dendroRschool

ADVANCED INTRODUCTION

dendroTools & rtG R packages

Pre-conference Workshop at TRACE 2022, Erlangen, Germany, May 24, 2022

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dendroTools R package

- A short introduction video is available at dendroschool.org https://dendroschool.org/an-introduction-to-the-dendrotools-package/

- A complete introduction workshop on dendroTools, which was presented at TRACE 2021

https://www.youtube.com/watch?v=fQvntMlJiXA (video)

https://github.com/jernejjevsenak/dendroTools-workshop-TRACE-2021 (materials)

dendroTools R package – brief recap

- Functions for studying statistical relationships between tree-rings and climate data with daily resolution
- All functions primarily developed for daily data, are also available for monthly data
    - *daily_response() & daily_response_seascorr()*
    - *monthly_response() & monthly_response_seascorr()*
- The moving window approach explores possible seasons and calculates correlation coefficients or other selected statistical metrices

dendroTools R package – key arguments

- Data is supplied with to response and env_data arguments
- Method can be *cor*, *lm* or *brnn*
- To calculate non-parametric correlations, use *cor_method = 'spearman'* or *cor_method = 'kendall’*
- To include the effect of previous year, use *previous_year = TRUE*
- The considered windows are controlled with *lower_limit* and *upper_limit* arguments

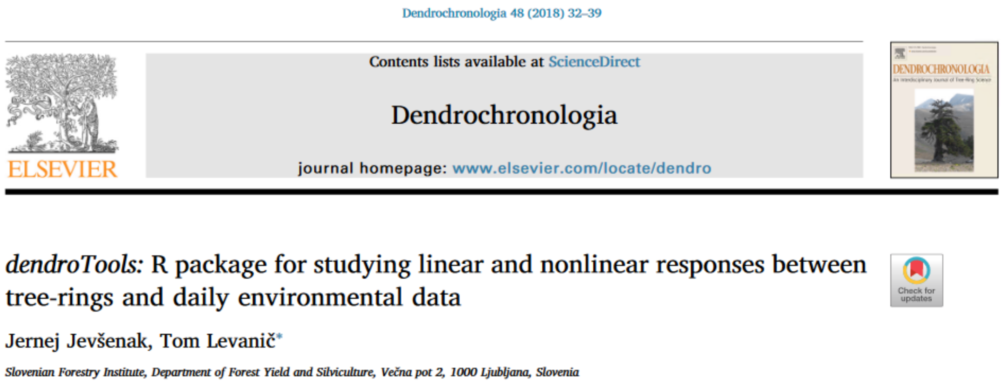
dendroTools R package – further readings

Two published articles describing the functionality of the dendroTools

- https://doi.org/10.1016/j.dendro.2018.01.005
- https://doi.org/10.1016/j.dendro.2020.125753

Recent publications applying the dendroTools R package

- https://doi.org/10.1016/j.dendro.2021.125906
- https://www.frontiersin.org/articles/10.3389/frwa.2021.801265/full
- https://www.mdpi.com/2073-4433/12/12/1690/htm
- https://www.mdpi.com/1999-4907/12/11/1433
- https://doi.org/10.1016/j.scitotenv.2021.149968
- https://www.frontiersin.org/articles/10.3389/fpls.2021.669229/full
- https://onlinelibrary.wiley.com/doi/10.1111/ecog.05671
- https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0249959
- https://doi.org/10.1016/j.foreco.2021.119194
- https://onlinelibrary.wiley.com/doi/10.1111/gcb.15560
- https://doi.org/10.1016/j.quascirev.2019.105868
- …


Dendrochronologia 48 (2018) 32–39

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journal homepage: www.elsevier.com/locate/dendro

dendroTools: R package for studying linear and nonlinear responses between tree-rings and daily environmental data

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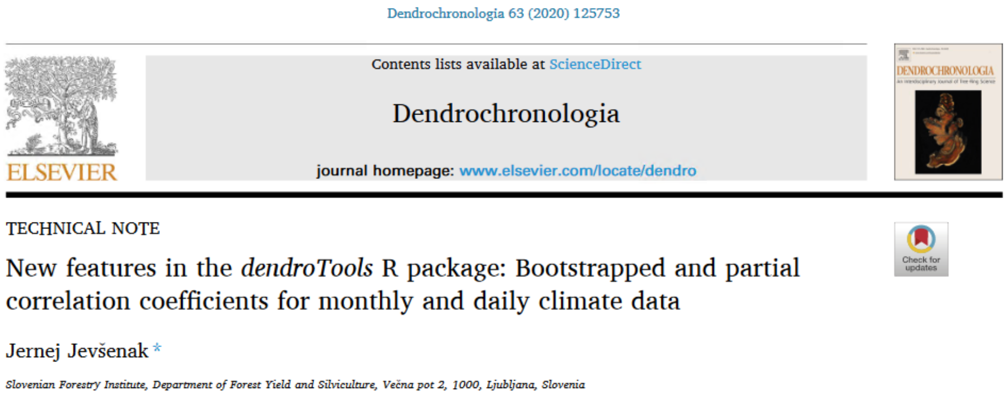
Dendrochronologia 63 (2020) 125753

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TECHNICAL NOTE

New features in the *dendroTools* R package: Bootstrapped and partial correlation coefficients for monthly and daily climate data

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dendroTools in Action

- Example tree-ring width data from International Tree-Ring Database
  - czec010 https://doi.org/10.1016/j.dendro.2021.125845
  - czec013 https://doi.org/10.1111/gcb.15922
  - czec017 https://doi.org/10.1111/gcb.15922
  - czec033 https://doi.org/10.1016/j.foreco.2016.08.013
- EOBS Climate data
  - https://www.ecad.eu/download/ensembles/download.php#datafiles

dendroTools in Action

- Example 1 – calculate daily climate growth correlations – baisc example

Newly implemented features in dendroTools

- Exercise 2 – limit the season of interest
- Exercise 3 – climate detrending

Advanced implementations of dendroTools

- Exercise 4 – Combine different chronologies in a "for loop" and *plot* all climate-growth correlations on the same plot

Advanced implementations of dendroTools

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- Exercise 5 – analyze the temporal stability of correlations calculated with dendroTools

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- Exercise 6 – analyze the temporal stability for all chronologies at once, using a "double for loop"

Advanced implementations of dendroTools

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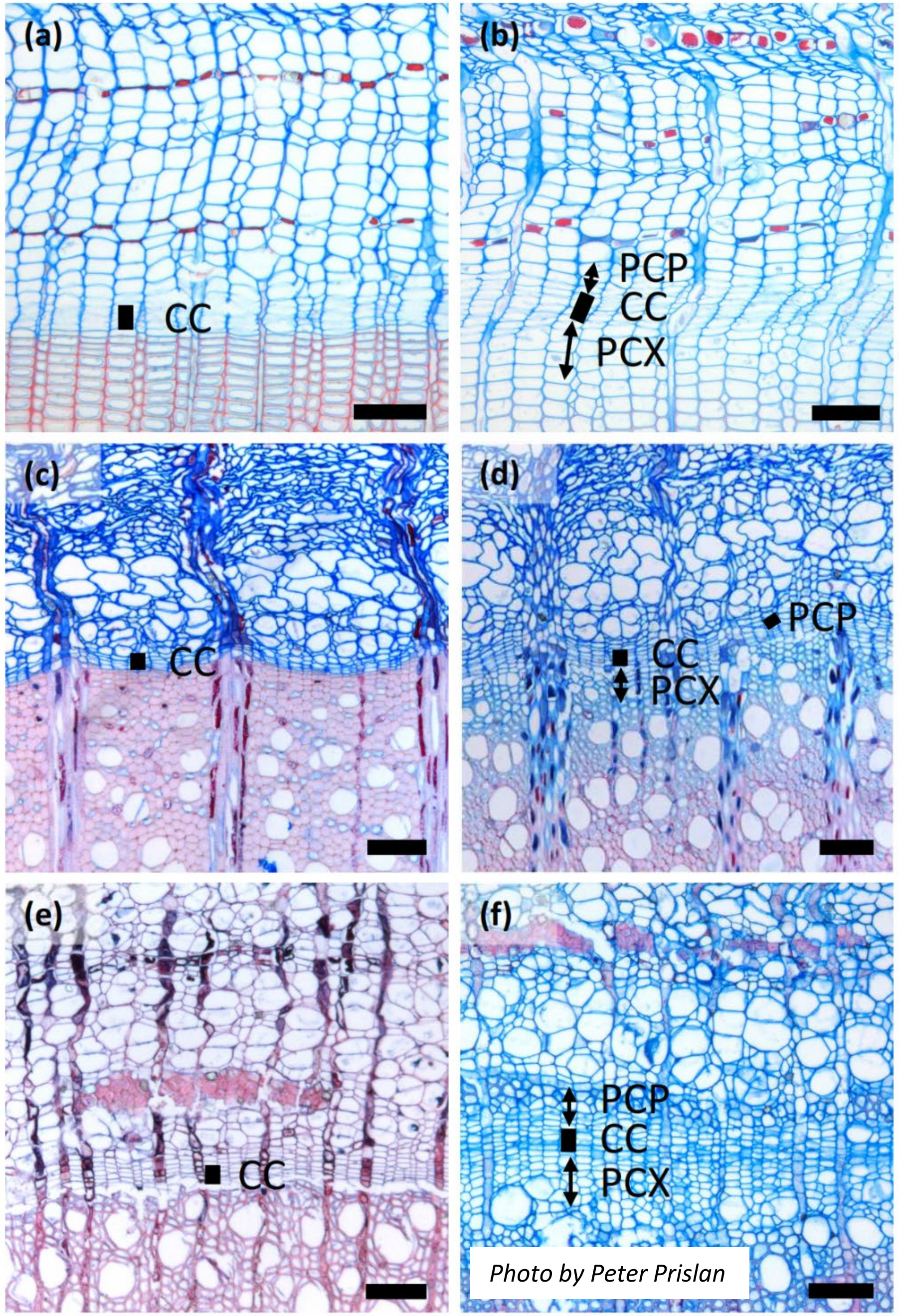
- Exercise 7 – compare daily correlations in wet/dry and hot/cold years

Advanced implementations of dendroTools

- Exercise 4 – Combine different chronologies in a "for loop" and *plot* all climate-growth correlations on the same plot
- Exercise 5 – analyze the temporal stability of correlations calculated with dendroTools
- Exercise 6 – analyze the temporal stability for all chronologies at once, using a "double for loop "
- Exercise 7 – compare daily correlations in wet/dry and hot/cold years
- Exercise 8 – compare daily correlations in wet/dry and hot/cold years for all chronologies at once using a "double for loop"

rTG – radial tree growth R package

- R package to assist the analysis in the field of wood formation
- The primary goal is to derive the temporal dynamics of secondary growth (xylem and phloem)



Cambium cells (CC) during dormant (a, c, e) and active period (b, d, f) in Norway spruce (*Picea abies*) (a, b), European beech (*Fagus sylvatica*) (c, d) and pubescent oak (*Quercus pubescens*) (e, f). Newly formed xylem (PCX) and phloem cells (PCP) in the expansion phase differ from the cambial cells by larger radial dimensions. Scalebar length is 100 µm. ->

Monitoring of secondary tree growth

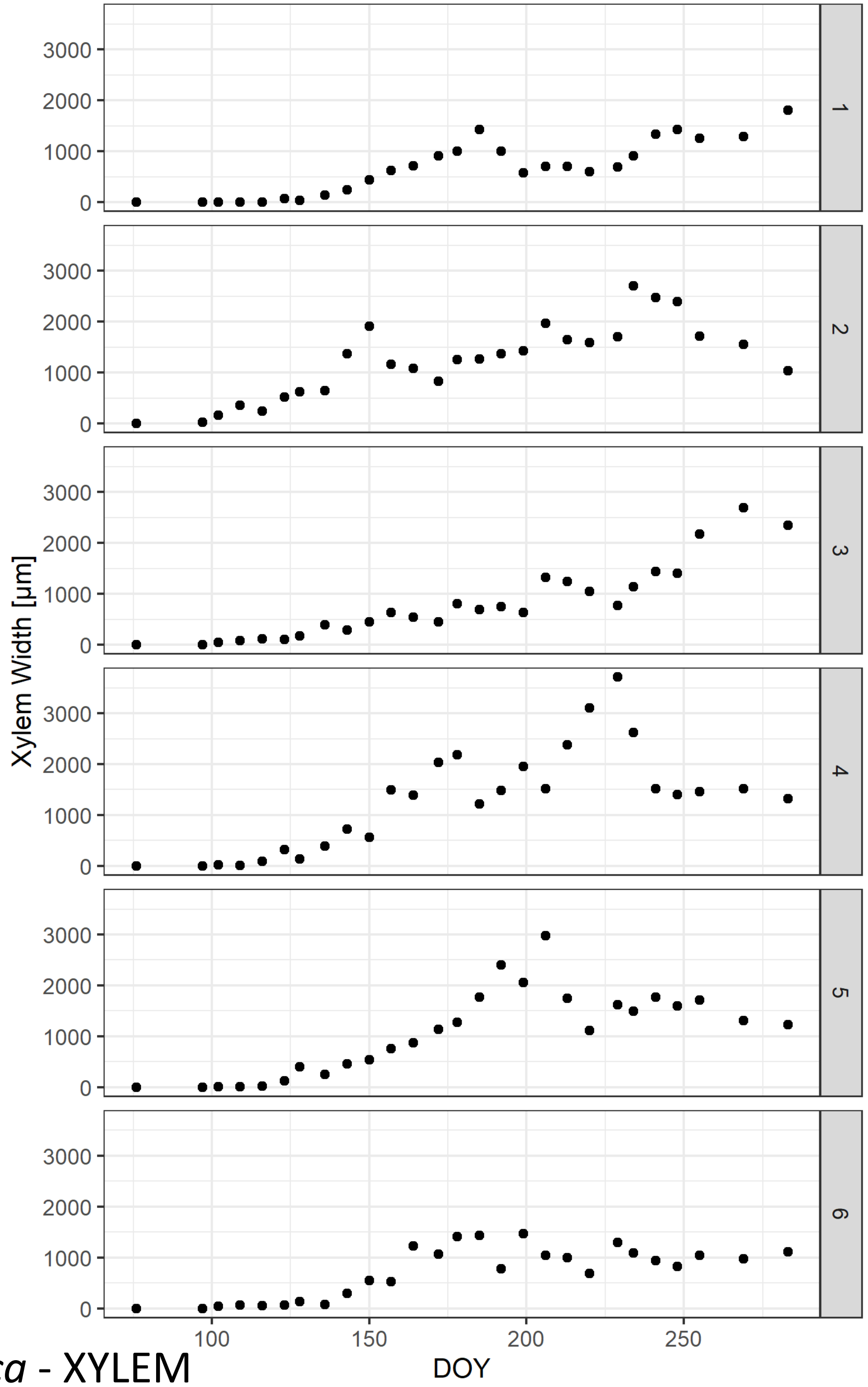
- The most common approaches include pinning, microcoring with trephor, dendrometers (https://doi.org/10.1007/s10342-007-0199-x)
- Examples on *Quercus pubescens, Fagus sylvatica* and *Picea abies*

Tree species	N	Site coordinates	Elevation	Year	Reference
Norway spruce ***(Picea abies)***	6	Panška reka 46°00′ N, 14°40′ E	400 m	2011	*(Gričar, et al. 2015)*
European beech ***(Fagus sylvatica)***	6	Panška reka 46°00′ N, 14°40′ E	400 m	2011	*(Prislan, et al. 2019)*
Pubescent oak ***(Quercus pubescens)***	6	Podgorski Kras 45°33′ N, 13°55′ E	430 m	2017	*(Gričar, et al. 2019)*

Guo et al., 2017 (DOI: 10.17521/cjpe.2017.0009)

Common issues when deriving the temporal dynamics of secondary tree growth

- Sampling did not capture the onset and cessation of cambium activity
- Radial growth around the circumference is usually heterogeneous
- Estimations should include winter cambium dormancy prior to growth reactivation in spring, and after the cambial cessation in late summer.
- The derived function is expected to be strictly monotone, with constant values prior to and after the end of cambial cell production.
- The same function should be flexible enough to appropriately capture the bimodal xylem growth often observed in Mediterranean climates.



Fagus sylvatica - XYLEM

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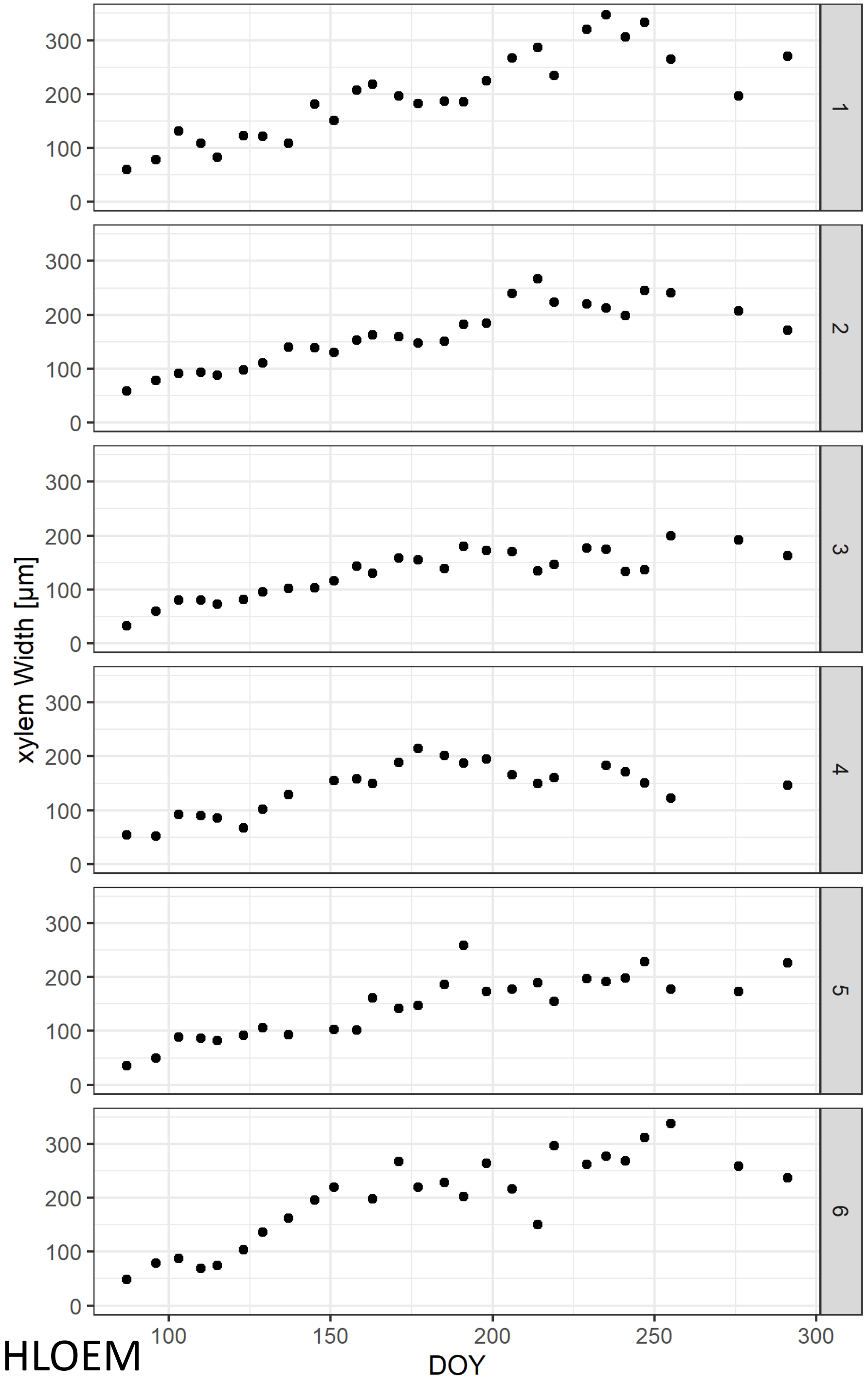


Quercus pubescens - PHLOEM

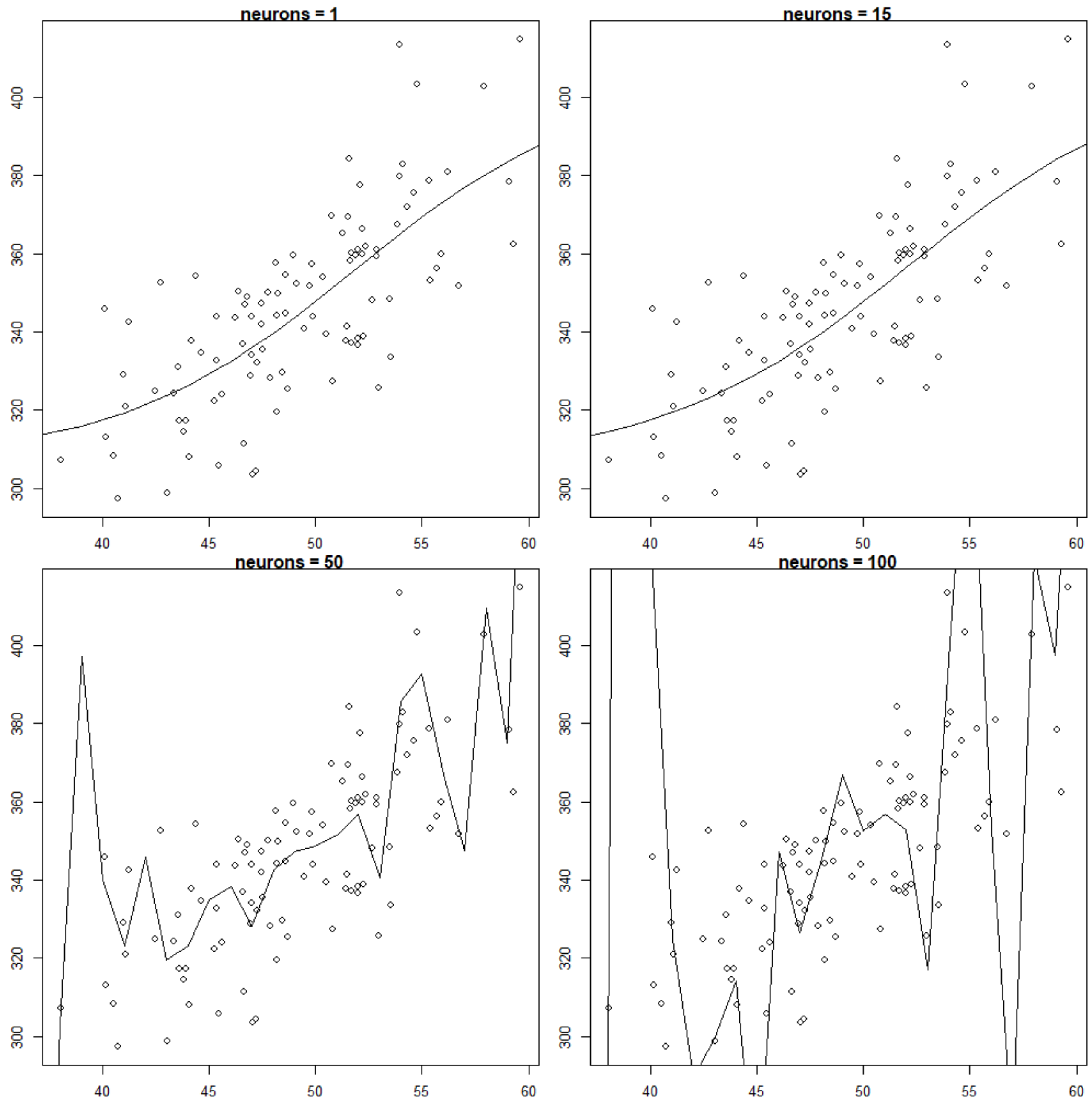
The most common methods for deriving the temporal dynamics of secondary tree growth

- Gompertz function
  - one of the most used sigmoid models
  - a common approach for modelling xylem and phloem formation
  - disadvantage is the need to select initial parameters
  - it often exhibits convergence problems when observations are highly variable
  - it is less suitable for the modelling of phloem growth due to the high growth rates at the beginning of the growing season
  - unable to model bimodal growth
  - parameters
    - a - represents asymptote or ultimate limiting value
    - b - represents displacement on the x axis
    - k - growth constant

The most common methods for deriving the temporal dynamics of secondary tree growth

- Gompertz function
- General additive models (GAMs)
  - a semi-parametric extension of generalized linear models (GLMs)
  - more flexible GAMs can better fit wood formation data
  - often fail to meet the desired constant behavior prior to and after the growing season
  - the final model could exhibit negative increments
  - the flexibility of GAM is determined by k and sp parameters
  - k represent the number of basis functions, while sp is smoothing parameter

Examples of overfitted (lower panels) and non-overfitted models (upper panels)



Artificial neural networks (ANNs) as alternative method

- Flexible, nonlinear brain-like structures
- A multilayer perceptron consists of an input, a hidden, and an output layer
- A backpropagation learning algorithm -> a process, where input-output pairs are presented to the network, and weights are adjusted to minimize the error between network output and actual value
- ANNs based on Bayesian regularization algorithm (BRNN) prevents overfitting and usually results in a sigmoid-shaped function
- The flexibility is determined by the *neurons* parameter

rTG R package

- The radial Tree Growth (rTG v1.0.1) R package was developed for deriving temporal dynamics of secondary tree growth, obtained from seasonal xylem and phloem widths or cell numbers.
- Freely available under the GPL 3.0 license from CRAN
- Can be installed using the standard command >install.packages("rTG")
- Alternatively, the most recent version may be installed from GitHub using the command >install_github("jernejjevsenak/rTG")
- Based on the core function XPSgrowth() and two generic S3 functions, i.e. plot() and summary()
- It relies on six other R packages
    - "brnn" (Pérez-Rodríguez, et al. 2013)
    - "ggplot2" (Wickham 2016)
    - "mgcv" (Wood 2011)
    - "knitr" (Xie 2017)
    - "dplyr" (Wickham, et al. 2020)
    - "magrittr" (Bache and Wickham 2020)

The *XPSgrowth()* function

- Can be used to compare and select fitting methods on xylem or phloem formation data to describe the temporal dynamics of secondary growth
- Input data

A) ***data_trees*** with selected ID variables and two additional variables: "DOY" represents day of a year, and "Width" is the target variable, which usually represents the number of radial cells (conifers) or radial width in µm (broadleaves). The "Sample" variable is optional.

A) data_trees						
Tissue	Species	Site	Year	Tree	DOY	Width
PHLOEM	FASY	PAN	2011	1	76	6.2
PHLOEM	FASY	PAN	2011	1	97	14.2
PHLOEM	FASY	PAN	2011	1	102	40.2
PHLOEM	FASY	PAN	2011	1	109	60.2
PHLOEM	FASY	PAN	2011	1	116	97
PHLOEM	FASY	PAN	2011	1	123	73.1
PHLOEM	FASY	PAN	2011	1	128	59.6
PHLOEM	FASY	PAN	2011	1	136	69.8
PHLOEM	FASY	PAN	2011	1	143	85
PHLOEM	FASY	PAN	2011	1	150	96.5
…	…	…	…	…	…	…

The *XPSgrowth()* function

- Can be used to compare and select fitting methods on xylem or phloem formation data to describe the temporal dynamics of secondary growth
- Input data

B) data frame ***parameters*** consist of selected ID variables and specified parameter values for the considered fitting methods

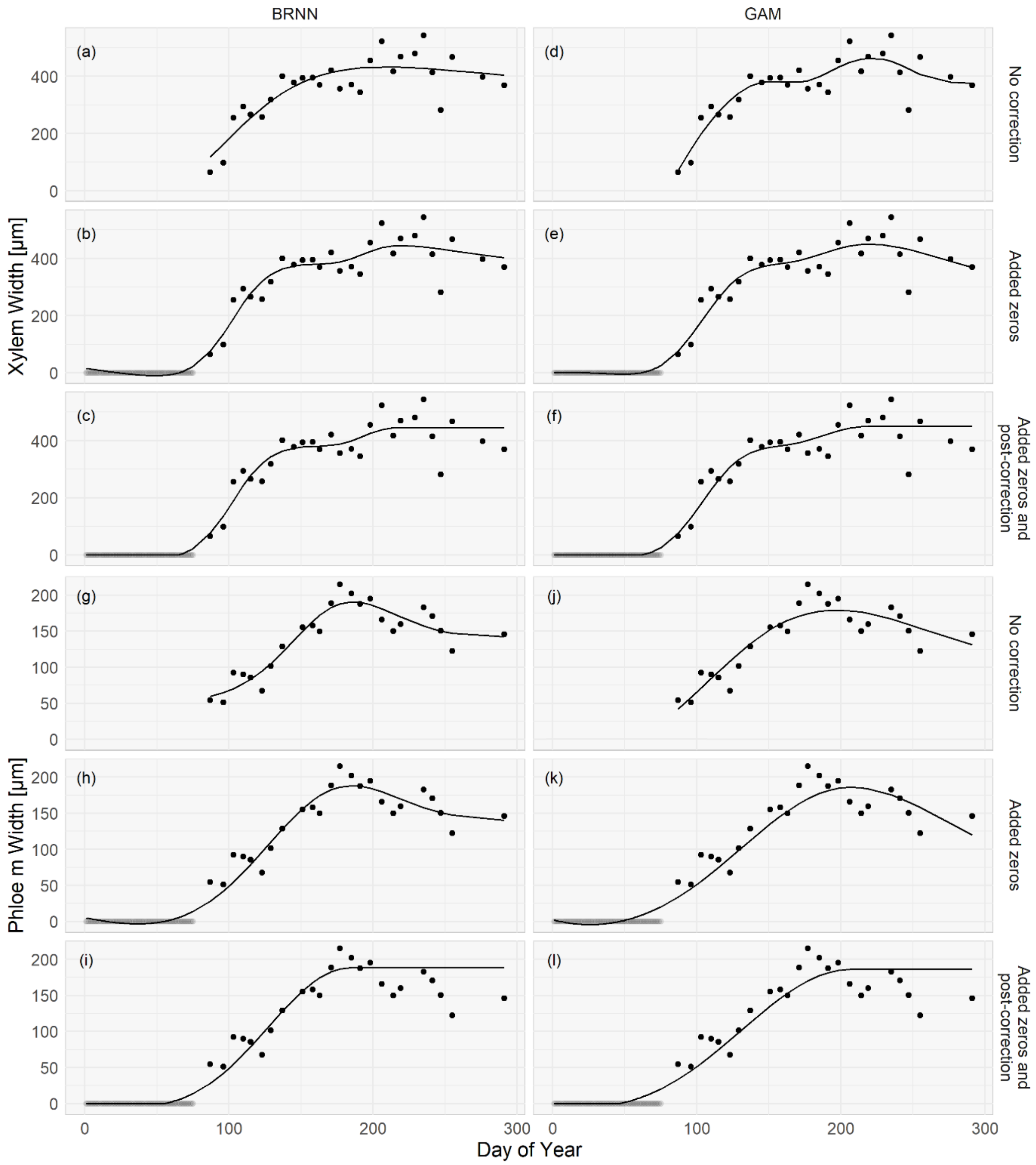
B) parameters										
Tissue	Species	Site	Year	Tree	gom_a	gom_b	gom_k	brnn_neurons	gam_k	gam_sp
PHLOEM	FASY	PAN	2011	1	3000	1534	1052	2	8	0.5
PHLOEM	FASY	PAN	2011	2	3000	472	375	2	11	0.5
PHLOEM	FASY	PAN	2011	3	3000	537	348	2	10	0.5
PHLOEM	FASY	PAN	2011	4	3000	166	118	2	10	0.5
PHLOEM	FASY	PAN	2011	5	3000	2019	856	2	10	0.5
PHLOEM	FASY	PAN	2011	6	3000	2025	1389	2	10	0.5
PHLOEM	PCAB	PAN	2011	1	3000	2017	1243	3	10	0.5
PHLOEM	PCAB	PAN	2011	2	3000	2017	1243	3	10	0.5
PHLOEM	PCAB	PAN	2011	3	3000	2017	1243	3	10	0.5
PHLOEM	PCAB	PAN	2011	4	3000	-	-	3	10	0.5
…	…	…	…	…	…	…	…	…	…	…

The *XPSgrowth()* function

Key parameters

- ***data_trees*** and ***parameters*** are input data
- ***search_initial_gom*** logical, should the algorithm to search initial Gompertz parameters be applied?
- ***fitting_method*** vector of one or more methods to be compared: "gompertz", "gam", "brnn"
- ***ID_vars*** character vector of variables which indicate column names of ID variables
- ***fitted_save*** logical, should the fitted curves be saved in current working directory?
- ***add_zeros*** logical, should zero observations at the beginning of growing season be added?
- ***add_zeros_before*** if 'min' (character) then zeros will be added prior to the first observation in each year. Alternatively, users can specify absolute DOY prior which zeros will be added.
- ***post_process*** logical, should the post-process algorithm be applied?

The effect of adding zeros at the beginning of a growing season and the post-process algorithm



The *XPSgrowth()* function

Example R code

```
> library(rTG)
> data(parameters); data(data_trees)
> simulation_1 <- XPSgrowth(data_trees,  parameters,
                             ID_vars = c("Species", "Tissue", "Site", "Year", "Tree"),
                            fitting_method = c("brnn", "gam", "gompertz"),
                            search_initial_gom = TRUE, fitted_save = TRUE,
                            add_zeros = TRUE, add_zeros_before = "min",
                            post_process = TRUE)

> plot(simulation_1)
> summary (simulation_1)
```

The *XPSgrowth()* function in action

- Example 9 – fit different Gompertz model, GAM and BRNN to example data of secondary tree growth

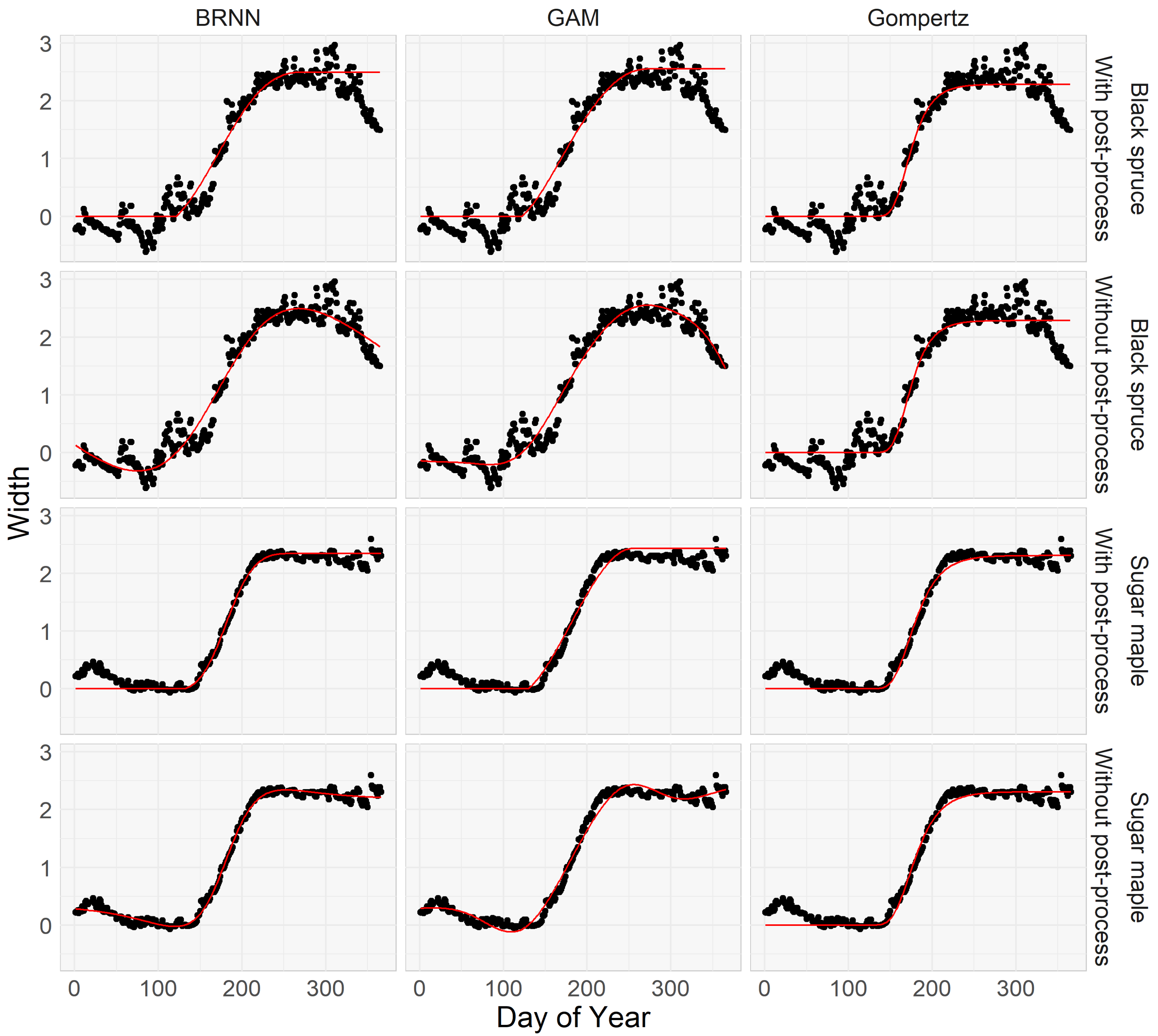
The *XPSgrowth()* function in action

- Example 9 – fit different Gompertz model, GAM and BRNN to example data of secondary tree growth
- Example 10 – compare the derived temporal dynamics of secondary growth with and without adding zeros and post-processing algorithms

The *XPSgrowth()* function in action

- Example 9 – fit different Gompertz model, GAM and BRNN to example data of secondary tree growth
- Example 10 – compare the derived temporal dynamics of secondary growth with and without adding zeros and post-processing algorithms
- Example 11 – apply the *XPSgrowth() on dendrometer data*

The *XPSgrowth()* applied on dendrometer data



Thank you very much for attending the dendroRschool workshop!

Any questions, comments suggestions?

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