# LANDSAT TIME SERIES ANALYSIS –
# The Impact of Forest Ecosystem History on Biodiversity

CHAIR OF FOREST INVENTORY AND REMOTE SENSING
UNIVERSITY OF GOETTINGEN, GERMANY
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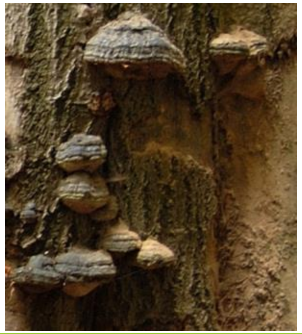
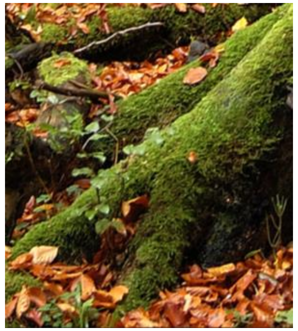
# Forest structure and biodiversity





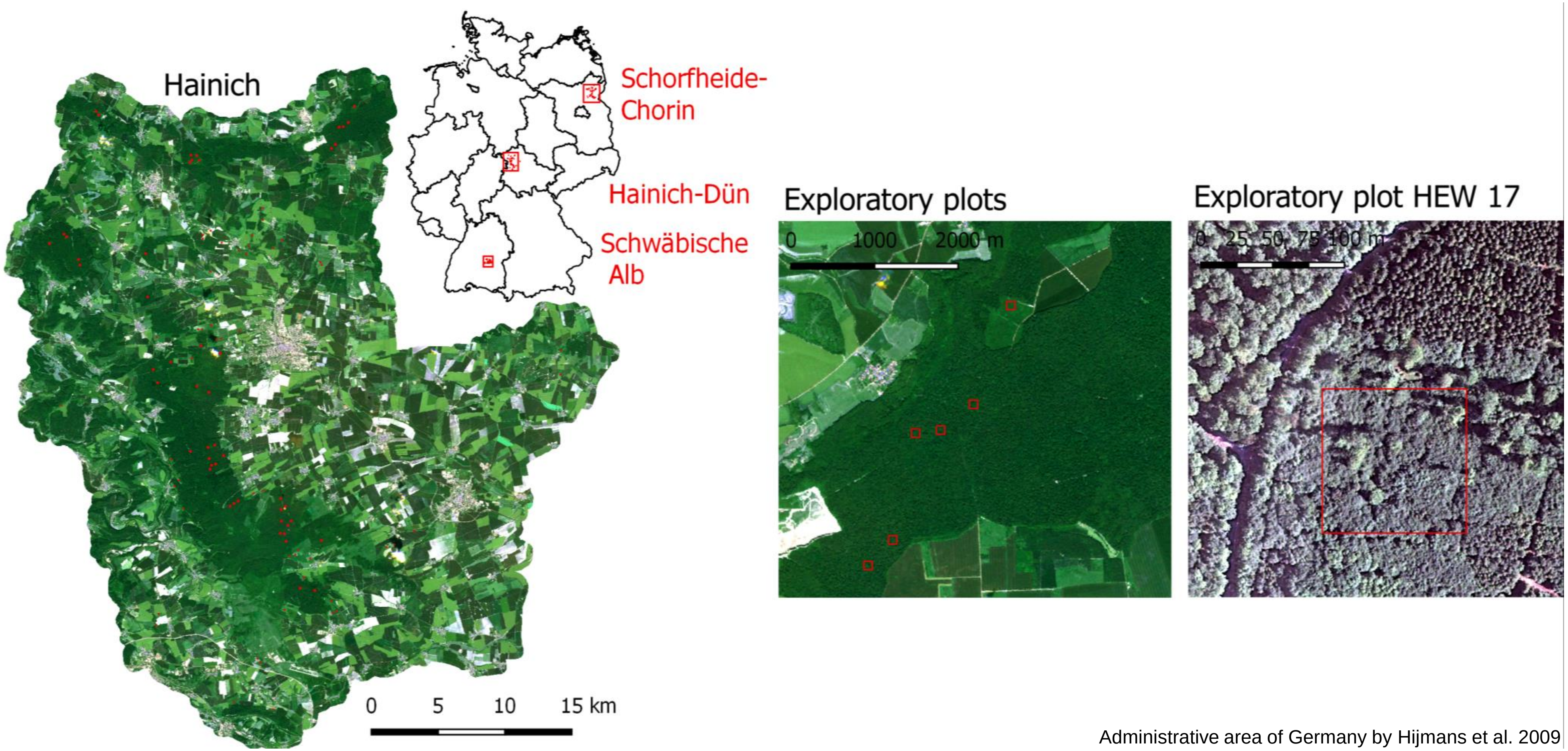
Pictures National Park Hainich
Thomas Stephan (www.thomas-stephan.com)
Rüdiger Biehl (Nationalpark-Hainich@NNL.thueringen.de)

# Objectives

Relationship of ecosystem history and biodiversity in temperate forests in Germany.

1. Can **trends, changes in trend** or **disturbances** be detected in Landsat time series of temperate forests from 1985 to 2015?
2. Do disturbances and changes in trend affect **herbal layer plant species diversity** in temperate forests?

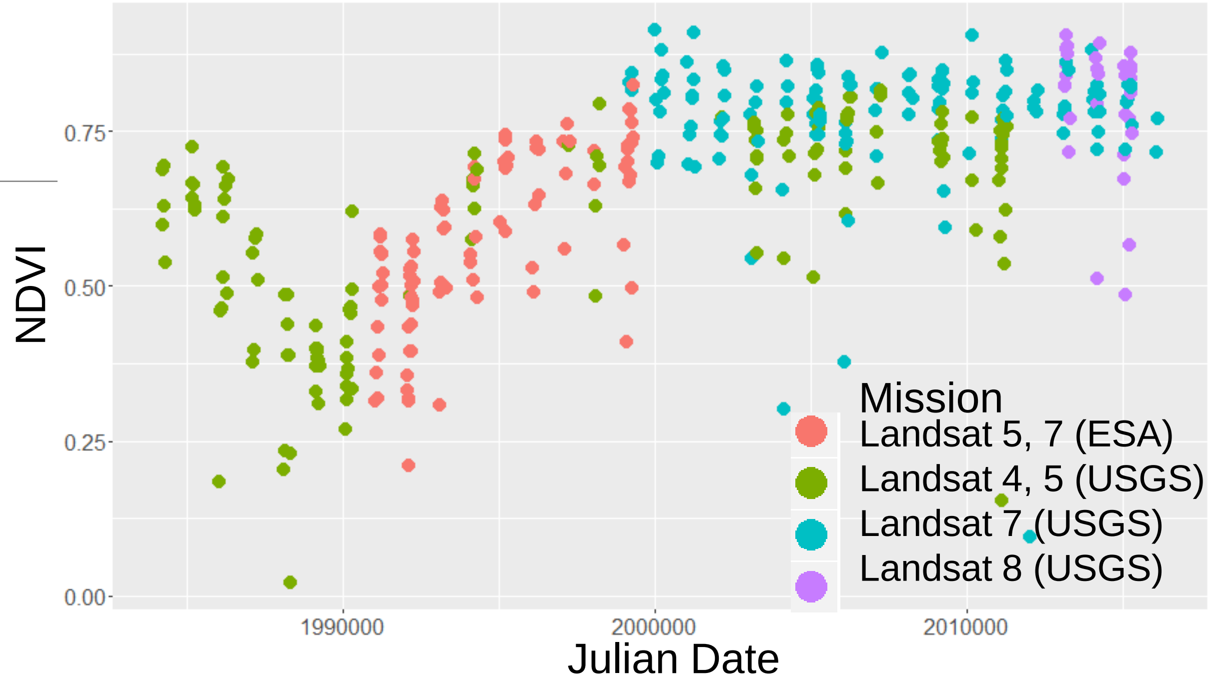
# Study Area & Project background




Administrative area of Germany by Hijmans et al. 2009

# Methods – NDVI time series

USGS archive (3365 images)




ESA archive (747 images)

Georeferenced data

LEDAPS

Surface reflectance

CFmask

Masking → Extraction of surface reflectance values → Calculation of NDVI → Exclusion of cloud pixels (NDVI < 0.002) → Mean NDVI for each EP → Maximum of mean NDVI for each growing season

# Methods – NDVI time series

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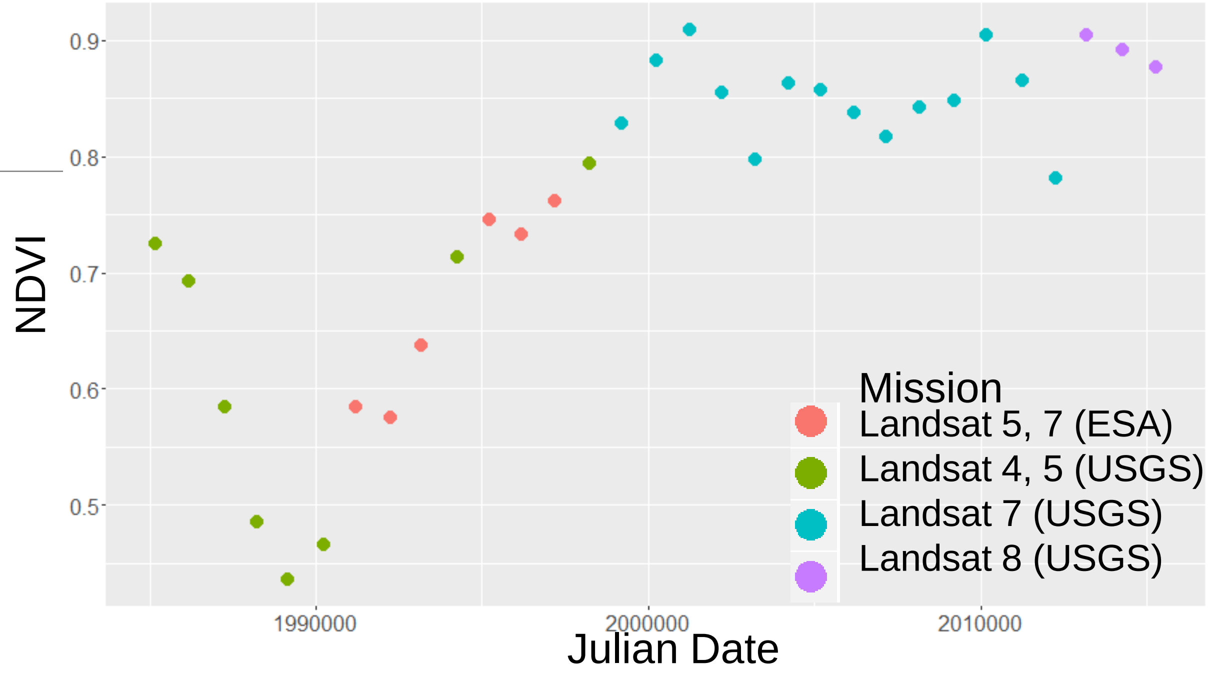


Surface reflectance

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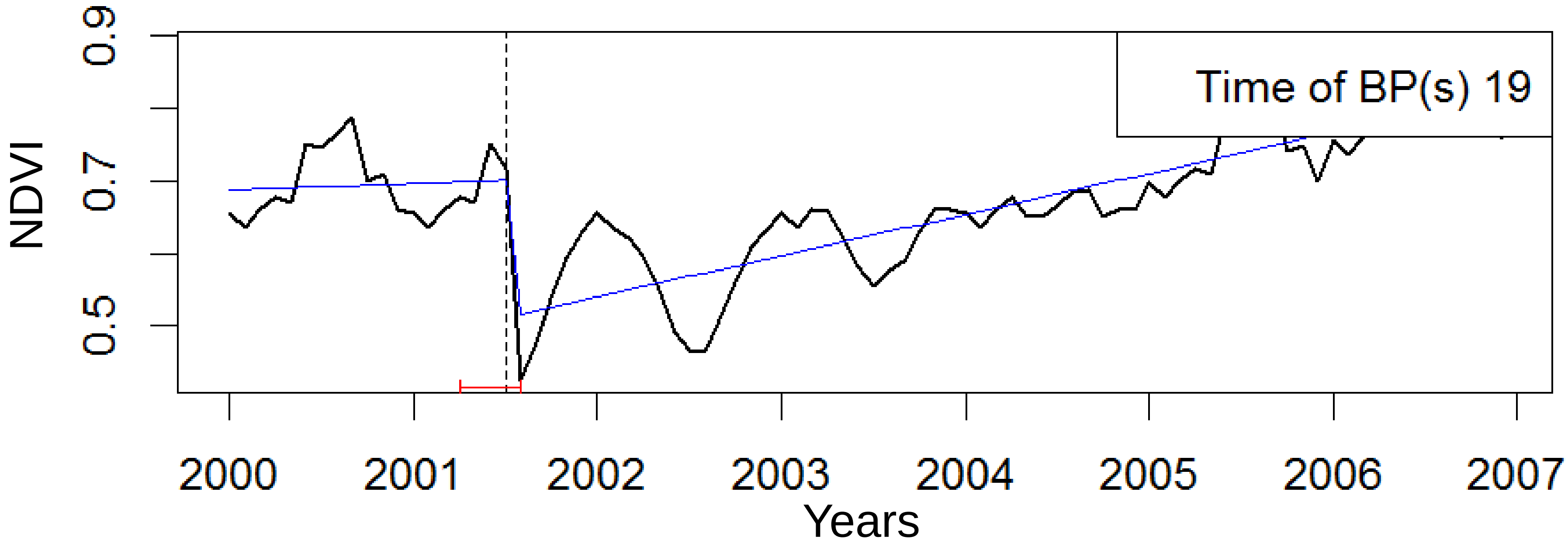
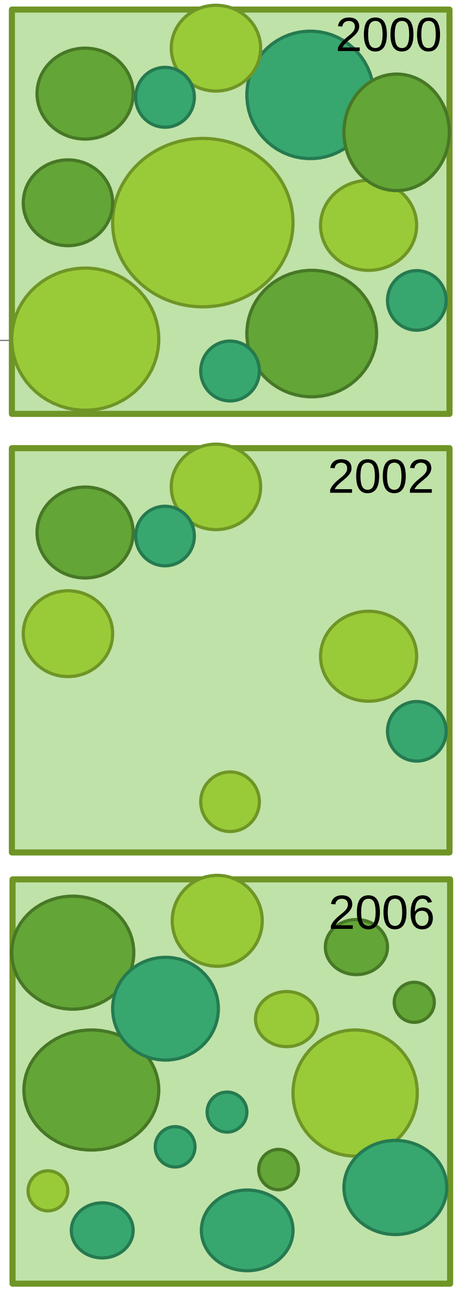
Masking → Extraction of surface reflectance values → Calculation of NDVI → Exclusion of cloud pixels (NDVI < 0.002) → Mean NDVI for each EP → Maximum mean NDVI for each growing season

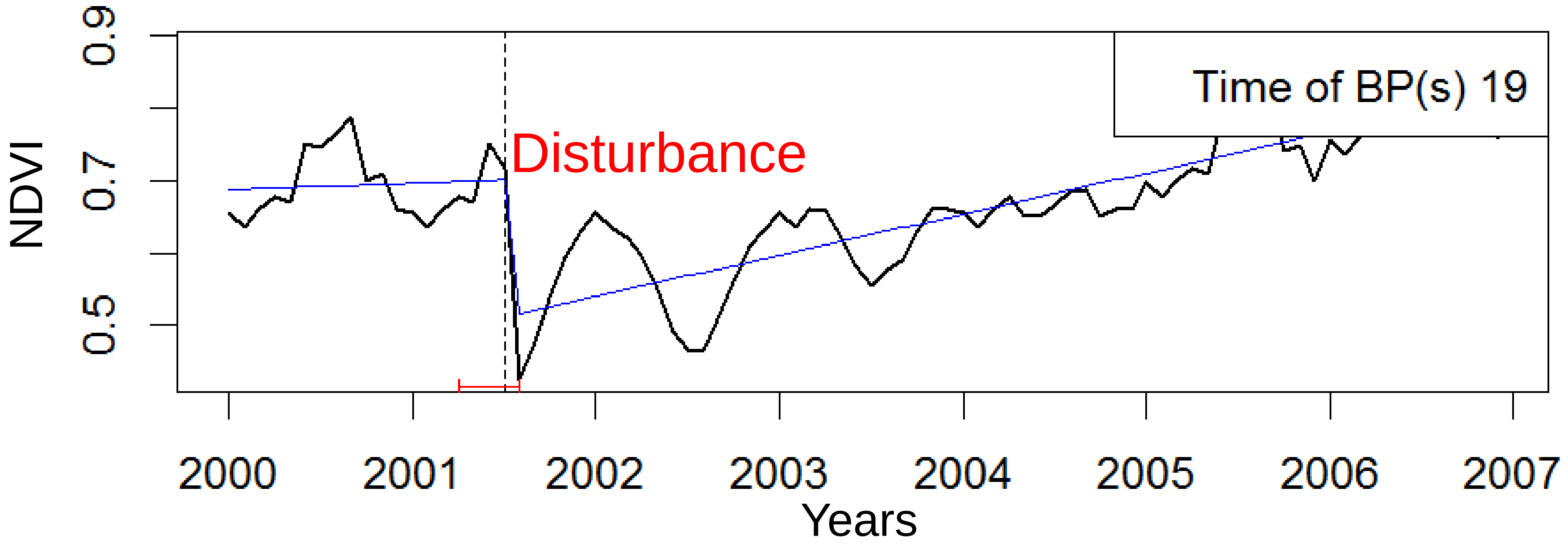
# Methods – Time series analysis

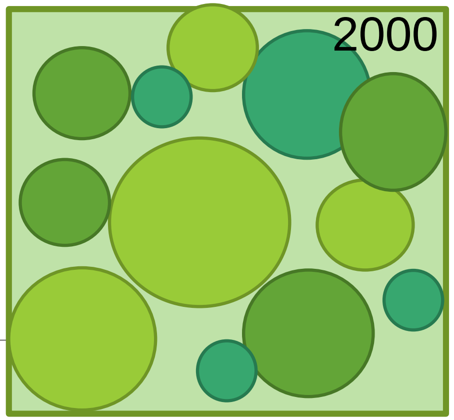


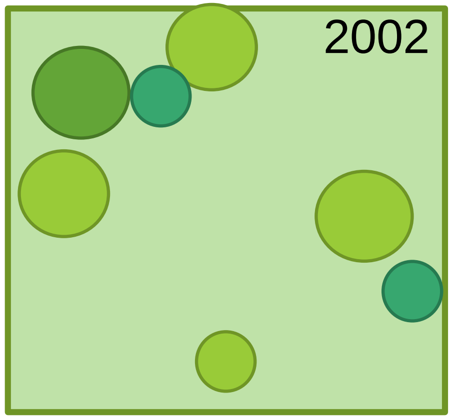



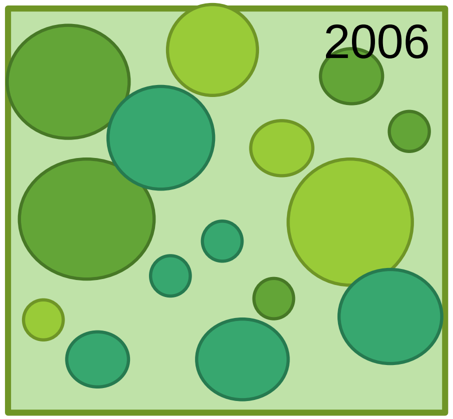

- Test for significant upward or downward trend:
  - **Mann-Kendall trend test** (Mann 1945)
  - R-package: Kendall (Davison and Hinkley 1997, Hipel and McLeod 2005)

# Methods – Time series analysis



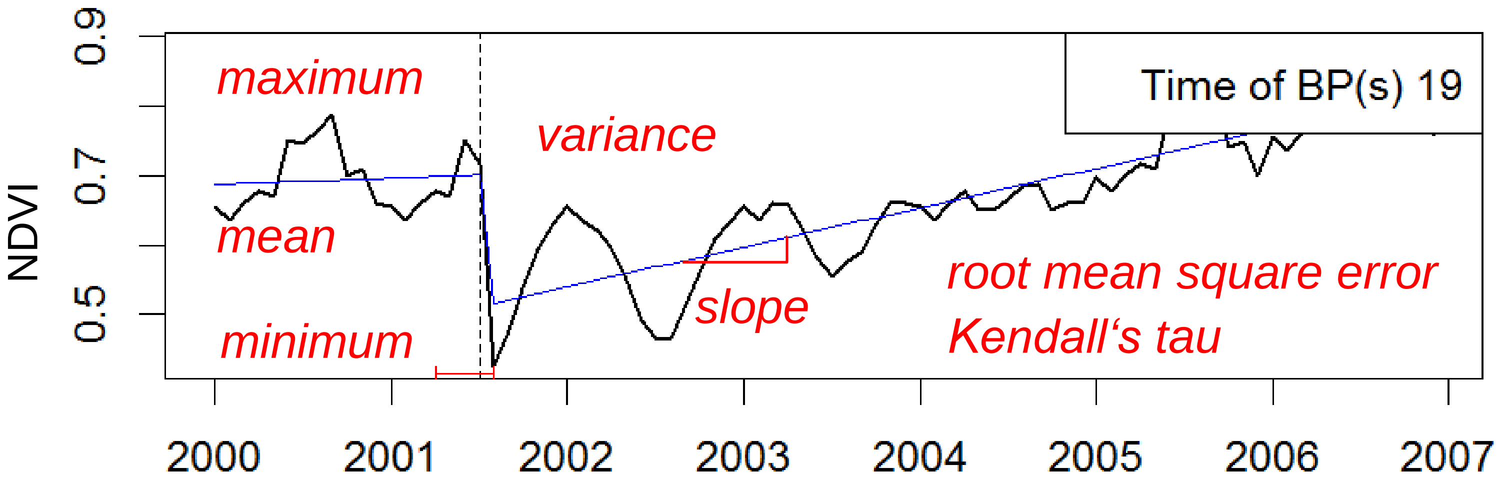



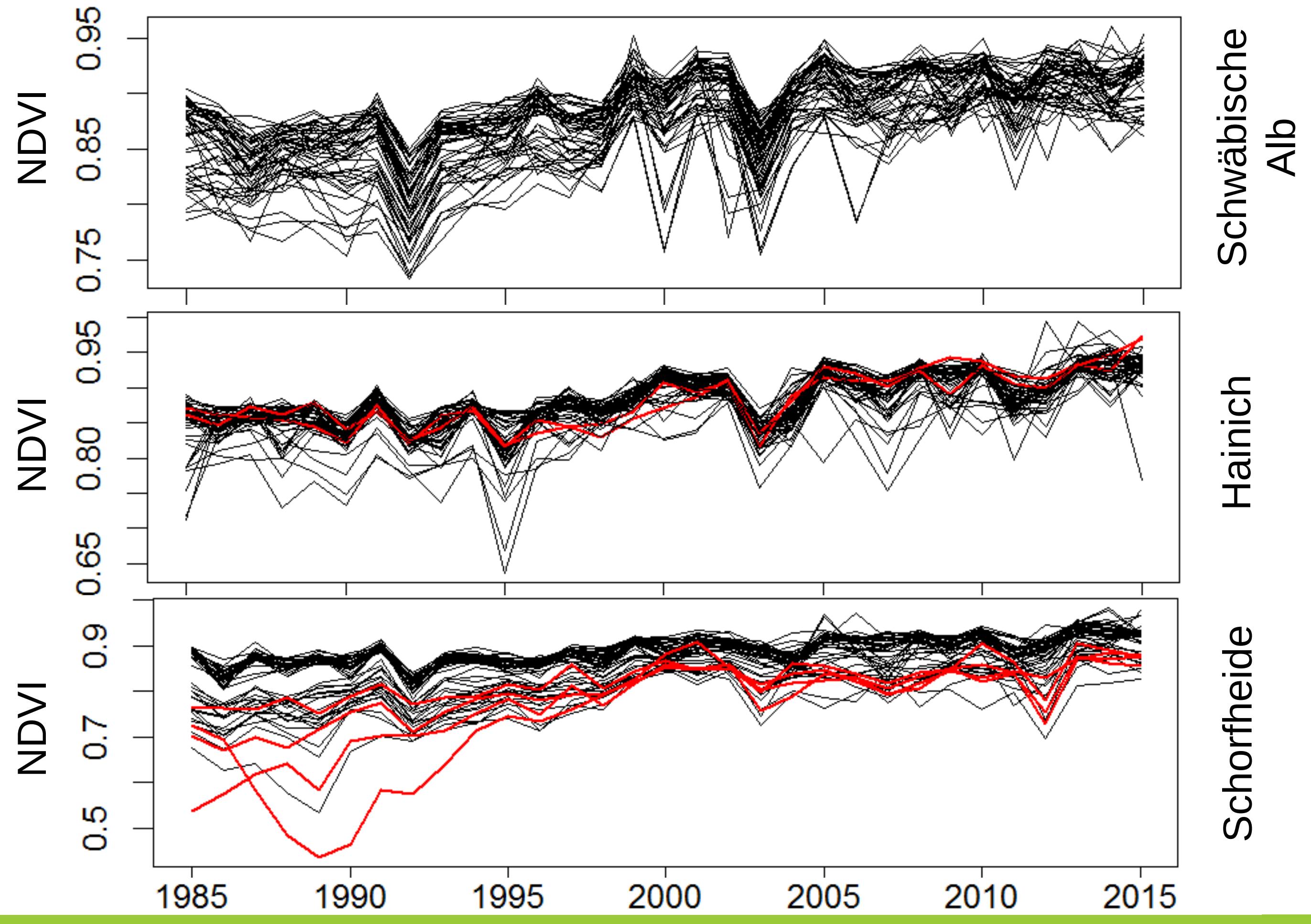

- Detection of breaking points and their magnitude in trend
  - **B**reaks **F**or **A**dditive **S**easonal and **T**rend (**BFAST**) algorithm
  - R-package: bfast (Verbesselt et al. 2010 a, b)
  - Ordinary least squares residuals based **MO**ving **SUM** (**MOSUM**) test (Zeileis et al. 2002)

# Methods – Relationship of biodiversity index and time series parameter

- **Simpson's diversity index** (Simpson 1949)
  - **Plant cover estimations** of species in the **herbal layer** in an area of 20x20m in all forest EPs in 2015 (Fischer et al. 2015)
- **Differences** in **Simpson's diversity index** between plots with and without **breaking points** (Wilcoxon-Mann-Whitney test (Bauer 1972))
- Linear relationship between **Simpson's diversity index** and **trend parameter**

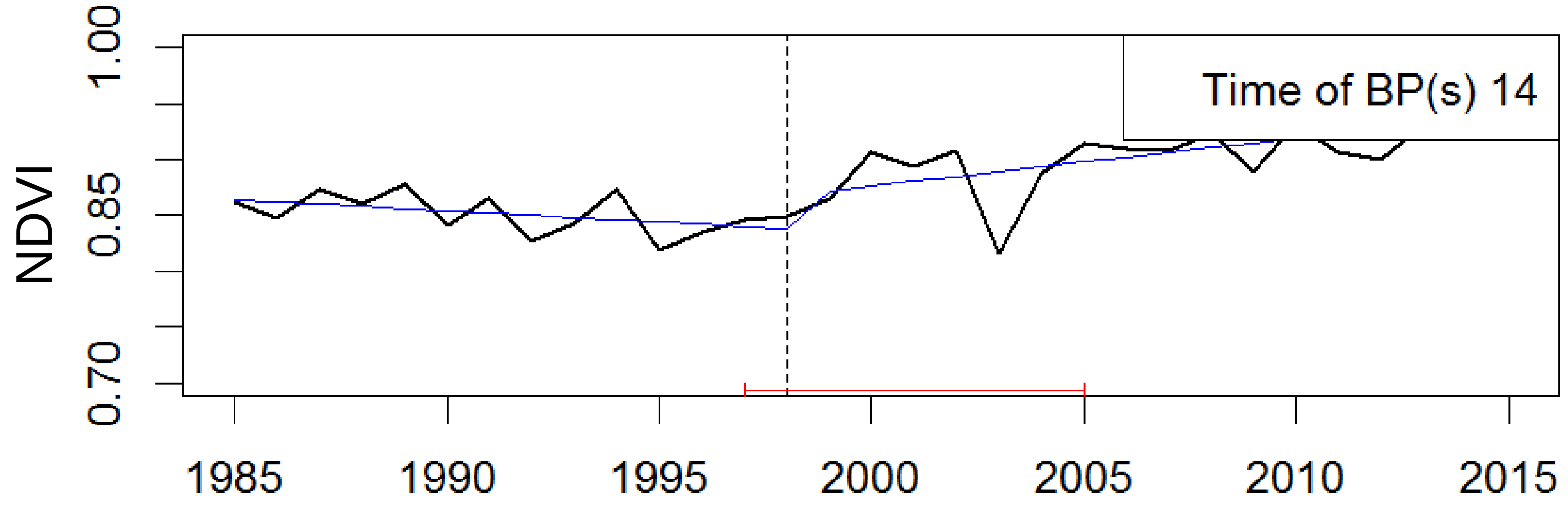


# Results – Trend

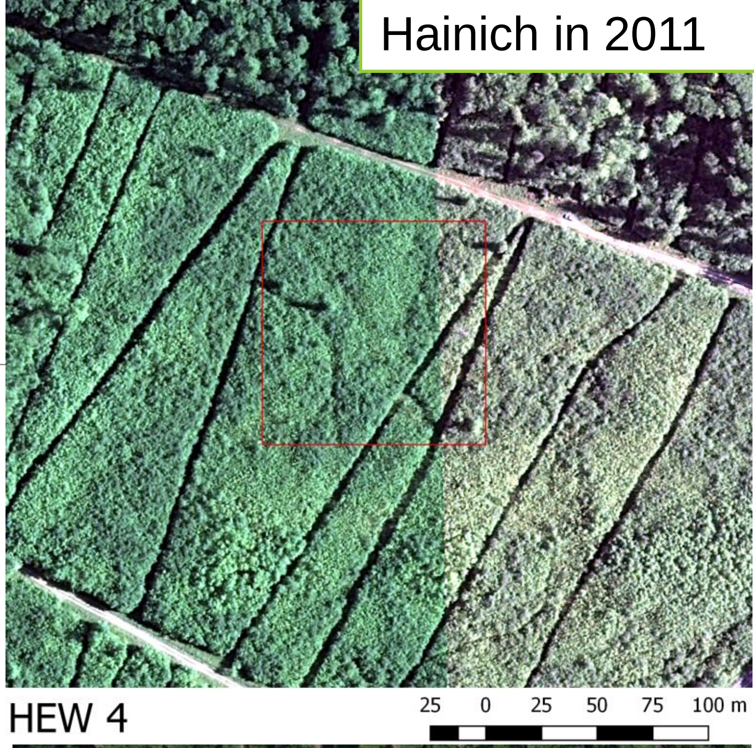


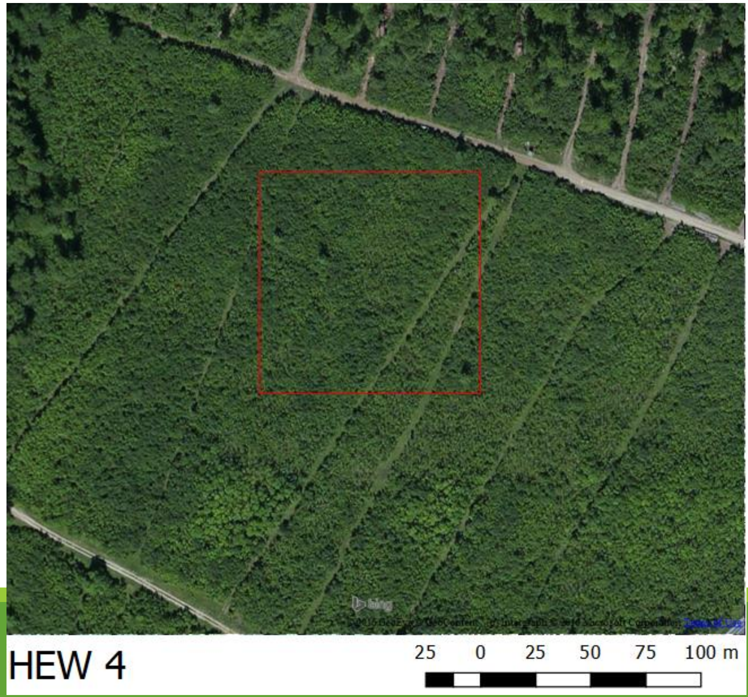

- Kendall‘s tau: positive between 0.31 and 0.82
- Significant at a significance level of 0.01 (44 trends) and 0.05 (3 trends)

# Results – Breaking points

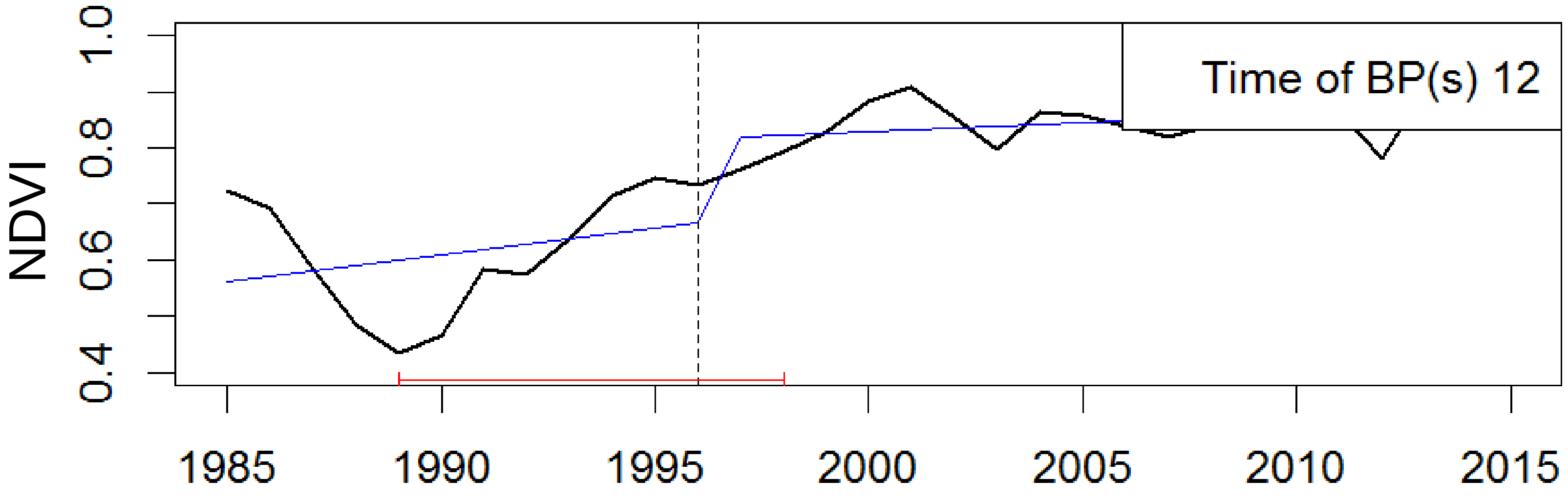



Magnitude of change: 0.033

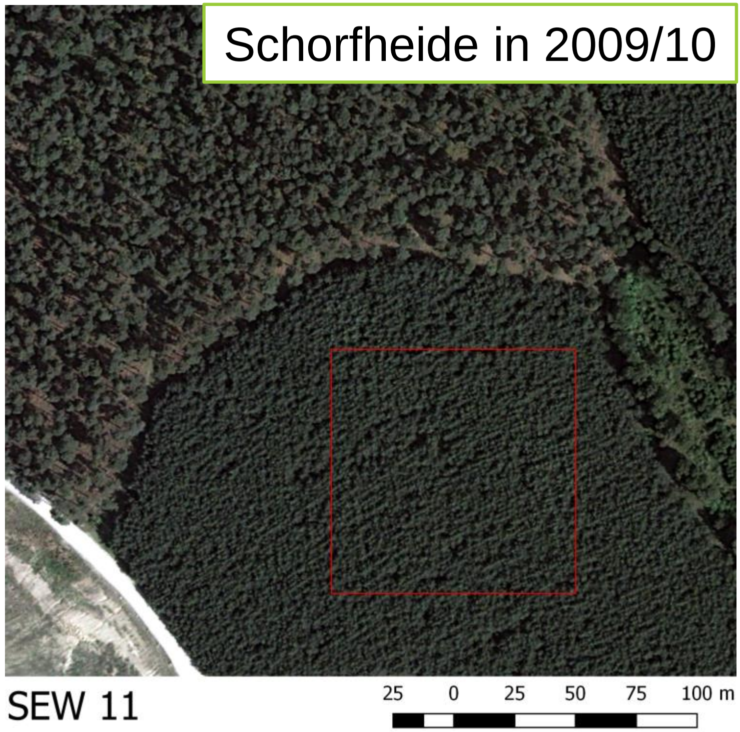


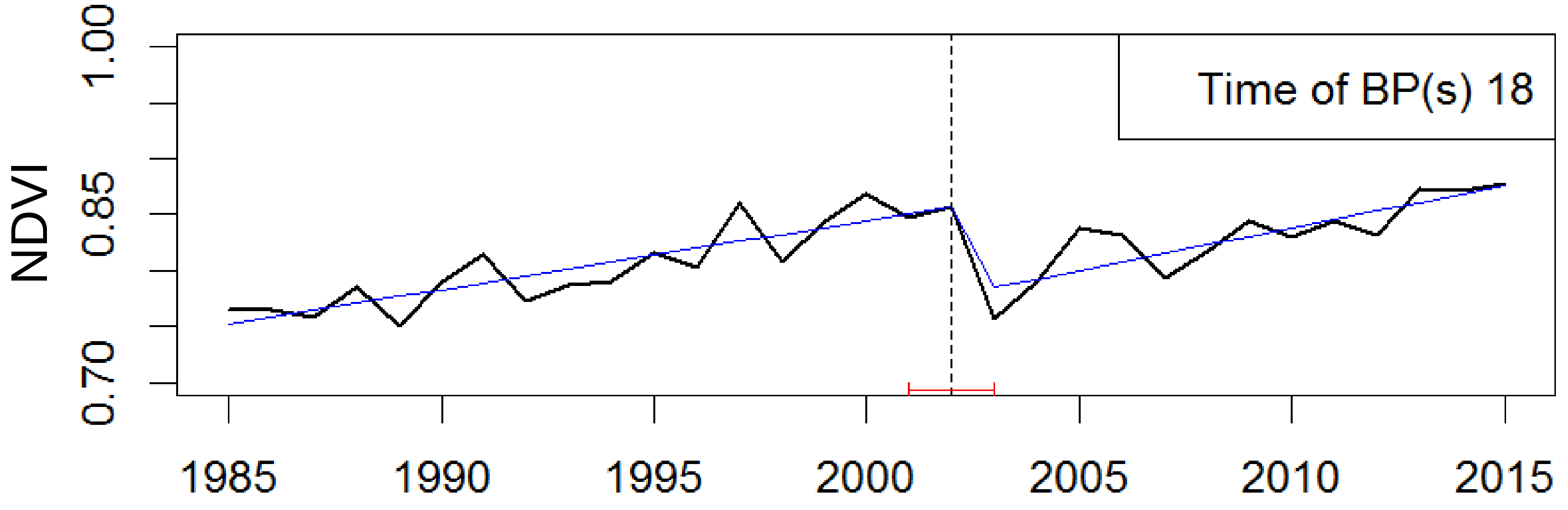
# Results – Breaking points



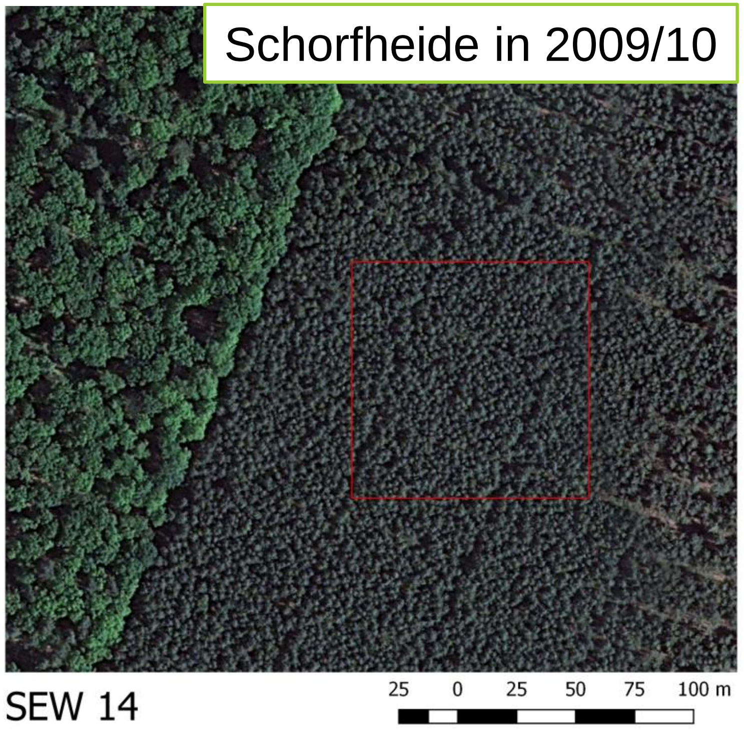

Magnitude of change: 0.152



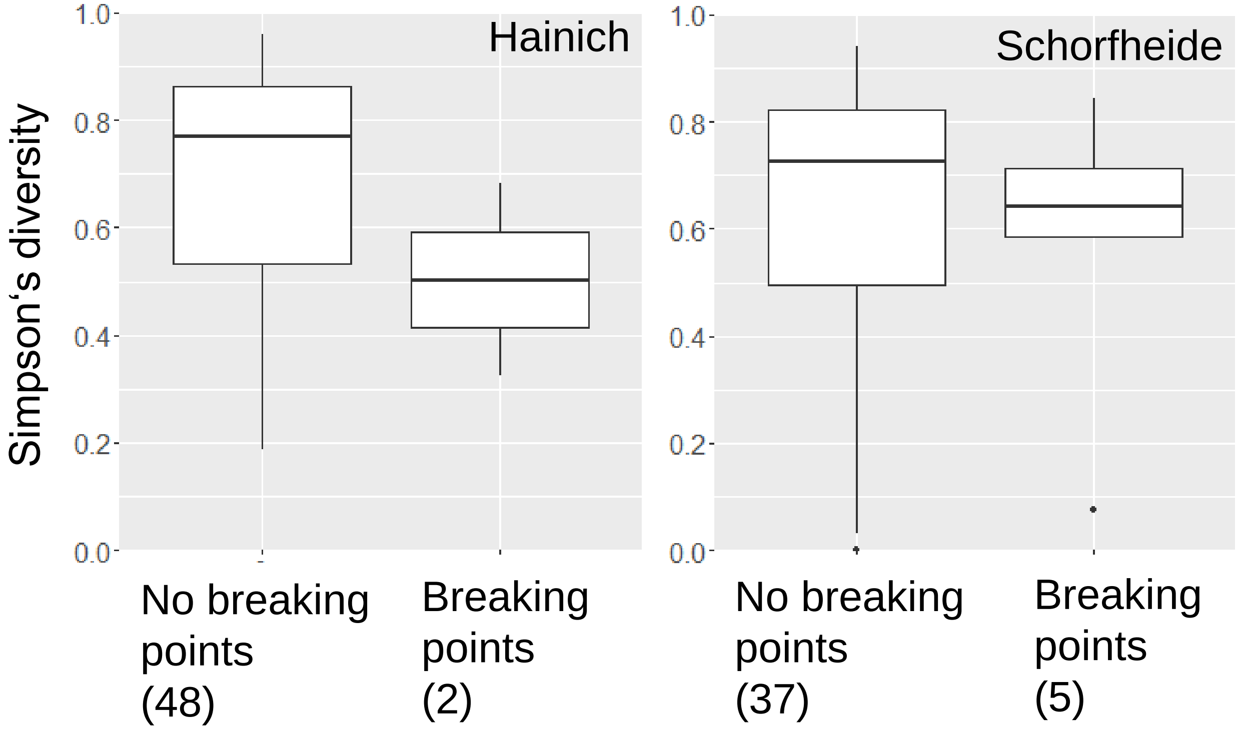
# Results – Breaking points




Magnitude of change: -0.072



# Results – Relationship of biodiversity index and time series parameter

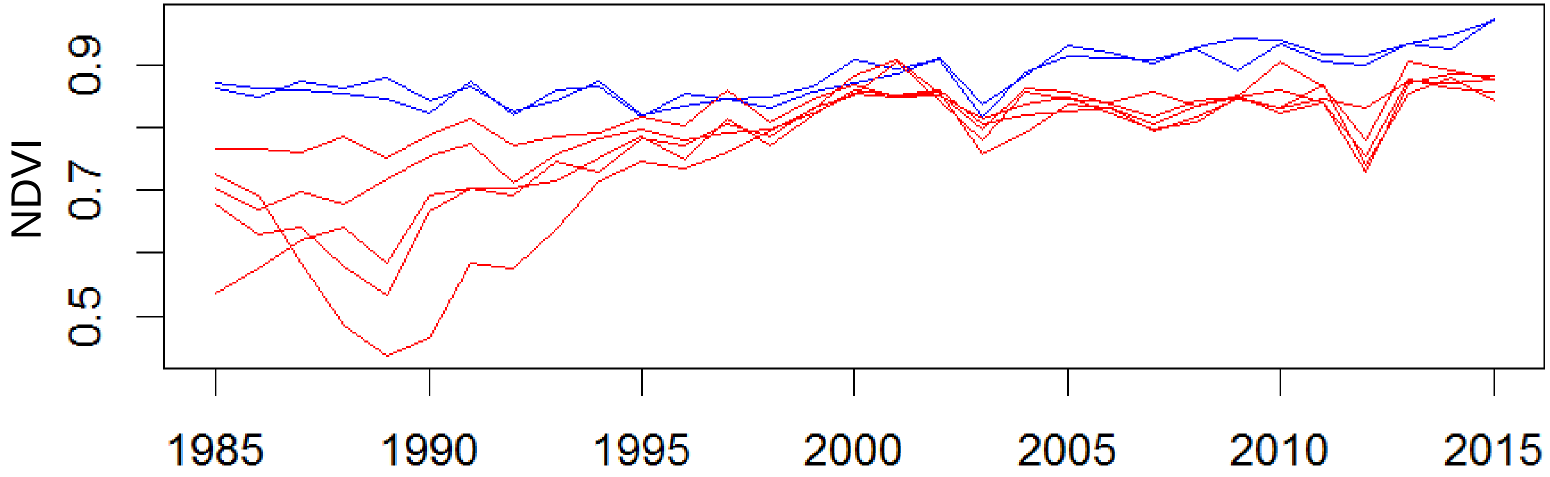



- **Significant positive** linear relationship with Simpson's diversity index:
  - RMSE: 0.1514 (Hainich)
    R-squared: 0.15
- **Significant negative** linear relationship with Simpson's diversity index:
  - Kendall's tau (Hainich)
  - Mean NDVI (Hainich, Schwäbische Alb)
  - Minimum NDVI (Hainich)
    R-squared: 0.04 – 0.20

(Significance level at 0.05 or 0.01)

- Not statistically significant (Wilcox-Mann-Whitney Test)

# Discussion




Time series of EPs with significant breaking points in Hainich
Time series of EPs with significant breaking points in Schorfheide


# Discussion & Conclusion

1. The combined Landsat time series of the archives of USGS and ESA can be used to analyze **ecosystem history** in temperate forests in Germany from 1985 to 2015.
2. Further research on the **relationship** between **Simpson's diversity index** and **ecosystem history** is needed.
3. **Continuous forest management** in our study areas causes **small-scale, low magnitude disturbances**, which do not affect the greenness over several years.

→ Analyses of the **seasonal component**

- Algorithms allowing for discontinuous time series data
  e.g. Continuous Change Detection and Classification (Zhu and Woodcock 2014)
- Fusion of Landsat and MODIS time series to obtain dense, continuous time series
  e.g. Spatial and Temporal Adaptive Reflectance Fusion Model (Gao et al. 2006)

# Thank you for your attention

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- **Landsat archives**
  - Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) Surface Reflectance data courtesy of the U.S. Geological Survey
  - Landsat 5 Thematic Mapper (TM ), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) 1992 – 1999 Data provided by European Space Agency

# Picture credits

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# Data

| Provider | Mission | Sensor | ALB | HAI | SCH |
|---|---|---|---|---|---|
| **USGS** | Landsat 4 | TM | 20 | 42 | 17 |
| **USGS** | Landsat 5 | TM | 454 | 684 | 458 |
| **USGS** | Landsat 7 | ETM+ | 404 | 504 | 343 |
| **USGS** | Landsat 8 | OLI | 166 | 168 | 105 |
| **ESA** | Landsat 5 | TM | 321 | 147 | 263 |
| **ESA** | Landsat 7 | ETM+ | 10 | 4 | 2 |
| **Total** | | | 1375 | 1549 | 1188 |

# BFAST

1. Additive decomposition model

*Yt observed value at time t*
*Tt trend component*
*St seasonal component*
*Et remainder component*

$$Y_t = T_t + S_t + e_t, \mathrm{t} = 1, \dots, \mathrm{n}$$

$$T_t = \alpha_j + \beta_j t$$

Assumption of Tt being piecewise linear with breakpoints $t_1^*, \dots, t_m^*$ $for\ t_{j-1}^* < t < t_j^*$

$$Magnitude = (\alpha_{j-1} - \alpha_j) + (\beta_{j-1} - \beta_j)t$$

2. Iterative test for occurrence of breakpoints
   - Ordinary least squares (OLS) residuals-based MOving SUM (MOSUM) test
   - Tested from Yt- St
   - Robust regression models for sections of a time series between the break points at the times where the changes occur (based on equation 1)
   - Only the most significant changes will be detected (depending on the length of the time series)

3. Model parameters
   - Type: OLS-Mosum algorithm, maximal number of breaks: 3, confidence level of the OLS-MOSUM: 0.1, maximum iteration: 10, season: none

# Mann-Kendall-Rank-Sum Test

- Kendall's tau (-1.0 – 1.0)

$$\tau = \frac{S}{D} = \frac{S}{\frac{1}{2}n(n-1)}$$

Where

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

Where

$$sgn(x) = \begin{cases} +1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases}$$

| Time | NDVI | sgn(x) = 1 | sgn(x) = 0 | sgn(x) = -1 |
|---|---|---|---|---|
| $t_1$ | 0.1 | 6 | 0 | 0 |
| $t_2$ | 0.4 | 4 | 0 | 1 |
| $t_3$ | 0.5 | 3 | 0 | 1 |
| $t_4$ | 0.3 | 3 | 0 | 0 |
| $t_5$ | 0.6 | 2 | 0 | 0 |
| $t_6$ | 0.8 | 0 | 0 | 1 |
| $t_7$ | 0.7 | | | |

- $\tau = \frac{18-3}{21} = 0.714$
- Test for statistical significance: two-sided p-value

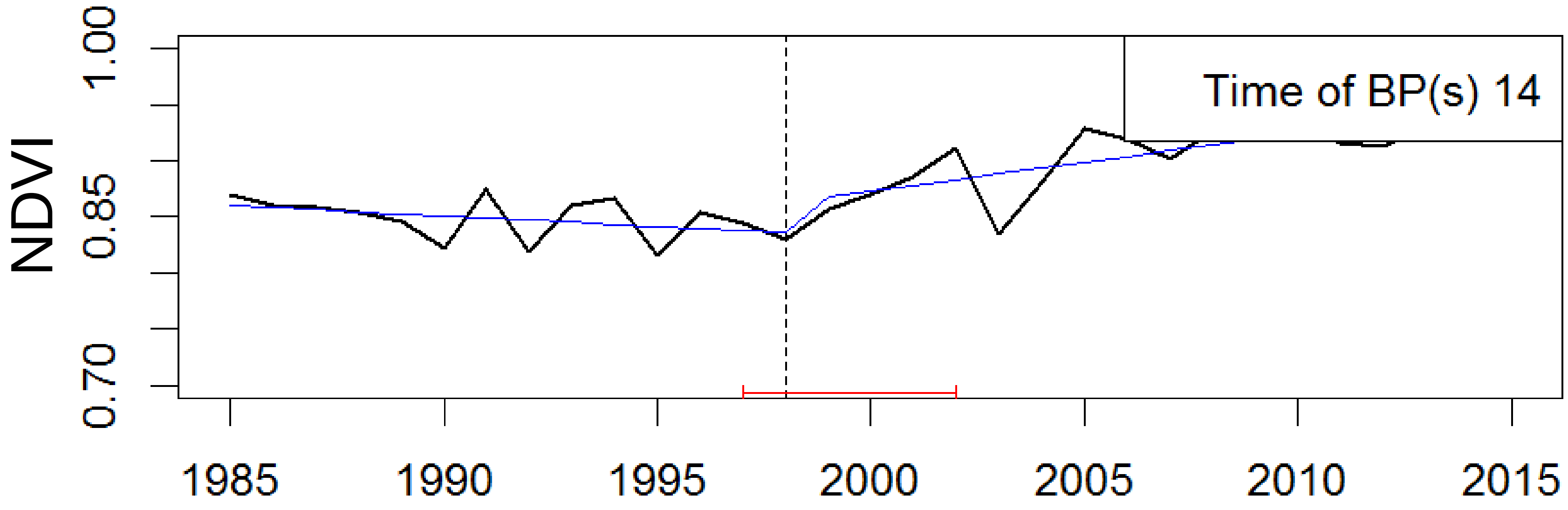
# Simpson Diversity Index

$$D = 1 - \sum_{i=1}^{S} p_i^2$$

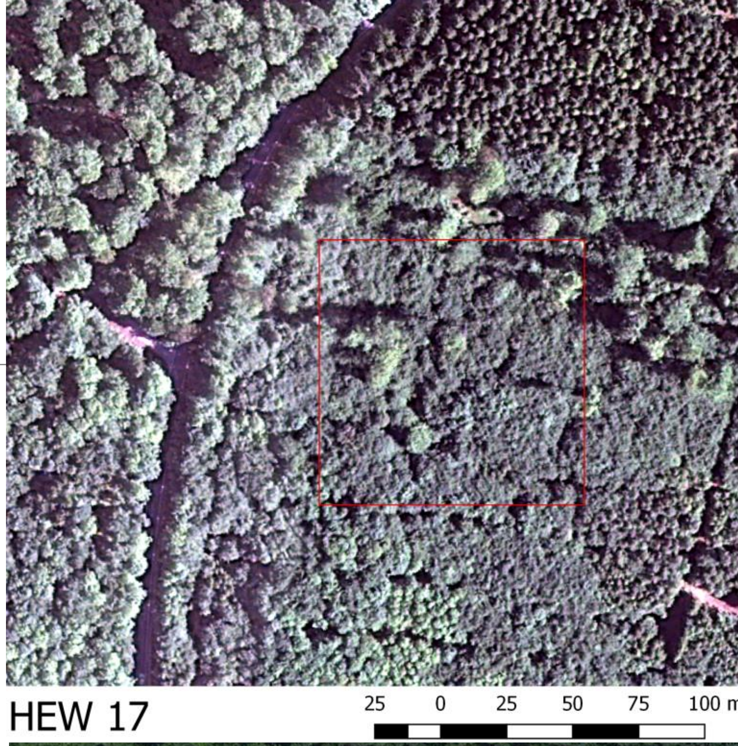
*pi: proportion of the cover of species i*

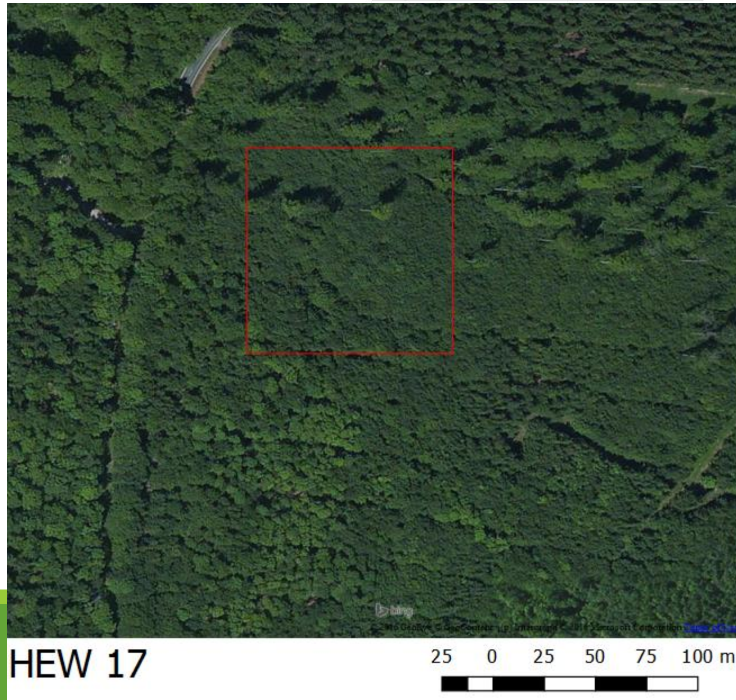
Calculated from plant cover estimates of species in the herbal layer

# Results – Breaking points

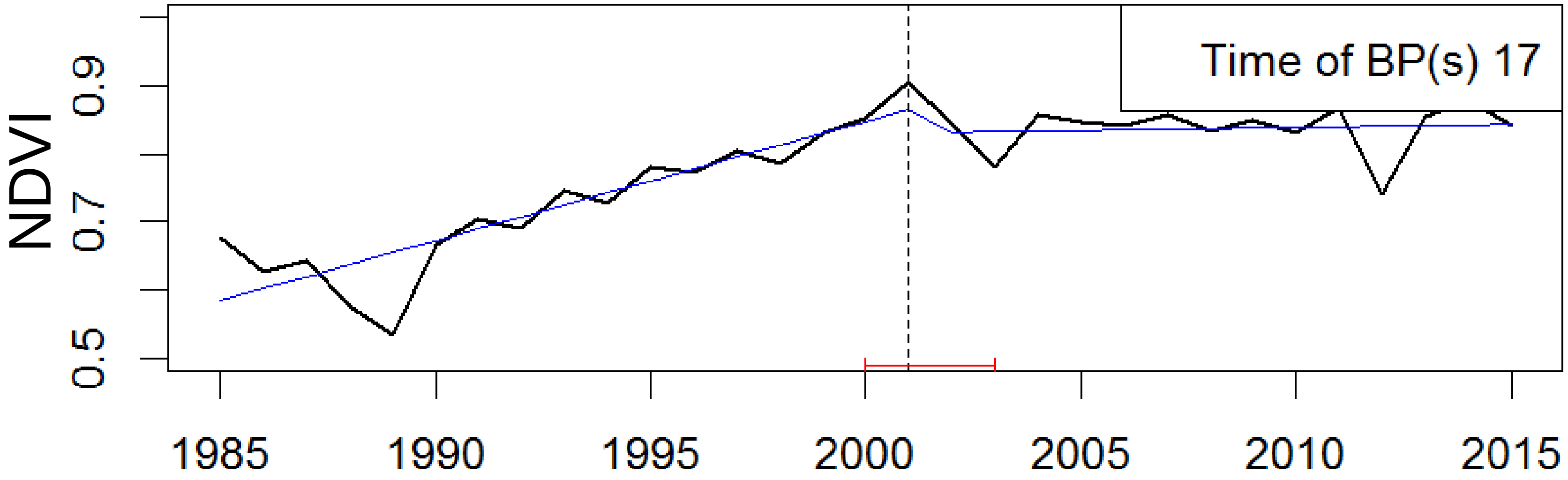



Magnitude of change: 0.031

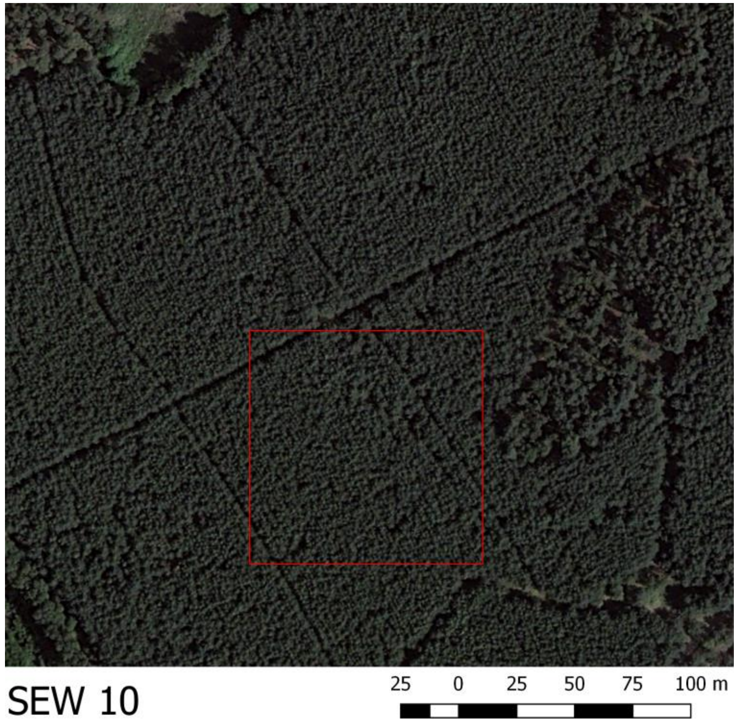


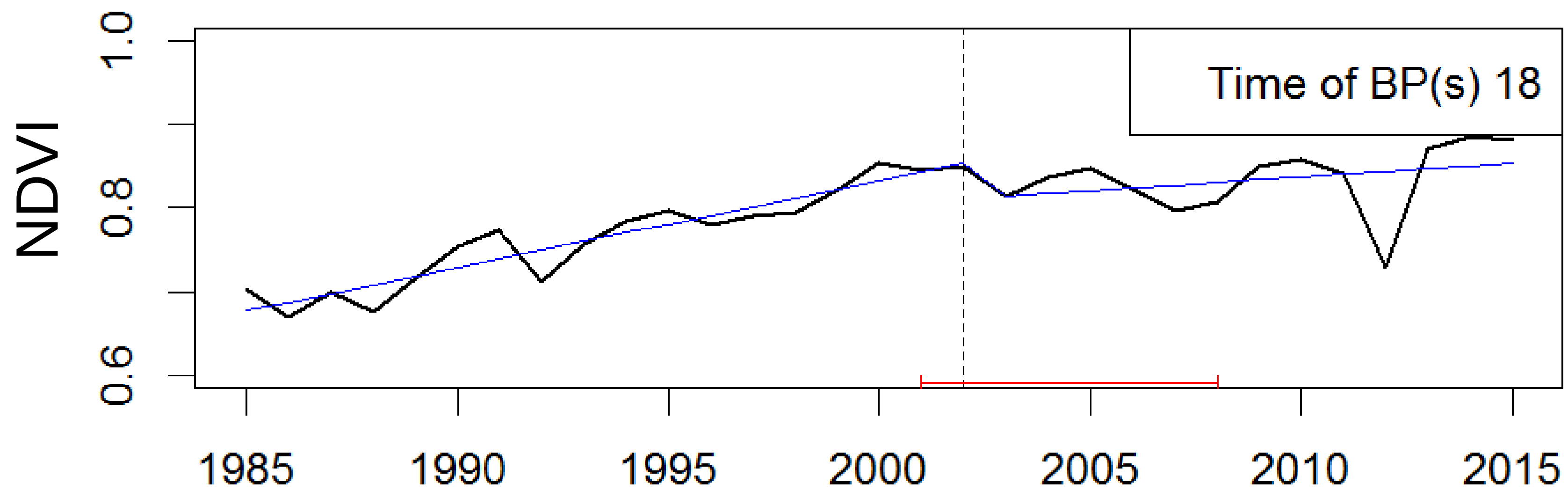
# Results – Breaking points



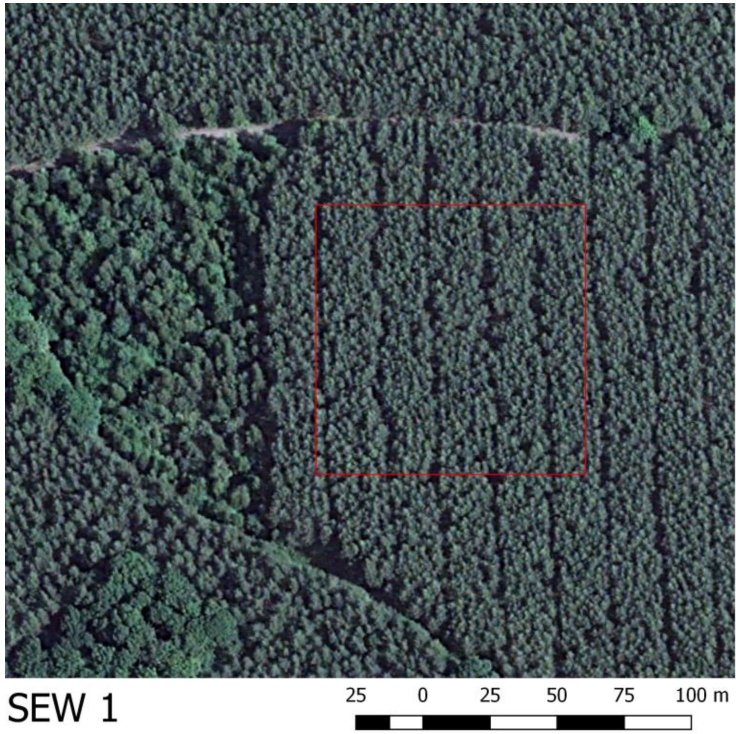

Magnitude of change: -0.034



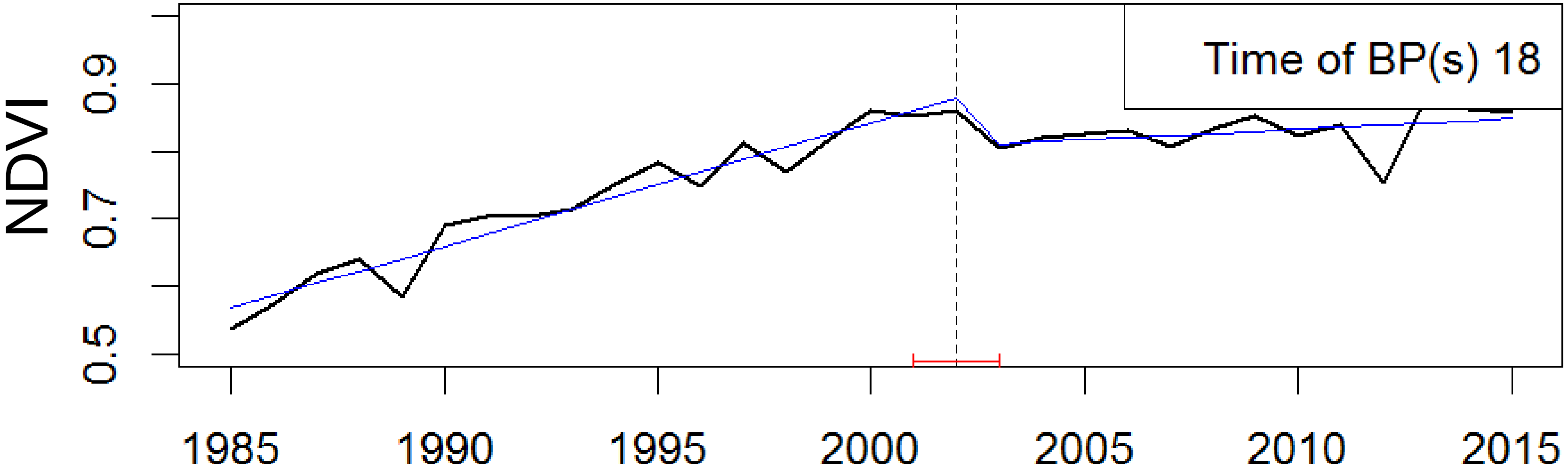
# Results – Breaking points



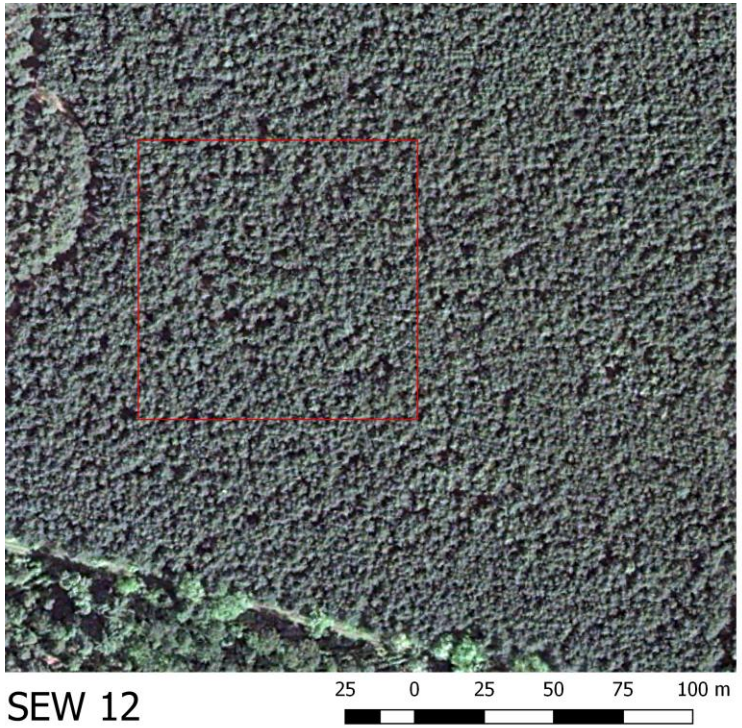

Magnitude of change: -0.040



# Results – Breaking points

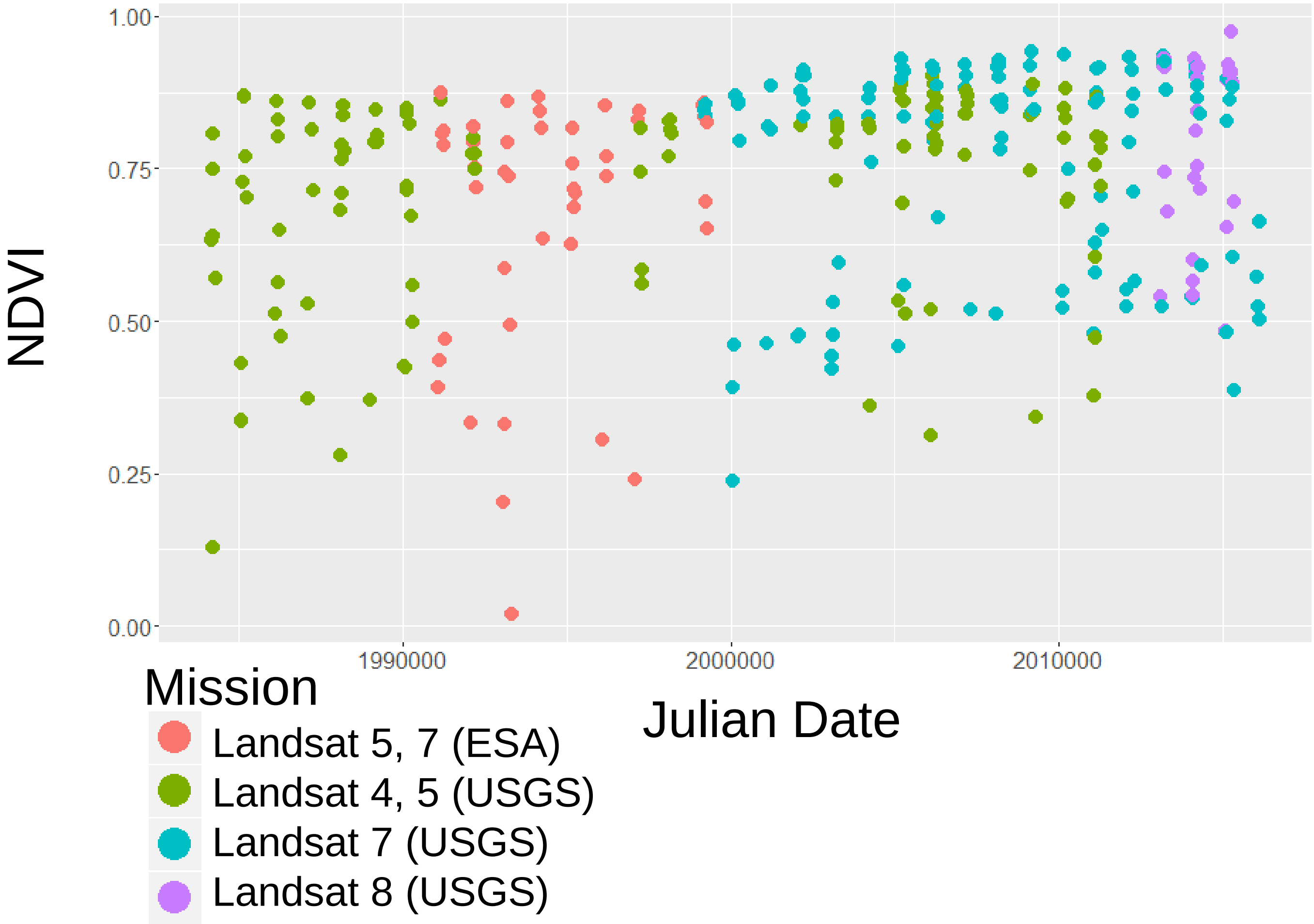


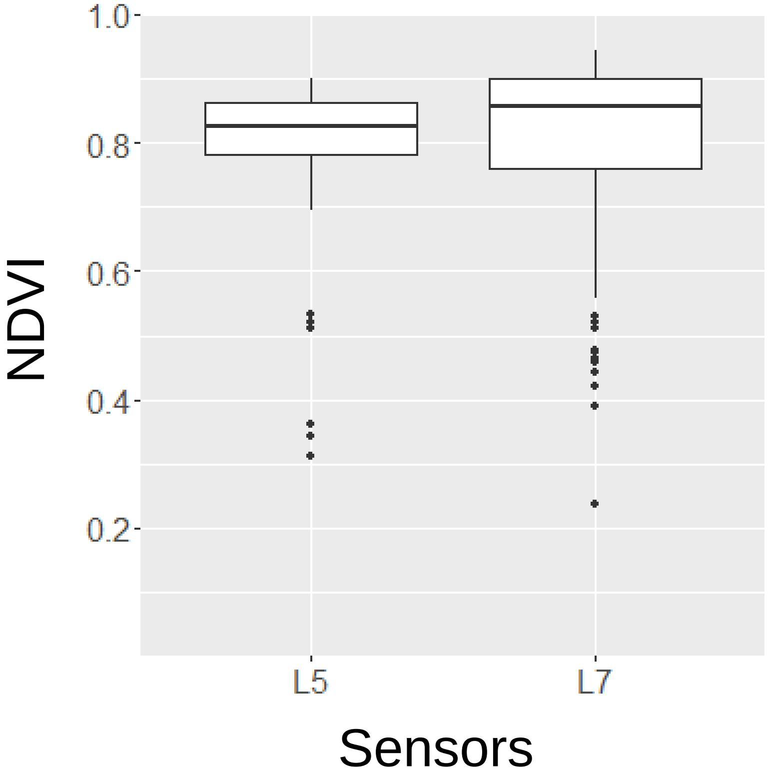

Magnitude of change: -0.068




SEW 12

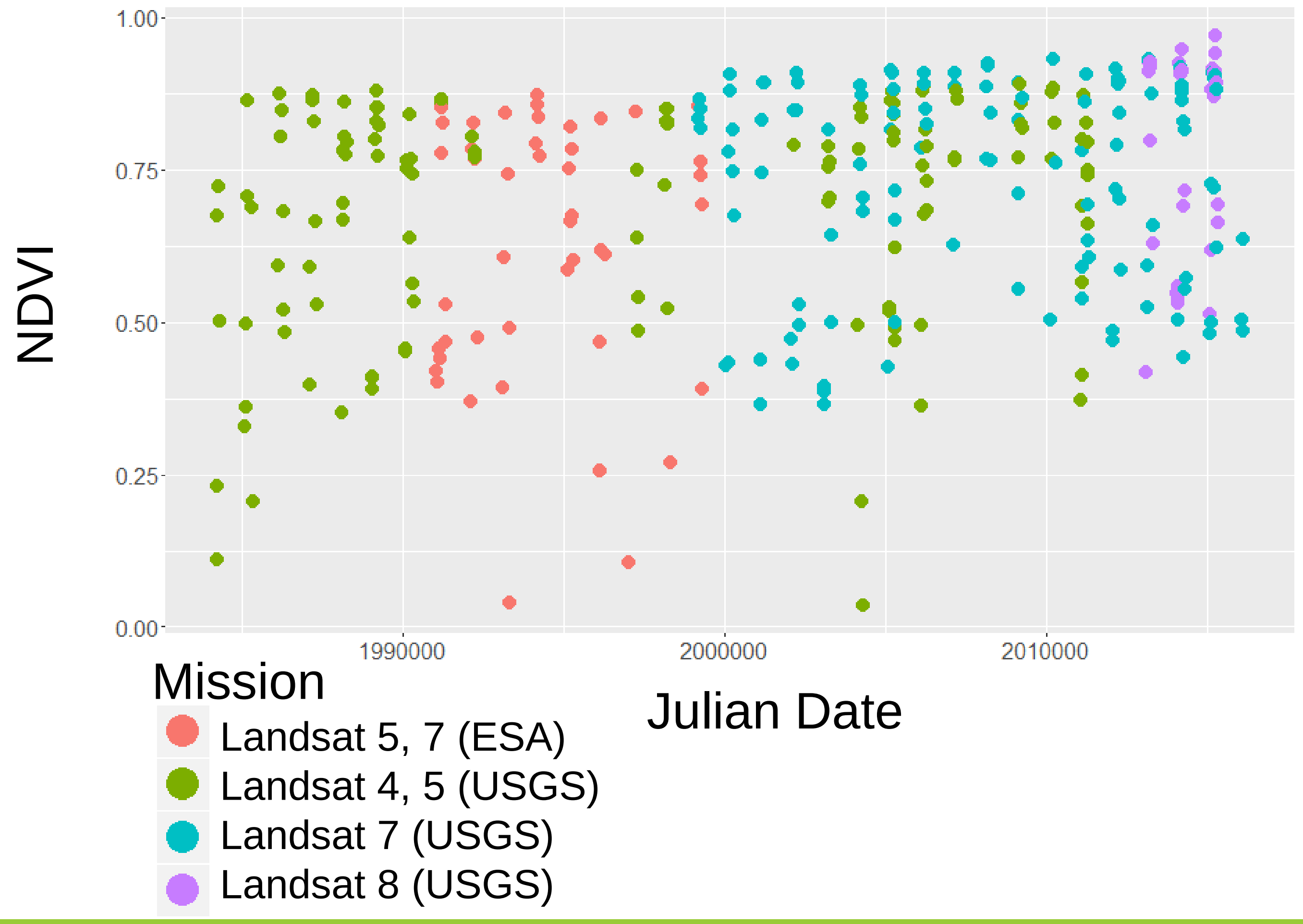
# Sensors in Landsat time series - Hainich 17

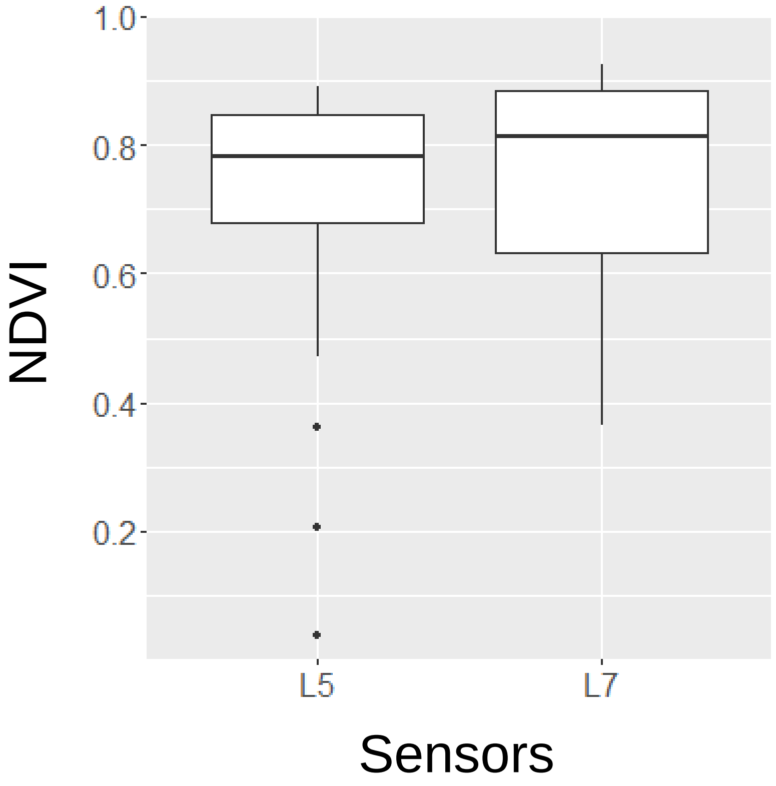



Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

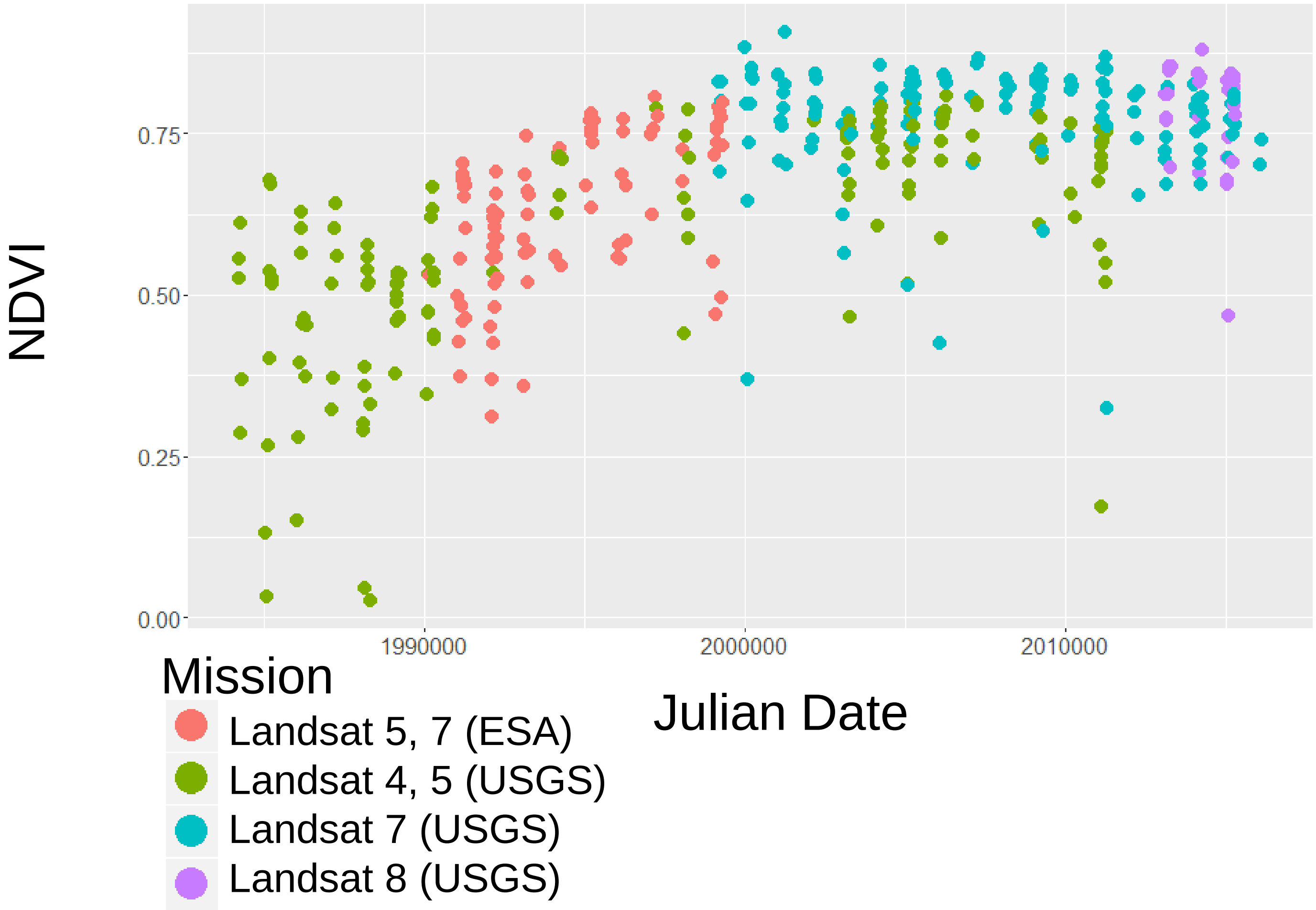
# Sensors in Landsat time series - Hainich 4

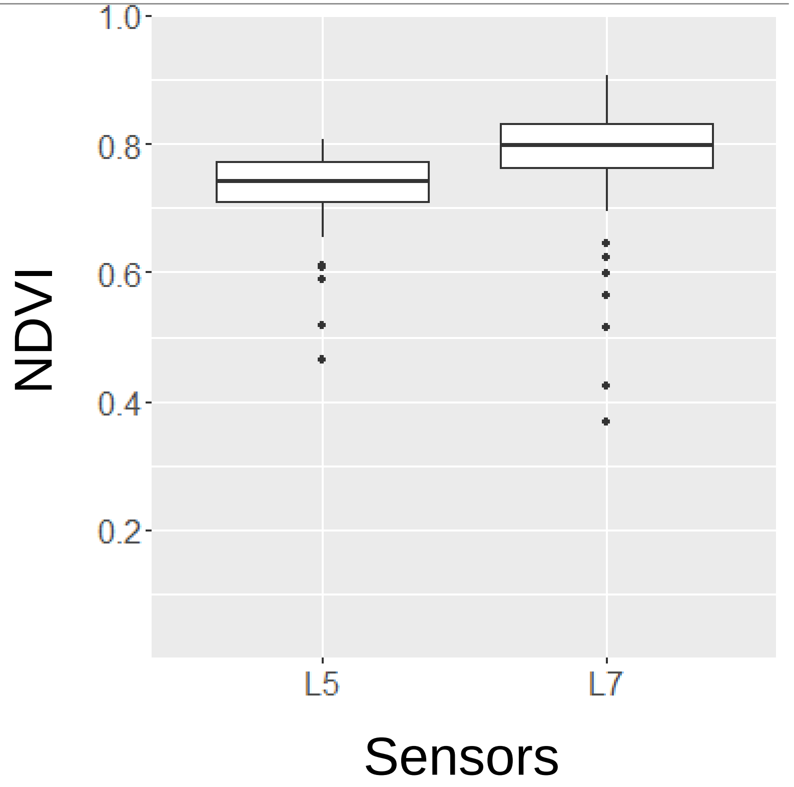



Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

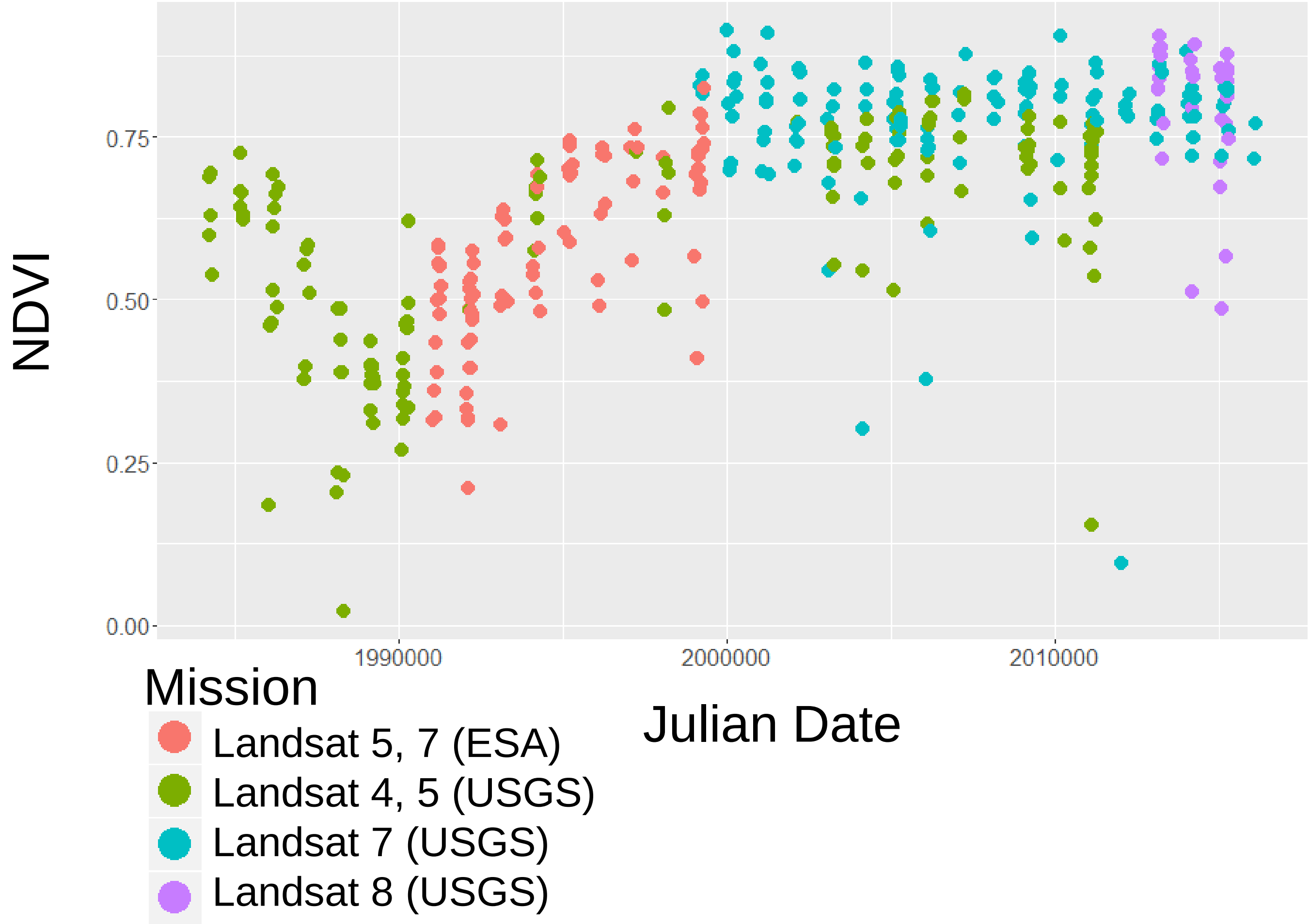
# Sensors in Landsat time series - Schorfheide 10

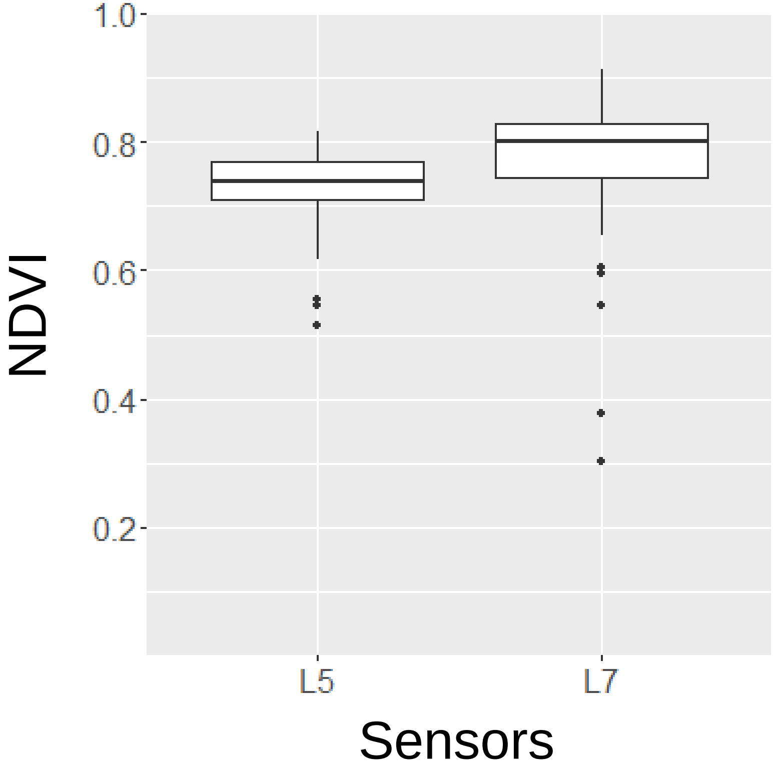



Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

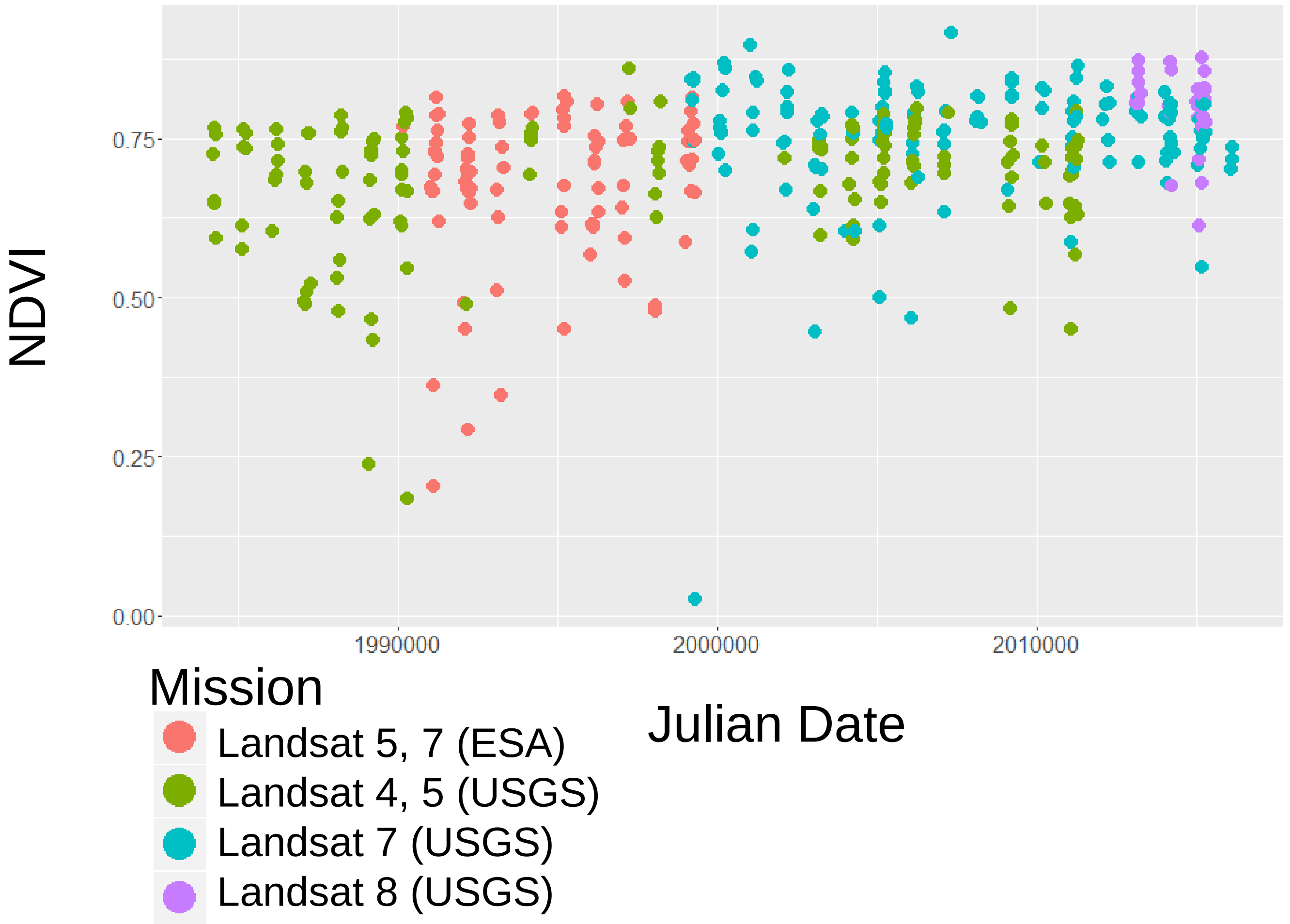
# Sensors in Landsat time series - Schorfheide 11

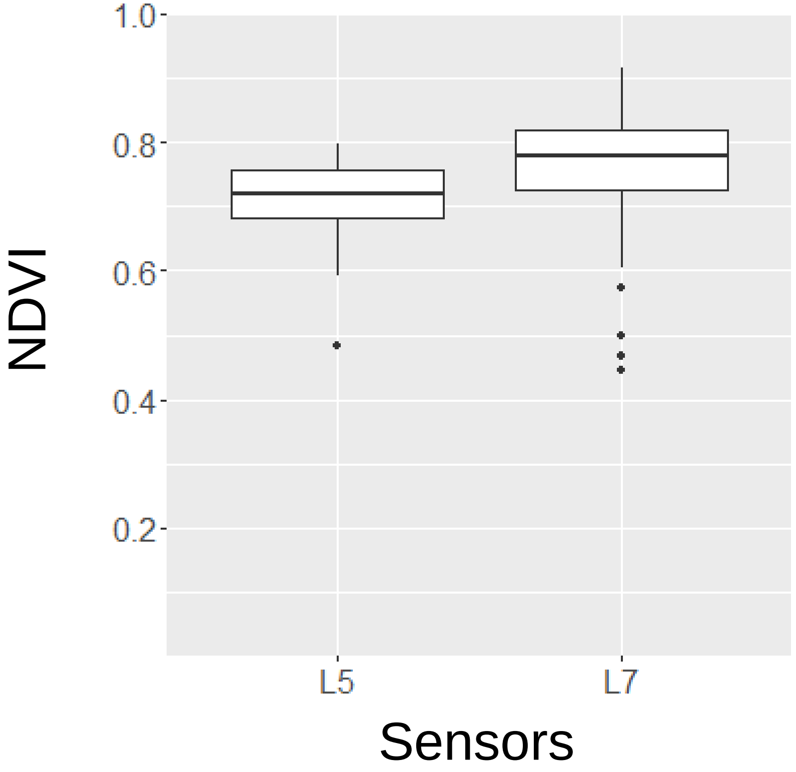



Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

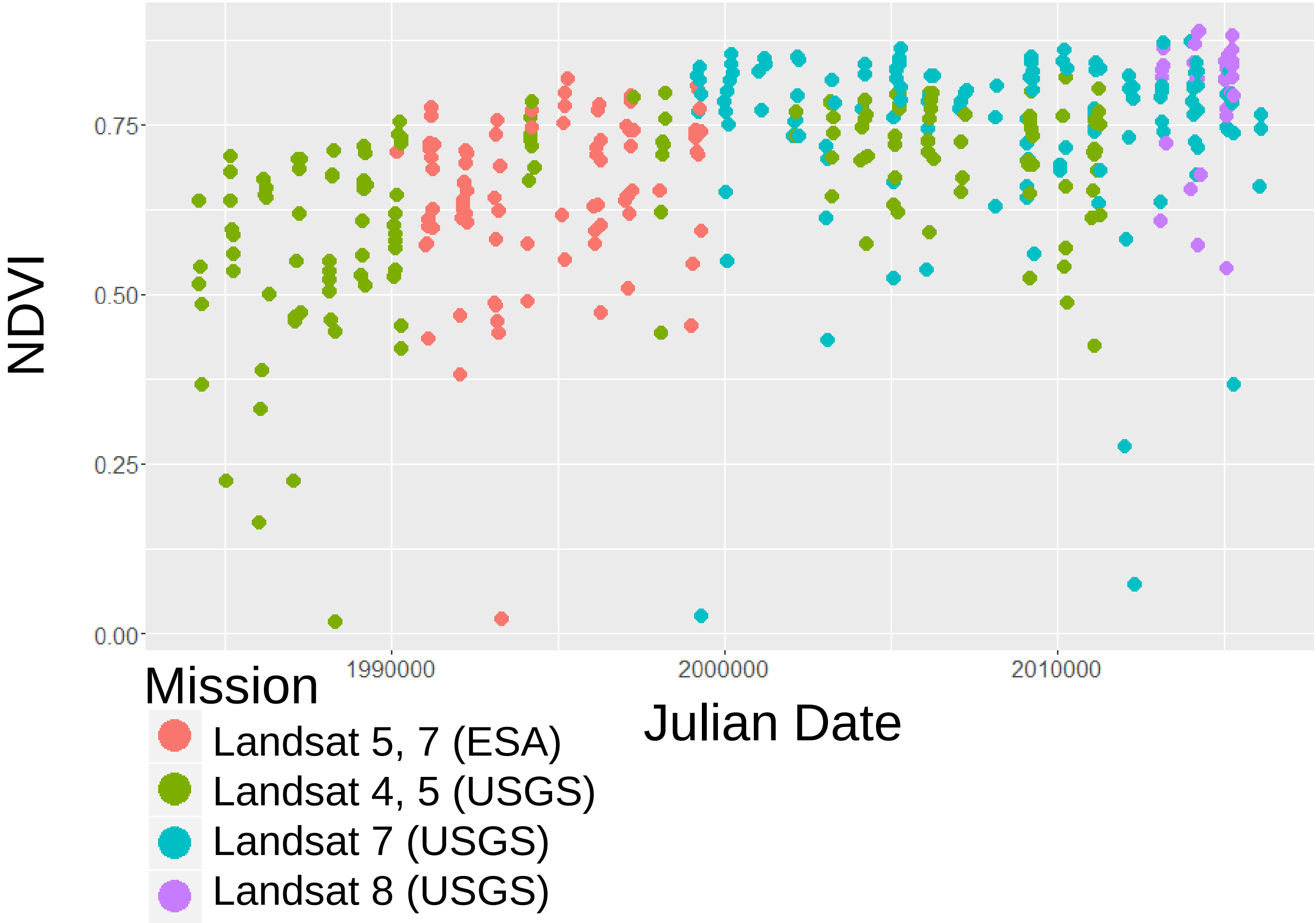
# Sensors in Landsat time series - Schorfheide 14

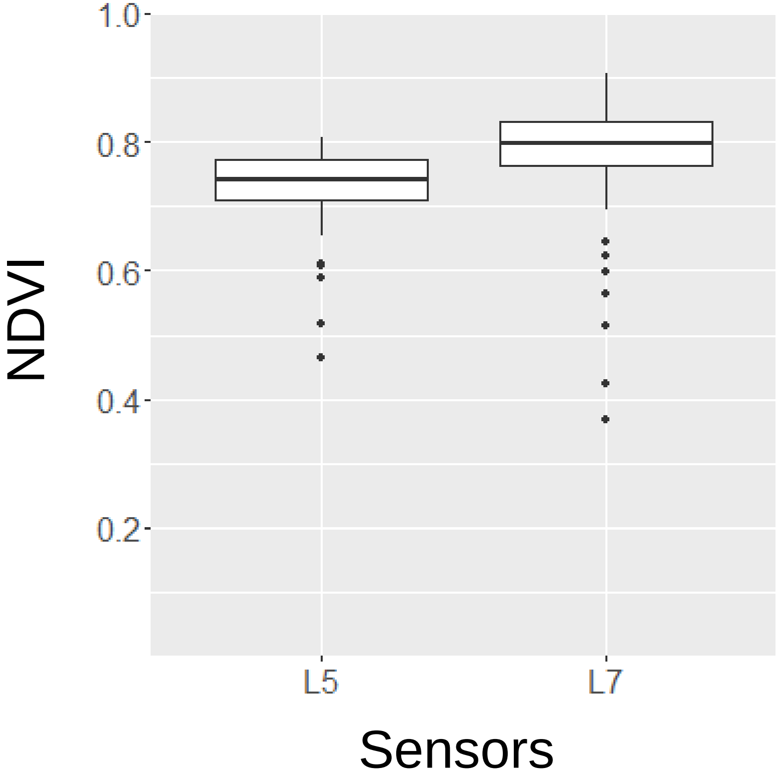



Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

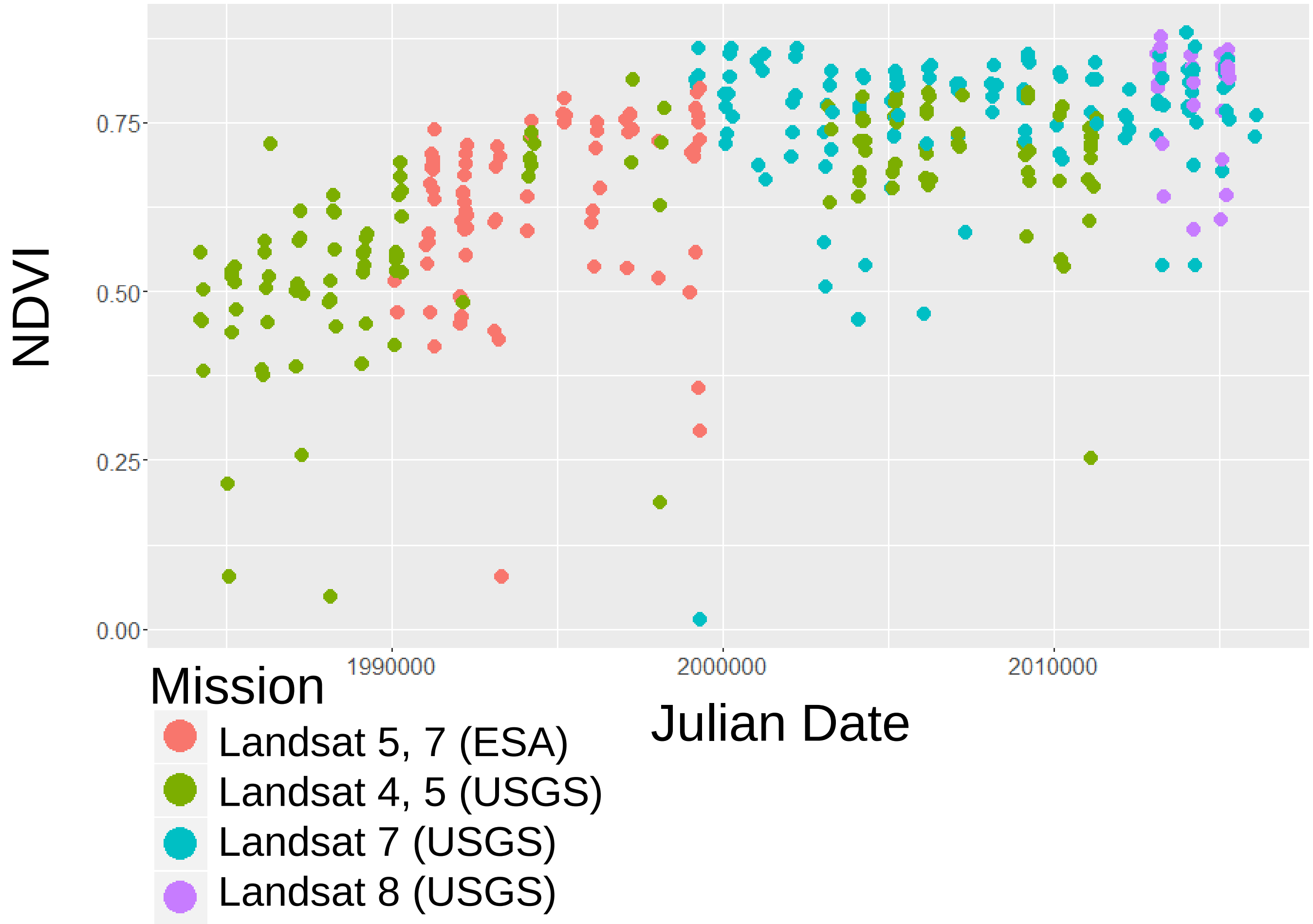
# Sensors in Landsat time series - Schorfheide 1

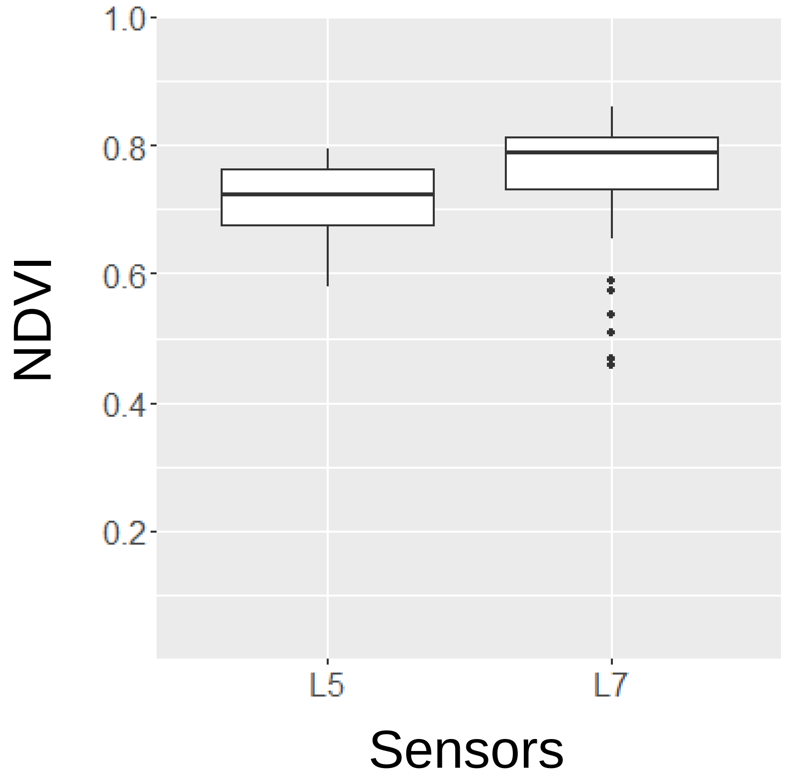



Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

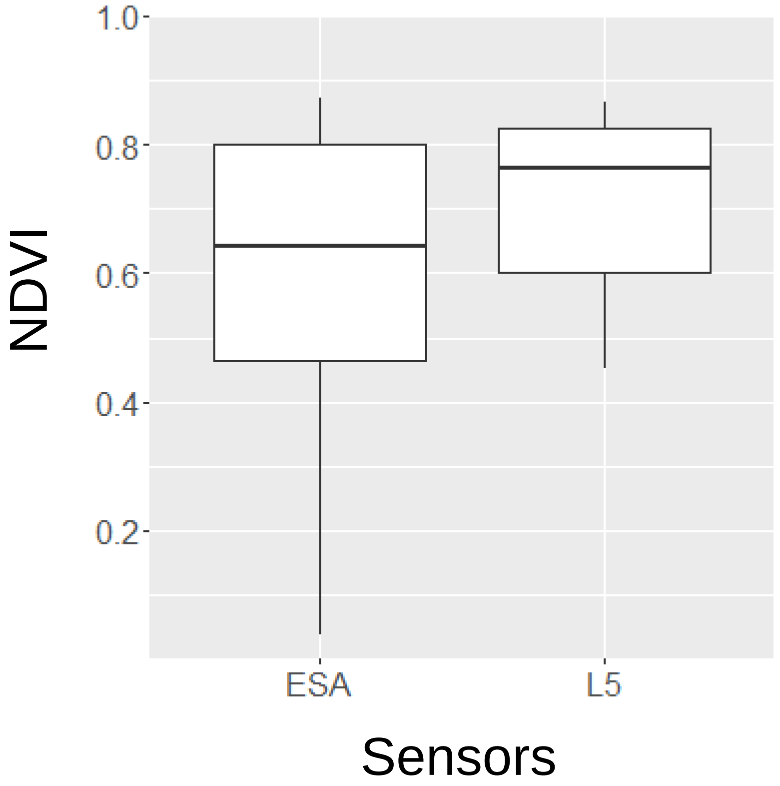
# Sensors in Landsat time series - Schorfheide 12



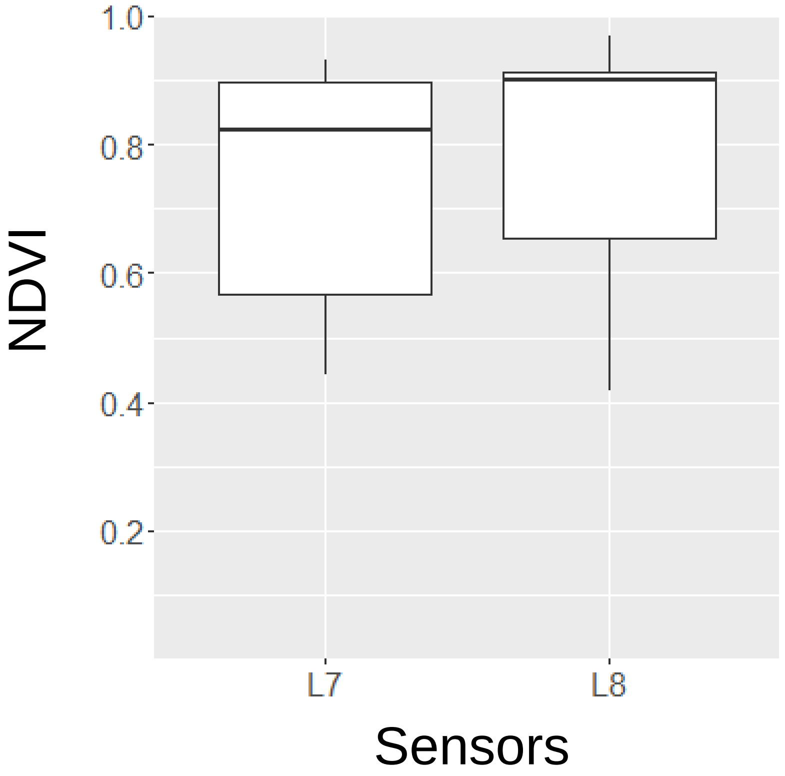




Comparison of NDVI values of Landsat 5 and Landsat 7 between 2000 and 2010

# Comparison of Landsat sensors Hainich 4

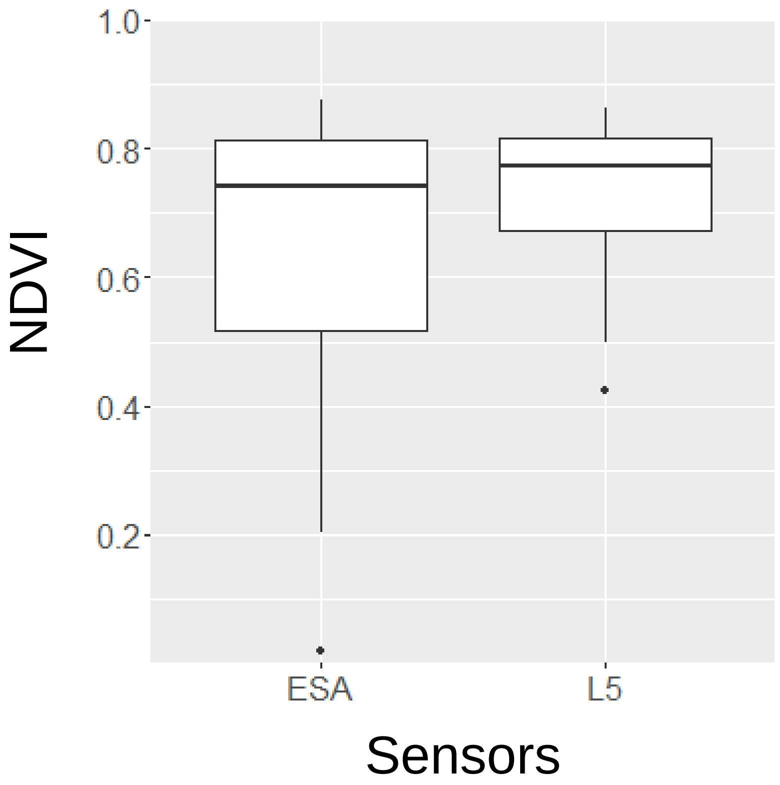



Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999

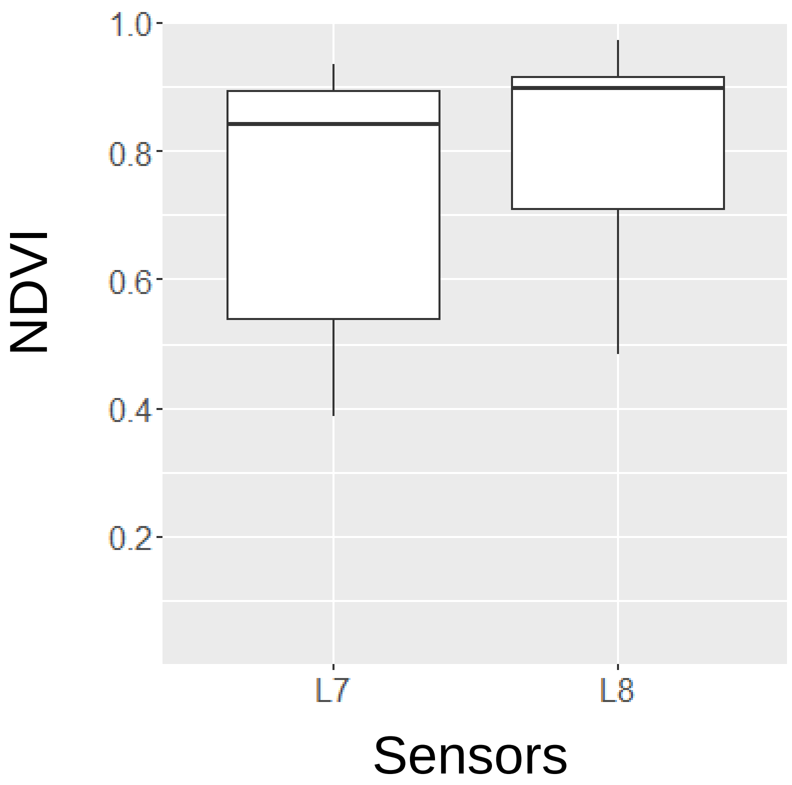



Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Comparison of Landsat sensors Hainich 17

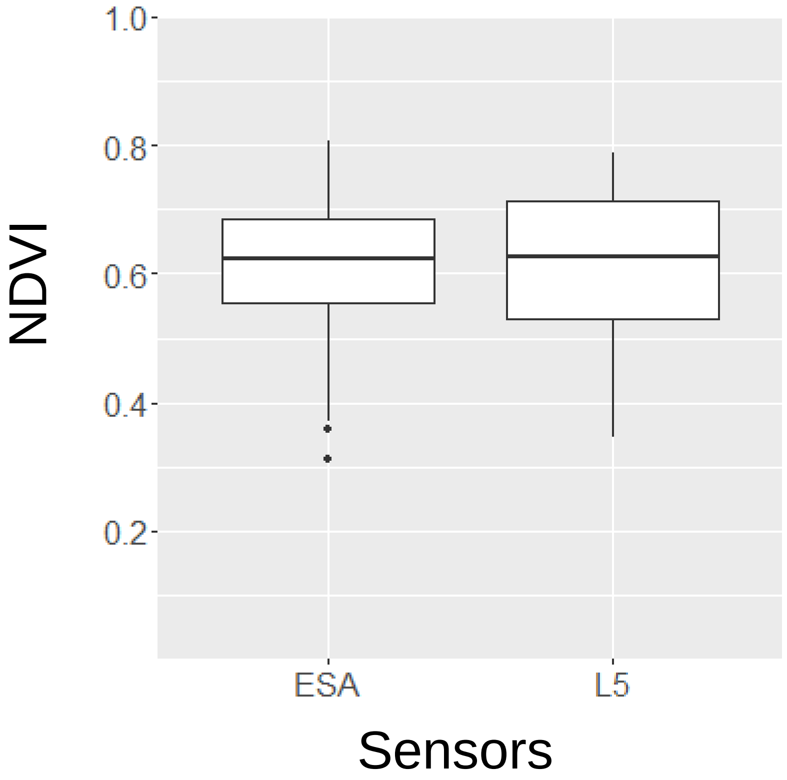



Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999

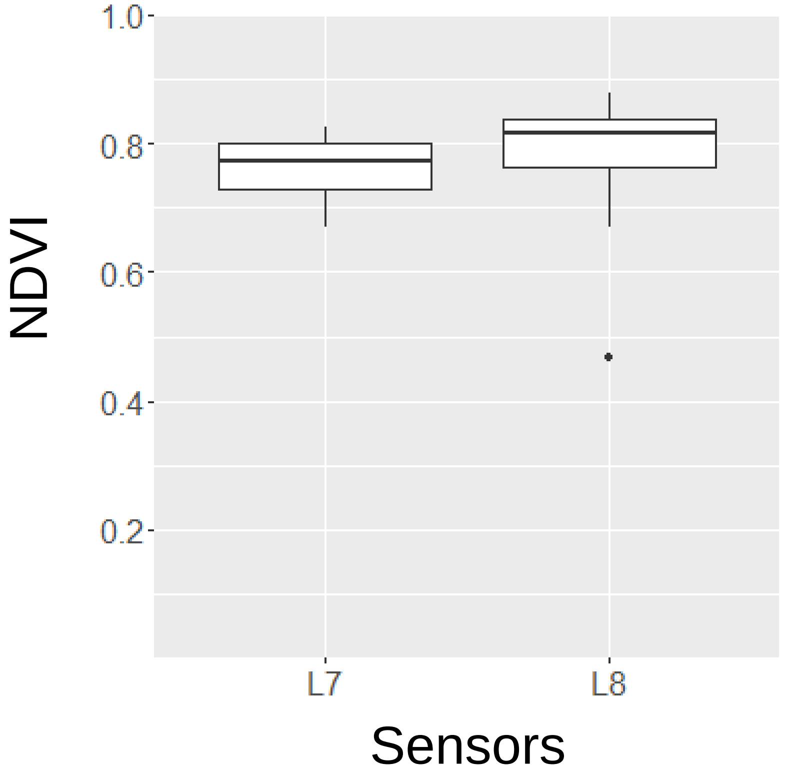



Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Comparison of Landsat sensors Schorfheide 10

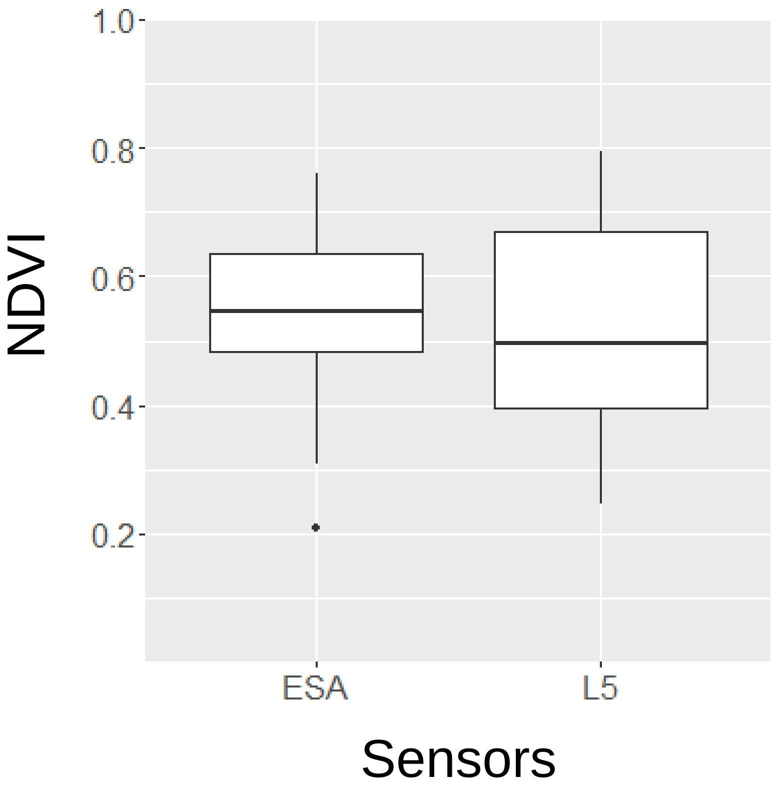



Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999

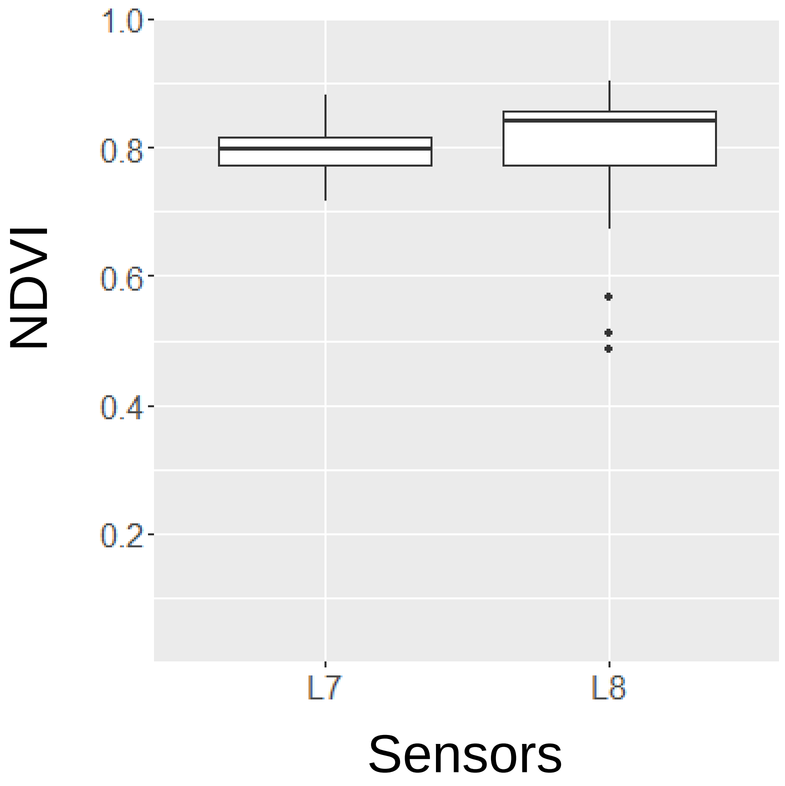



Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Comparison of Landsat sensors Schorfheide 11

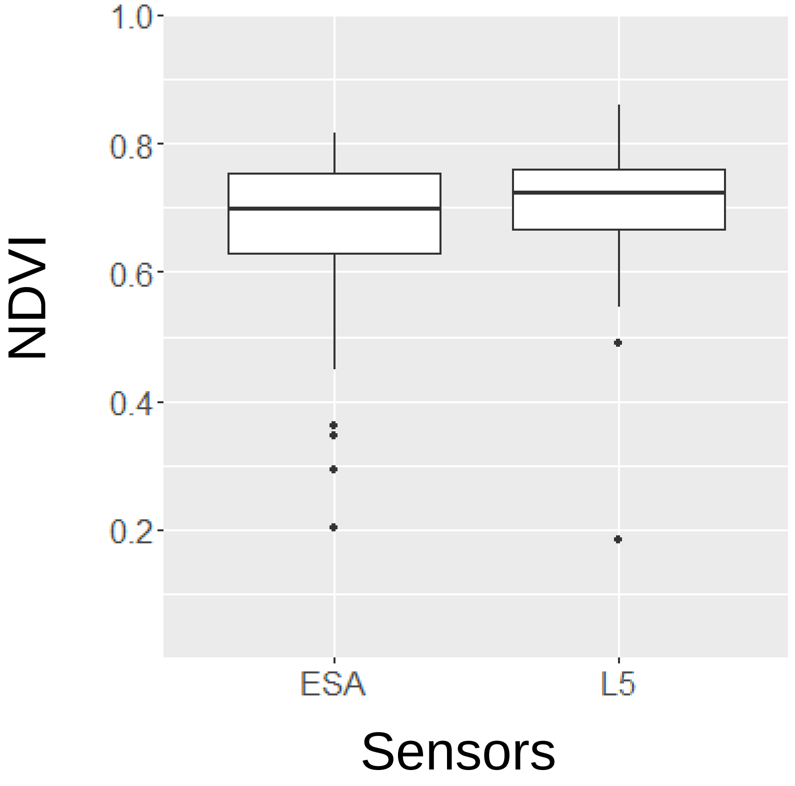



Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999

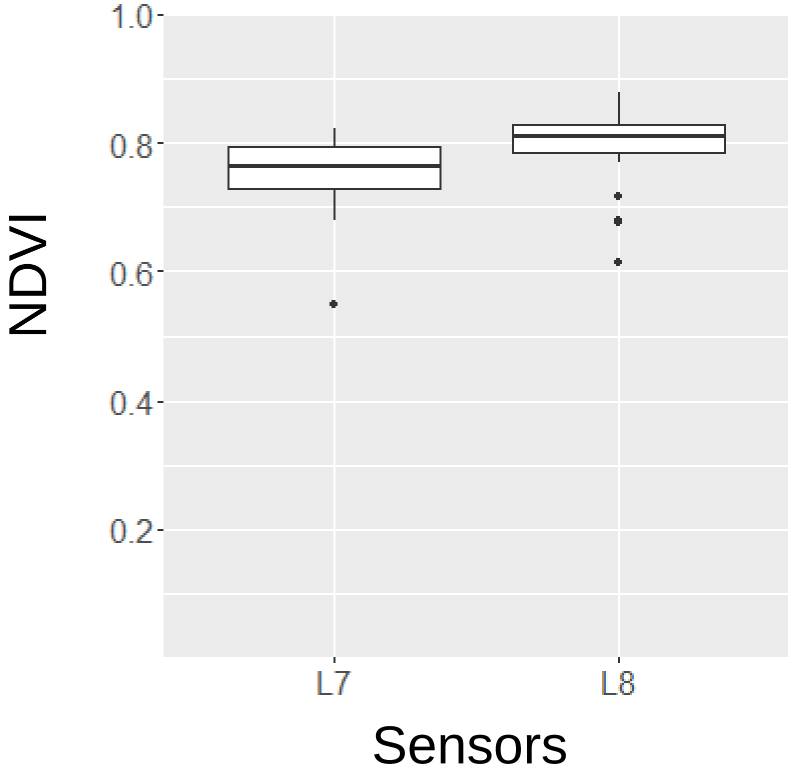



Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Comparison of Landsat sensors Schorfheide 14

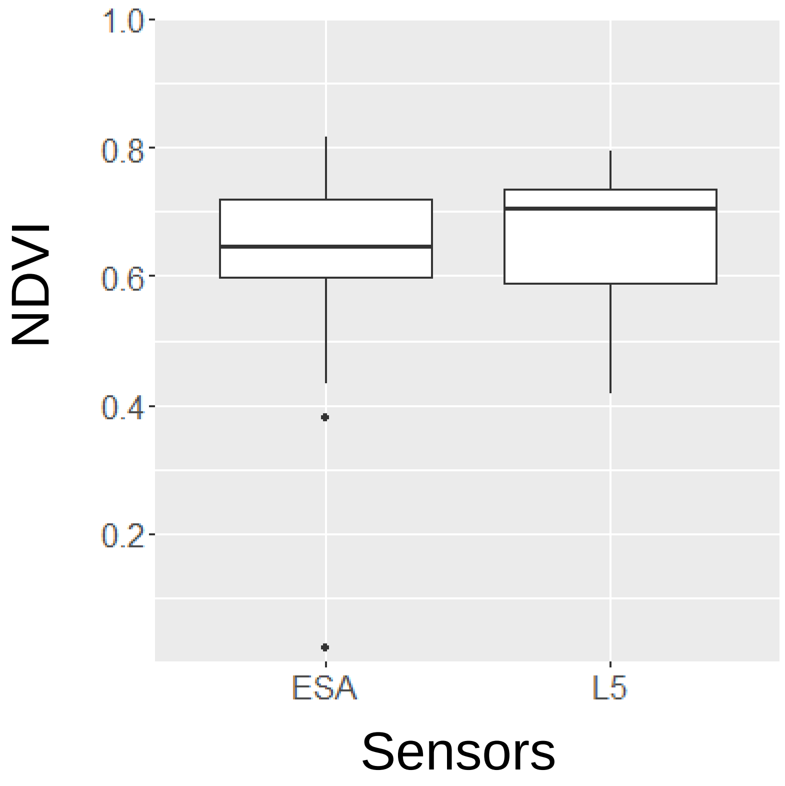



Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999

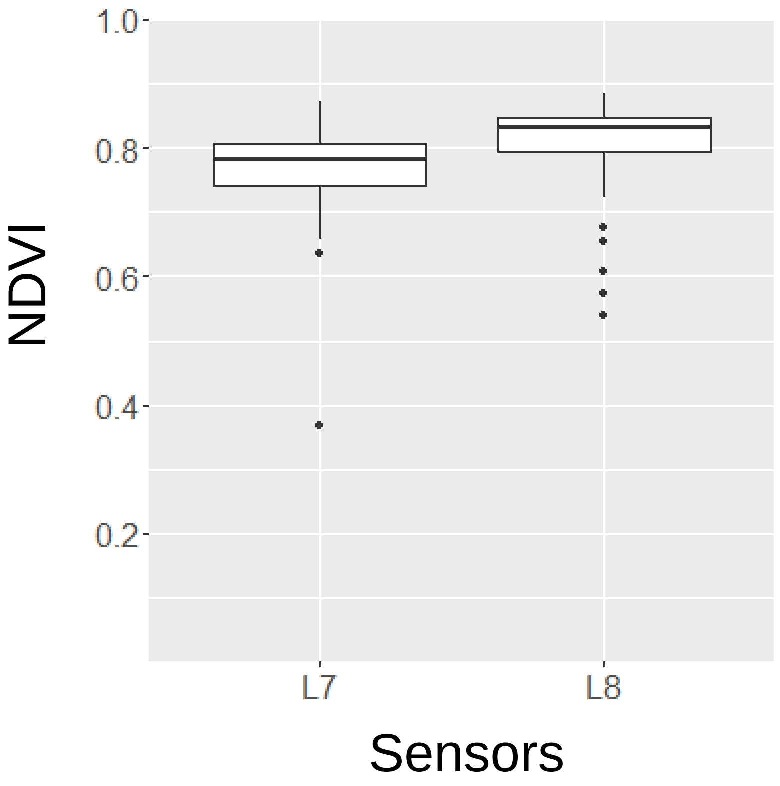



Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Comparison of Landsat sensors Schorfheide 1

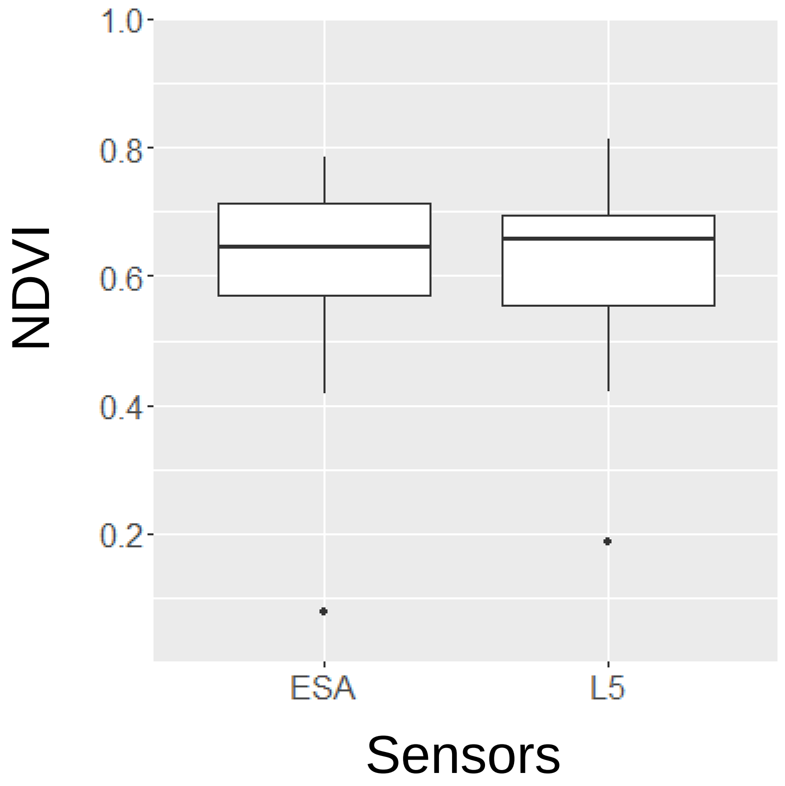



Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999

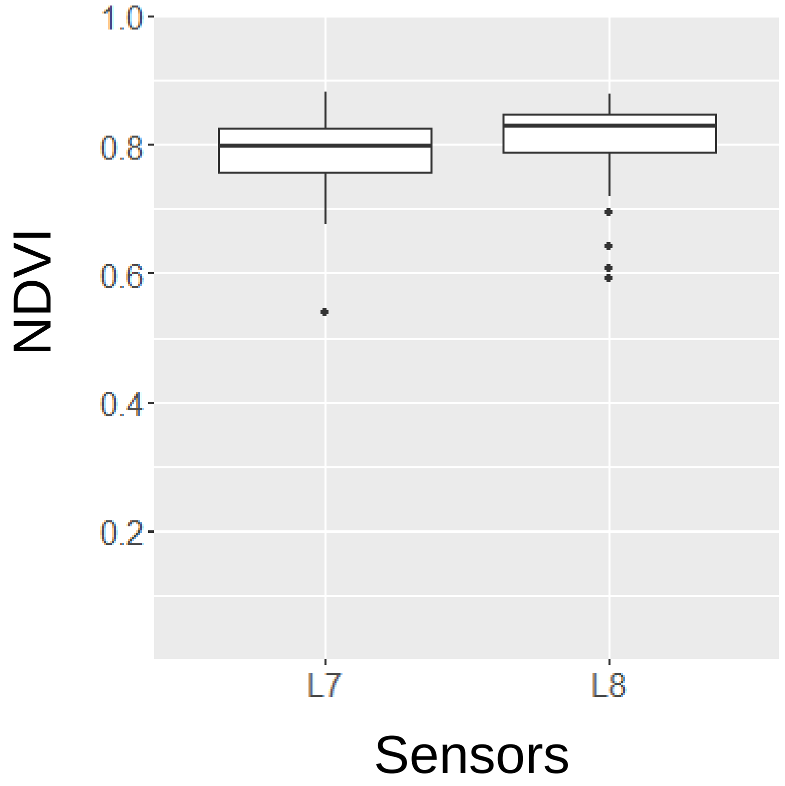



Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Comparison of Landsat sensors Schorfheide 12




Comparison of NDVI of Landsat by ESA and USGS between 1990 and 1999




Comparison of NDVI values of Landsat 7 and Landsat 8 between 2013 and 2016

# Coniferous monoculture Schorfheide 1

# Coniferous monoculture Schorfheide 10

# Coniferous monoculture Schorfheide 11

# Coniferous monoculture Schorfheide 12

# Coniferous monoculture Schorfheide 14

# Beech forest in thicked stage Hainich 17

# Beech forest in thicked stage Hainich 4

# Schorf-heide

## Coniferous monocultures


SEW 11


SEW 10


SEW 14

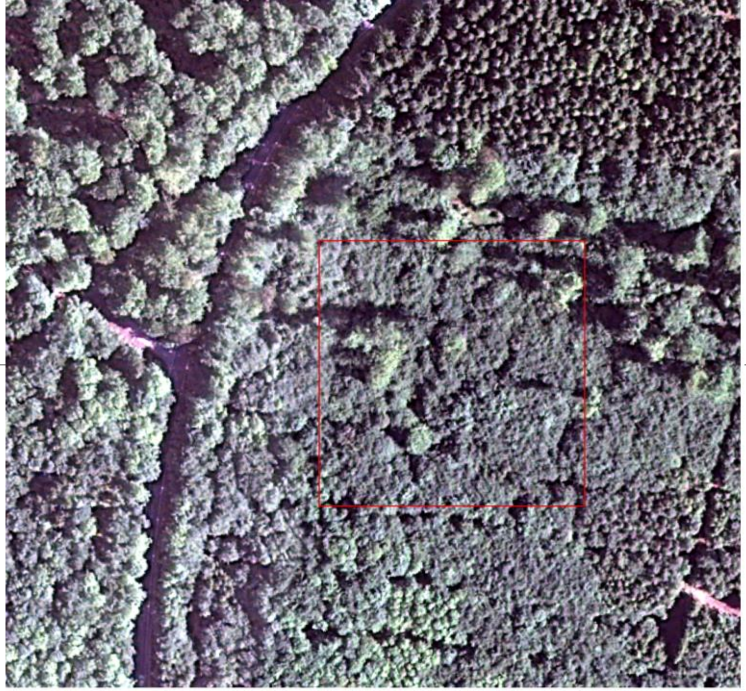

SEW 12

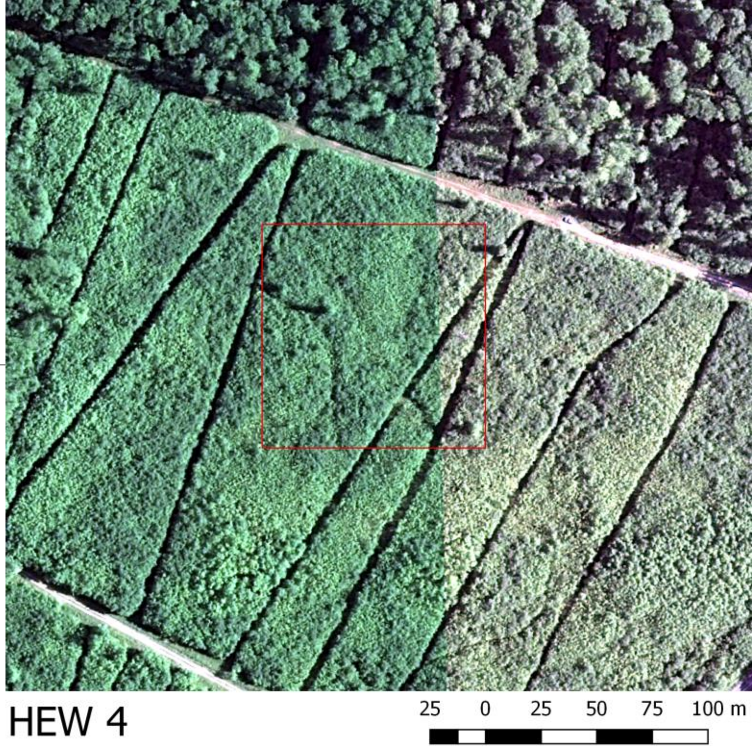

SEW 1

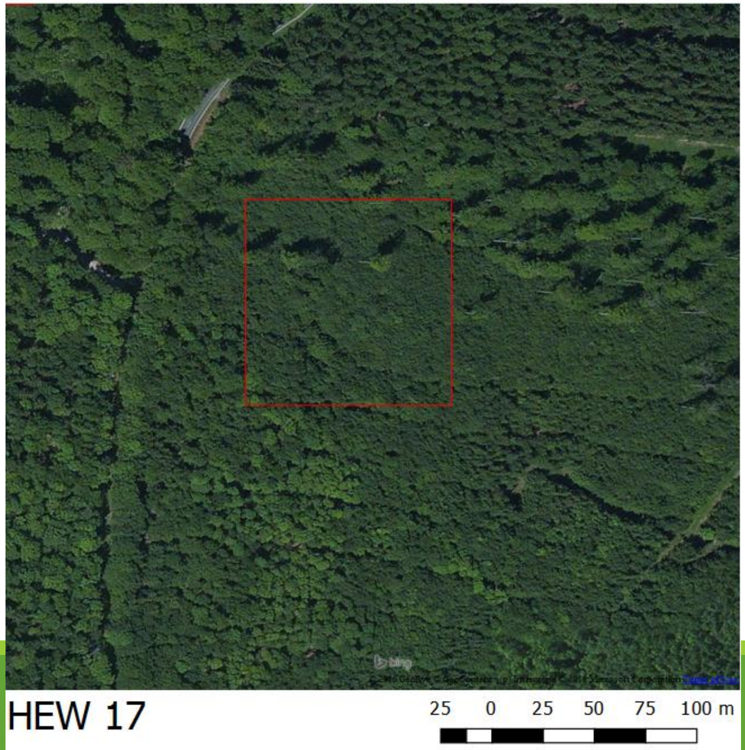
# Hainich

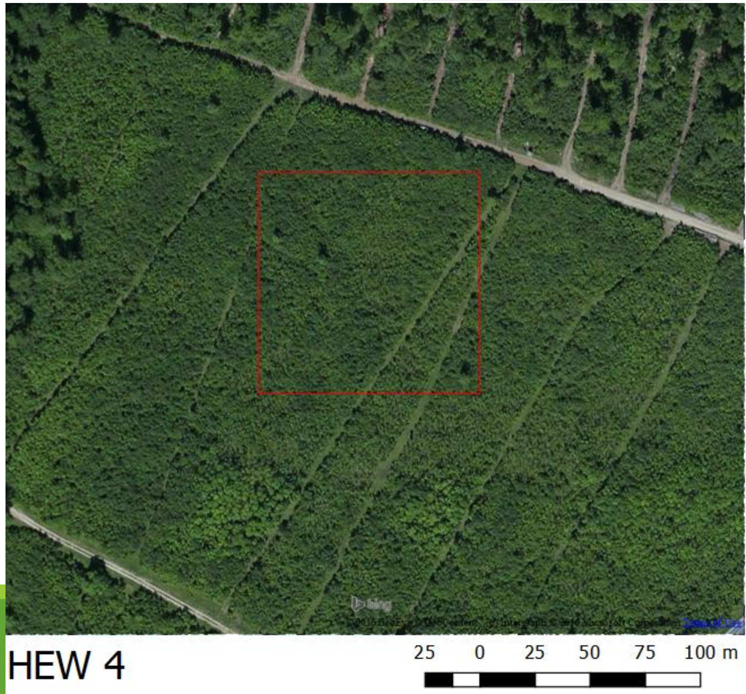
HEW 17:
25-30 year old forest plantation

HEW 4:
thicket stage with DBH < 7cm and with emergent trees

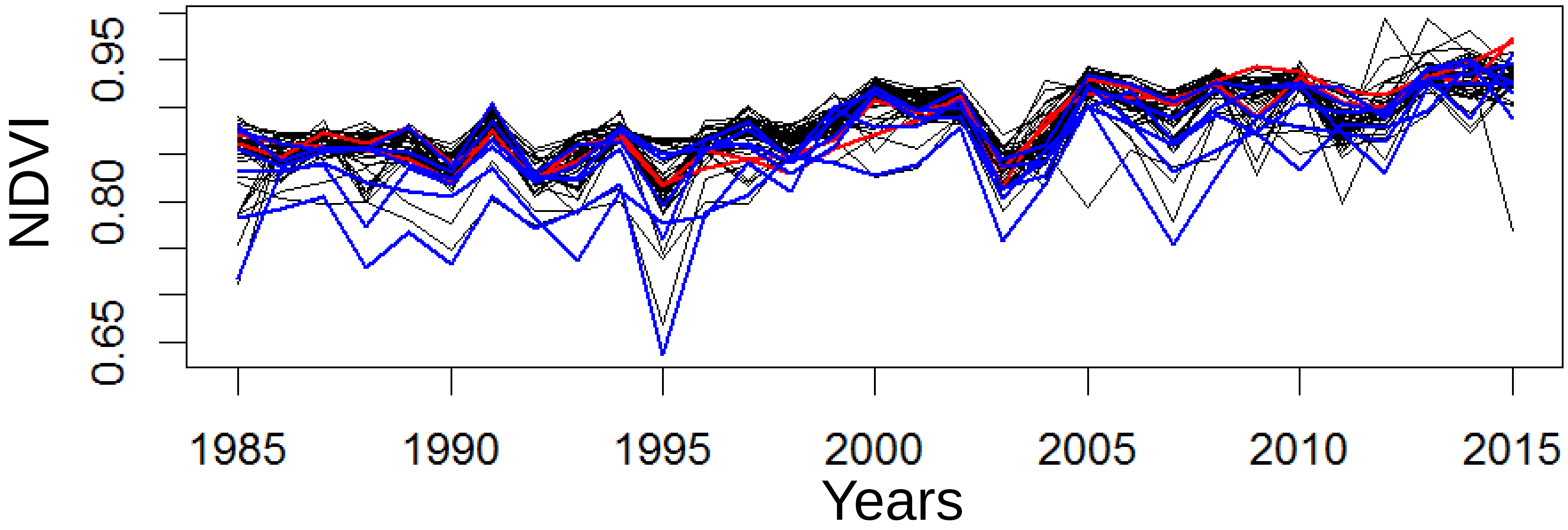




# Hainich

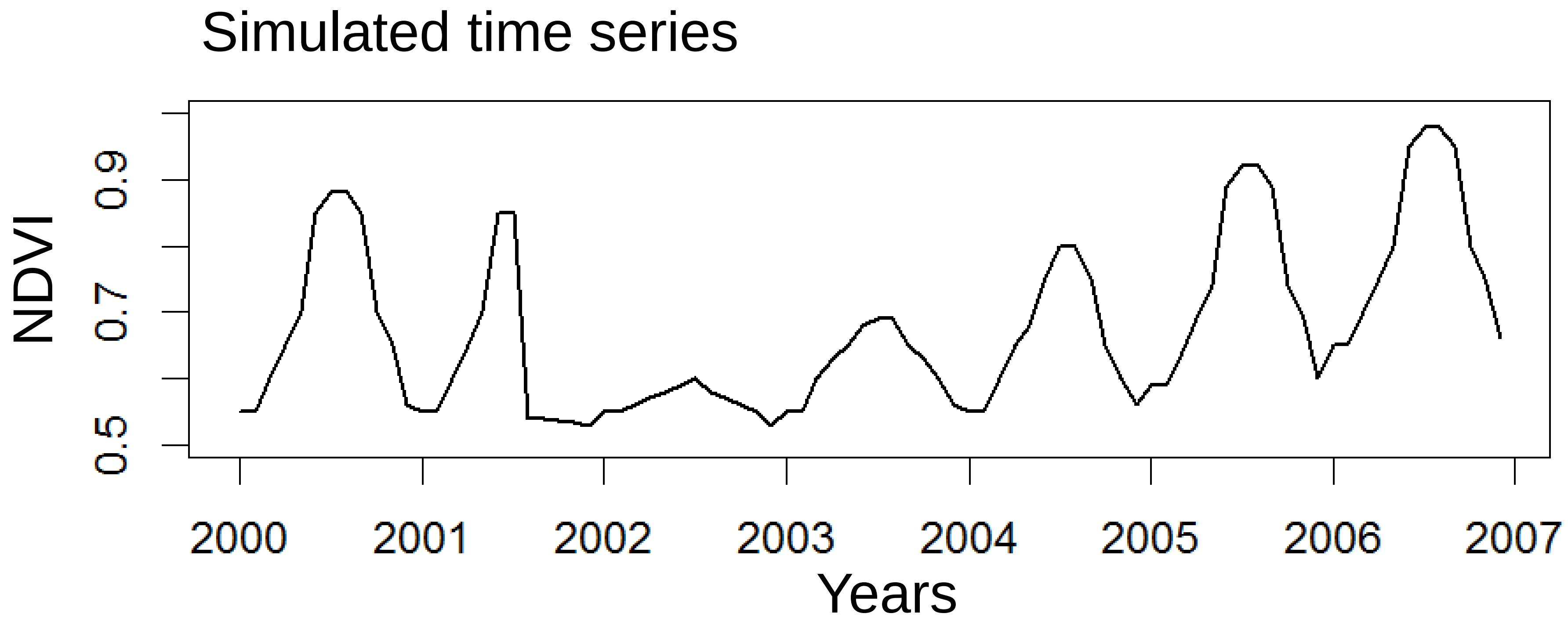


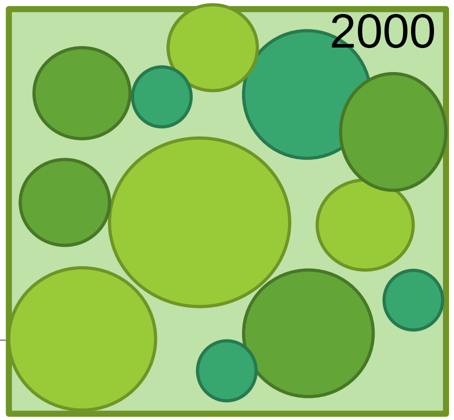

Time series of EPs with significant breaking points
Time series of EPs without significant breaking points
Time series of EPs without significant breaking points, with low values in 1998

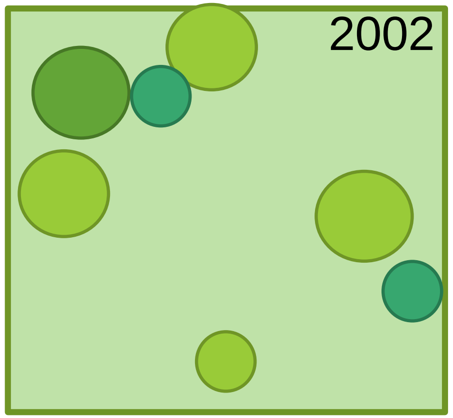
# Future studies

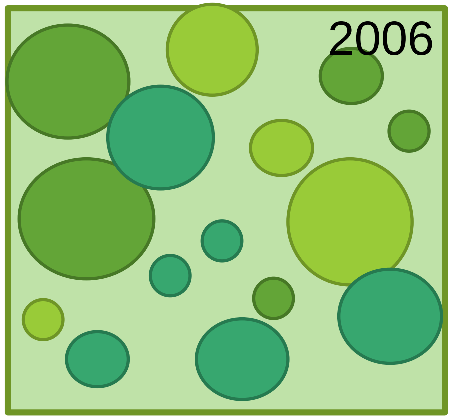
- Further analysis considering the seasonality -
  Continuous Change Detection and Classification (CCDC) (Zhu and Woodcock 2014)
- Time series of additional indices
- Combining Landsat and MODIS to obtain denser time series - STARFM
- Considering larger study areas than EP level
- Adjusting georeferenciation
- Finding a suitable way to adjust the sensor differences

# Ecosystem History



# Ecosystem History