Identifying Forest Structure-Biodiversity Relationships in the Context of Experimental Silvicultural Treatments Based on Multi-source Remote Sensing and Multi-taxa Biodiversity Data

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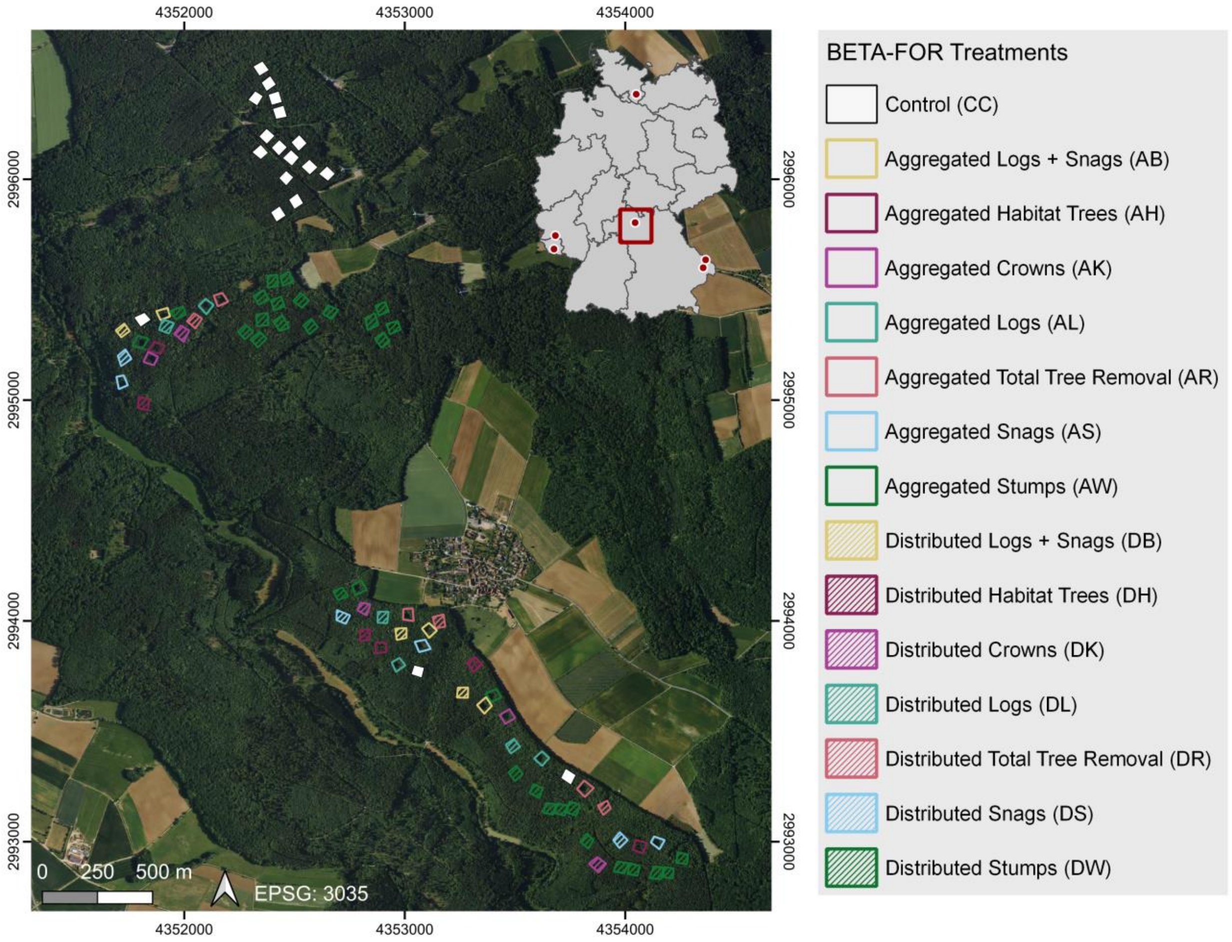
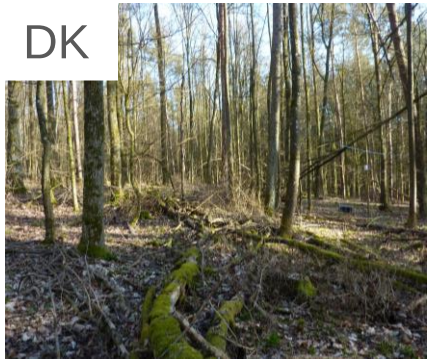
Institute of Geography and Geology, Department of Remote Sensing

University of Würzburg

Experimental Silvicultural Treatments Manipulate Forest Structure

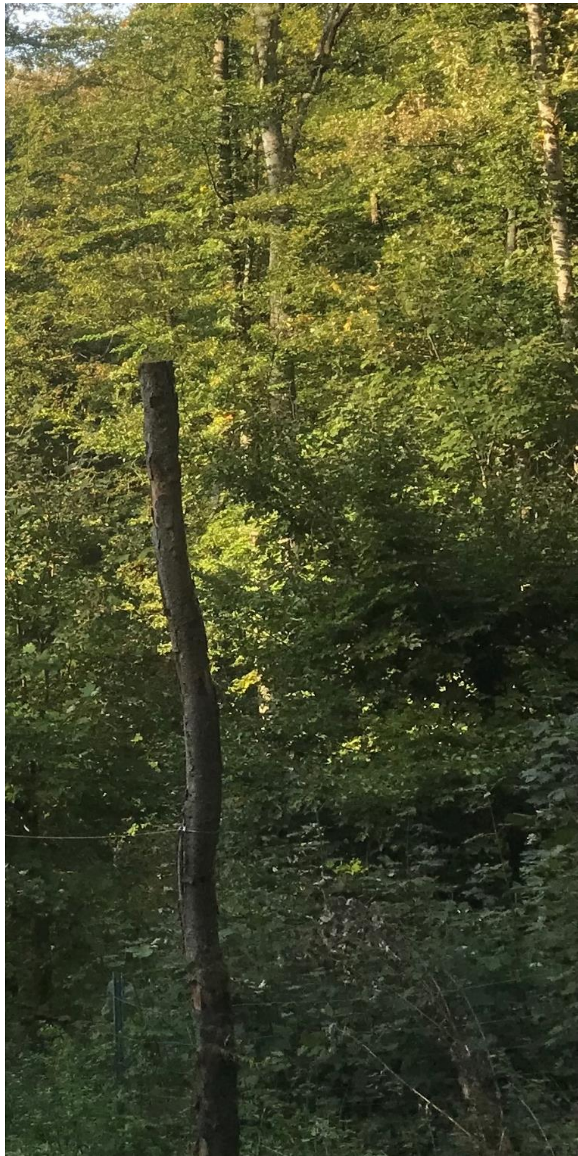
Experimental silvicultural treatments (50 x 50 m) in six German regions:





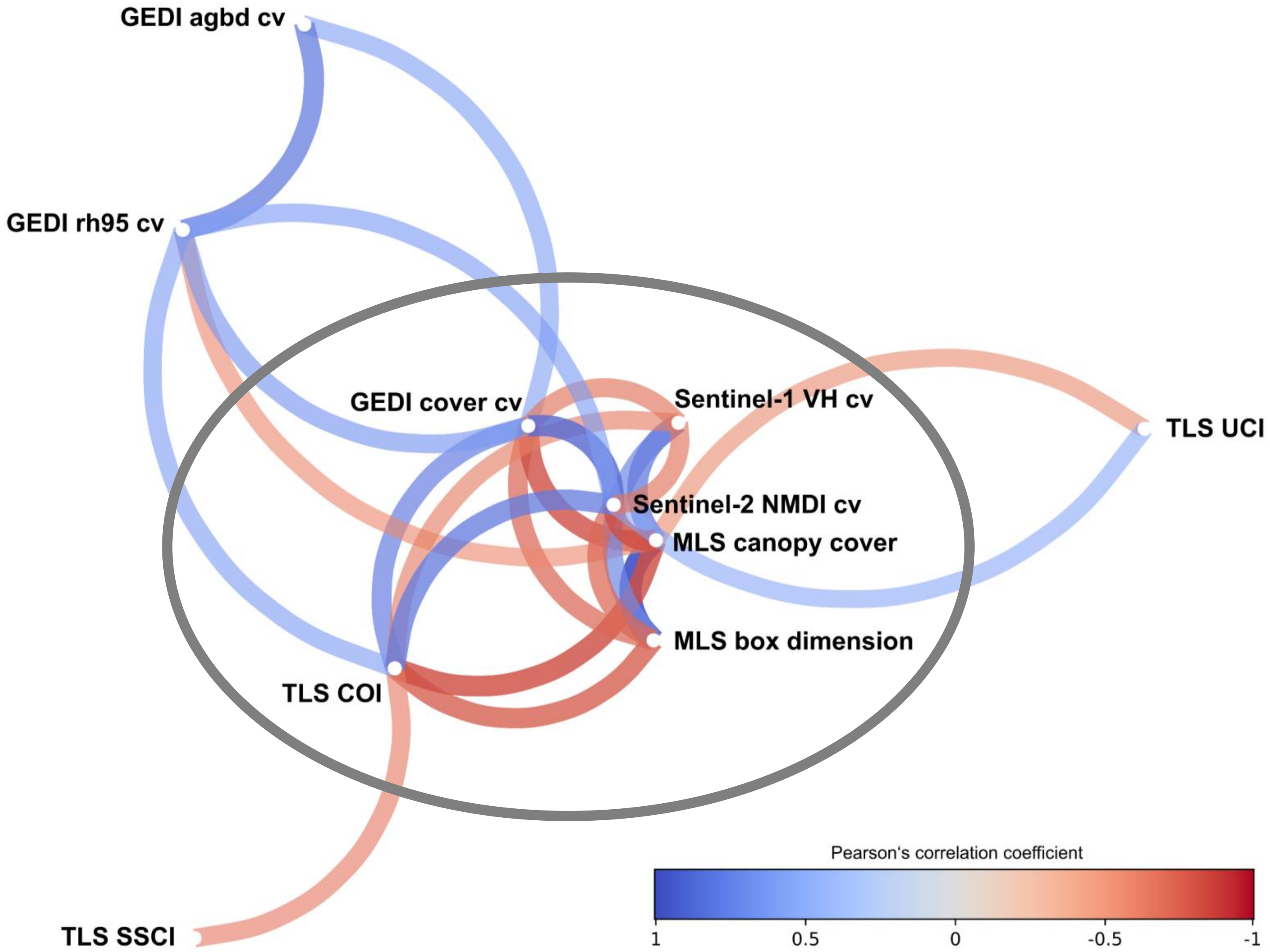
Assessing Forest Structural Complexity

Forest structural attribute	Platforms: **MLS** (Mobile Laser Scanning)	Platforms: **TLS** (Terrestrial Laser Scanning)	Platforms: **Spaceborne**
Canopy cover / openness	Canopy cover	Canopy Openness Index (COI)	-
Structural complexity	Box dimension	Stand Structural Complexity Index (SSCI), Understory Complexity Index (UCI)	-
Structural heterogeneity	-	-	Sentinel-1 VH cv, Sentinel-2 NMDI cv, GEDI rh95 (canopy height) cv, GEDI cover cv, GEDI agbd cv



Correlation Network of Remotely Sensed Data

- **Correlation network** to present multivariate relationships
- Only **correlations with an absolute value > 0.5** are shown
- The **proximity of indicators indicates a high number of strong correlations**
- **Core network group (most correlative):**
  - GEDI cover cv
  - Sentinel-1 VH cv
  - Sentinel-2 NMDI cv
  - MLS canopy cover
  - MLS box dimension
  - TLS COI

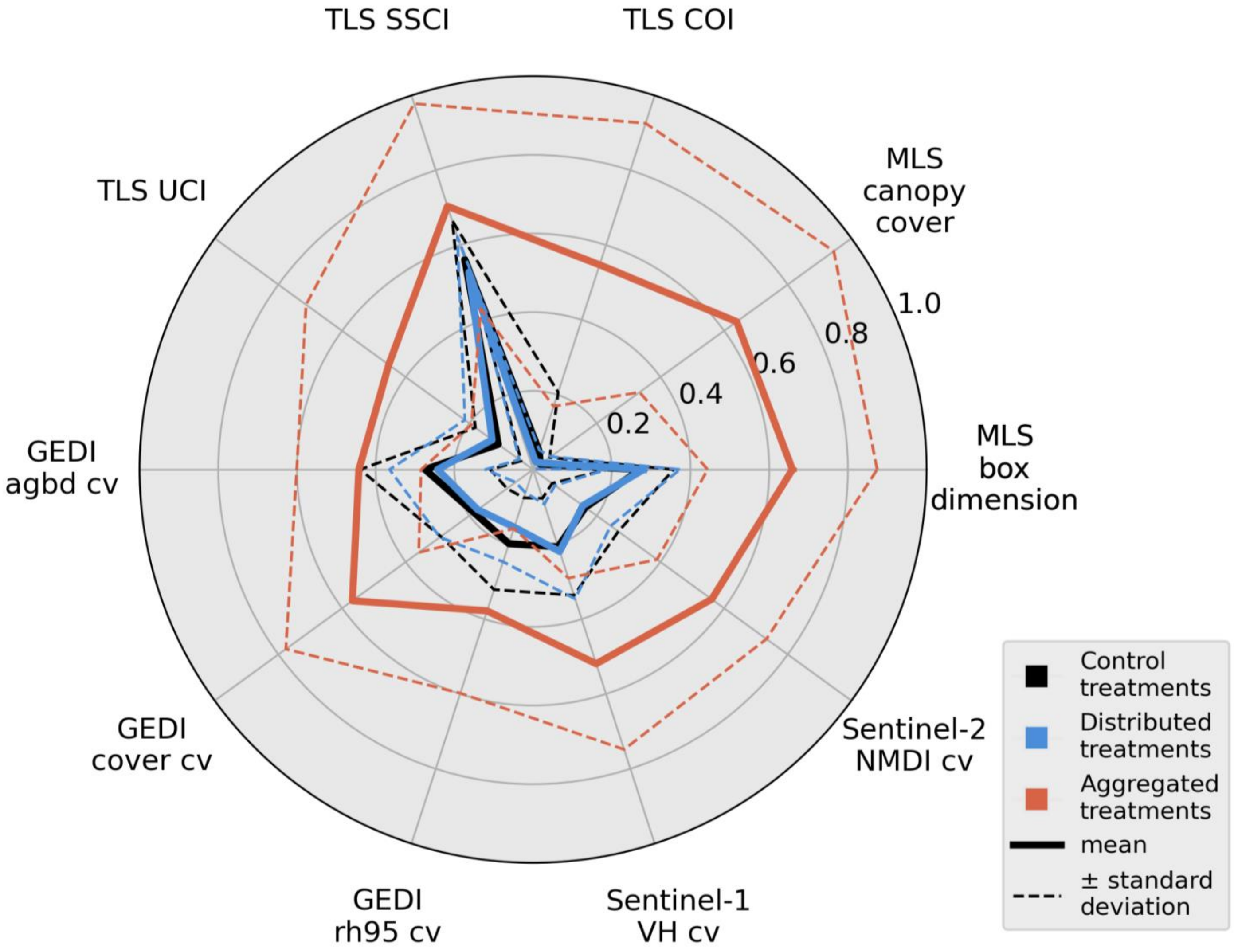


Comparative Analysis of Treatment Groups

- **Treatment groups:**
  Control (unaltered structure)
  Distributed (selective removal of trees)
  Aggregated (gap felling)

- Indicators were **rescaled:**
  0 indicating a **low structural complexity**
  1 representing a **high structural complexity**

- **Indicators of all platforms delineate well** among **aggregated** and **control/distributed treatments**



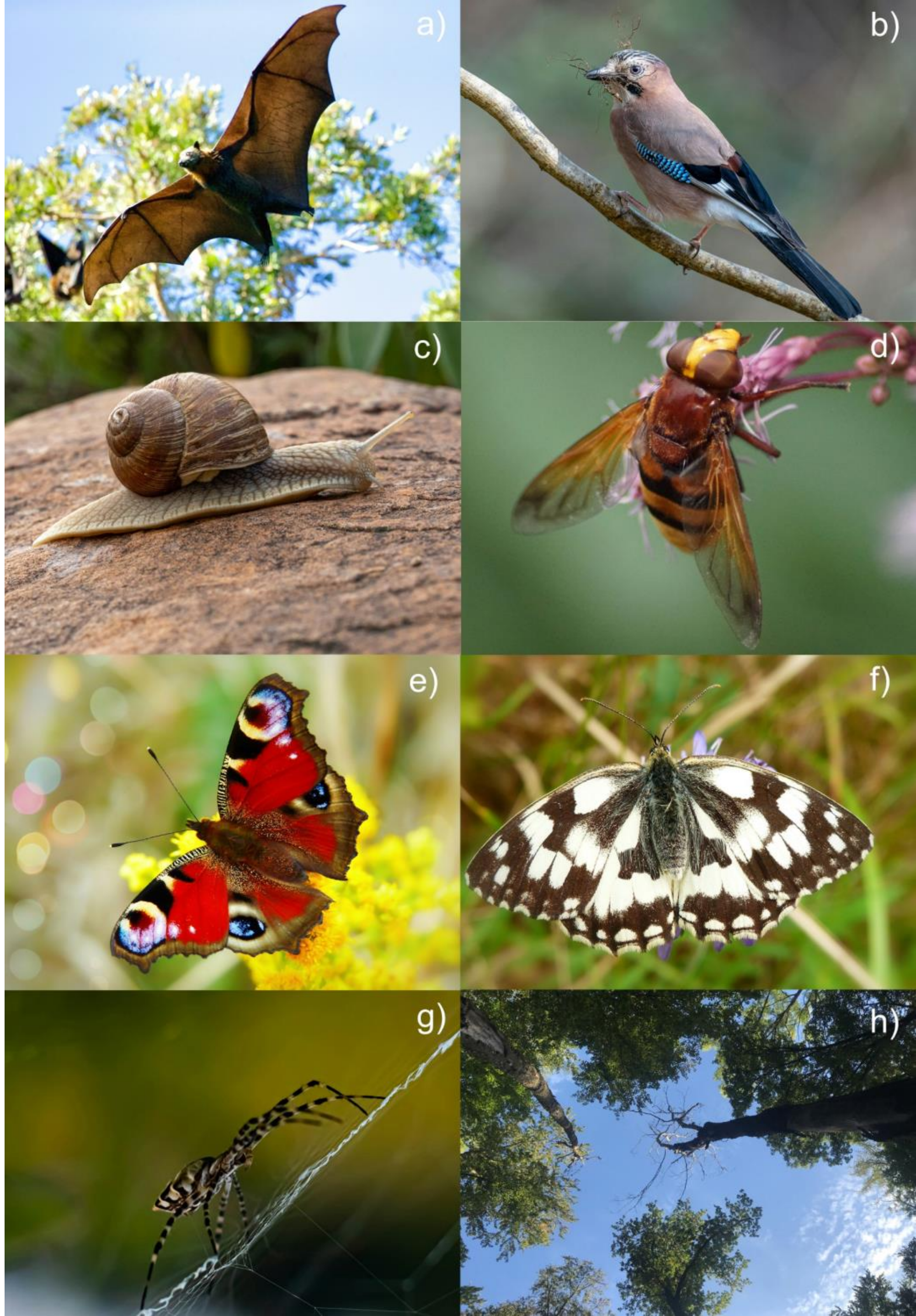
Assessing Structure-Biodiversity Relationships

- **Integration of in-situ biodiversity data**

- **Assessment of best spaceborne forest structure indicator per taxonomic diversity level:**
  - q = 0 (species richness)
  - q = 1 (Shannon index)
  - q = 2 (Simpson index)

- **Moderate correlations** for
  - **Birds**
  - **Gastropods**
  - **Hoverflies**
  - **Insects**

- **Seasonal biases**



Overall Summary

- **Strong correlations of indicators on structural complexity could be identified across sensors and platforms:**
  - MLS box dimension, MLS canopy cover,
  - TLS COI,
  - Sentinel-1 VH cv, Sentinel-2 NMDI cv, GEDI cover cv

- **The increase in forest structure complexity of aggregated treatments** compared to control and distributed treatments can be **identified from all remote sensing platforms**

- **Spaceborne indicators of forest structure complexity** from complementary sensors **hold similar capability to characterize experimental silvicultural treatments as close-range techniques**

- The **delineation of different levels of forest structural complexity** is essential to **characterize structure-biodiversity relationships**

Foto: Lisa Albert, Forest of University of Würzburg, Germany)

Assessment of Forest Structure - Publications

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

DLR

remote sensing

MDPI

Article

Forest Structure Characterization in Germany: Novel Products and Analysis Based on GEDI, Sentinel-1 and Sentinel-2 Data

Patrick Kacic [1,*], Frank Thonfeld [2], Ursula Gessner [2] and Claudia Kuenzer [1,2]

Remote Sensing in Ecology and Conservation

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RESEARCH ARTICLE

Assessing experimental silvicultural treatments enhancing structural complexity in a central European forest – BEAST time-series analysis based on Sentinel-1 and Sentinel-2

Patrick Kacic[1], Ursula Gessner[2], Stefanie Holzwarth[2], Frank Thonfeld[2] & Claudia Kuenzer[1,2]

BETA-FOR

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Characterizing local forest structural complexity based on multi-platform and -sensor derived indicators

Patrick Kacic [a,*], Ursula Gessner [b], Christopher R. Hakkenberg [c], Stefanie Holzwarth [b], Jörg Müller [d,e], Kerstin Pierick [f,g], Dominik Seidel [f], Frank Thonfeld [b], Michele Torresani [h], Claudia Kuenzer [a,b]

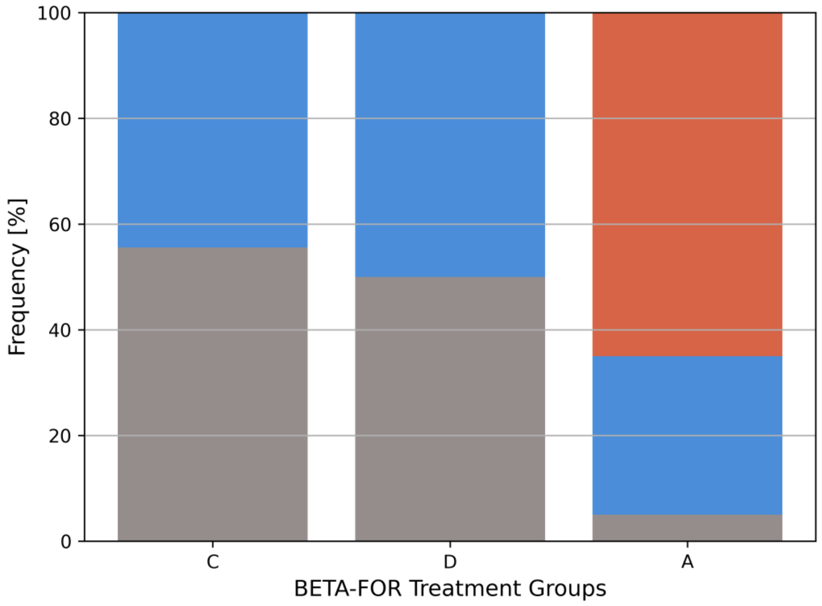
SUPPLEMENTARY FILES

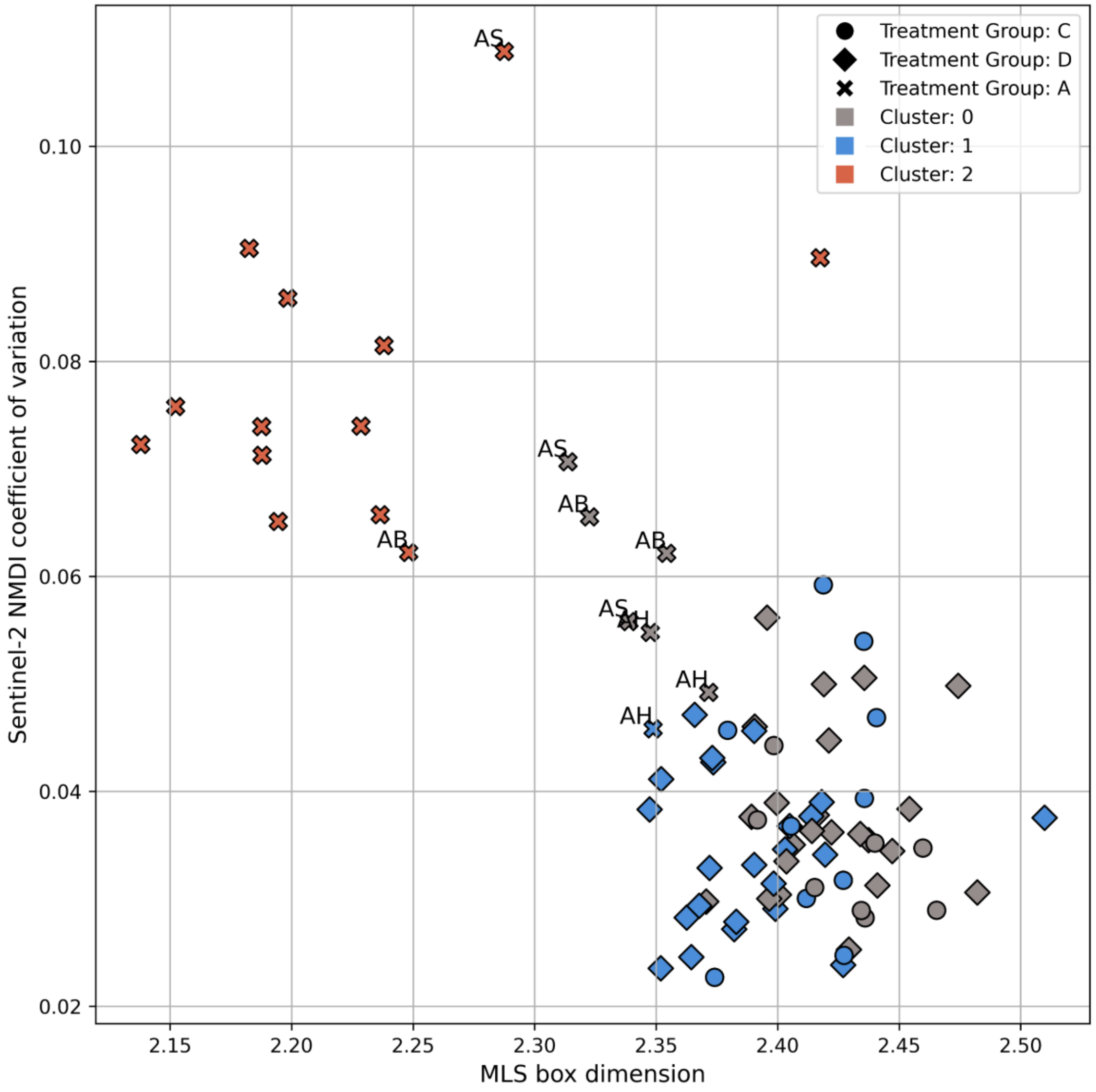
Foto: P. Kacic, Forest of University of Würzburg, Germany)

Clustering Analysis –
Pooled Spaceborne and In-Situ Indicators

- Assess **clustering of indicators** using k-means

- **Identification of sensitivity towards standing deadwood:**
  - Aggregated treatments with habitat trees are not clustered with aggregated treatments without standing deadwood
  - Aggregated treatments with standing deadwood structures are more likely clustered with control/distributed treatments





BETA-FOR Project

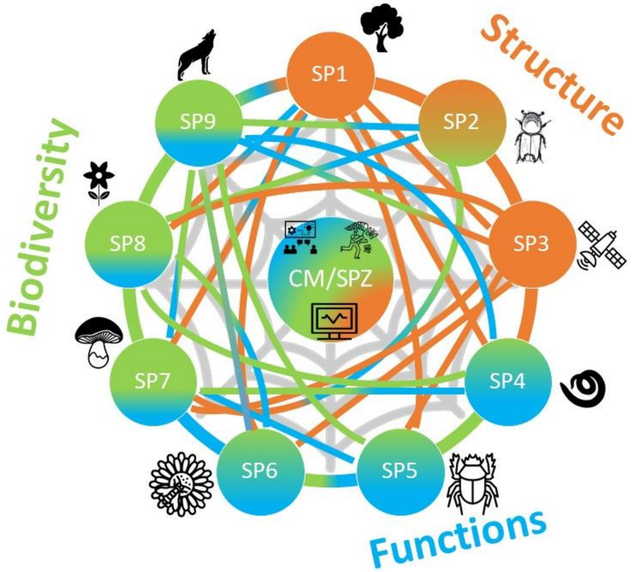
Assess the **effect of experimental silvicultural interventions on biodiversity based on a unique patch-network** in German broad-leaved forests

Current situation in German forests:

- homogeneity of **structures** (age, species, vertical and horizontal properties)
- low amount and diversity of **deadwood**

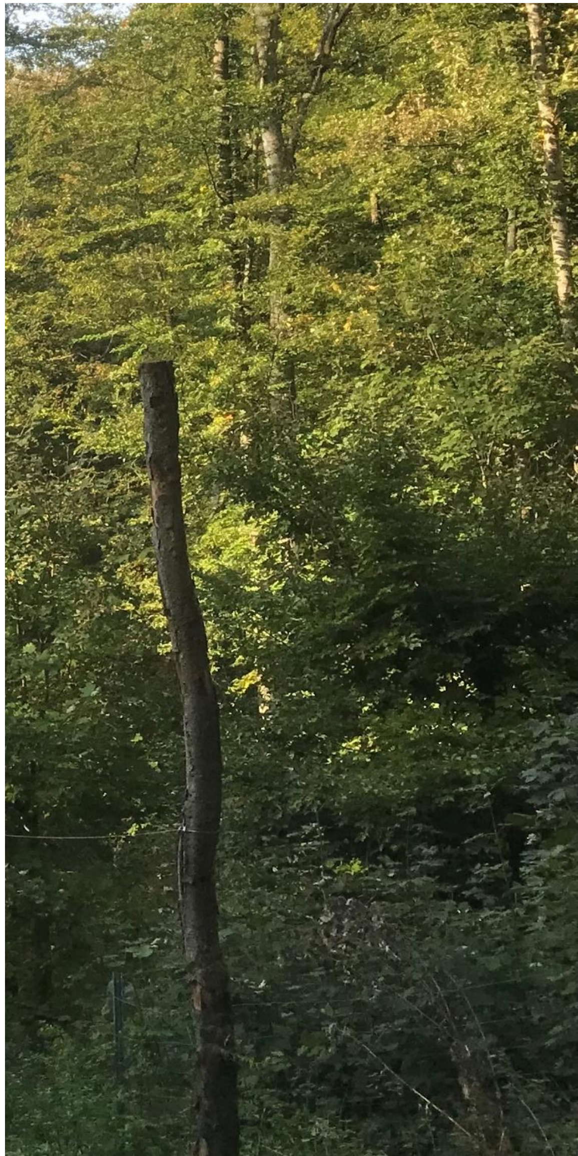
Motivation:

- **interdiscliplinary** analysis of forest structure and biodiversity
- assess **arrangements of cuttings** and **deadwood structures** that **enhance structural complexity** to **increase biodiversity**



Methodology to assess forest structural complexity across platforms and sensors

- Calculation of **forest structure complexity for different platforms and sensors**:
  - **Mobile laser-scanning (MLS, leaf-on, July 2023)**: box-dimension, canopy cover
  - **Terrestrial laser-scanning (TLS, leaf-on, August 2023)**: stand structural complexity index (SSCI), understory complexity index (UCI), canopy openness index (COI) (https://doi.org/10.2139/ssrn.5157921)
  - **Spaceborne remote sensing (leaf-on, summer, 2016 to 2023)**:
    - **Sentinel-1** (Synthetic-Aperture-Radar, C-band): VH coefficient of variation (https://doi.org/10.1002/rse2.386)
    - **Sentinel-2** (Multispectral, VIS-NIR-SWIR): NMDI (Normalized Multi-band Drought Index) coefficient of variation (https://doi.org/10.1002/rse2.386)
    - **GEDI** (LiDAR, NIR): canopy height (rh95), total canopy cover (cover), above-ground biomass density (agbd) coefficient of variation (https://doi.org/10.3390/rs15081969)

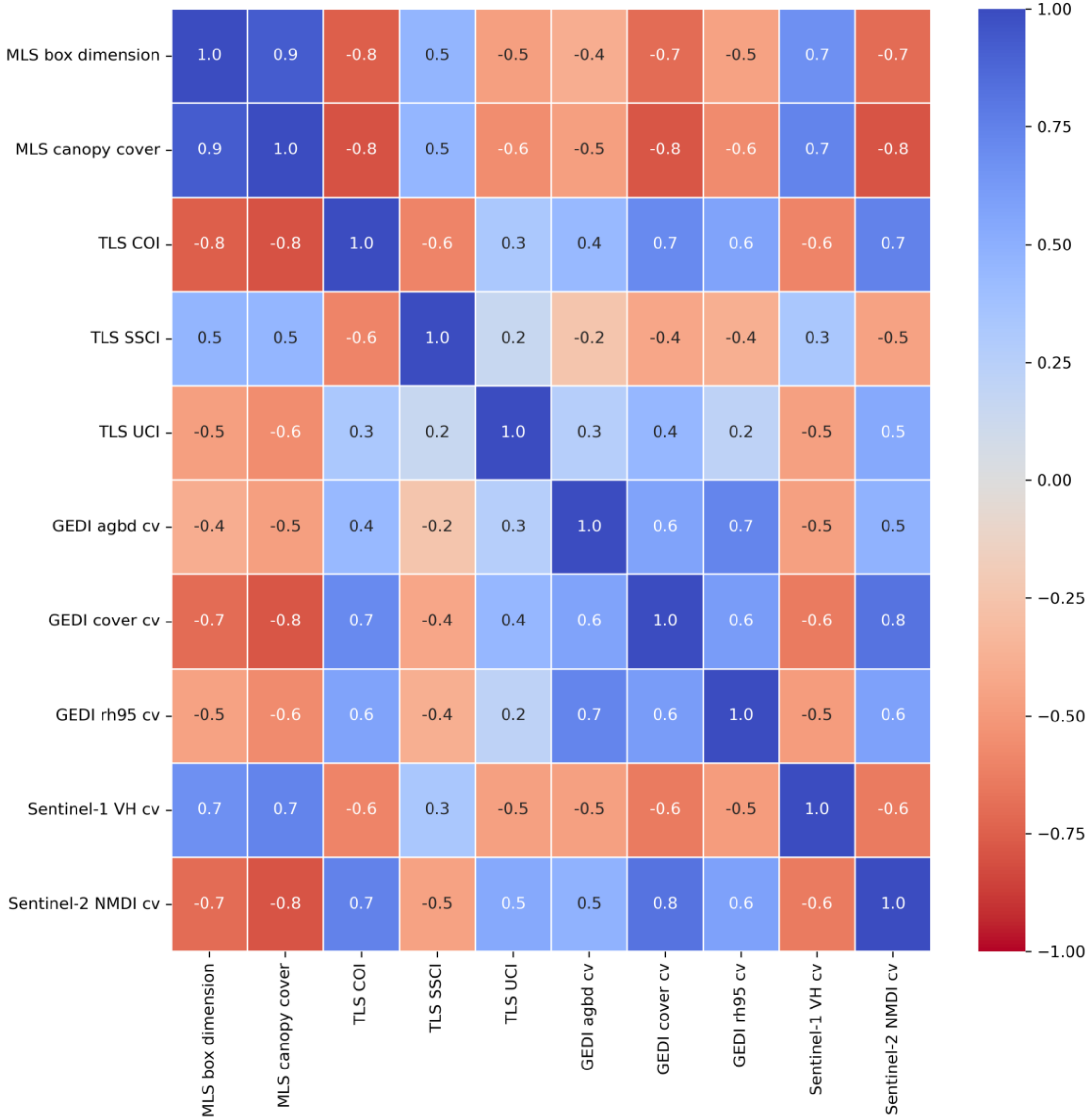


Correlation Heatmap for 2023 Data

- Correlation method: **Pearson‘s correlation**

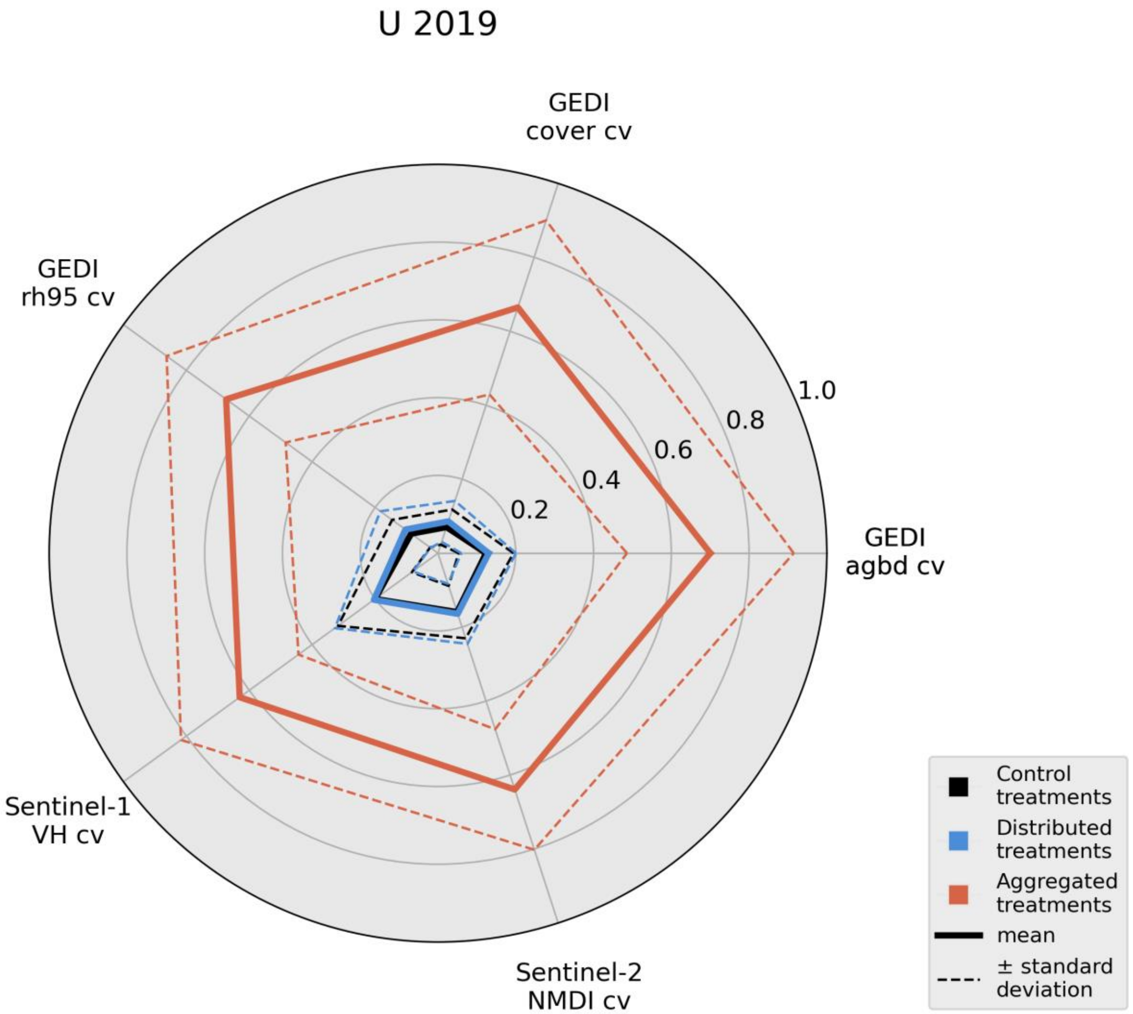
- **Strong positive and negative correlations** (>= |0.7|) of
  - MLS (box dimension, canopy cover),
  - TLS COI,
  - spaceborne metrics of forest structure complexity (S1 VH cv, S2 NMDI cv, GEDI cover cv)

- **Moderate positive and negative correlation** (|0.4| to |0.6|) of
  - MLS (box dimension, canopy cover),
  - TLS (SSCI, UCI),
  - GEDI (agbd = above-ground biomass density, rh95 = canopy height as 95th percentile)
  - S1 VH cv, S2 NMDI cv



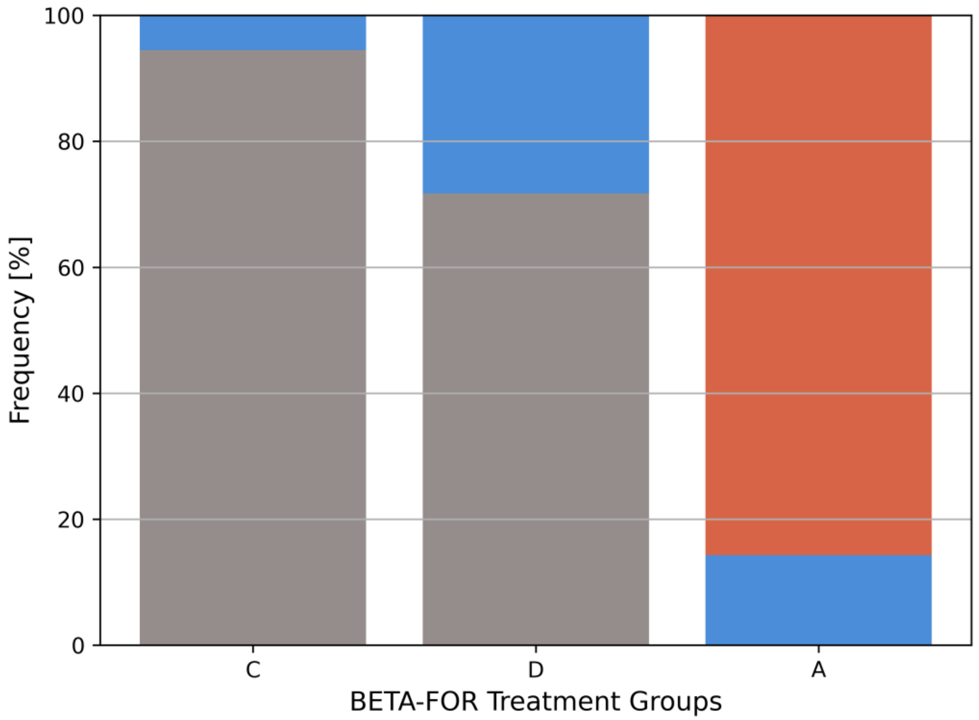
Radar Plots for Treatment Groups – Spaceborne variables only 2019 vs. 2023

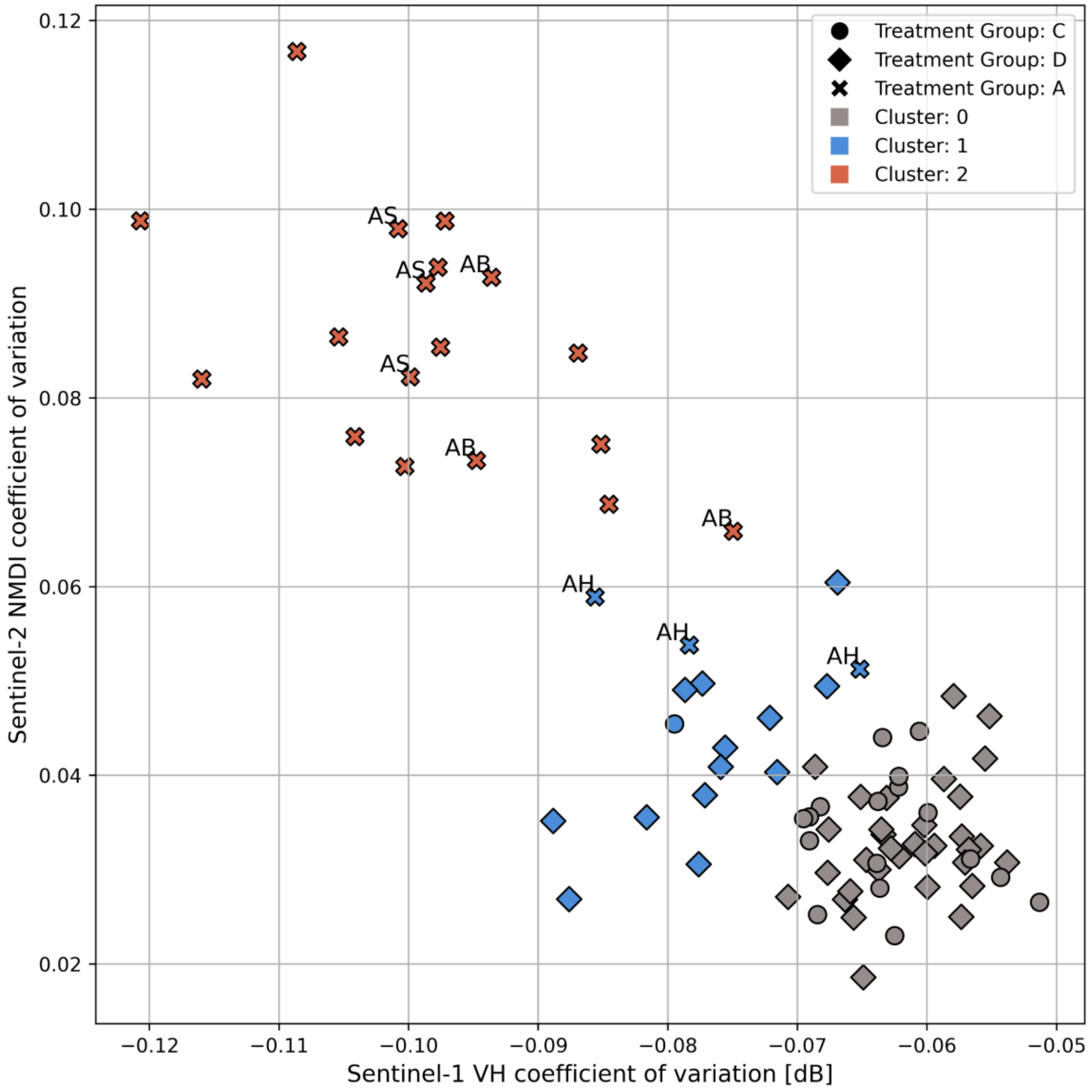
- **University Forest 2019** (first summer after treatment implementation) **vs. 2023**
- All remote sensing variables were **rescaled to values of 0 to 1** with values close to **0 indicating a low structural complexity** and values close to **1 representing a high structural complexity**
- **Higher structural complexity for A* treatments**
- **Clear decline in structural complexity for A* treatments**
- **D* and C* treatments relatively constant**



k-Means Clustering Analysis – spaceborne variables only (2019)

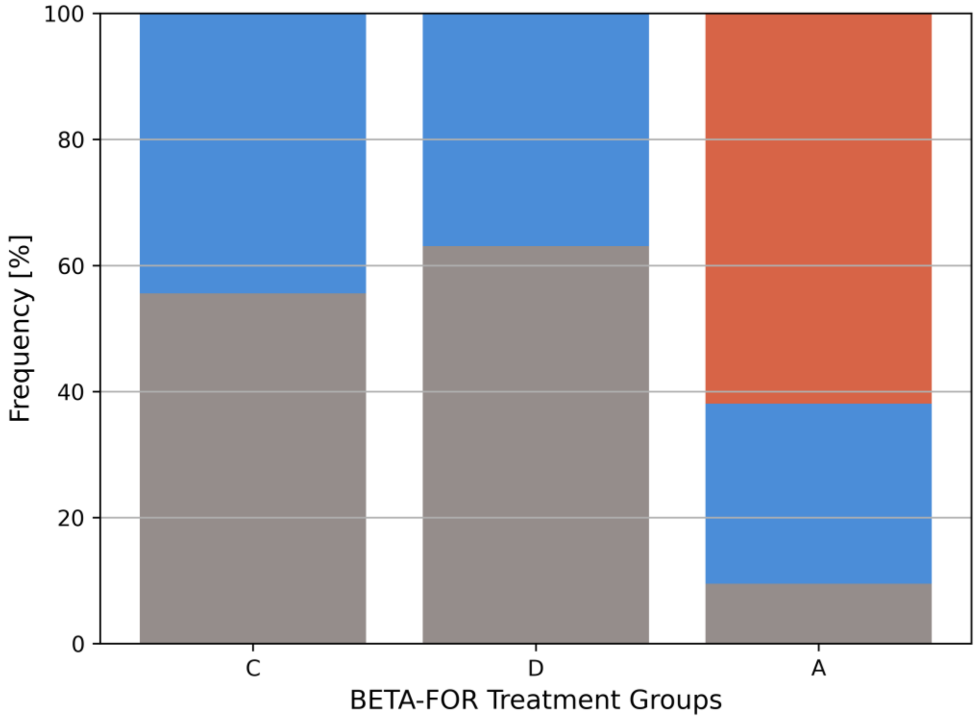
- **Improved clustering of A* treatments** at earlier stage after treatment implementation (**2019**) compared to 2023
- **Correct assignment of aggregated treatments** in individual cluster amounts to about **85 %**
- Control and distributed treatments still can not be distinguished

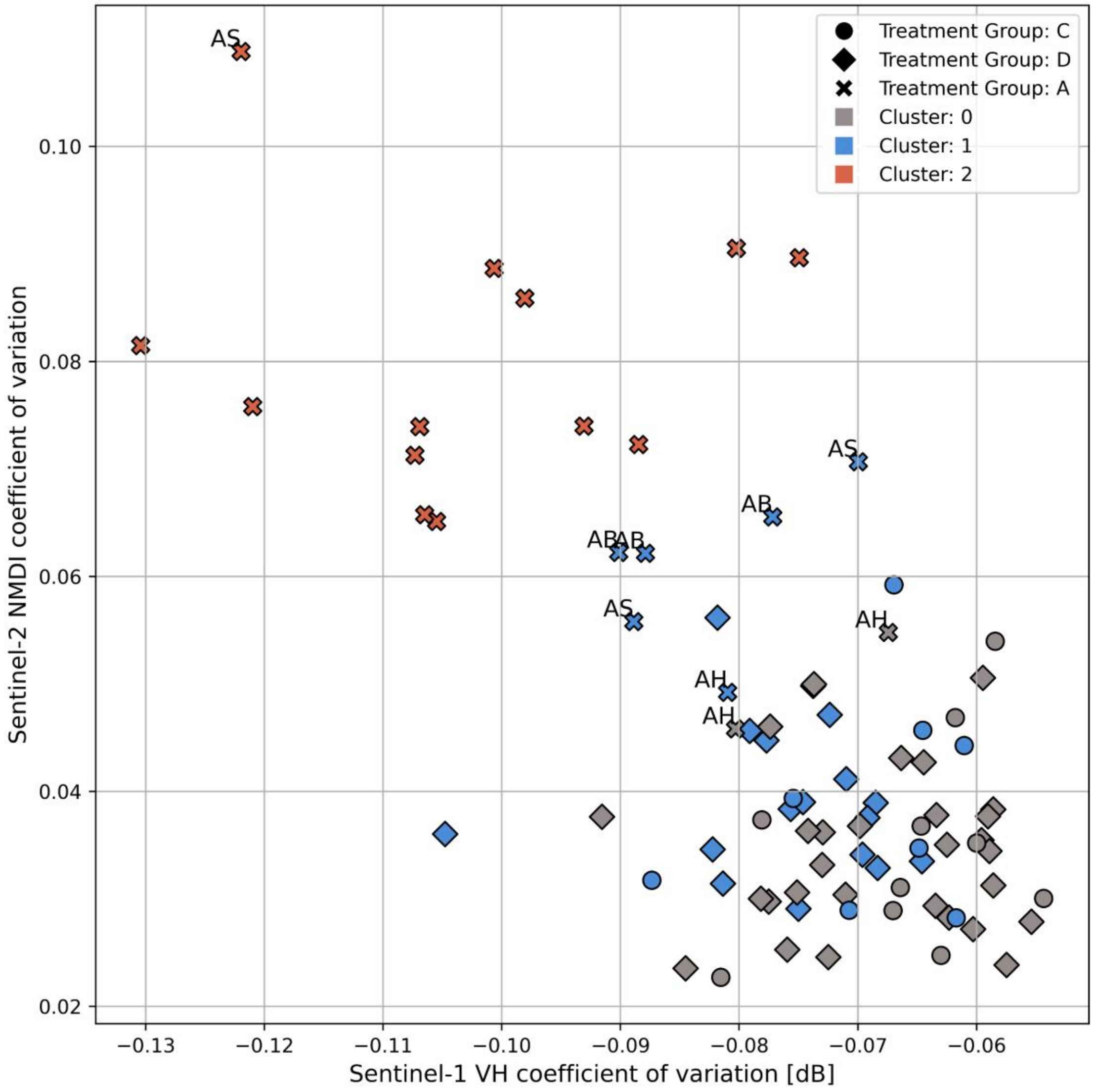




k-Means Clustering Analysis – spaceborne variables only (2023)

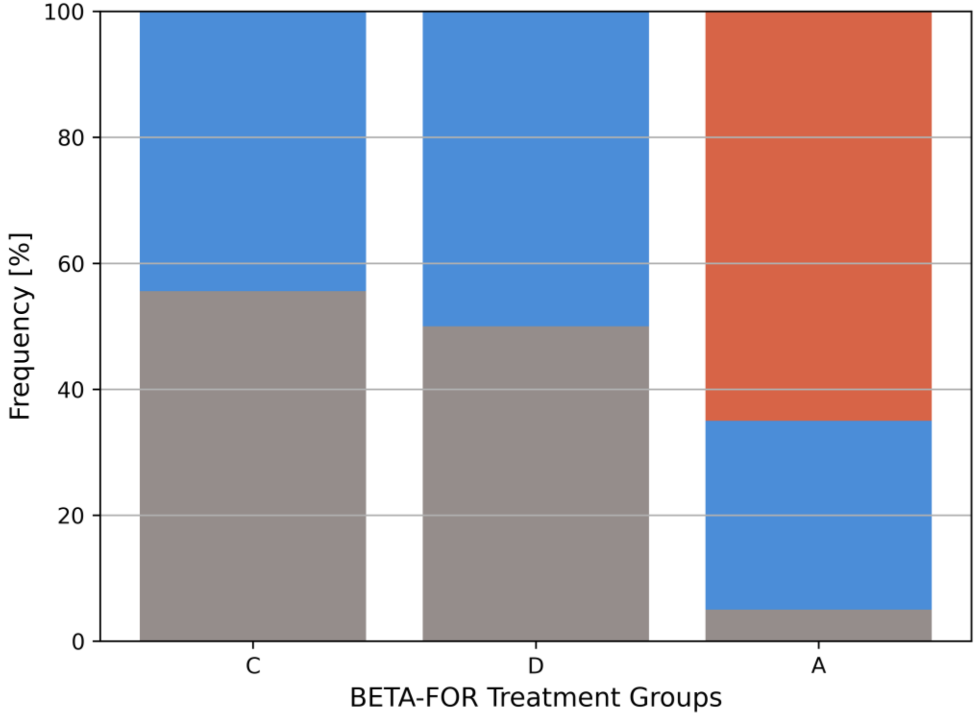
- C* and D* treatments have similar shares of cluster 0 and 1, with slight increments for cluster 0 for C* and cluster 1 for D*
- One mis-classification of cluster 2, i.e. relatively accurate classifications as A* treatments
- Mis-classifications of A* treatments are likely due to standing deadwood structures (AH, AS, AB treatments)
- **Cluster 2 for A* treatments holds a share of about 60 %**

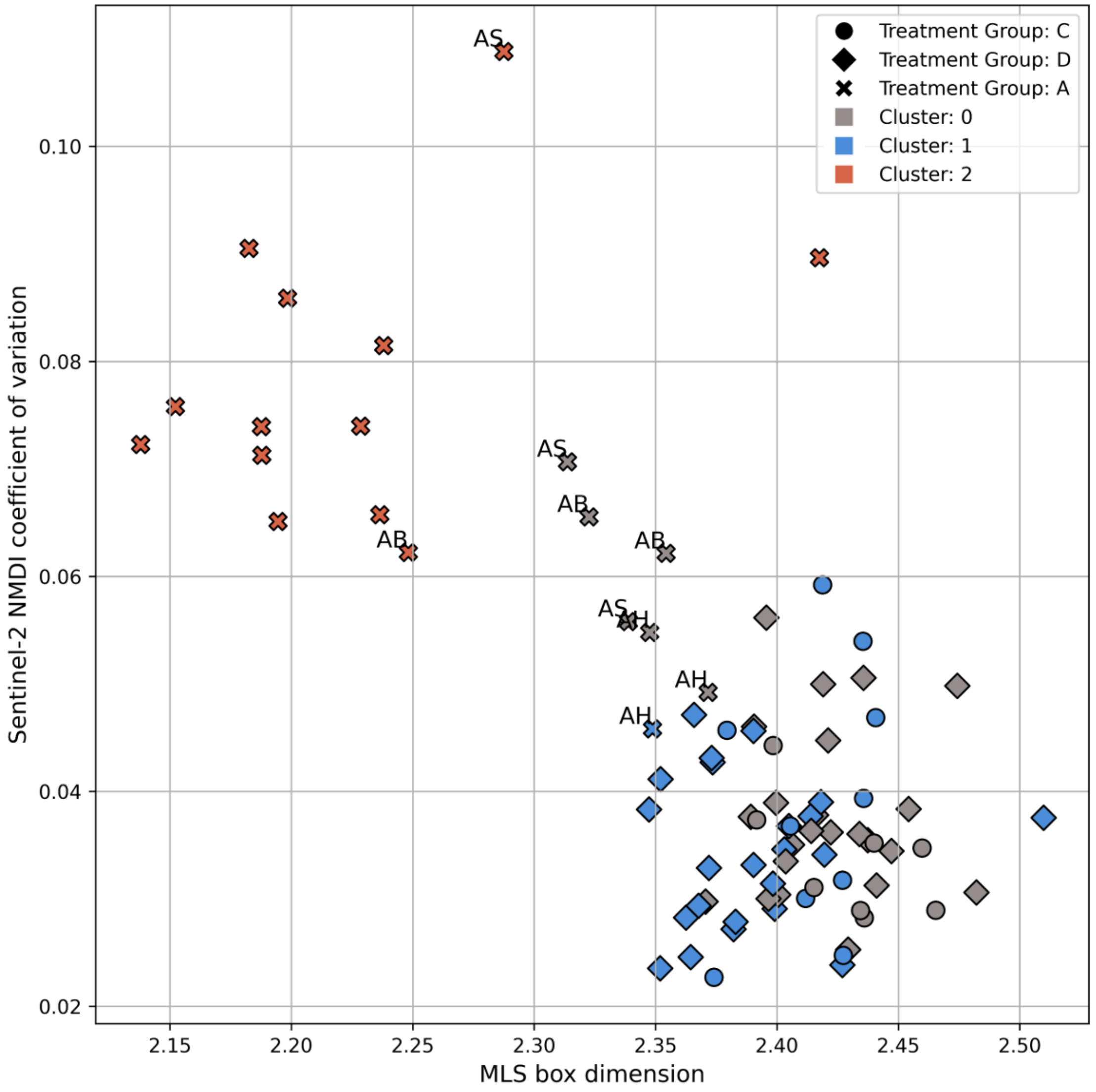




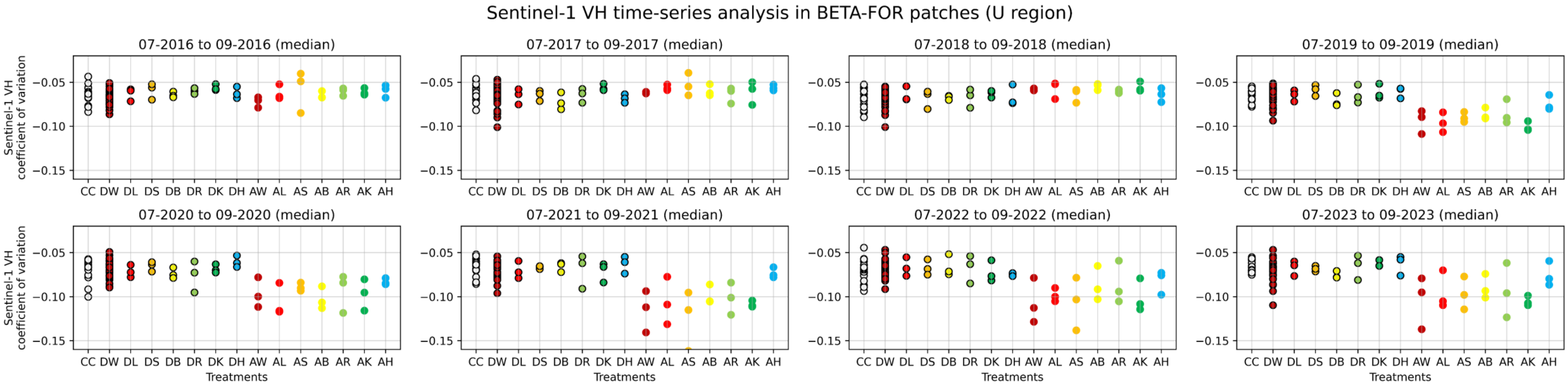
k-Means Clustering Analysis – all variables (2023)

- C* and D* treatments have similar shares of cluster 0 and 1, i.e. no reliable differentiation
- No mis-classification of cluster 2
- Mis-classifications of A* treatments are likely due to standing deadwood structures (AH, AS, AB treatments)
- Cluster 2 for A* treatments holds a share of about 65 %

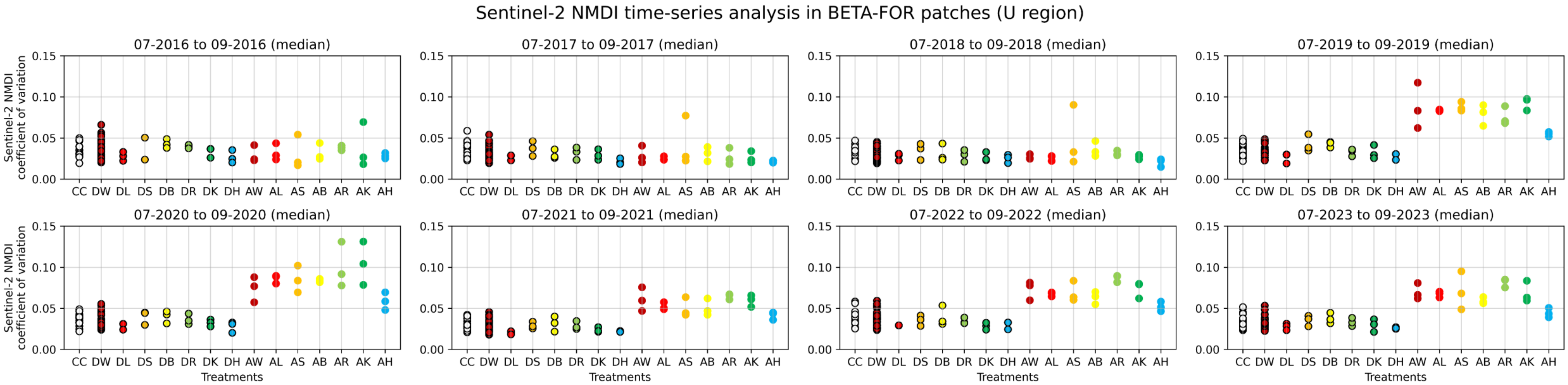




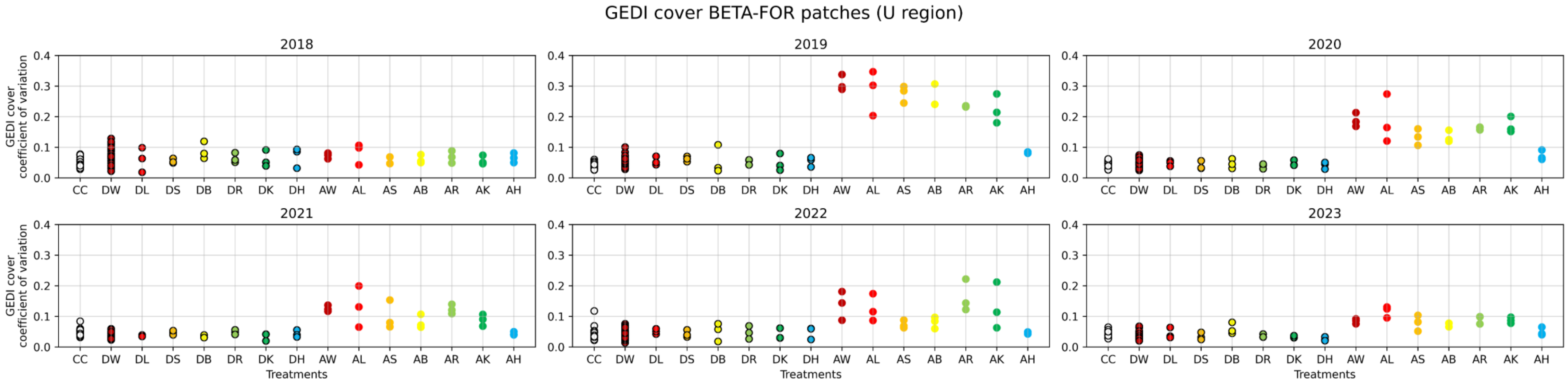
Sentinel-1 data



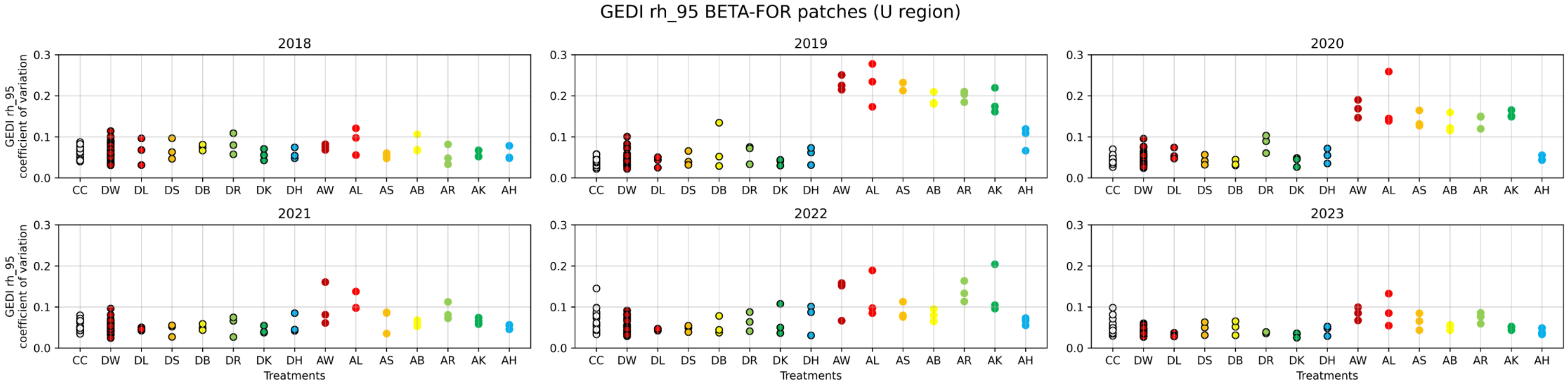
Sentinel-2 data

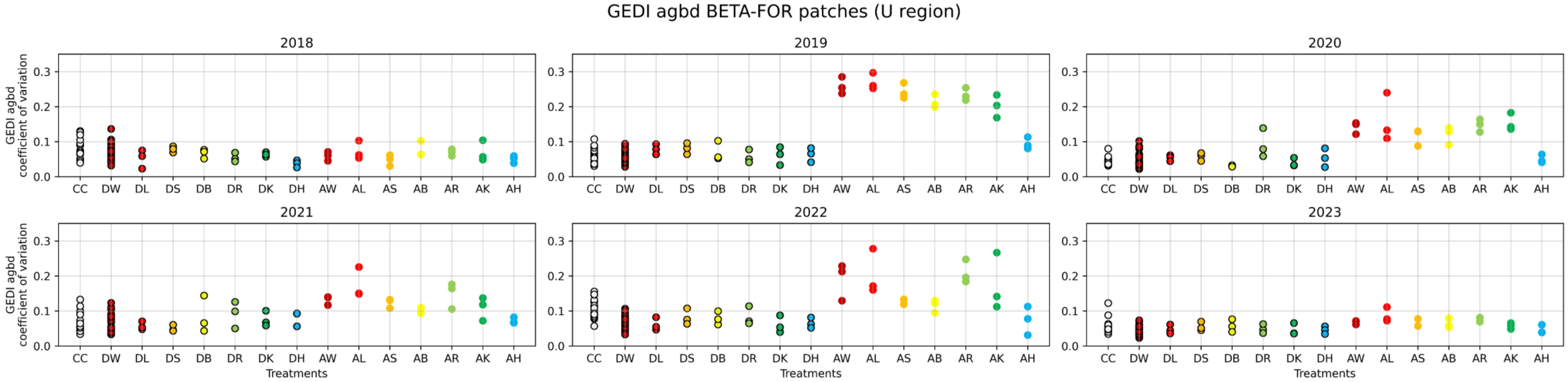


GEDI data – Total Canopy Cover

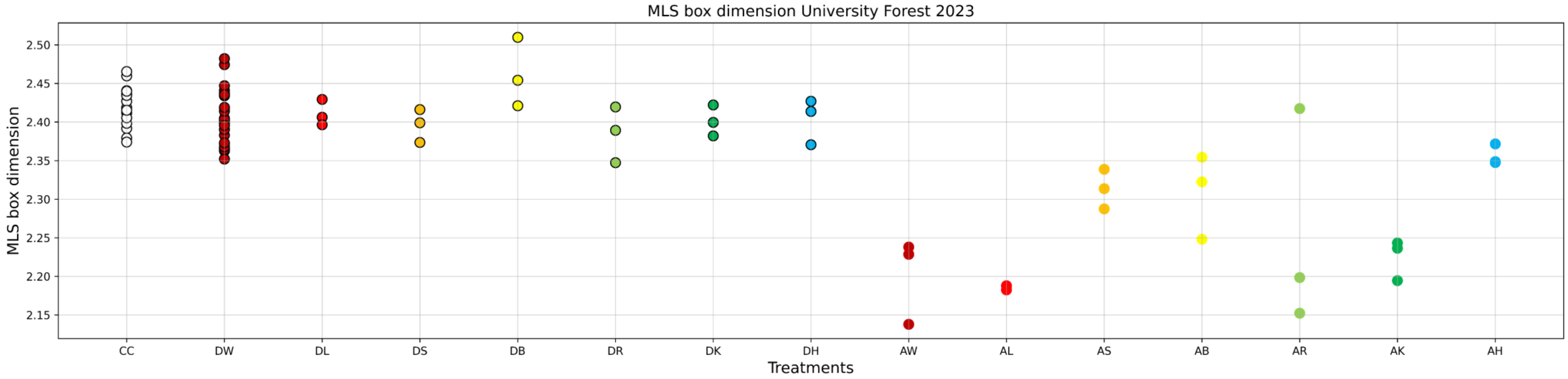


GEDI data – Canopy height and AGBD

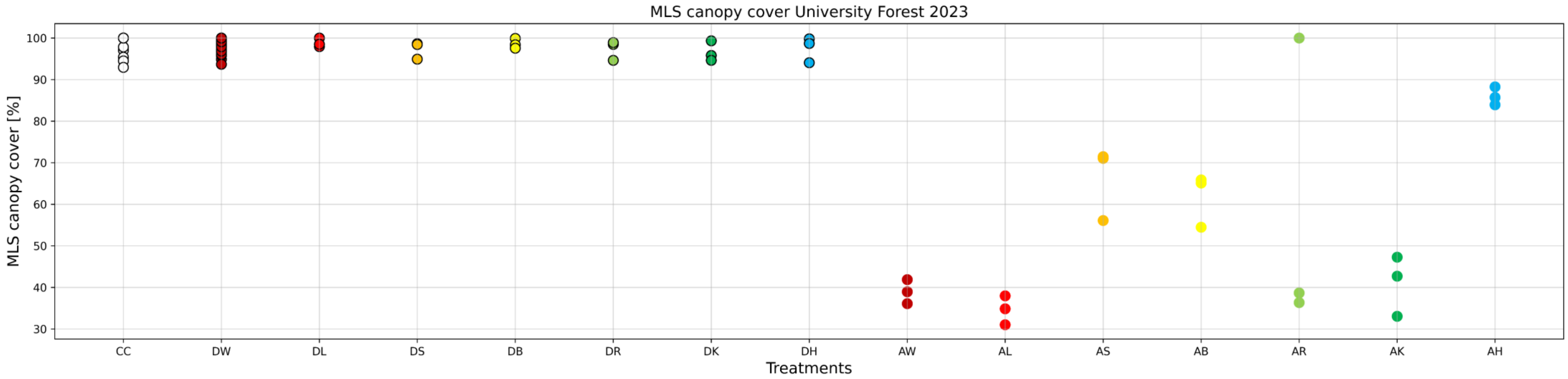




MLS data

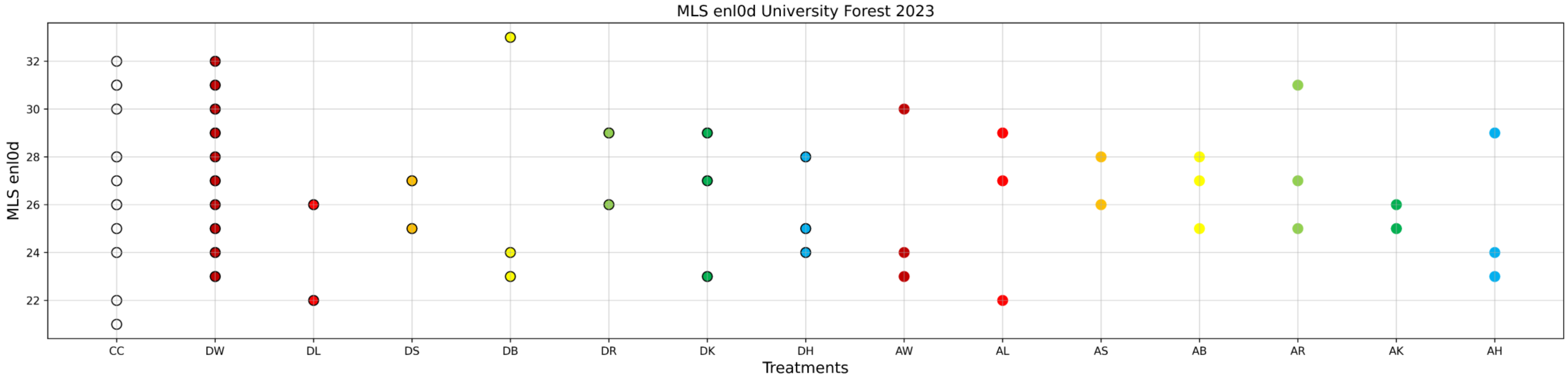


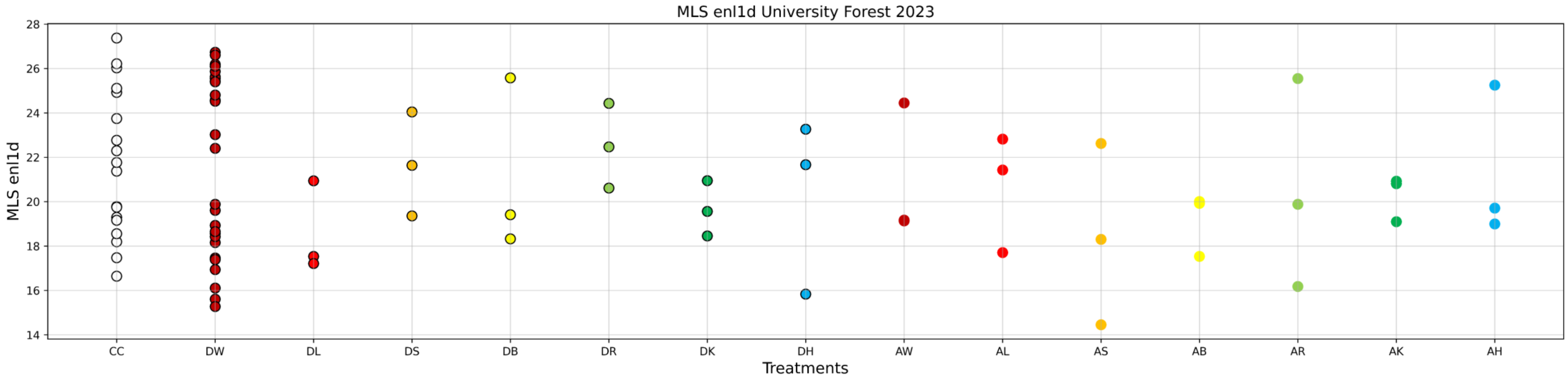
MLS box dimension University Forest 2023
MLS box dimension
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
CC DW DL DS DB DR DK DH AW AL AS AB AR AK AH
Treatments



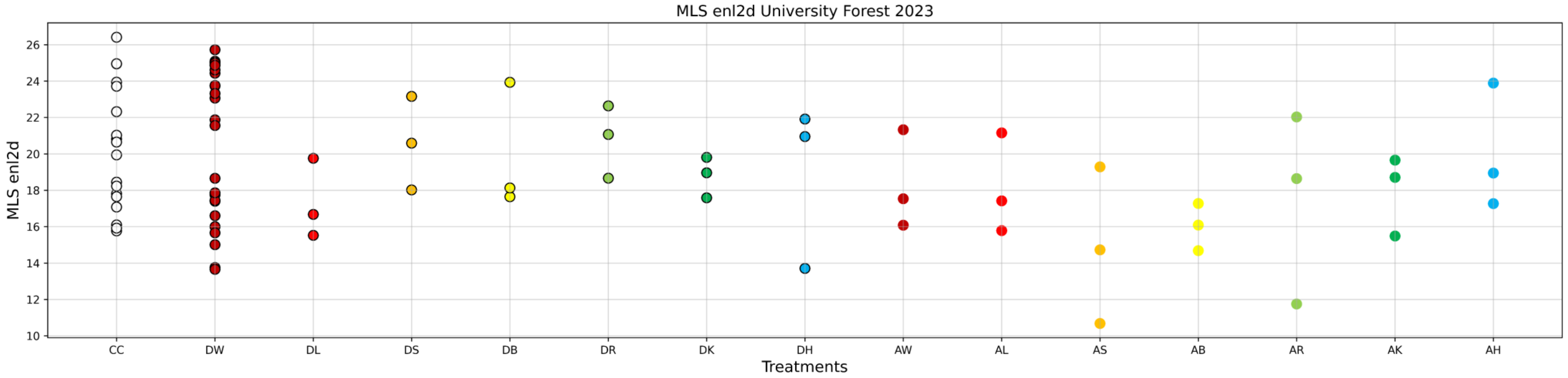
MLS canopy cover University Forest 2023
MLS canopy cover [%]
100
90
80
70
60
50
40
30
CC DW DL DS DB DR DK DH AW AL AS AB AR AK AH
Treatments

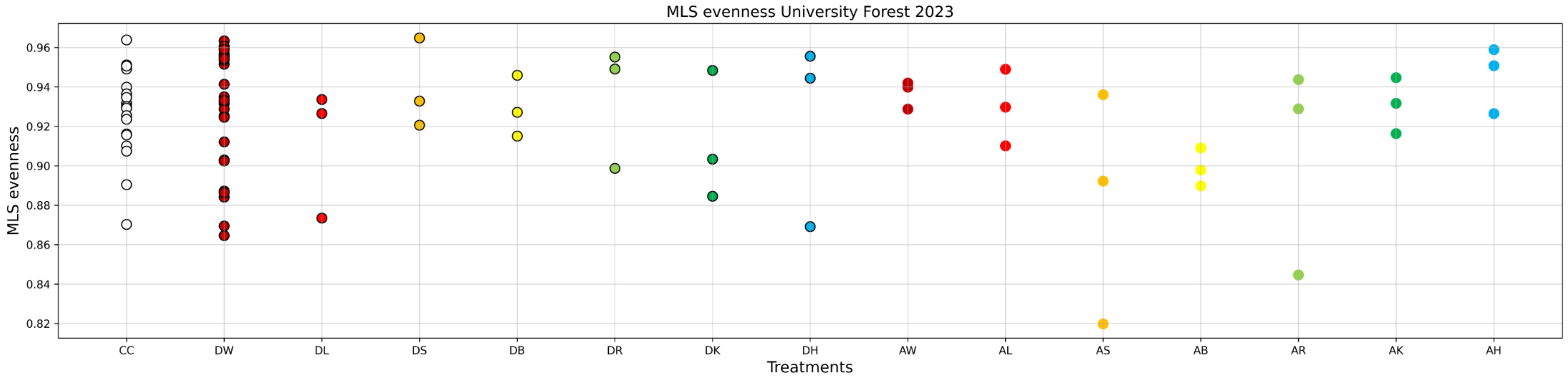
MLS data


MLS enl0d University Forest 2023
MLS enl0d
Treatments
CC DW DL DS DB DR DK DH AW AL AS AB AR AK AH
22 24 26 28 30 32

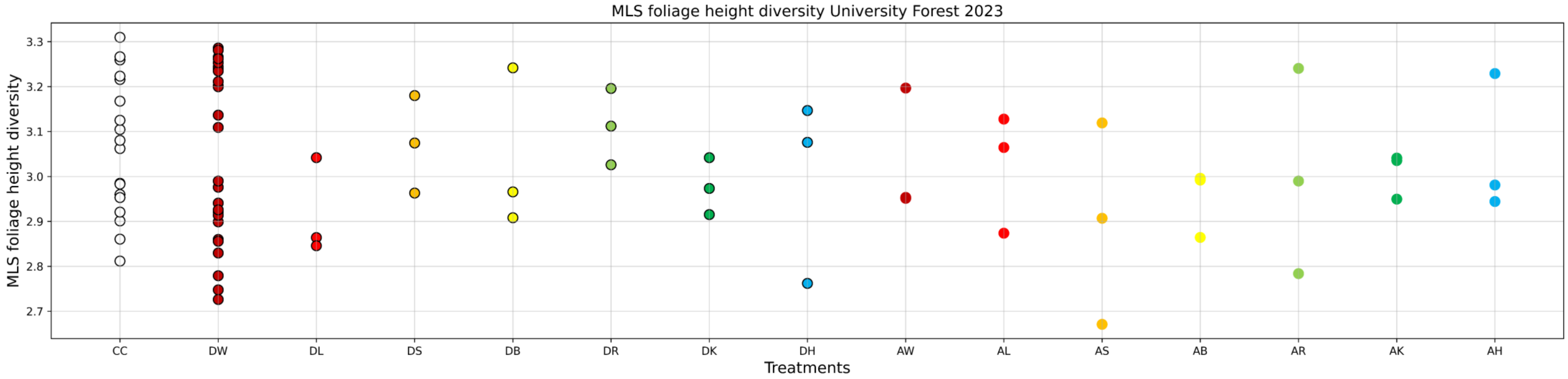

MLS enl1d University Forest 2023
MLS enl1d
Treatments
CC DW DL DS DB DR DK DH AW AL AS AB AR AK AH
14 16 18 20 22 24 26 28

MLS data


MLS enl2d University Forest 2023
MLS enl2d
26
24
22
20
18
16
14
12
10
CC
DW
DL
DS
DB
DR
DK
DH
AW
AL
AS
AB
AR
AK
AH
Treatments

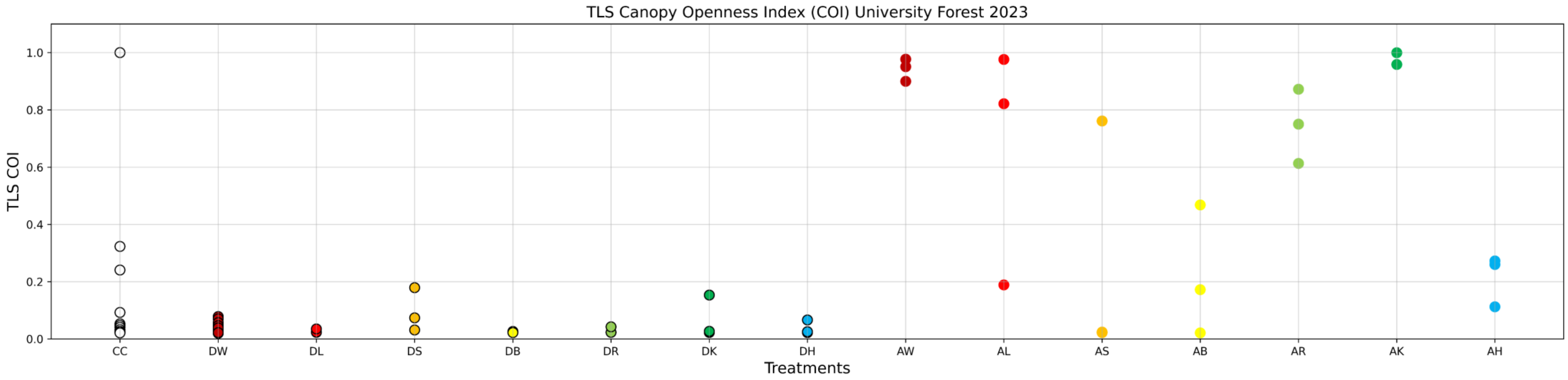

MLS evenness University Forest 2023
MLS evenness
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
CC
DW
DL
DS
DB
DR
DK
DH
AW
AL
AS
AB
AR
AK
AH
Treatments

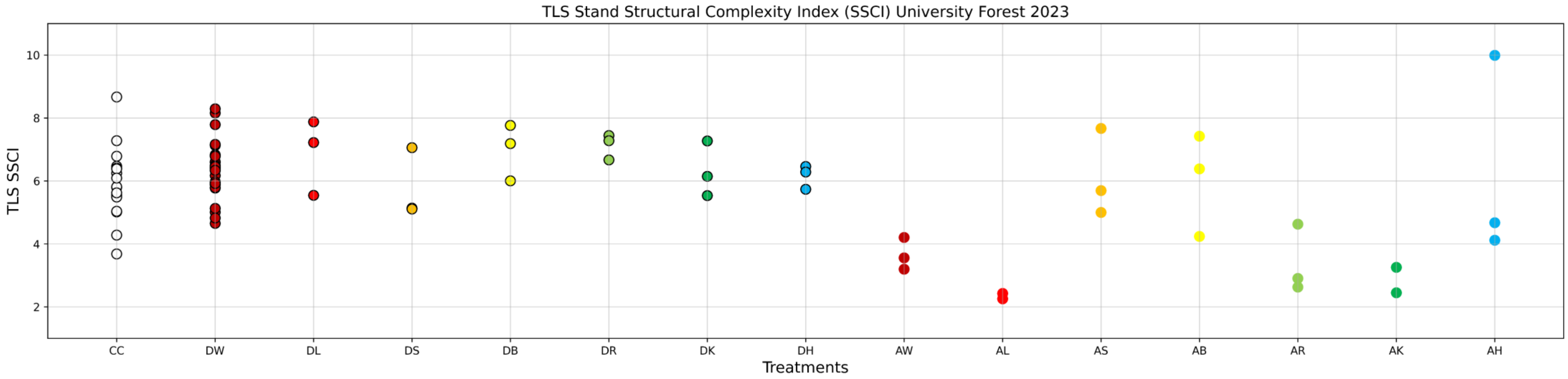
MLS data



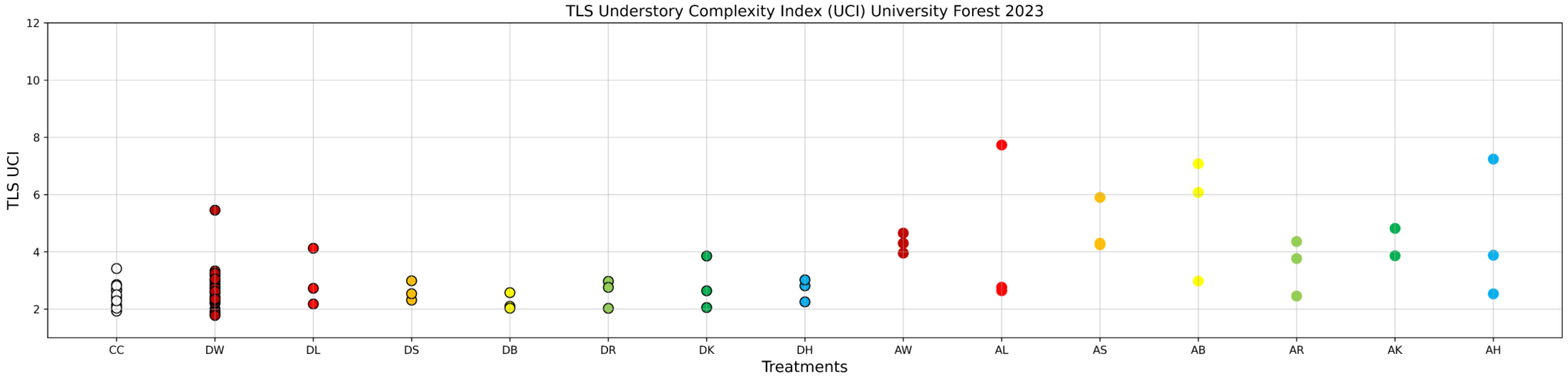
- Comment to MLS data:
  - Only the variables **„box dimension“ and „canopy cover“** (slide 32) **can delineate differences in structural complexity among treatment groups** (C*|D* vs. A*), i.e. increased structural complexity in A* treatments
  - Therefore, **only results for „box dimension“ and „canopy cover“ are shown for correlation and multivariate analyses**
  - **Correlation Heatmap (2023) for all MLS variables** are in the **Supplementary files** (slide 39)

TLS data


TLS Canopy Openness Index (COI) University Forest 2023
TLS COI
1.0
0.8
0.6
0.4
0.2
0.0
CC
DW
DL
DS
DB
DR
DK
DH
AW
AL
AS
AB
AR
AK
AH
Treatments


TLS Stand Structural Complexity Index (SSCI) University Forest 2023
TLS SSCI
10
8
6
4
2
CC
DW
DL
DS
DB
DR
DK
DH
AW
AL
AS
AB
AR
AK
AH
Treatments

TLS data



- Comment to TLS data:
  - **TLS variables (2023) do not delineate A* treatments as clearly from C*|D*** as MLS box dimension and canopy cover
  - AS, AB, and AH treatments are often more similar to C*|D* than AW, AL, AR, and AK
  - **Standing deadwood structures (AS, AB, AH)** influence the structural complexity measured as COI (canopy openness index), stand structural complexity index (SSCI), and understory complexity index (UCI)