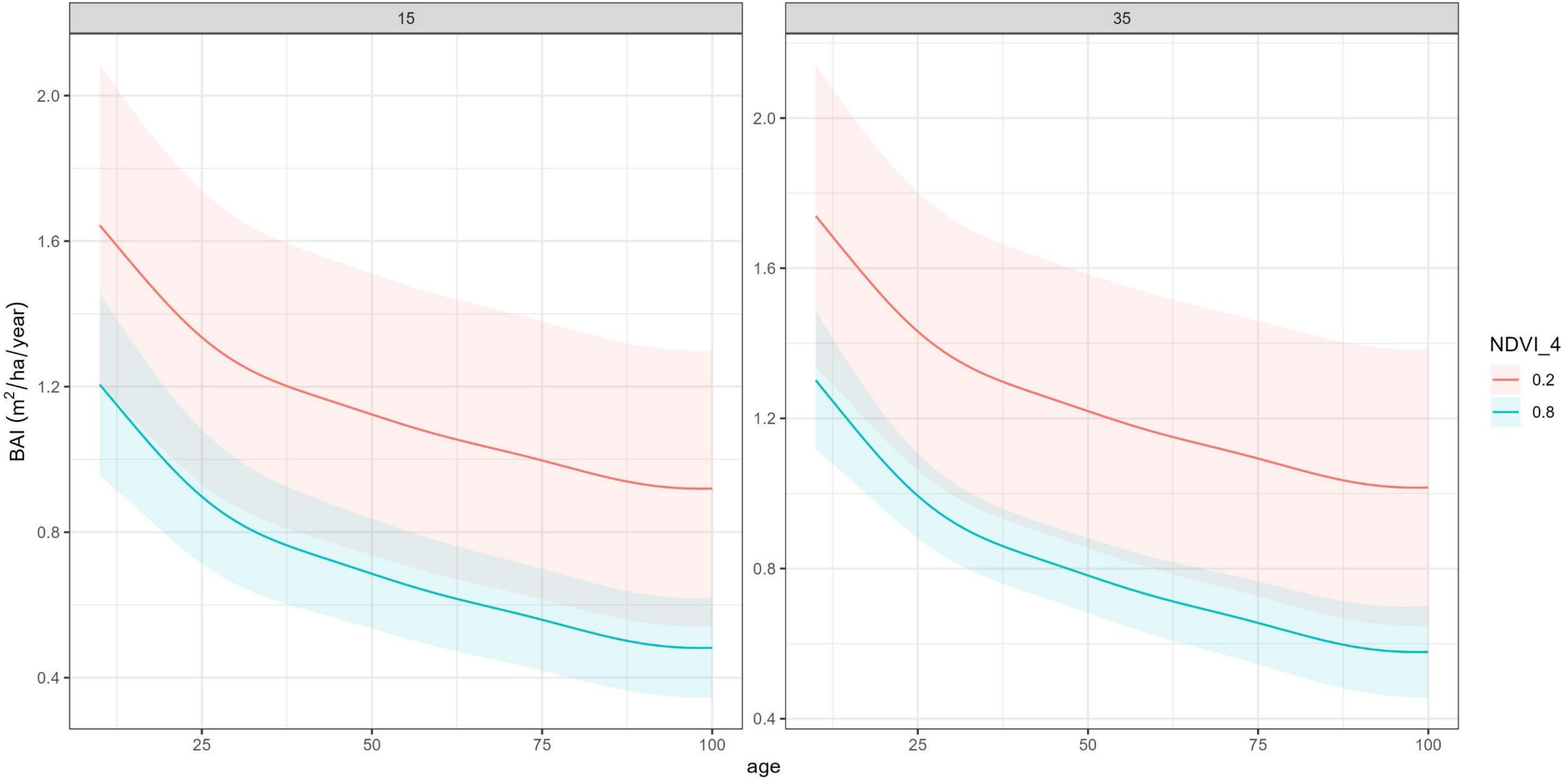


# Results – adjusted predictions



# Summary / Conclusions

- RSI and site index were the best ALS-derived predictors
- spectral data substantially improved model performance
- spectral predictors improved model more than climatic variables
- NDVI was the best predictor of BAI among tested VIs

# Next steps

- evaluation of how ALS-derived BA accuracy influence predictions of BAI
- separate models for thinned / not thinned stands – data from previous field campaign (2015-2022)
- cummulative values of VIs and climatic variables
- extend analysis to new regions and species
- analyse single tree growth including RS-derived metrics
- any suggestions?

## Thank you for your attention!