RingdateR
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Citing RingdateR

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RingdateR Overview

RingdateR is an open source crossdating application constructed using the R programming language as an interactive shiny application. RingdateR is designed to facilitate visual and statistical crossdating of annually resolved measurement time series (e.g. tree rings widths, mollusc and otolith growth increments). RingdateR has a focus on facilitating crossdating dead-collected samples, with unknown antiquities, either against each other or against an existing absolutely dated chronology. The tools within RingdateR are designed to facilitate the easy identification of missing or false rings within measurement time series to facilitate the rapid development of robustly crossdated measurement time series. As such RingdateR is designed to operate closely with measurement programmes, such as CooRecorder and Image Pro.

As RingdateR is a crossdating application it has not been designed for the construction of chronologies and as such does not contain facilities for performing regional curve standardisation or signal free detrending or tools for combining measurement time series into robust mean chronologies.

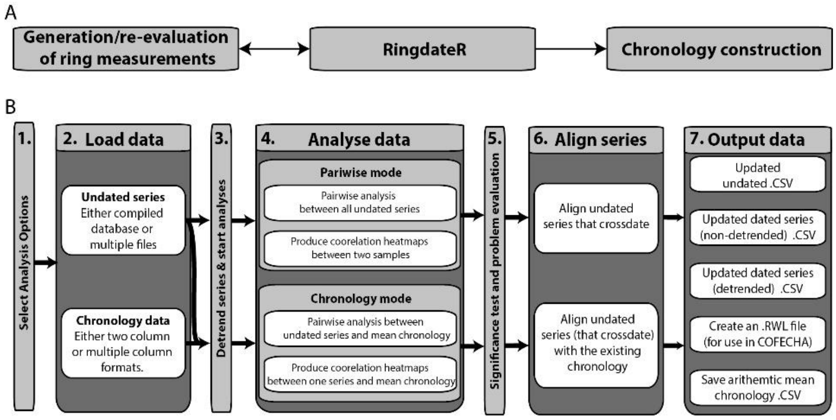


Fig 1: A) A schematic showing the general position of RingdateR in the overall chronology construction workflow. B) A generalised schematic of the RingdateR workflow. 1) User defines the options for the analyses (i.e. detrending method, lag range; Step one of Starting Point page). 2) Individual series and chronology data are loaded (Step two of Starting Point page). 3) These data are detrended and lead-lag analyses performed (Step four of starting point page). 4) The results of the lead-lag analyses are displayed along with running lead-lag correlation analysis heat maps. At this point it is possible to view the results of the matches between each sample (Pairwise Comparison and Chronology Analysis Results pages respectively). 5) The results are filtered using statistics and sample names to select a subset of samples to align in time. It is then possible to evaluate if any of the selected samples contain potential problems relative to the arithmetic mean chronology built with replacement. 6) The aligned data are then plotted and the corresponding Rbar and expressed population statistics calculated. These results are displayed on the Aligned Data and New Chronology pages for the Pairwise and Chronology Analysis Modes respectively. 7) It is also then possible to save the aligned crossdated timeseries as non-detrended or detrended CSV files or create an RWL file to transfer the analysis to other programmes such as COFECHA. It is also possible to save the undated series that did not crossdate into a separate .csv file and to save the arithmetic mean chronology in two column (year/chronology) format.

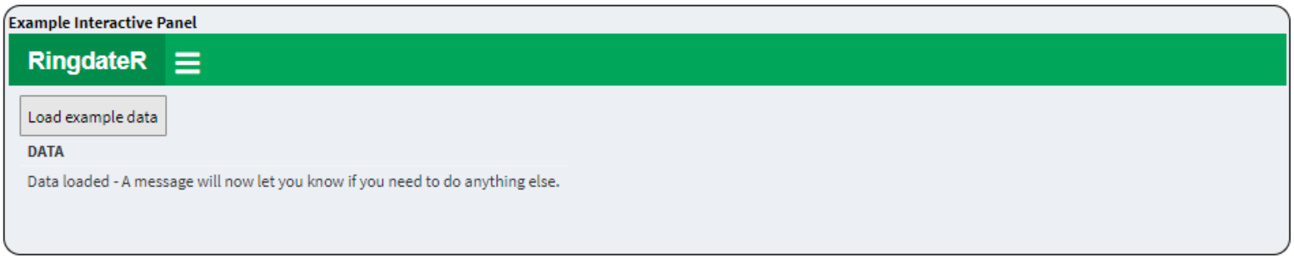
Operation of this document

This document sets out the operation of the RingdateR application. The document is structured to closely mirror the order of operations in running the RingdateR app. In addition to the text and standard figures, this document also contains interactive panels. To more clearly distinguish between the interactive panels and figures, which do look very similar, the interactive panels have been given a Panel title and a strong black border (see example below).

Note, the interactive panels only operate in the online version of this document and not in the pdf version.

Each of the interactive panels have example data that can be loaded by clicking on the buttons displayed in the top left corner of each panel. Text will then display once the data is loaded. When required, additional information will also display with additional instruction. These data allow the interaction with the panels in the same manner as if operating the RingdateR app.

Whilst these interactive panels are near identical to the pages within the RingdateR app, to make this document quick to operate, the settings for the analysis which would normally be set on the Starting Point page have been pre-set. For reference, these settings are: the data are detrended with a 21 year spline, running correlations are calculated over 21 year running window with a 20 year period of overlap, lead-lag limits are set to ±20 years and RingdateR is operating in Chronology Analysis Mode. The example data are annually resolved tree ring width data from douglas fir.



Interactive panel 1: An example interactive panel with the load example data button located in the top left corner of the page. Once the data is loaded the message "Data Loaded - " will display. If necessary a second message will also appear with further instructions.

Running RingdateR

RingdateR can be run either directly as a web page or locally using RStudio. The sections below provide information about launching RingdateR in both the online and offline modes.

Launching RingdateR app online

RingdateR Online is launched via the RingdateR web page (https://ringdater.github.io/ringdater/). Clicking the Launch RingdateR Online button on the right side of the RingdateR home page will launch the RingdateR Online launch window. From the launch window, click the Launch RingdateR Online button to launch a new session on an available server.

RingdateR online is identical to the offline (local) version of RingdateR, that runs directly in R. It should be noted, due to server space limitations, RingdateR online will automatically time out after 30 minutes of inactive use. Any analyses that are displayed on the screen after this time will be lost. **It is advisable, that users who intend to use RingdateR regularly should run the offline version of RingdateR. The offline version operates in the exact same way as the online version and there are no time out limits on the offline version of RingdateR.**

Launching RingdateR app offline

To run RingdateR on your own computer, both R (https://www.r-project.org/) and R Studio (https://www.rstudio.com/) should already be installed.

RingdateR can be downloaded and installed directly from Github by running the following code in Rstudio:

```
install.packages("devtools")
library(devtools)
devtools::install_github("ringdater/ringdater_pkg")
```

Requirements

RingdateR requires R version 4.0. There are also a number of dependencies, listed in the help file, that will automatically install when the RingdateR package is first installed. If you are currently using an older version of R, you can automatically install the latest version using the following code:

```
install.packages("installr")
library(installr)
updateR()
```

Installing the package will automatically install any package dependencies (listed at the end of this document) not already installed.

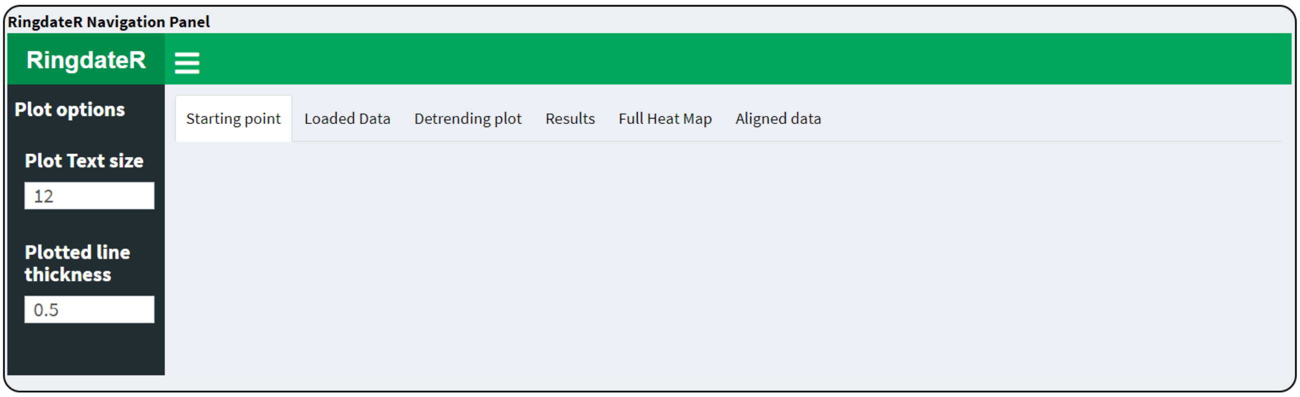
Once RingdateR is installed, to launch the RingdateR app use the following code:

library(ringdater)
run_ringdater()

The run_ringdater() function will automatically launch RingdateR in the systems default web browser. Alternatively, RingdateR can also operate in R console. For more information on this see the Pairwise Mode Vignette and the Chronology Analysis Mode vignette (https://ringdater.github.io/ringdater/help.html) .

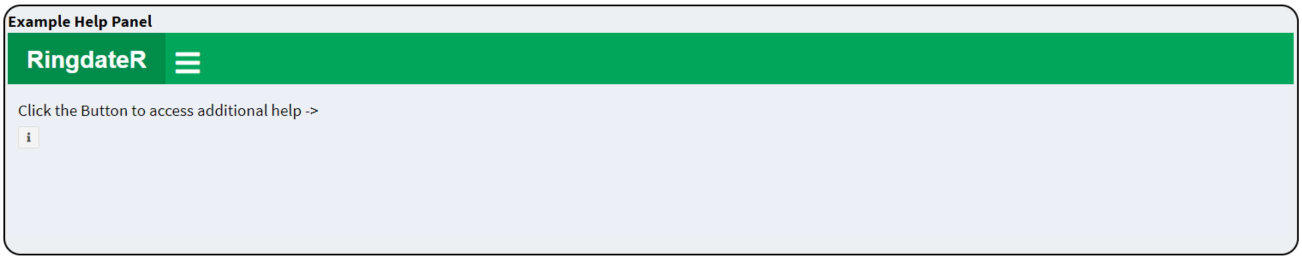
General navigation in RingdateR
The RingdateR app operates in a similar way to a web page. The navigation bar at the top of the page can be used to navigate between pages.

There is also a toggleable menu on the left of the page containing options for modifying plots. The ≡ button, next to the RingdateR title, can be used to show and hide the plot option menu. The plot options accessed on this menu will change the settings for every graph in RingdateR, however, the plot options may have limited use in this help file.



Interactive panel 2: A panel showing the general structure of the RingdateR app. The Plot option panel on the left of the page is toggleable using the ≡ button.

Access to help
Additional help can be found throughout RingdateR by using the “I” buttons. Each button will bring up a text panel with more information about that part of the application.



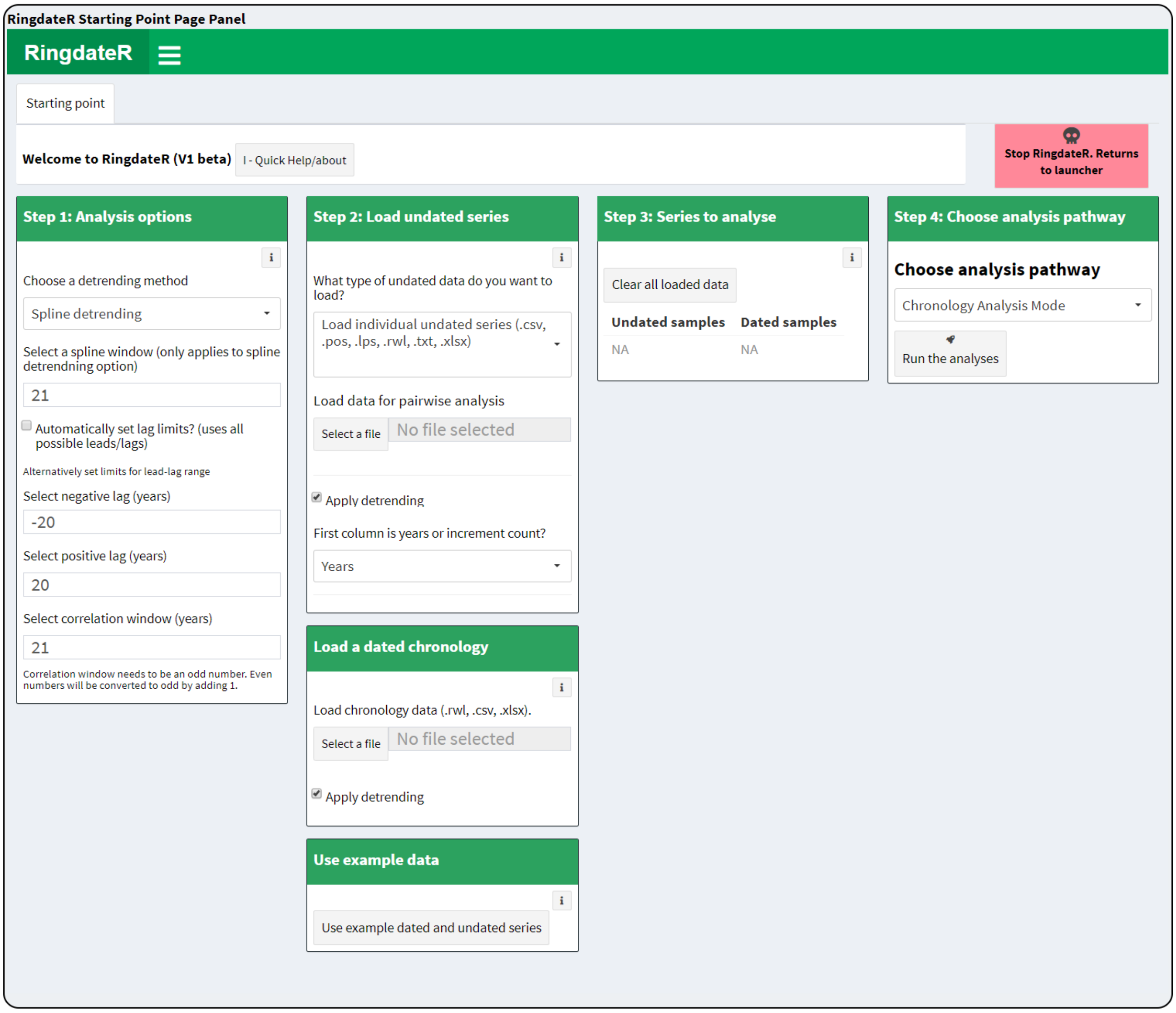
Interactive panel 3: An example help button. Pressing the I button makes a text panel display with additional help. You can scroll to view the whole panel. Clicking anywhere off the text panel will make it disappear.

Step by step overview of running analyses in RingdateR

To run analyses in RingdateR:
1: Set basic analysis settings using the Step one: analysis settings box on the Starting Point Page
2: Load you undated measurement time series
3: (optional step) Load the dated chronology – only required if using Chronology Analysis Mode.
4: Check the detrending applied on the Detrending Plot page and adjust as necessary.
5: On the Starting Point Page select analysis pathway in the Step four box.
6: click Run Analysis and automatically jump to Results Page
7: Using the options menus on the results page manually check the results of the lead-lag analyses.
8: Apply statistical filter check to reduce the number of analyses to examine by removing non-significant matches.
9: Begin to align the data by selecting a target sample and check for potential problematic samples.
10: Repeat the problem sample check using varying window lengths.
11: Select the samples to align.
12: Click the Align data button and evaluate the aligned data on the aligned data page
13: If necessary, perform the secondary problem sample check
14: Output the aligned data.

Starting Point page
The Starting Point page can be considered RingdateR's home page. From here users can select the detrending and correlation settings, load their own data or select to use example data, and select which analysis pathway to analyse the data with (Pairwise or Chronology Analysis mode).

Step one box: Set the detrending method to use and the limits for the range of leads and lags to analyse the data over
Step two box: Load undated series box is for uploading individual measurement time series and floating chronologies. The load a dated chronology box is for loading an absolutely dated chronology for use in the Chronology Analysis mode. Alternatively, the Use example data box allows users to load both undated and dated series.
Step three box: Display the IDs of all the series that are loaded into RingdateR.
Step four box: Set the analysis mode to use and a button to start the analyses.



Interactive Panel 4: The Starting Point page interactive panel. On this page users can set the analysis settings, loaded undated and dated measurement time series or use preloaded example data. The step three box displays the sample ID's of the loaded data. The clear all data button can be used to remove the loaded data and reset RingdateR to default settings. Note, as this panel is purely to demonstrate the layout of the Starting Point page, the run analysis, stop RingdateR and load example data buttons have been disabled in this panel.

Loading data - acceptable data formats

A variety of data formats can be loaded into RingdateR. The following sections (4.1 to 4.4 gives an overview for the acceptable file types as well as the corresponding formatting for the data for both the online and offline versions of RingdateR as well as the console version. The RingdateR app provides summary tables of all the data that has been loaded into RingdateR on the Loaded Data page.

Compiled file formats – chronology data and individual measurement time series

Excel (.xlsx), text tab delimited (.txt), comma separated value (.csv) and .rwl files can containing compiled measurement time series either aligned as a chronology or aligned by ontogenetic age. These data can be loaded in as dated chronologies, undated (floating) chronologies or undated individual series (i.e. not crossdated) using the corresponding file browsers on the Starting Point page of the RingdateR app. It should be noted that RingdateR sometimes has issues loading data from .rwl files due to the inconsistent formatting of these files.

All compiled file formats, except .rwl, should be formatted such that the first column contains either year values or ring numbers (in ascending order; e.g. Table 2). Each of the following columns should contain a uniquely named measurement series. The first row of the compiled file should contain the sample numbers/names. Each sample number/name must be unique. Samples cannot contain missing values within a measurement series. Years that do not contain data for each sample, i.e. years before or after growth in a dated chronology (e.g. Table 2A), can contain either NA values or simply be left empty.
It is possible to load multiple compiled files in as undated series, either as undated floating chronologies or as compiled files containing individual undated measurement time series. However, only one dated chronology can be loaded.

Example data, to check formatting, can be accessed from https://ringdater.github.io/ringdater/. In addition, the RingdateR app has preloaded example data which can be used in both the Pairwise and Chronology Analysis Modes.

Table 1: Compiled data sets can either be loaded in as (A) date aligned or (B) ontogenetically aligned data.

A

Year	Series_1	Series_2	Series_3
1901	NA	NA	0.45
1902	NA	NA	0.99
1903	NA	0.06	0.20
1904	NA	0.76	0.08
1905	NA	0.13	0.33
1906	0.51	0.78	0.38
1907	0.34	0.64	0.01
1908	0.02	0.09	0.41
1909	0.64	0.77	0.83
…	…	…	…

B

Ring	Series_1	Series_2	Series_3
1	0.51	0.06	0.45
2	0.34	0.76	0.99
3	0.02	0.13	0.20
4	0.64	0.78	0.08
5	0.26	0.64	0.33
6	0.57	0.09	0.38
7	0.76	0.77	0.01
8	0.52	0.64	0.41
9	0.60	0.08	0.83
…	…	…	…

Non-compiled file formats

In addition to compiled file formats, it is possible to load in multiple files containing data from one sample per file, as undated series, through the Load Undated Series file browser. The sections below provide more information about each of these file formats.

Using Image Pro Line Profile Series files (.lps)

Measurement series created in Image Pro as a line profile series can be loaded into RingdateR as an undated series. The .lps files can contain more than one line profile. RingdateR will automatically detect that more than one measurement series is in the file and load them as separate measurement series with the sample ID set as the file name (minus the extension), for example file_name_l1, file_name_l2 etc. As the .lps files contain cumulative growth data, RingdateR converts the cumulative growth data into absolute growth increment series.

RingdateR automatically detects that an .lps file has been loaded and will allow users to then load multiple .lps files. When multiple .lps files are loaded RingdateR compiles the data into a single data frame. The series in the data frame are aligned by ontogenetic age.

Figures 2, 3 and 4 show the process of creating .lps files in Image Pro for use in RingdateR.

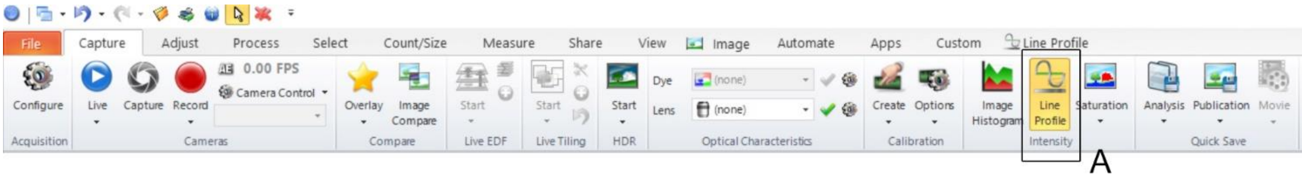


Fig 2: To start the Line profile series, once an image has been loaded and calibrated, use the Line Profile tool (box A).

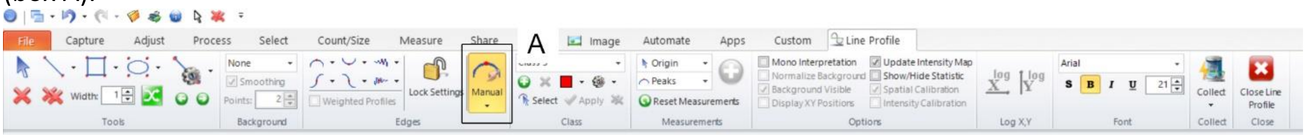
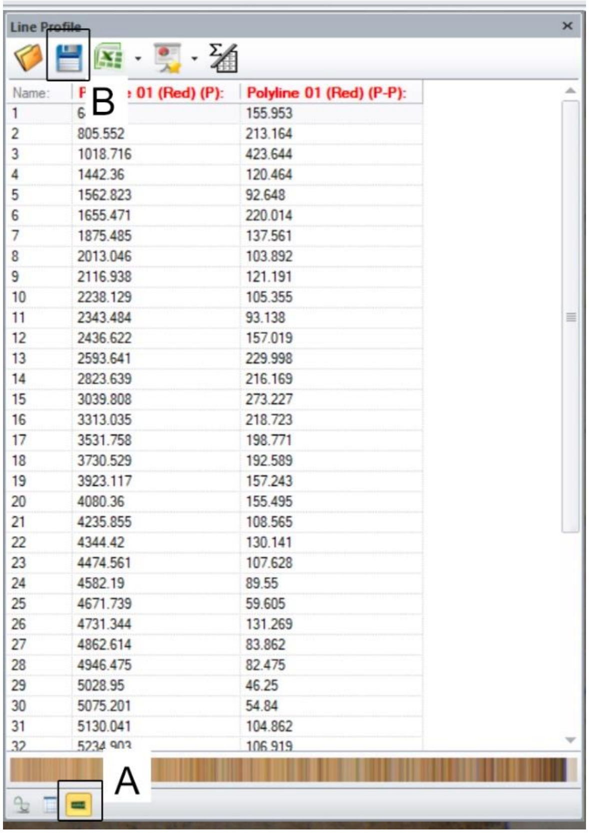


Fig 3: When using the line profile, the Manual measurement option (box A) provides the most consistent results for creating measurement series that can be incorporated into RingdateR.



Name:	F : 01 (Red) (P):	Polyline 01 (Red) (P-P):
1	6	155.953
2	805.552	213.164
3	1018.716	423.644
4	1442.36	120.464
5	1562.823	92.648
6	1655.471	220.014
7	1875.485	137.561
8	2013.046	103.892
9	2116.938	121.191
10	2238.129	105.355
11	2343.484	93.138
12	2436.622	157.019
13	2593.641	229.998
14	2823.639	216.169
15	3039.808	273.227
16	3313.035	218.723
17	3531.758	198.771
18	3730.529	192.589
19	3923.117	157.243
20	4080.36	155.495
21	4235.855	108.565
22	4344.42	130.141
23	4474.561	107.628
24	4582.19	89.55
25	4671.739	59.605
26	4731.344	131.269
27	4862.614	83.862
28	4946.475	82.475
29	5028.95	46.25
30	5075.201	54.84
31	5130.041	104.862
32	5234.903	106.919

Fig 4: When saving the .lps file ensure that the results window is set to the third tab (Box A: displays the cumulative growth measurements in the first column). The save icon (box B) will then allow you to save the measurements as an .lps file.

Using CooRecirder files (.pos)

Measurement timeseries created by CooRecorder (.pos) can be loaded directly into RingdateR. As each .pos file contains measurements from one series, multiple .pos files can be loaded in as undated series. These files can then be used in either the Pairwise or Chronology Analysis Modes. AS no date values are included in .pos files, when the files are loaded into RingdateR, the data are aligned relative to the measurement corresponding to the youngest ontogeny of each series.

Two column text tab delimited files (.txt)

Multiple two column txt files, with the first column containing either a year or ring count value and the second column containing the measurements, can be loaded as undated series. The file should not contain headers, I.e. the first row of the file should contain the first measurement.

Loading floating chronologies as undated series

The Starting Point page provides users the ability to load both dated and undated measurement time series. The undated measurement time series can either be individual measurement time series, i.e. measurements from an individual core, or from a collection of measurement time series aligned in time relative to each other but not yet absolutely dated, i.e. a floating chronology. Using the undated series loading browser it is possible to load multiple floating chronologies as undated series for comparison either against other floating series or dated chronologies.

To load floating chronologies as undated series, first set the type of undated data selection option to “Load undated chronologies”. Each chronology should be contained in a separate compiled file (see above for acceptable formats). It is important that prior to loading the chronologies that the detrending mode is selected. Unlike loading individual measurement time series, the detrending mode cannot be adjusted after the data are loaded if analysing undated chronologies. This is because as the data are loaded, the individual series contained in each chronology are automatically detrended and an arithmetic mean chronology calculated. As multiple files can be loaded, these arithmetic mean chronologies are then compiled ready for analysis.

If multiple undated chronologies are loaded the series can be analysed against each other using the Pairwise Analysis Mode, or against a dated chronology through the Chronology Analysis Mode. The dated chronology should be loaded through the Dated Chronology file browser. The operation of RingdateR is identical for analysing multiple undated chronologies and multiple individual measurement time series.

Detrending

RingdateR includes seven options for detrending the raw measurement time series. Firstly, the “Do nothing to my data” option leaves the data undetrended. Secondly, whilst not technically detrending, the data can be converted to z-score anomalies. The spline, modified negative exponential, Friedman and modified Hugershof detrending curves are applied using the detrend.series function in dplR (Bunn et al., 2010). The first difference of the measurement series is the final detrending approach available. The first difference of the data is generated by calculating the difference between measurement years.

Detrending is performed by dividing the raw measurement series by the detrending curve, to standardise variance through time.

A 21-year spline is set as the default detrending method in RingdateR. Adjusting the length of the spline can lead to a greater/lesser proportion of lower frequency variability being removed from the measurement time series.

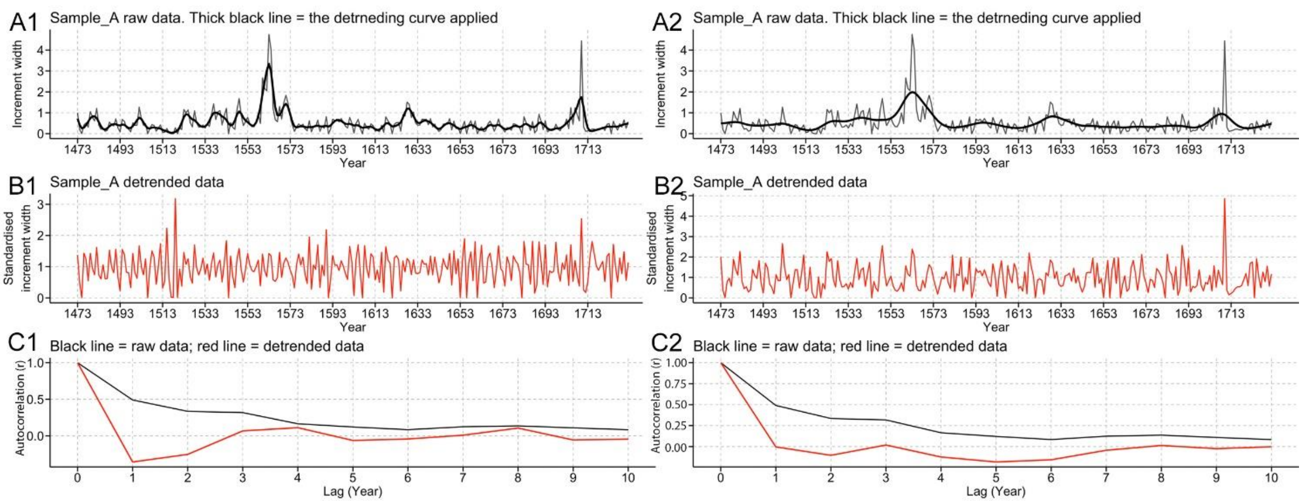


Fig 5: Comparison between applying a 7-year spline detrending (A1-C1) and a 21-year spline detrending (A2-C2). A1-2) Raw measurement timeseries plotted with the fitted detrending curve (thin and thick black lines respectively). B1-2) the residuals calculated by dividing the raw measurement times series against the fitted detrending curve. C1-2) Plots showing a comparison between the autocorrelation calculated over the full record for both the raw data and detrended data (black and red lines respectively). Plots generated on the Detrending Plot page in RingdateR.

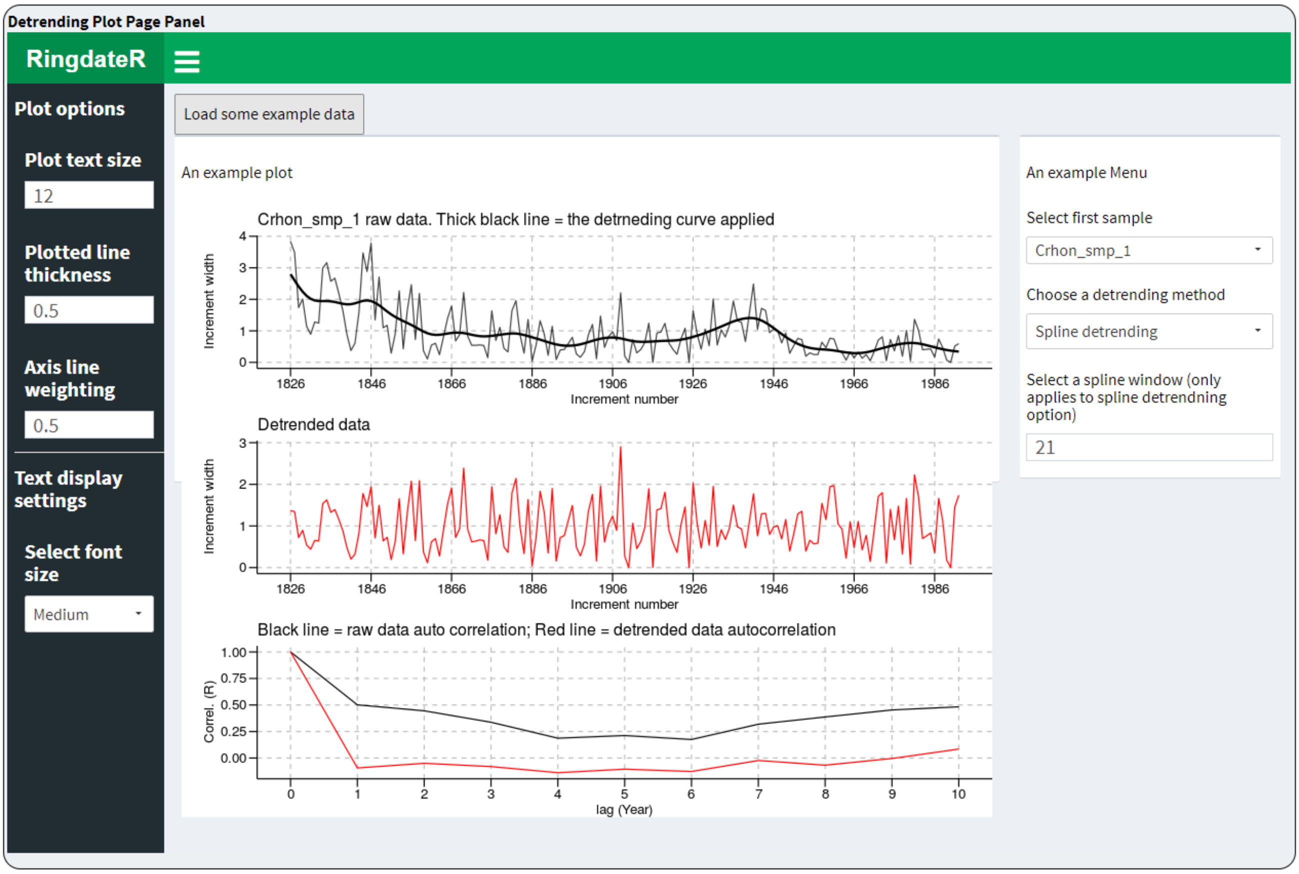
Once data has been loaded, it is possible to evaluate the impact of the detrending options before committing to starting to run the analyses by viewing the detrended data on the Detrending Plot page (see below). It is also possible to view basic statistics of the loaded data, pre and post detrending, as well as to download the detrended data on the Loaded Data page via the Detrended Data tab.

Detrending Plot Page

The detrending plot page allows users to evaluate the impact of the selected detrending options on each individual measurement timeseries loaded as an undated series. The menu panel on the left of the page allows users to modify the detrending method. The change in settings made here automatically updates the detrending method set on the starting point page.

Once data is loaded the plot will automatically generate. The menu on the right of the page will allow users to change the detrending that is applied. The detrending method set on this menu will be the detrending method applied for the analysis.

Once satisfied the detrending is suitable, the analyses can be initiated on the Starting Point page.



Interactive panel 5: The Detrending plot page. This interactive panel allows users to experiment with the different detrending techniques on preloaded data. The plot options menu also works to modify the visual appearance of the plot.

Crossdating - The Results Page
Crossdating overview
crossdating in RingdateR is a multi-step process. After setting the analysis options, loading in the data and initialising the analysis by clicking Run the Analysis button on the Starting Point page, RingdateR performs lead-lag analysis between every pair of individual measurement time series in Pairwise Analysis Mode, and between the loaded chronology and each individual measurement time series in Chronology Analysis Mode. The results of these analyses are then presented in both graphical and tabular form on the Results page. Given that large numbers of analyses can be conducted during lead-lag analysis, a Bonferroni correction is applied to the probability values for each of the lead-lag analyses. The Bonferroni correction is derived based on the total number of correlations calculated between two samples, which is dictated by the total range of lags evaluated.

Once the lead-lag analyses have been completed, RingdateR provides users with a series of graphs designed to facilitate the interrogation of the lead-lag results to determine, if significant correlations are identified, whether identified crossdates are spurious or if there are possible missing or false rings in the measurement time series. The following sections provide more information on each of the plots and corresponding menus.

Results Page The large results table

The large results table (Fig. 6) provides the statistics for the three most probable crossdates between the analysed measurement time series. The table is fully interactive and can be filtered/ordered by clicking the headers in the table (to change the order of the column from ascending to descending) or using the statistical and sample ID filters in the menus provided (Fig. 7). The results table can be downloaded as a comma separated values (.csv) file.

Results from the table can also be easily plotted. In the sample selection menu, on the right of the Results page (Fig. 8), set the “Selection Option” to “select row from results table”. This changes the samples to be plotted from manual selection to a user defined row from the table. Once the Selection option has been changed, to select which row is plotted simply click on a row in the table, the plots will then automatically update.

Show 10 entries Search:

	Series_1	Series_2	First_ring	Last_ring	First_lag	First_R	First_P	First_Overlap	Sec_lag	Sec_R	Sec_P	Sec_Overlap	Third_lag	Third_R	Third_P	Third_Overlap
2	Mean_chronology	Sample_A	1671	1930	7	0.844	5.7526e-69	260	267	0.389	1.1671	62	19	0.178	2.6234	260
3	Mean_chronology	Sample_B	1664	1734	0	0.679	5.2078e-8	71	146	0.462	0.032903	71	188	0.355	1.57	71
4	Mean_chronology	Sample_C	1693	1950	29	0.853	2.5977e-71	258	6	0.223	0.19572	258	152	0.212	2.9966	177
5	Mean_chronology	Sample_D	1692	1755	28	0.794	3.1332e-12	64	14	0.337	4.2941	64	68	0.311	8.1789	64
6	Mean_chronology	Sample_E	1692	1755	28	0.774	4.335e-11	64	14	0.321	6.3797	64	-49	0.578	15.782	15
7	Mean_chronology	Sample_F	1758	1900	94	0.774	5.4971e-27	143	-105	0.513	0.64608	38	61	0.272	0.68112	143
8	Mean_chronology	Sample_G	1769	1900	105	0.857	2.1463e-36	132	271	0.403	1.109	58	73	0.269	1.1852	132
9	Mean_chronology	Sample_H	1741	1950	77	0.815	2.2853e-48	210	-149	0.448	0.19374	61	100	0.224	0.69454	210
10	Mean_chronology	Sample_I	1761	1950	97	0.846	1.7185e-50	190	263	0.476	0.035877	66	120	0.231	0.88331	190
11	Mean_chronology	Sample_J	1741	1811	77	0.733	2.3008e-10	71	92	0.44	0.081159	71	110	0.364	1.1944	71

Showing 1 to 10 of 13 entries Previous 1 2 Next

Fig 6: An interactive results table displaying the statistics associated with the best three matches for each pair of measurement time series analysed.

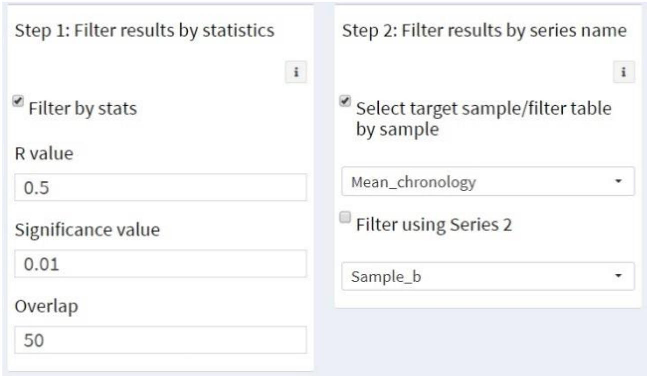


Fig 7: Two menus displayed on the Results page to facilitate the filtering of the large results table. These filters allow the table to be filtered to show only results that pass user defined statistical thresholds as well as to only show results for user specified samples. To apply the filters the check boxes in each of the respective menus must be checked.

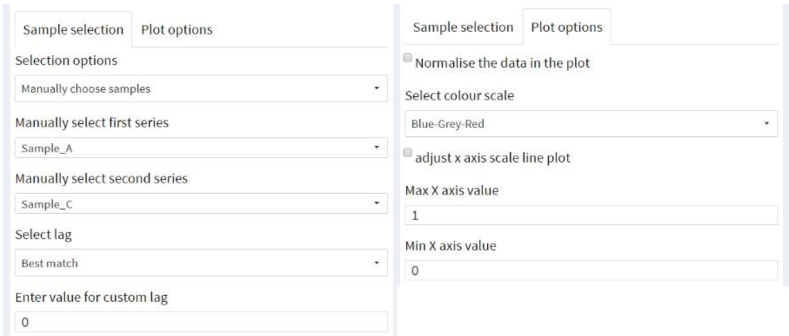


Fig 8: The sample selection and plot options menus from the Results page. These menus allow the user to manually select the samples plotted on the Results page, the lag with which the second sample is plotted with as well as general plot settings for both the line plot and the running correlation heat map.

Results Page Line plot

The line plot displayed on the Results page presents the two selected measurement time series aligned in time based, initially, based on the best possible crossdate identified by the lead-lag analyses. The second sample (plotted in red) is always the sample that is moved in time relative to the first sample (plotted in black). The Sample Selection menu (Fig. 8) provides options to change the lag that the second series is plotted with from either the three best possible matches or a user defined lag. Samples plotted can either be selected manually or by selecting a row from the large results table using the sample selection menu (Fig. 8).

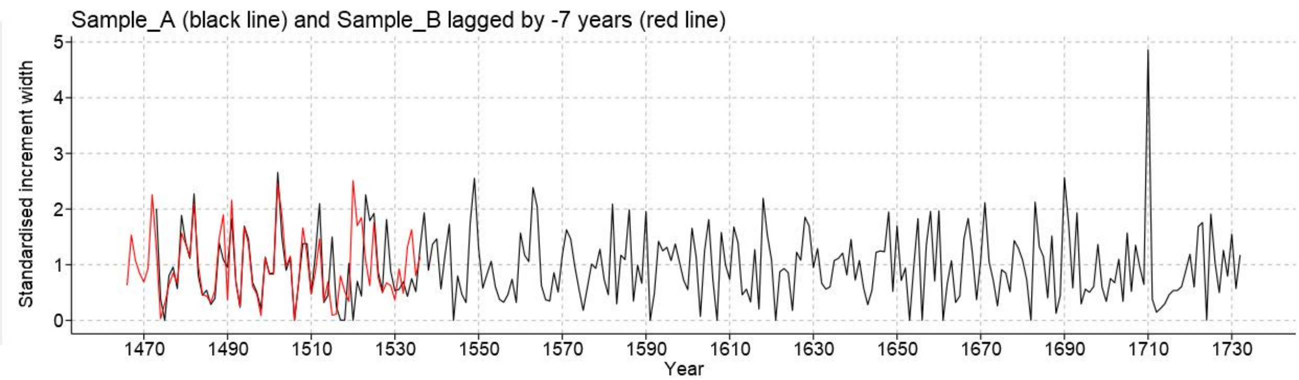


Fig 9: A line plot showing the comparison between two measurement time series aligned in time based on the most likely crossdate.

Results Page Heat Map

The heat map displayed on the Results page (Fig 10) presents the running correlations calculated between the two selected measurement time series over a ±10 year lead-lag range. The correlations are calculated over a defined window (21 years by default) set on the Starting Point page (analysis settings menu). The running correlations are calculated with an overlap one year less than the window length. The heat map automatically centres the lag on the selected lag with which the series are plotted in the line graph (Fig. 9). Due to the fact the heat maps are based on correlations, there is a minimum threshold of data required to produce the plots. Therefore, measurement timeseries with an insufficient overlap between the series will result in no plot being generated. An error message will display to communicate this error.

Whilst the running correlation heat map displayed on the Results page is limited to a ±10 year lead-lag range, it is possible to produce heat maps over the full lead-lag range on the Full Heat Map page (see Full Heat Map section below).

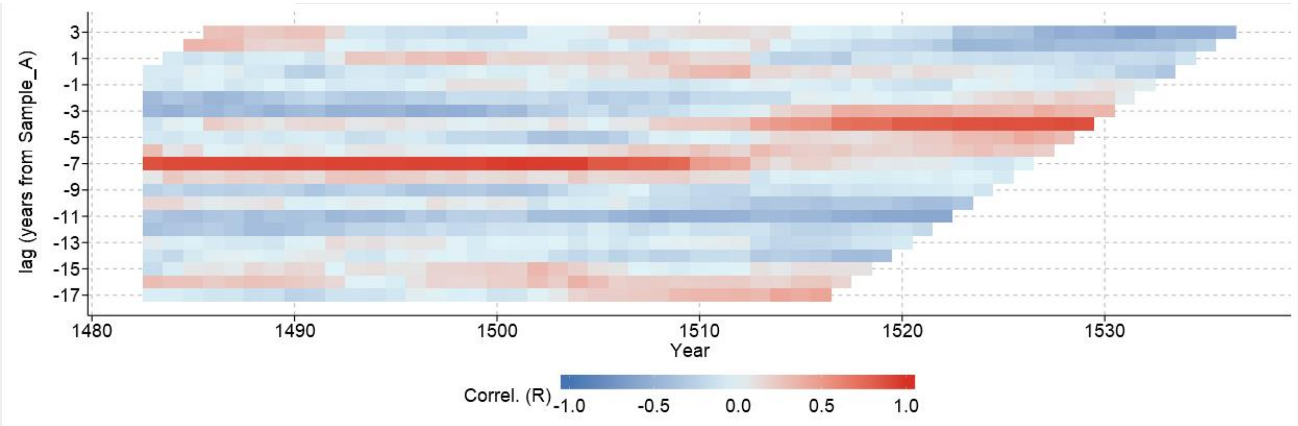


Fig 10: A heat map showing the running correlations calculated between the two measurement time series plotted in The running correlations in the heat map are calculated over a ±10 year lead-lag range centred around the lag with which the second sample is plotted with in Fig 9.

T-value bar chart

As the correlation heat map and results table provided on the Results page do not provide the results of the full range of leads and lags analysed, RingdateR provides bar graphs which display the T-values for the lead-lag correlations calculated over the full range of leads and lags being analysed (e.g. Fig 11). The bar graphs are automatically generated when running in either Pairwise or Chronology Analysis Modes. The graphs plot the lags with positive correlations and highlights the best three matches with red, blue and green bars respectively. The bar charts are accessed from the lead-lag results tab.

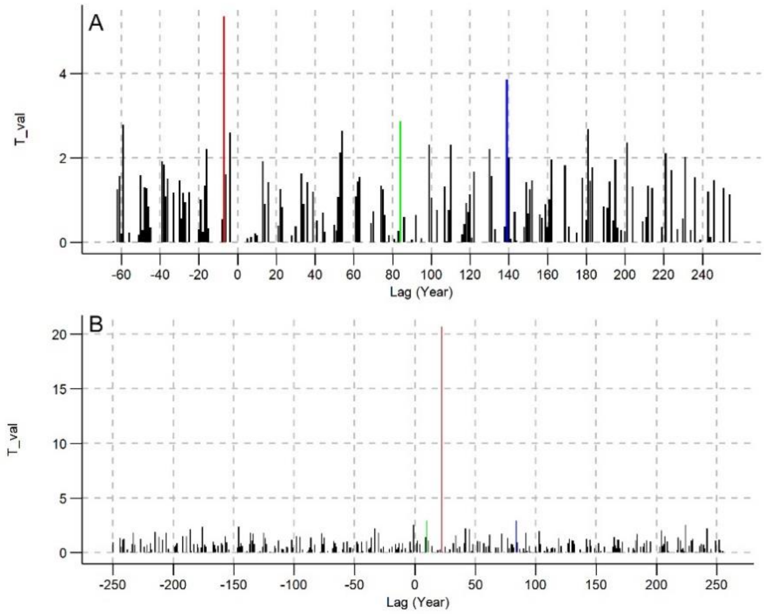


Fig 11: Bar graphs displaying the T-values for the correlations between two measurement time series. Plots only show the positive correlations. The red, blue and green bars show the first, second and third best matches respectively. Panels A and B show a comparison between the appearance of the bar graphs when A) he two measurement time series either don't crossdate or possibly contain errors; and B) when the two measurement time series likely crossdate, highlighted by the best match containing a stand out T-value relative to all other leads and lags.

Checking for Problematic Samples

For series which pass the statistical tests (set up by applying the statistical filter in Fig. 7) RingdateR provides the facility to automatically evaluate for potential problematic samples. To use the problem sample checker, apply both the statistical filter and select a target sample. The problem sample check can then be applied. The problem sample check aligns all of the data automatically aligns, based on the best match, all the measurement time series that pass the user defined statistical thresholds against the target sample. Running correlations are then calculated, with 50% overlap, with replacement against the arithmetic mean chronology derived using the aligned data (i.e. the chronology is calculated excluding the sample being correlated against it). RingdateR utilises the corr.rwl.seg function from the dplR package to evaluate if individual series exhibit instabilities in their correlation with the mean chronology (Bunn et al., 2010).

It should be noted that samples can be flagged as problematic for two principal reasons. Firstly, If the measurement time series contain missing or falsely identified rings the running correlations will contain a phase shift corresponding to the number of missing or falsely added rings (e.g. Fig 12 A2-B2). Secondly, the correlation between the measurement time series and the mean chronology could be variable through time (e.g. Fig 12 A1-B1). These fluctuations in the amplitude of the correlation, which are flagged as problems, may not necessarily mean there is a problem with the measurement time series. The problem checker is designed to flag potential problems and therefore takes a conservative approach.

These analyses are highly sensitive to the bin size that is used to perform the analysis. It is therefore recommended that these analyses are replicated using multiple window lengths. This can be done simply by changing the window length that the correlations are performed over several times and re-evaluating the outputs.

RingdateR also provides a second opportunity to evaluate for problem samples on the Aligned Data page. The secondary evaluation works in the same manner as on the Results page. However, there is added functionality. On the Aligned Data page it is possible, if the secondary problem check finds potentially problematic samples, to generate a running correlation heat map between the identified problematic sample and the arithmetic mean chronology constructed from the aligned data excluding the potentially problematic sample.

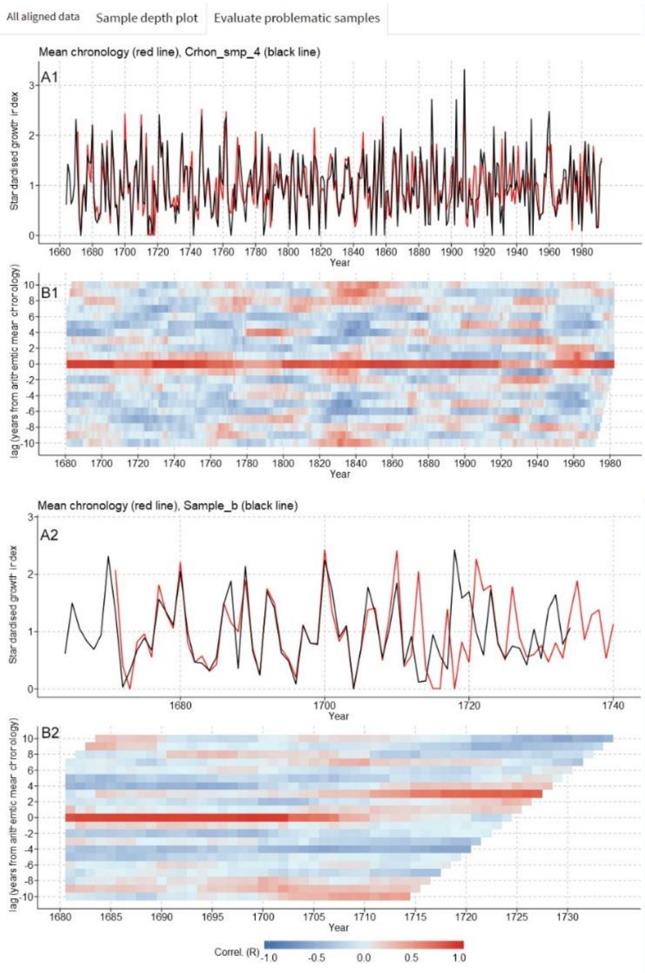
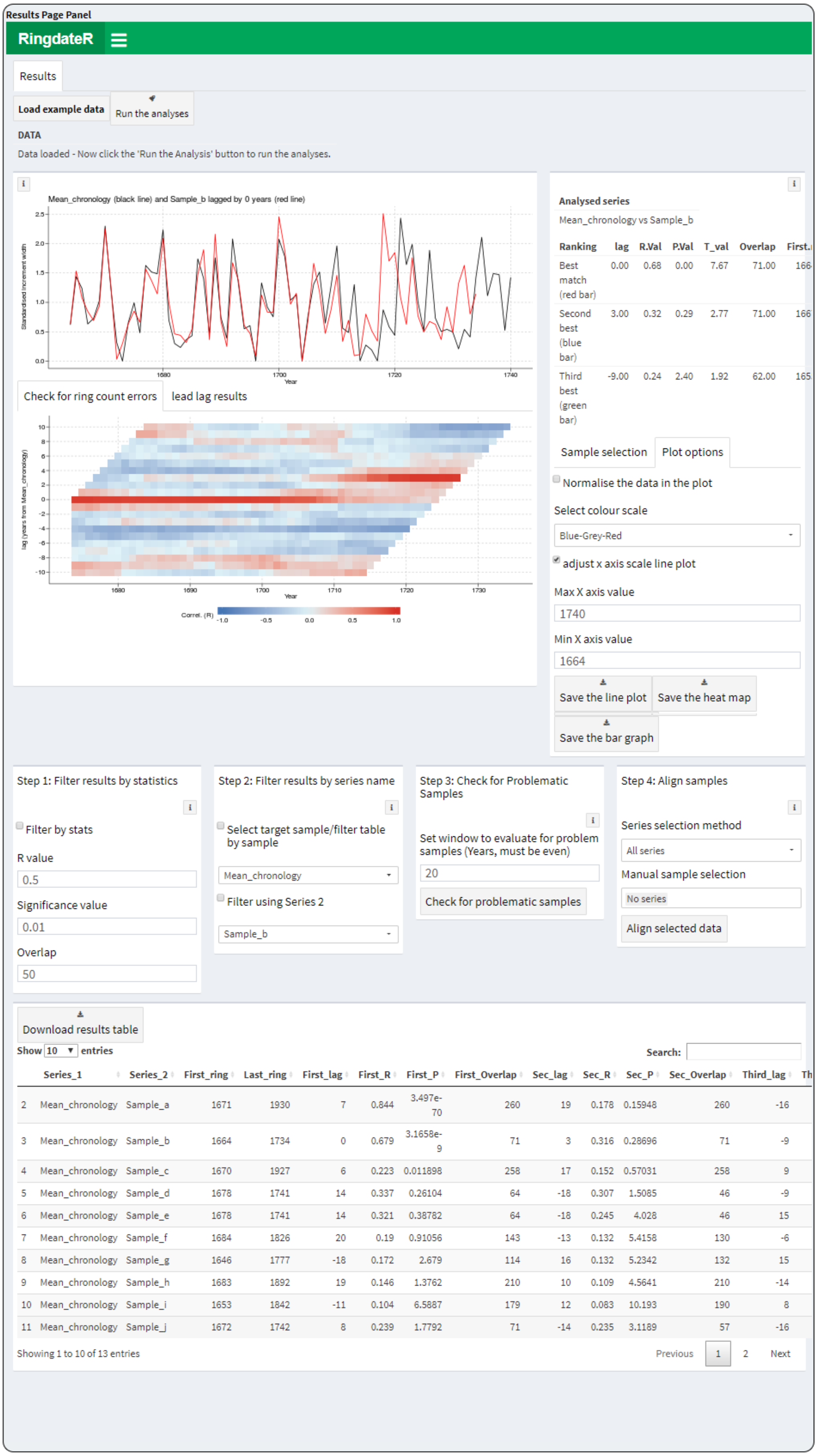


Fig 12: Example plots demonstrating the correlation characteristics of two pairs of measurement time series that have been flagged as containing potential problems. A1 and A2) Line plots of the two respective pairs of measurement time series. B1 and B2) Running correlation heat maps between the two respective pairs of measurement time series. The analyses plotted in B1 contains strong positive correlations between the two measurement time series at zero year lag. However, there are two intervals which show decreased correlation. This drop in correlation is sufficient to flag this sample as a problem. However, evaluation of the correlations in adjacent lags indicates that this sample likely does not contain problems. The heat map plotted in B2 shows a phase shift of the strong correlation from zero year lag to a lag of two years. This sample likely does contain an error. The actual measurements for this time series should therefore be re-evaluated.

These analyses are highly sensitive to the bin size that is used to perform the analysis. It is therefore recommended that these analyses are replicated using multiple window lengths. This can be done simply by changing the window length that the correlations are performed over several times and re-evaluating the outputs.



Interactive panel 6: An interactive panel showing the Results page.

Full Heat Map Page
To produce full heat maps, first load data in the same manner as if performing full Pairwise or Chronology Analysis Modes. When the data is loaded, if selected, the data is automatically detrended. It is then possible to jump straight to the Full Heat Map page to generate the heat map. For comparison against a chronology, it is required that the Chronology Analysis Mode is selected on the Starting Point page. However, the analyses do not need to be initiated on the Starting Point page.

Note the full heat maps do not centre on the best possible crossdate. However, the menus displayed below the plot can be used to refine the x- and y-axis as required. It is also possible to modify the colour scale.

Interactive panel 7: An interactive panel showing the Full Heat Map page.

Automatically aligning data
Samples that significantly crossdate can be aligned either against each other, in Pairwise Analysis Mode, or against he loaded chronology data.

Before aligning the data, whilst on the Results page, the user must apply the statistical filters (Fig. 10 step 1), select a target sample (Fig. 10 step 2) and perform the problem sample check (Fig. 10 step 3). In the menu in the Step 4 (Fig. 10), users then have the option to align all the samples that are displayed in the large results table, to align all the samples in the large results table excluding any sample which has been identified as a problem sample, or to only align samples that have been manually selected. It should be noted that only samples that pass the significance tests against the target sample can be aligned. The results of aligning the data are then displayed on the Aligned Data page.

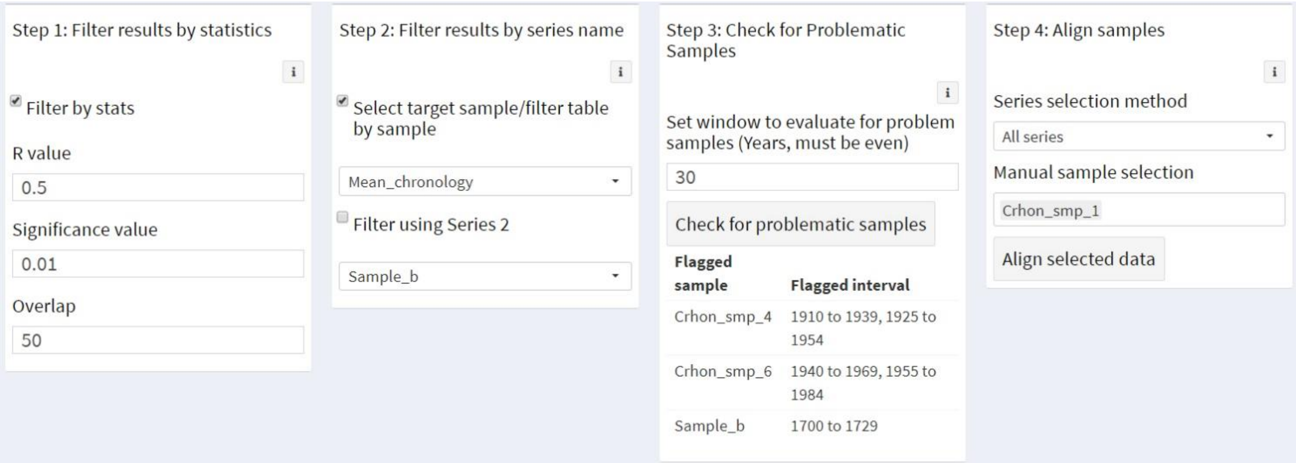


Fig 13: The menus from the Results page highlighting that, once the statistical filter is applied, the target sample selected and the problem checker run, the data can be aligned. The Align samples menu allows users to define which samples are aligned: All samples – aligns all samples that pass the significance tests against the target sample; All samples, excluding problematic samples – aligns all samples that pass the significance tests against the target sample excluding samples which are defined as potential problems; Manual sample selection – User can manually select samples to align that pass the significance tests against the target sample.

Once the first three steps from the results menus have been completed users can select which samples are aligned in the Align samples menu (Fig. 13).

All samples – aligns all samples that pass the significance tests against the target sample.
All samples, excluding problematic samples – aligns all samples that pass the significance tests against the target sample excluding samples which are defined as potential problems.
Manual sample selection – User can manually select samples to align. Only samples which pass the user defined statistical significance thresholds against the target sample will appear in the list of samples to manually select.

Once the sample selection is made, clicking the “Align selected data” button will align the data and automatically navigate the user to the Aligned Data Page.

The Aligned Data page
The Aligned Data page displays the results of the alignment process for both the Pairwise and Chronology Analysis Modes.

Whilst RingdateR is not a chronology construction application, the Aligned Data page facilitate the evaluation of the common signal amongst the measurement time series that have been aligned. This is done through the evaluation of the mean running correlation between all the series aligned (Rbar) and the expressed population statistic (EPS; Fig. 14). Both the Rbar and EPS statistics are calculated using a default 25-year window with a 50% overlap. The length of the window can be adjusted using the options menu (Fig 15). The Rbar and EPS analyses are conducted using the rwi.stats.running function from the dplR package (Bunn et al., 2010).

In both the Chronology and Pairwise Analysis Modes, it is possible to move back and forth between the Results page and the Aligned Data page. This allows for the evaluation of, for instance, the impact of including different combinations of measurement time series into the chronology.

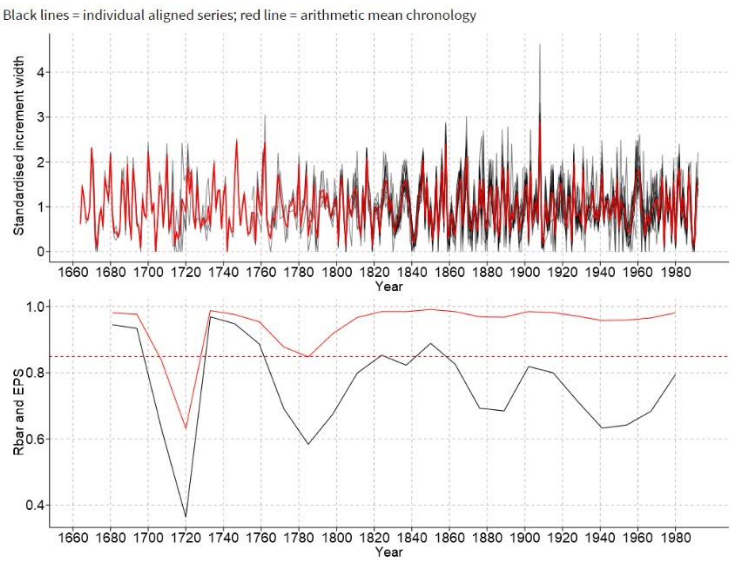


Fig 14: A line plot showing all of the detrended measurement time series (black lines) plotted with the arithmetic mean chronology (red line). 2) A plot of the running Rbar and expressed population statistics (EPS; red and black lines respectively). The dashed red line marks the 0.85 EPS threshold.

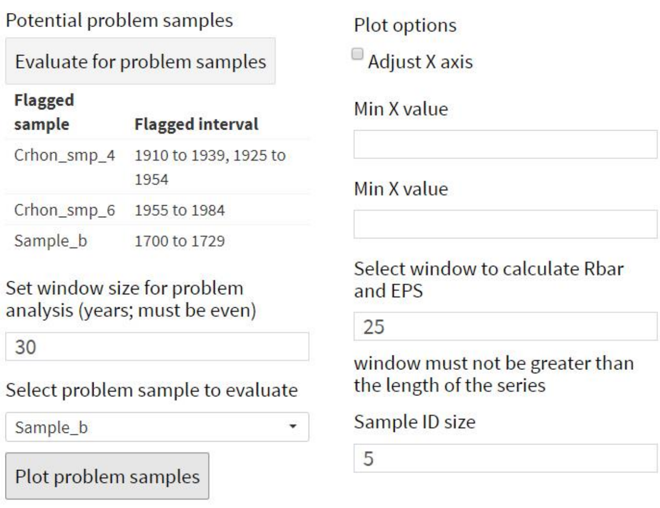


Fig 15: Options for performing a secondary check for problematic samples. 6) An options menu for modifying the line plots and modifying the window used for calculating the EPS and Rbar statistics.

In addition to the Rbar and EPS statistics, RingdateR evaluates the mean correlation between each sample and the arithmetic mean chronology with replacement (i.e. the correlation between each sample and the mean chronology constructed excluding the measurement time series being correlated against it). These correlations are provided in a table at the bottom of the Aligned Data page (e.g. Fig. 16).

Correlations between individual series and mean chronology with replacement

Series ID	First Ring	Last ring	R value	P value	Overlap with chronology
Crhon_smp_1	1826	1992	0.89	0.00	167
Crhon_smp_2	1828	1992	0.91	0.00	165
Crhon_smp_3	1821	1992	0.71	0.00	172
Crhon_smp_4	1664	1992	0.80	0.00	329
Crhon_smp_5	1755	1992	0.83	0.00	238
Crhon_smp_6	1810	1992	0.77	0.00	183
Crhon_smp_7	1798	1992	0.90	0.00	195
Crhon_smp_8	1792	1992	0.88	0.00	201
Crhon_smp_9	1780	1992	0.87	0.00	213
Crhon_smp_10	1824	1992	0.82	0.00	169
Crhon_smp_11	1827	1992	0.83	0.00	166
Crhon_smp_12	1821	1992	0.92	0.00	172
Crhon_smp_13	1809	1992	0.91	0.00	184
Sample_a	1671	1930	0.81	0.00	260
Sample_b	1664	1734	0.64	0.00	71

Fig 16: A table containing summary statistics for each sample contained in the chronology. The correlations are calculated with replacement.

The Sample Depth plot tab on the aligned data page provides a plot showing the position of every individual measurement timeseries that have been aligned (Fig 17). If the secondary problem sample check has been performed, samples that are identified as potentially containing problems are highlighted with red lines. Samples that do not contain problems are highlighted with black lines.

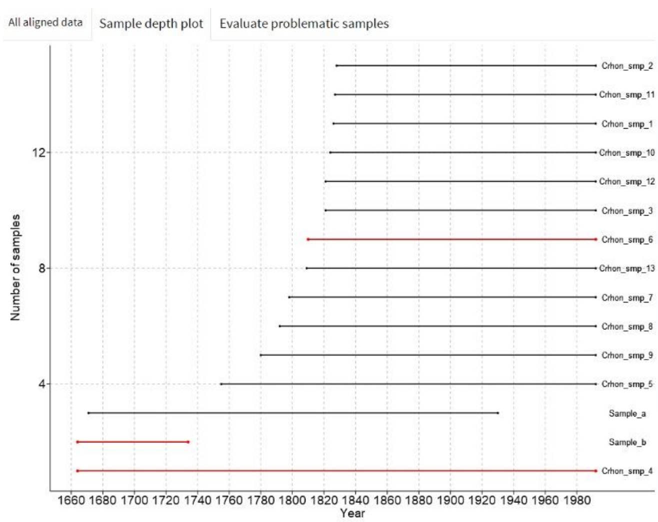


Fig 17: Plot showing the distribution of each of the series that have been aligned through both the Pairwise and Chronology Analysis Modes. samples that are identified as potentially containing problems are highlighted with red lines. Samples that do not contain problems are highlighted with black lines.

Secondary Problem Sample Check

The Aligned Data page provides the option to perform a secondary problem sample check. The secondary problem sample check is performed in the same manner as the primary problem sample check (see Checking for Problematic Samples section above). However, the secondary check allows more in-depth analyses. If problematic measurement time series are found, it is possible to compare the potentially problematic measurement time series against the mean chronology constructed using only samples that do not contain potential problems (e.g. Fig. 18).

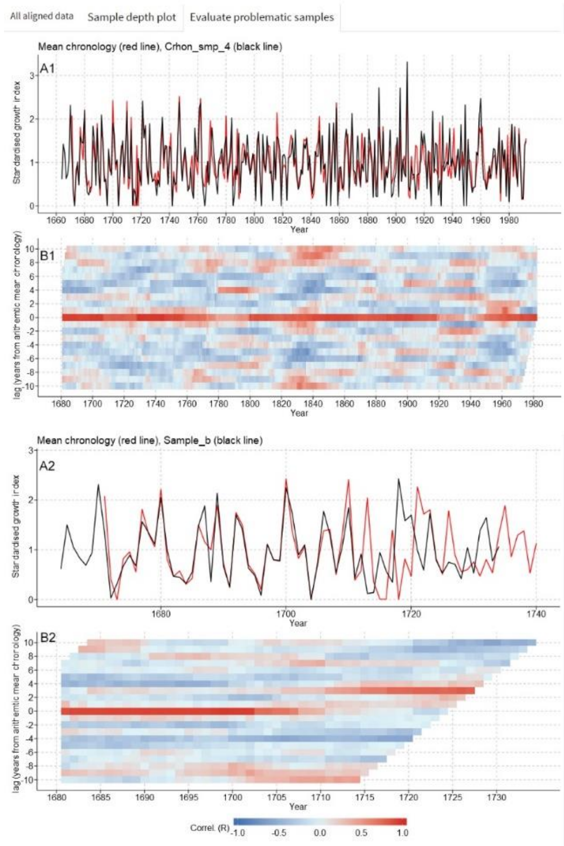
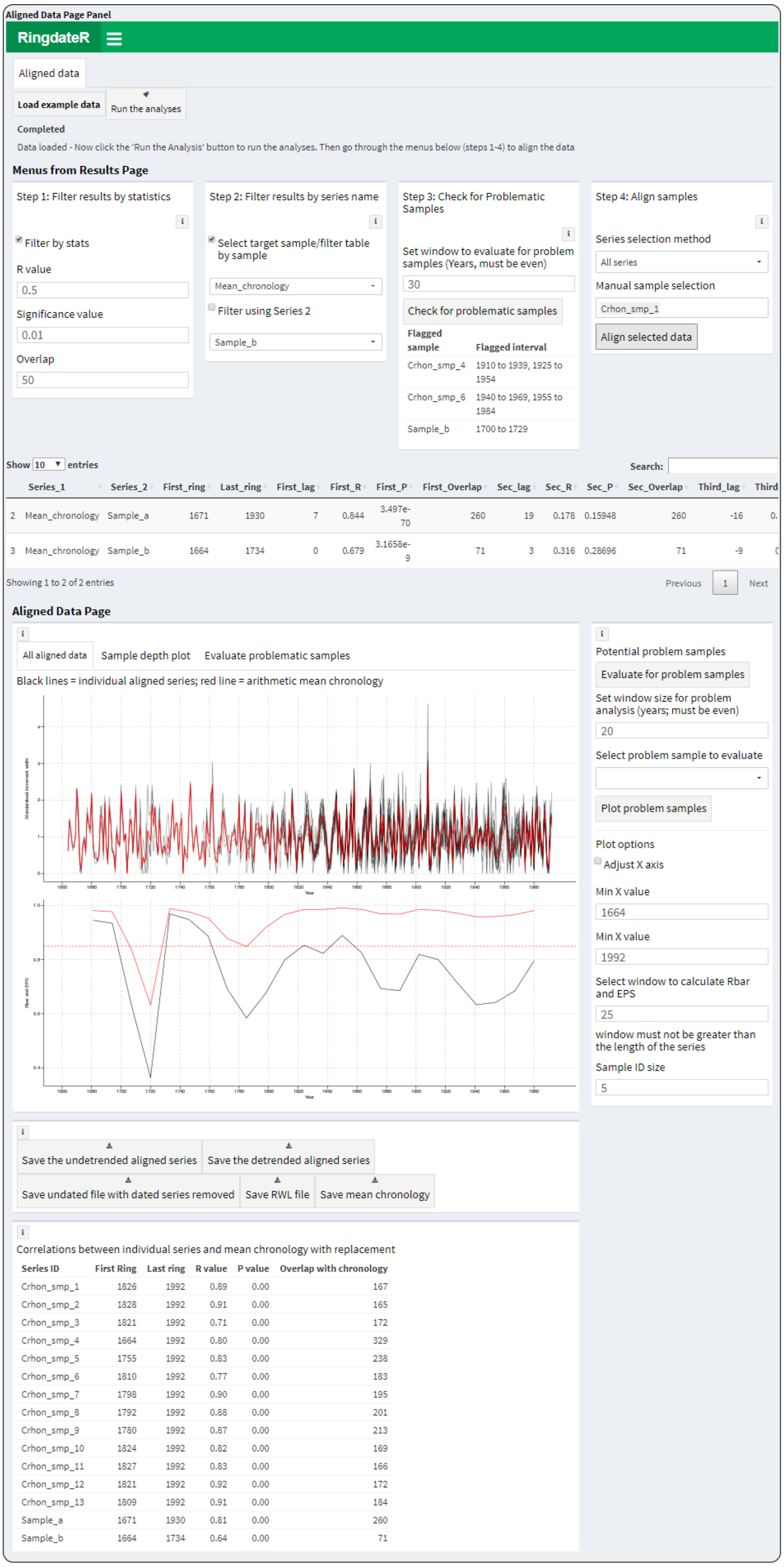


Fig 18: Example plots demonstrating the correlation characteristics of two pairs of measurement time series that have been flagged as containing potential problems. A1 and A2) Line plots of the two respective pairs of measurement time series. B1 and B2) Running correlation heat maps between the two respective pairs of measurement time series. The analyses plotted in B1 contains strong positive correlations between the two measurement time series at zero year lag. However, there are two intervals which show decreased correlation. This drop in correlation is sufficient to flag this sample as a problem. However, evaluation of the correlations in adjacent lags indicates that this sample likely does not contain problems. The heat map plotted in B2 shows a phase shift of the strong correlation from zero year lag to a lag of two years. This sample likely does contain an error. The actual measurements for this time series should therefore be re-evaluated.



Interactive panel 8: An interactive panel showing the Aligned Data page.

Saving Data
Download buttons are located throughout the application and allow both data and plots to be saved. All saved files are automatically saved to the default download location used by your web browser. This is usually the downloads folder. Figures are saved as png files. Data are saved mostly as csv files however there is also the option to create an rwl file of the newly aligned data.

RingdateR Package Dependencies

Package	Version	Citation
data.table	1.12.2	Matt Dowle and Arun Srinivasan (2019). data.table: Extension of `data.frame`. R package version 1.12.2. https://CRAN.R-project.org/package=data.table
DataCombine	0.2.2	Christopher Gandrud (2016). DataCombine: Tools for Easily Combining and Cleaning Data Sets. R package version 0.2.21. https://CRAN.R-project.org/package=DataCombine
DescTools	0.99.28	Andri Signorell et mult. al. (2019). DescTools: Tools for descriptive statistics. R package version 0.99.28.
doParallel	1.0.14	Microsoft Corporation and Steve Weston (2018). doParallel: Foreach Parallel Adaptor for the 'parallel' Package. R package version 1.0.14. https://CRAN.R-project.org/package=doParallel
dplR	1.6.9	Andy Bunn, Mikko Korpela, Franco Biondi, Filipe Campelo, Pierre Mérian, Fares Qeadan, Christian Zang, Darwin Pucha-Cofrep and Jakob Wernicke (2018). dplR: Dendrochronology Program Library in R. R package version 1.6.9. https://CRAN.R-project.org/package=dplR
dplyr	0.8.3	Hadley Wickham, Romain François, Lionel Henry and Kirill Müller (2019). dplyr: A Grammar of Data Manipulation. R package version 0.8.3. https://CRAN.R-project.org/package=dplyr
DT	0.5	Yihui Xie, Joe Cheng and Xianying Tan (2018). DT: A Wrapper of the JavaScript Library 'DataTables'. R package version 0.5. https://CRAN.R-project.org/package=DT
ggplot2	3.1.0	H. Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016.
grid	3.5.3	R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
gridExtra	2.3	Baptiste Auguie (2017). gridExtra: Miscellaneous Functions for "Grid" Graphics. R package version 2.3. https://CRAN.R-project.org/package=gridExtra
htmlwidgets	1.3	Ramnath Vaidyanathan, Yihui Xie, JJ Allaire, Joe Cheng and Kenton Russell (2018). htmlwidgets: HTML Widgets for R. R package version 1.3. https://CRAN.R-project.org/package=htmlwidgets
readxl	1.1.0	Hadley Wickham and Jennifer Bryan (2018). readxl: Read Excel Files. R package version 1.1.0. https://CRAN.R-project.org/package=readxl
shiny	1.2.0	Winston Chang, Joe Cheng, JJ Allaire, Yihui Xie and Jonathan McPherson (2018). shiny: Web Application Framework for R. R package version 1.2.0. https://CRAN.R-project.org/package=shiny
shinyalert	1	Dean Attali and Tristan Edwards (2018). shinyalert: Easily Create Pretty Popup Messages (Modals) in 'Shiny'. R package version 1.0. https://CRAN.R-project.org/package=shinyalert

shinycssloaders	0.2.0	Andras Sali (2017). shinycssloaders: Add CSS Loading Animations to 'shiny' Outputs. R package version 0.2.0. https://CRAN.R-project.org/package=shinycssloaders
shinydashboard	0.7.1	Winston Chang and Barbara Borges Ribeiro (2018). shinydashboard: Create Dashboards with 'Shiny'. R package version 0.7.1. https://CRAN.R-project.org/package=shinydashboard
shinyjs	1	Dean Attali (2018). shinyjs: Easily Improve the User Experience of Your Shiny Apps in Seconds. R package version 1.0. https://CRAN.R-project.org/package=shinyjs
shinyWidgets	0.4.8	Victor Perrier, Fanny Meyer and David Granjon (2019). shinyWidgets: Custom Inputs Widgets for Shiny. R package version 0.4.8. https://CRAN.R-project.org/package=shinyWidgets
stats	3.5.3	R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
xml2	1.2.2	Hadley Wickham, Jim Hester and Jeroen Ooms (2019). xml2: Parse XML. R package version 1.2.2. https://CRAN.R-project.org/package=xml2
zoo	1.8-4	Achim Zeileis and Gabor Grothendieck (2005). zoo: S3 Infrastructure for Regular and Irregular Time Series. Journal of Statistical Software, 14(6), 1-27. doi:10.18637/jss.v014.i06
zoocat	0.2.0.1	Ran-Ran He (2018). zoocat: 'zoo' Objects with Column Attributes. R package version 0.2.0.1. https://CRAN.R-project.org/package=zoocat