RingdateR

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Citing RingdateR

Reynolds, D.J., Edge, D.C., Black, B.A., In submission. RingdateR: A Statistical and Graphical tool for Crossdating.

Glossary of Terms

Time series: any time series, undated or dated; a single measurement time series or the mean of many measurement time series (chronology).

Measurement time series: a single measurement time series; one set of measurements

Chronology: the average of many measurement time series.

Floating: undated and "floating" in time; no calendar years assigned. ring counts are assigned.

Collated data: multiple measurement time series or multiple chronologies in a single file.

Ring count: sequential ring numbering for a time series (or collated dataset of time series) in which the first observation is assigned a value of 1. This is the default increment numbering system for undated (floating) data.

RingdateR Overview

RingdateR is an open source crossdating application constructed using the R programming language. It is an interactive shiny application that runs from an internet browser and does not require knowledge of or interaction with the R language. RingdateR is designed to facilitate visual and statistical crossdating of annually resolved measurement time series (including but not limited to tree ring, mollusc, and otolith growth increments). RingdateR specializes in crossdating dead-collected samples with unknown antiquities, either against one another or against an existing absolutely dated chronology. RingdateR also helps identify missing or false rings within floating or absolutely dated measurement time series to facilitate rapid alignment of annually-resolved data. As such, RingdateR is can accept data in a range of data formats including tab delimited and comma separated values (.txt and .csv), dendrochronology Tucson format (.rwl files), and from widely-used measurement programmes including CooRecorder (.pos files) and Image Pro (.lps files).

RingdateR is a crossdating application and has not been designed for chronology construction. It therefore does not contain facilities for combining measurement time series into mean chronologies that would be of use beyond dating purposes.

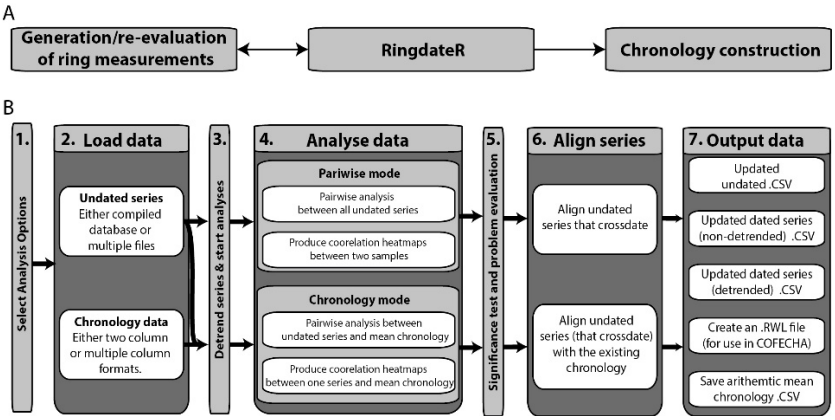


Fig 1: A) A schematic of the general role of RingdateR in the overall chronology construction workflow. B) A generalised schematic of the RingdateR workflow. 1) User defines the options for the analyses (i.e. detrending method, lag range; Step one of Starting Point page). 2) Individual series and chronology 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.

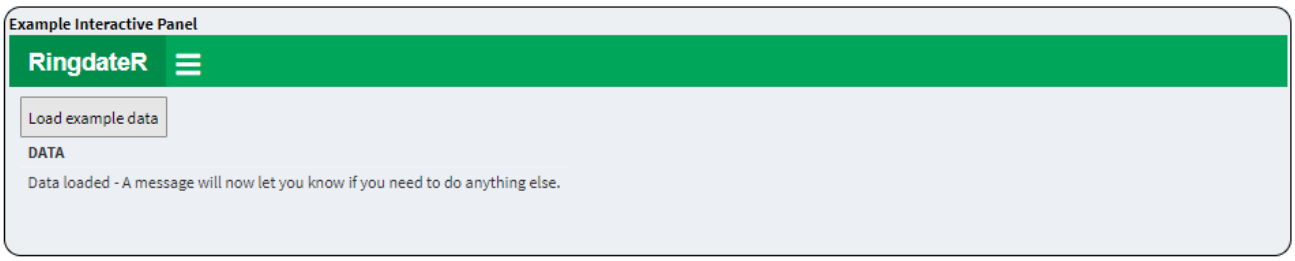
Operation of this document

This document sets out the operation of RingdateR and closely mirrors it's order of operations. In addition to the text and standard figures, this document also contains interactive panels. To more clearly distinguish between the interactive panels and figures, 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 instructions or information will display. These data allow the user to interact with the panels in the same manner as the RingdateR app.

These interactive panels are almost identical to the pages within the RingdateR app except that several options that could be changed in the RingdateR Starting Point have been pre-set. Options that have been pre-set 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 Douglas-fir tree-ring widths.



Interactive panel 1: 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 are loaded, the message "Data Loaded -" will display. If necessary, a second message will appear with further instructions.

Running RingdateR

RingdateR can be run either remotely through a server or locally using RStudio. The sections below provide information about launching RingdateR in both the remote, online server mode and local RStudio mode.

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, which has no time- out limits.**

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.

Next, download the RingdateR package (saved as a zipped ringdater_0.1.0.tar.gz file) from https://ringdater.github.io/ringdater/. Then open RStudio, click the "Package" tab, and click "Install packages." Change the "Install From" option to "Package Archive File (.tgz, .tar.gz)" and use the "Package Archive" browser to select the downloaded ringdater_0.1.0.tar.gz file and click install.

Installing RingdateR will automatically install any package dependencies (listed at the end of this document) that have not already been installed. Once installed, launch the RingdateR app using the following code:

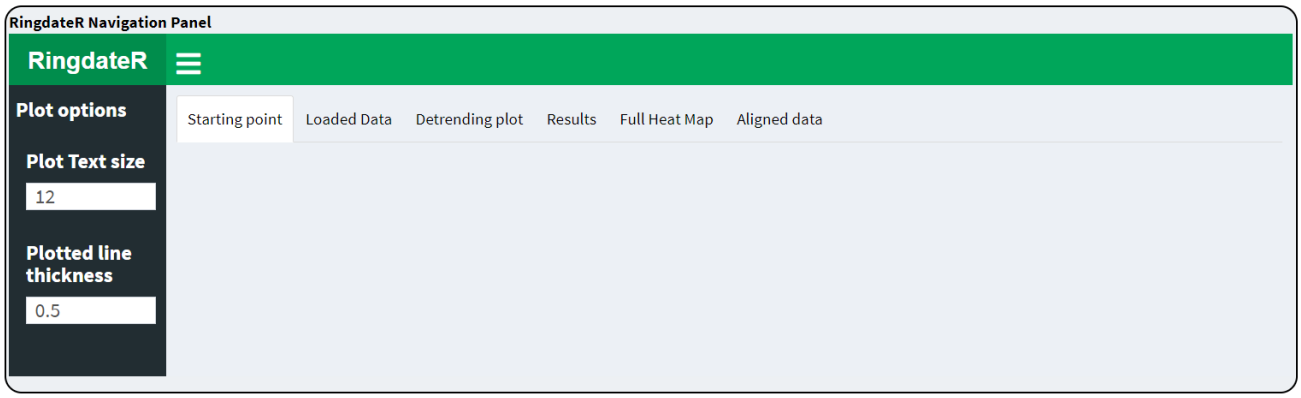
```
library(ringdater)
run_ringdater()
```

RingdateR runs through a web browser. Thus, the run_ringdater() function will automatically launch RingdateR in the systems default web browser. Alternatively, RingdateR can also operate in the R console. For more information on this see the Pairwise Mode Vignette and the Chronology Analysis Mode vignette.

General navigation in RingdateR

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

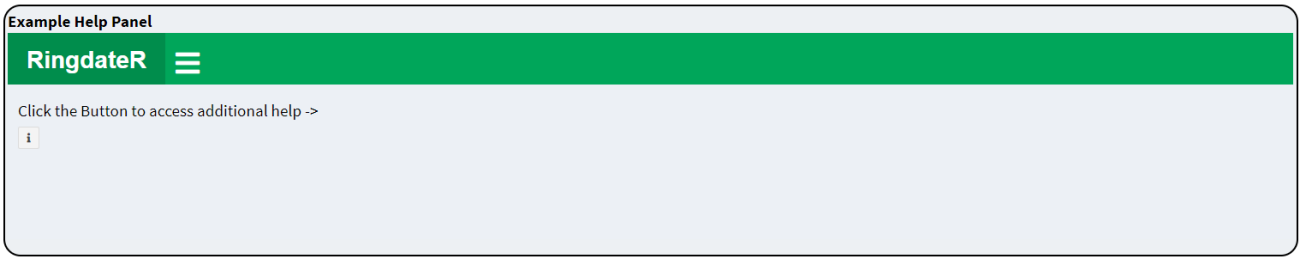
There is also a toggleable menu on the left of the page with options for modifying plots. The ≡ button, next to the RingdateR title, can be used to show or hide the plot option menu. The plot options accessed on this menu will change the settings for every graph in RingdateR. However, the plot options are limited 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, which will open a text panel with more information about the feature in question.



Interactive panel 3: An example help button. Pressing the i button displays a text panel with additional help. 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 your undated measurement time series.

3: (optional step) Load a dated chronology – only required if using Chronology Analysis Mode.

4: Adjust the detrending options on the "Detrending Plot" page as desired.

5: On the "Starting Point" page select analysis pathway in the "Step four" box.

6: click "Run Analysis" and automatically jump to the "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 remove non-significant matches.

9: Select a target sample, make pairwise comparisons, including line plots and heat maps, to screen for any possible dating problems. Repeat using varying window lengths.

10: Select samples to align.

11: Click the “Align data” button to compare the measurement time series to the average of all others; screening for any remaining errors that may not have been evident in pairwise comparisons.

12: Output the aligned data.

Starting Point Page

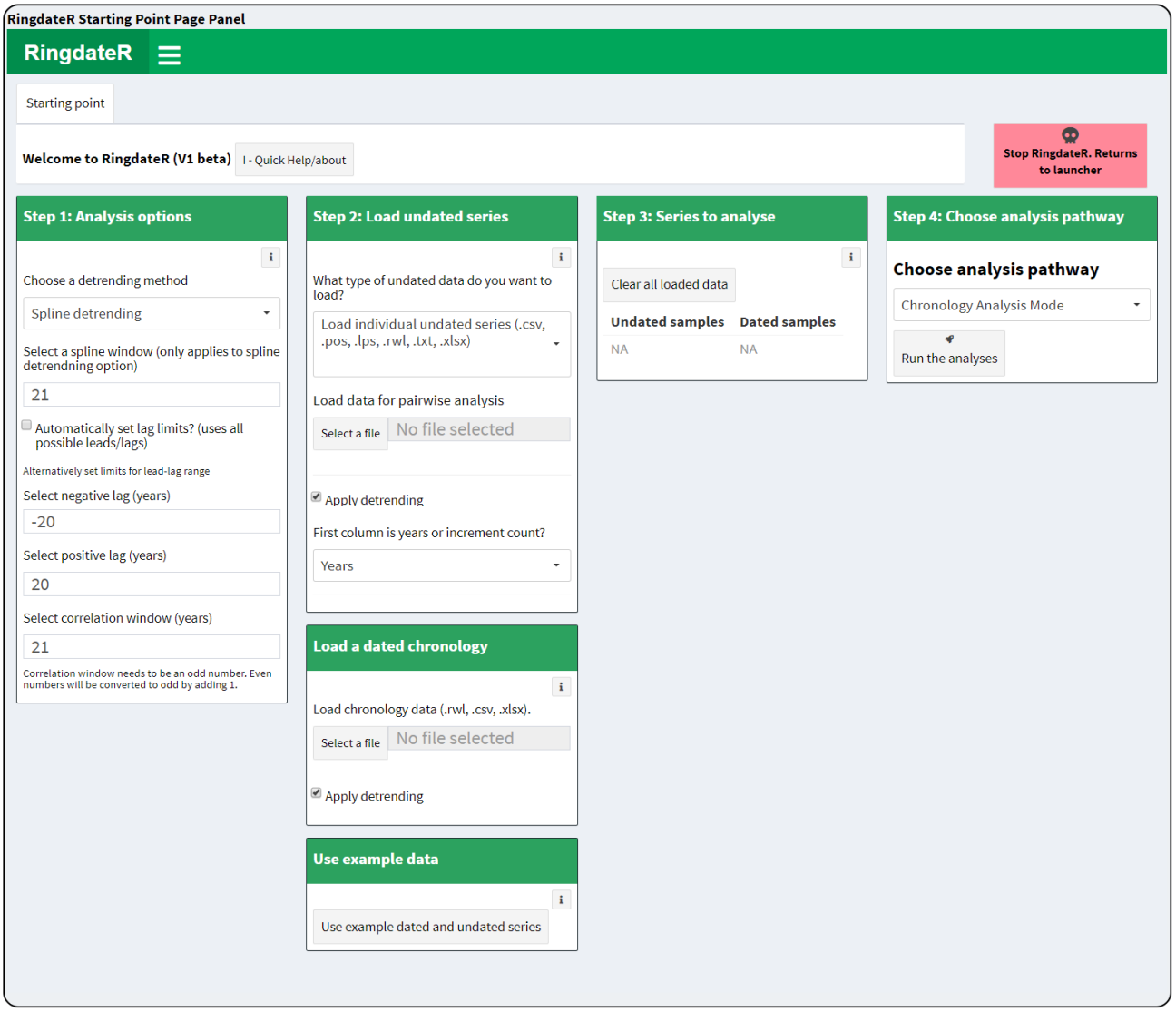
The Starting Point page can be considered RingdateR’s home page. From here users can select detrending and correlation settings, load their own data, choose to use example data, and select analysis pathway (Pairwise or Chronology Analysis mode).

“Step 1” box: Set the detrending method and range of leads and lags.

“Step 2” box: This has three elements: First, the “Load undated series” is for uploading undated (“floating”) measurement time series or chronologies. Second, the “Load a dated chronology” box is for loading an absolutely dated chronology, which would be used in the Chronology Analysis mode. Alternatively, the “Use example data” box allows users to load example data, which includes undated and dated series.

“Step 3” box: Display the IDs of all the series that are loaded into RingdateR. The “Clear all loaded data” button can be used to remove the loaded data and reset RingdateR to default settings.

“Step 4” box: Set the analysis mode (“Chronology analysis” or “Pairwise” mode).



Interactive Panel 4: The Starting Point page interactive panel. Note, as this panel is purely to demonstrate the layout of the Starting Point page, the "Run the analyses", "Stop RingdateR" and "Use example dates and undated series" buttons have been disabled. 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.

Loading data - acceptable data formats

A variety of data formats can be loaded into RingdateR, either collated (e.g. with multiple time series in a file) or individual (e.g. single time series in a file) formats. A summary tables of all data loaded into RingdateR are available on the "Loaded Data" page.

Compiled file formats – chronology data and individual measurement time series

RingdateR can import Excel (.xlsx), tab delimited text (.txt), comma separated value (.csv) and Tucson Format (.rwl) files containing multiple time series. Data may be aligned with respect to calendar year

or ring count. Note that RingdateR sometimes has issues loading .rwl files due to their frequently inconsistent formatting.

All Collated file formats, except .rwl, should be formatted such that the first column contains either calendar years or ring numbers (in ascending order as shown in Table 2). All other columns should contain a time series, each labelled with a unique sample number/name in the first row. Time series cannot contain missing values. Cells with missing values (preceding or following the time series, may contain either "NA" or simply be left empty (e.g. Table 2A). It is possible to load multiple undated series, but only one dated chronology can be loaded.

For the purposes of example, properly formatted data 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: Collated data sets can either be loaded in as (A) date aligned or (B) ring count (undated).

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
…	…	…	…

Single time series file formats

In RingdateR it is also possible to load in files containing a single undated time series, which is completed 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 (.lps)

Measurement series created in Image Pro as a line profile series can be loaded into RingdateR as an undated series. A single .lps file can contain more than one line profile (measurement time series). 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 annualised 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 according to increment number, assigning the first measured increment a value of one. Note that ontogenetic age or calendar year are not recorded in .lps files; thus, increments in each time series are numbered sequentially from one.

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

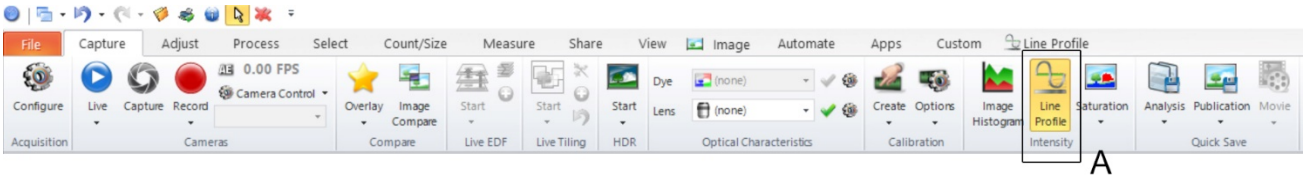


Fig 2: Load and calibrate the image use the Line Profile tool (box A).

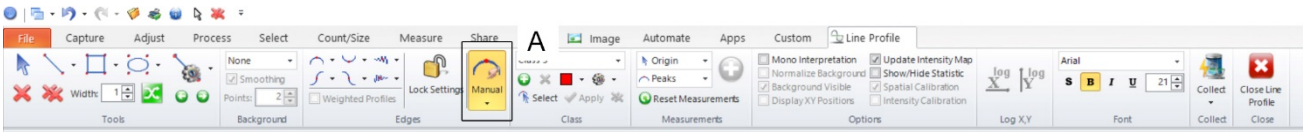
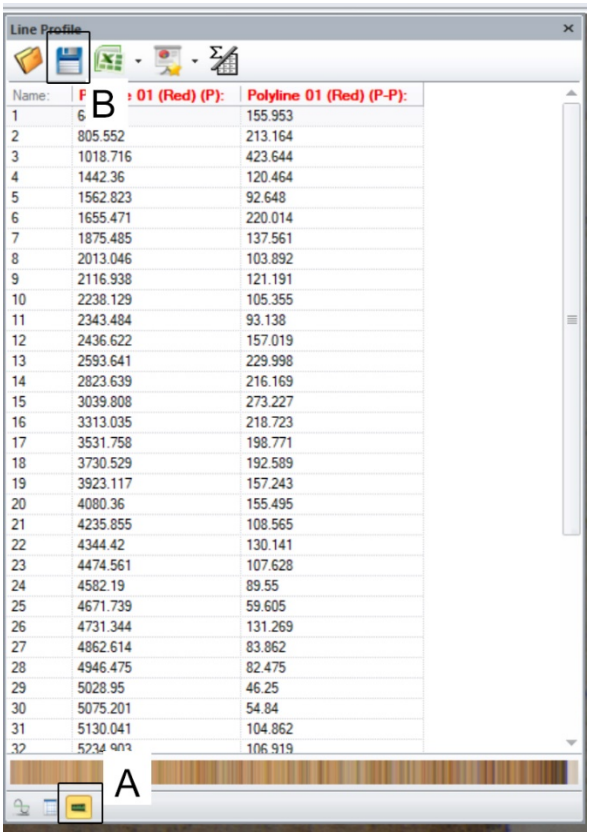


Fig 3: When using the line profile, growth increments may be manually delineated using the "Manual" option (box A).



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 at the bottom of the screen (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. The third column in this example contains the growth-increment widths (the first difference of the cumulative measurements). However, calculation of each increment width is not a default option in Image Pro and requires some additional configuration of the software. Thus, RingdateR uses cumulative measurements from Image Pro that are saved as default when outputting an lps file.

CooRecirder files (.pos)

CooRecorder saves each measurement time series in a single "position file" (.pos), which can be loaded directly into RingdateR. Multiple .pos files can be loaded into a single session and then be used in either the Pairwise or Chronology Analysis Modes.

Two column text tab delimited files (.txt)

Data may be organized into two-column text files in which the first column contains either a year or ring count and the second column contains the measurements. 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

Floating chronologies can be uploaded in "Step 2: Load undated chronologies" on the Starting Point page. Each chronology should be contained in a separate compiled file (see above for acceptable formats). It is important that the detrending mode is selected prior to uploading the floating chronology data. Unlike loading individual measurement time series, the detrending mode cannot be adjusted after the collated chronology data are loaded. This is because as the data are loaded, the individual series are automatically detrended and an arithmetic mean chronology calculated.

If multiple undated chronologies are loaded, these series can be compared 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.

Sample Names

Sample names should follow R conventions of naming variables. These include:

Sample names should not start with a number.

Sample names should not contain any special characters or spaces, for example: (),.-/:#

RingdateR will automatically adjust sample names to mitigate potential errors. Special characters and spaces are replaced with an underscore, and samples that begin with a number are prefaced with "ID_".

Detrending

RingdateR has seven options for detrending measurement time series. If, however, data are to be imported with no detrending or transformation, choose the "Do nothing to my data" option. This is useful if importing data that have been standardized in another program. Secondly, the data can be converted to z-score anomalies. Alternatively, spline, modified negative exponential, Friedman and modified Hugershof detrending functions can be used for detrending. Standardised indices are derived by dividing the observed measurements by those predicted by the selected mathematical function. These options are applied using the detrend.series function in dplR (Bunn et al., 2010). The final detrending option is to calculate the first difference of the measurement series, defined as the difference between the current and prior measurement in the time series.

A 21-year spline is set as the default detrending method in RingdateR. Decreasing (increasing) the length of the spline will can remove (retain) a greater (lesser) proportion of low-frequency variability from the measurement time series.

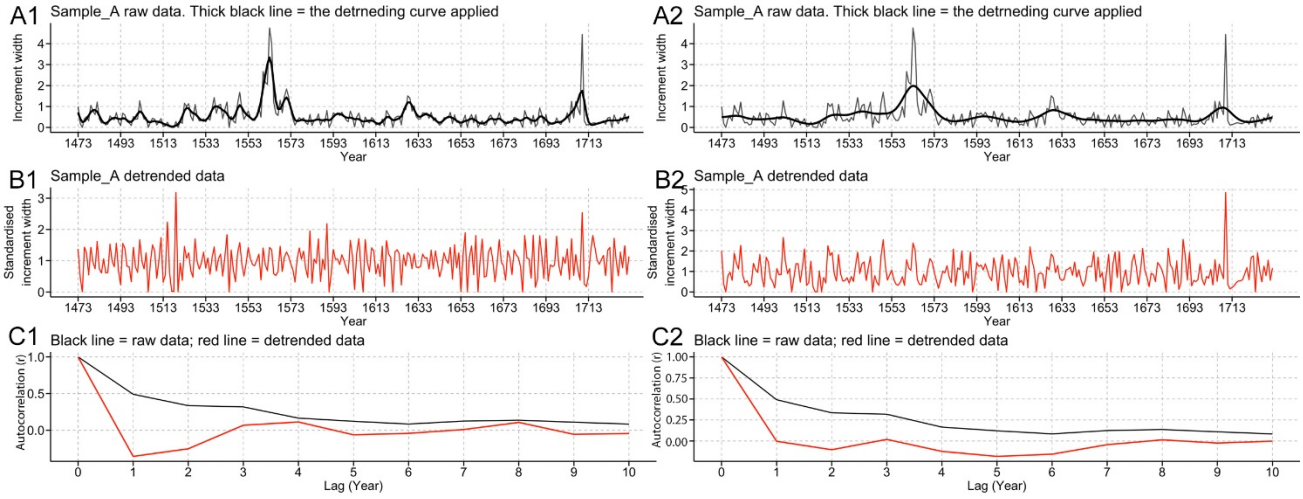


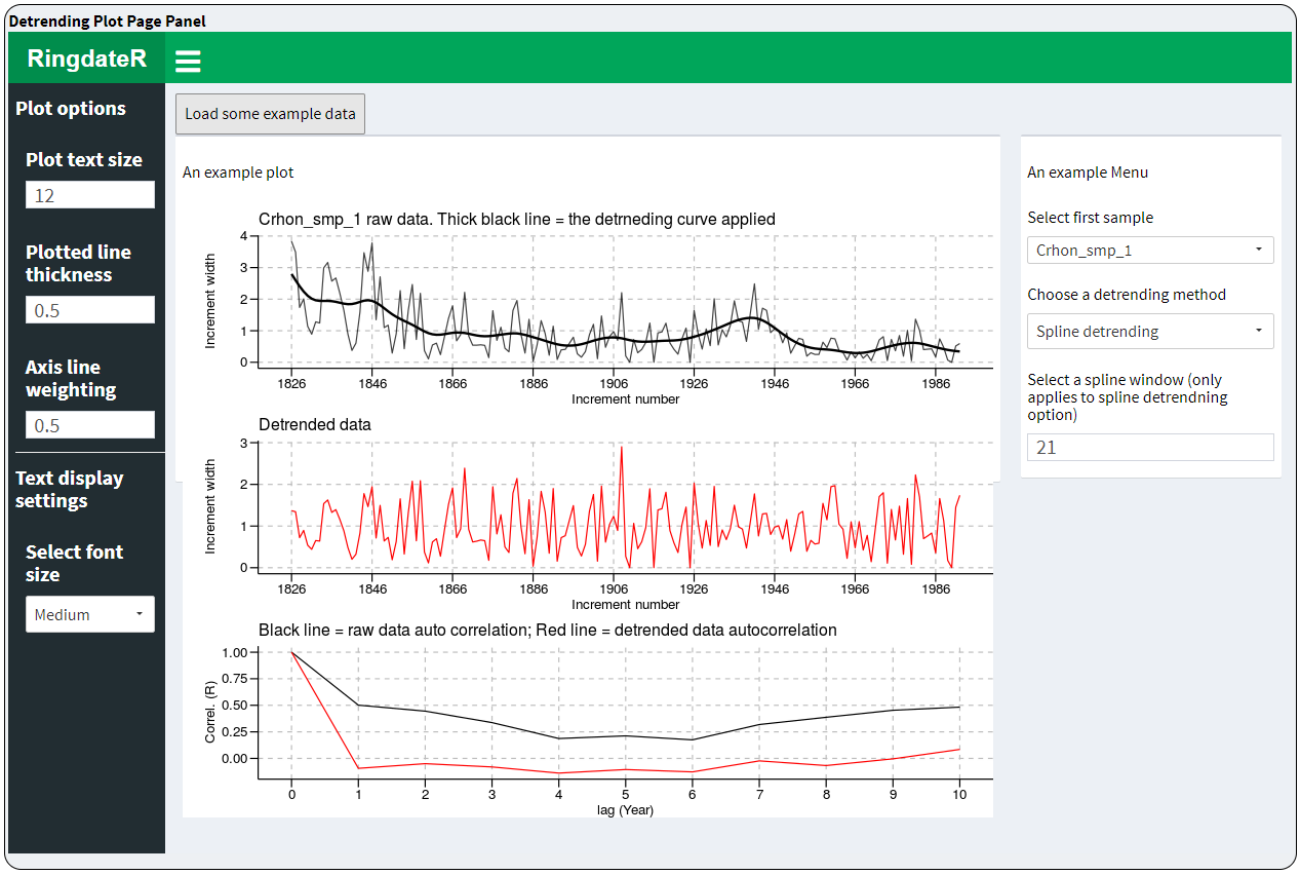
Fig 5: Comparison between a 7-year spline detrending (A1-C1) and a 21-year spline detrending (A2-C2). A1-2) Raw measurement timeseries plotted with the detrending curve (thin and thick black lines respectively). B1-2) the residuals calculated by dividing the raw measurement times series against the fitted detrending curve. C1-2) Plots comparing the autocorrelation for the raw data and detrended data (black and red lines respectively). Plots are 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 option on each measurement time series. The menu panel on the right of the page allows users to modify the detrending method from the one that had been originally chosen on the “Starting Point” page. The detrending method set on this menu will be the detrending method applied for all loaded time series.

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 different detrending techniques. The "Plot options" menu allows the user 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 full results table

The “Results table” (Fig. 6) summarises the three most probable crossdates among the analysed time series. The table is fully interactive and can be filtered/ordered by clicking the table headers (to sort the column from ascending to descending) or using the “Filter results by statistics” and “Sample ID” filters in the menus provided (Fig. 7). The results table can be exported 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”. The user can choose any row from the table, by clicking on the row, and the plots will 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: The Results Table displaying the best three matches for each measurement time series analysed.

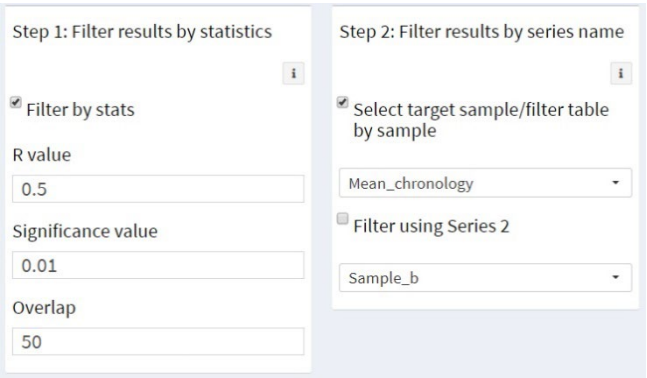


Fig 7: Two menus on the “Results” page that filter the full results table to show only results that pass user-defined statistical thresholds or to show user-specified samples. To apply the filters, the check boxes in the menus must be checked.

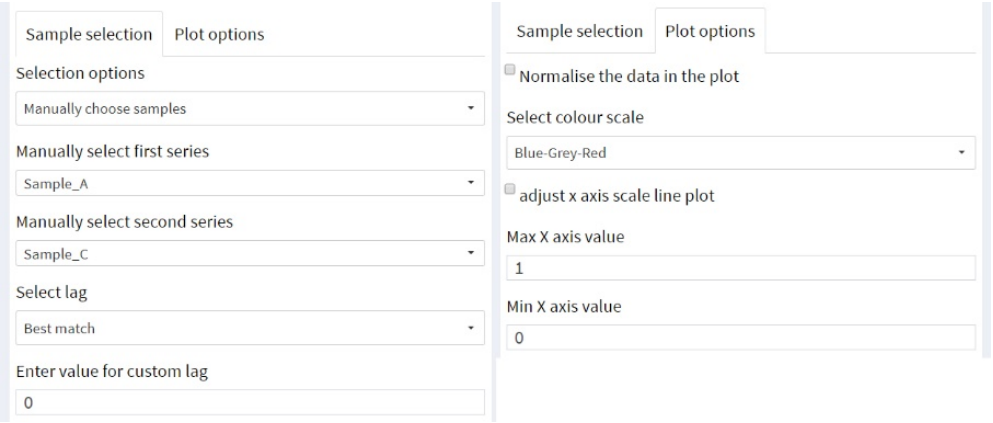


Fig 8: The "Sample selection" and "Plot options" menus from the "Results" page. These menus allow the user to manually select the samples plotted on the Results page, adjust the lag with which the two sample are plotted, as well as change general plot settings for both the line plot and the running correlation 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 on the best possible match 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) allows the user to change the lag of the second series from either of the three best possible matches or a user-defined lag. Samples plotted can either be selected manually or by selecting a row from the full results table using the "Sample selection" menu (Fig. 8).

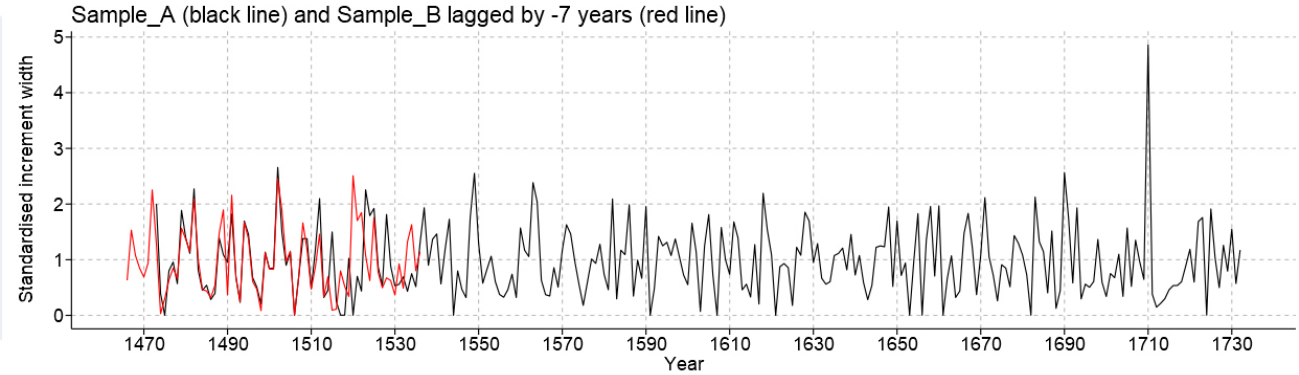


Fig 9: A line plot of two measurement time series aligned in time based on the most likely statistical match.

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 length (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 output the lag on the selected lag with which the series are plotted in the line graph and on the mid-point of the running window (Fig. 9). Measurement timeseries with insufficient overlap will result in error message.

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 all possible lead-lag combinations on the "Full Heat Map" page (see "Full Heat Map" section below).

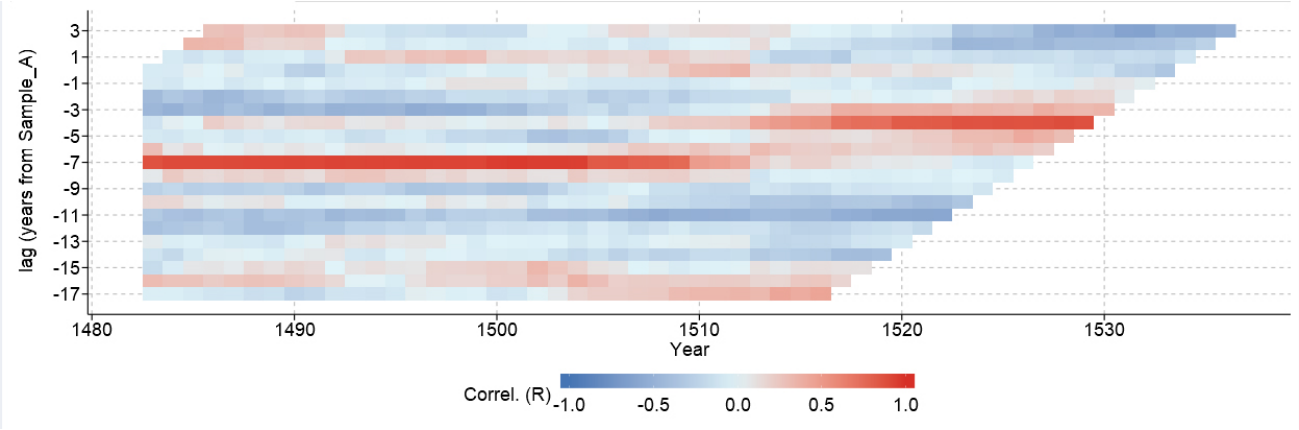


Fig 10: A heat map showing the running correlations calculated between two measurement time series. The running correlations in the heat map are calculated over a ±10 year lead-lag range centred around the selected lag.

T-value bar chart

RingdateR presents bar graphs with the T-values calculated over the full interval of each lead-lag analysed (e.g. Fig 11). T-values account for the correlation value as well as the varying degrees of freedom that occur as the edges of the lead / lag analysis are approached and overlap between the time series decreases. The bar graphs are automatically generated when running in either "Pairwise" or "Chronology Analysis Modes". The graph highlights the best three matches with red, blue and green bars, respectively. The bar charts are accessed from the "Lead-lag results" tab.

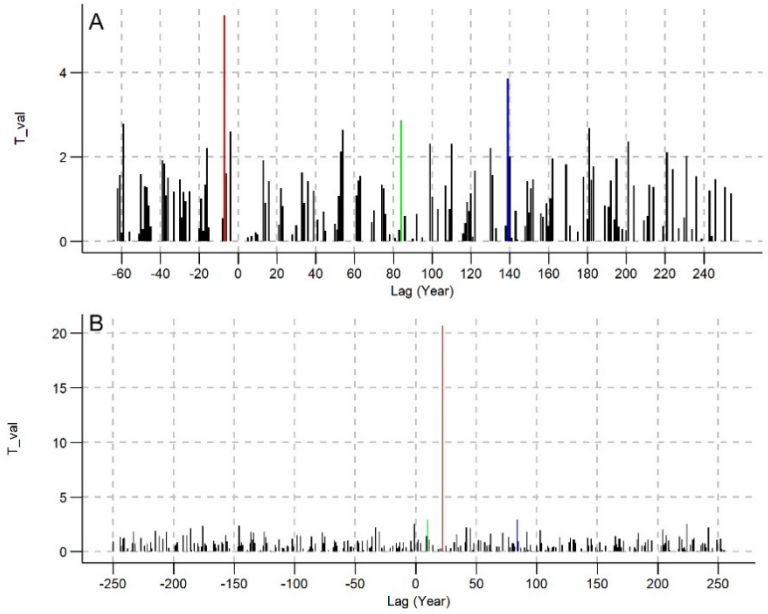


Fig 11: Bar graphs displaying the T-values for the lead-lag analyses between two measurement time series. Plots only show the positive correlations. The red, blue and green bars represent the first, second and third best matches, respectively. A) The two measurement time series either don't crossdate or possibly contain errors; and B) When the two measurement time series likely crossdate. Note the conspicuously high T-value relative to all other leads and lags, which is strong evidence for one and only one match between series.

Additional Check for Problematic Samples

For series which pass the statistical tests (the criteria for which are set using the statistical filter in Fig. 7) RingdateR automatically evaluates whether there are any remaining potential dating errors. This is accomplished by comparing each detrended time series to the average of all others, as opposed to earlier comparisons which often involved pairwise comparisons among series. The average of all others should amplify the sample-wide growth pattern for comparison with the individual time series, reducing the chances of a spurious match. To use the "Problem sample checker", apply a statistical filter and then select a target sample. The "Problem sample check" aligns the individual sample and the average of all others based on the best match. 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 (Bunn et al., 2010).

Further visualization of any series with potential errors can be accomplished on the "Aligned Data" page in which the potentially problematic sample is plotted relative to the mean of all others (Fig 12 A1, A2). The running correlation between the series and the mean of all others is calculated in a default 21-year running window with plus or minus ten years of lags (Fig 12 B1, B2). It should be noted that a series can be flagged as problematic if it contains missing or falsely identified rings, which induces a frame shift in time beginning at where the error occurred (e.g. Fig 12 A2-B2). Another possibility is that the correlation between the measurement time series and the mean chronology may be variable through time, which could be due to such causes as extreme competition, disturbance, or growth complacency (e.g. Fig 12 A1-B1). The running correlations and resulting heat maps provide clues as to the nature of these flags (Fig. 12). Note that 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.

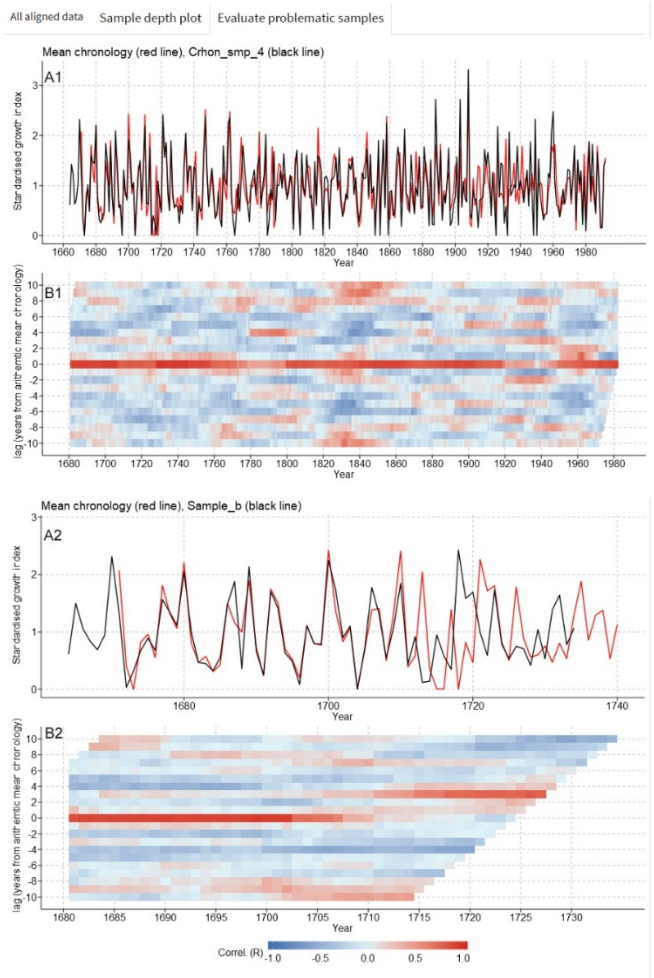
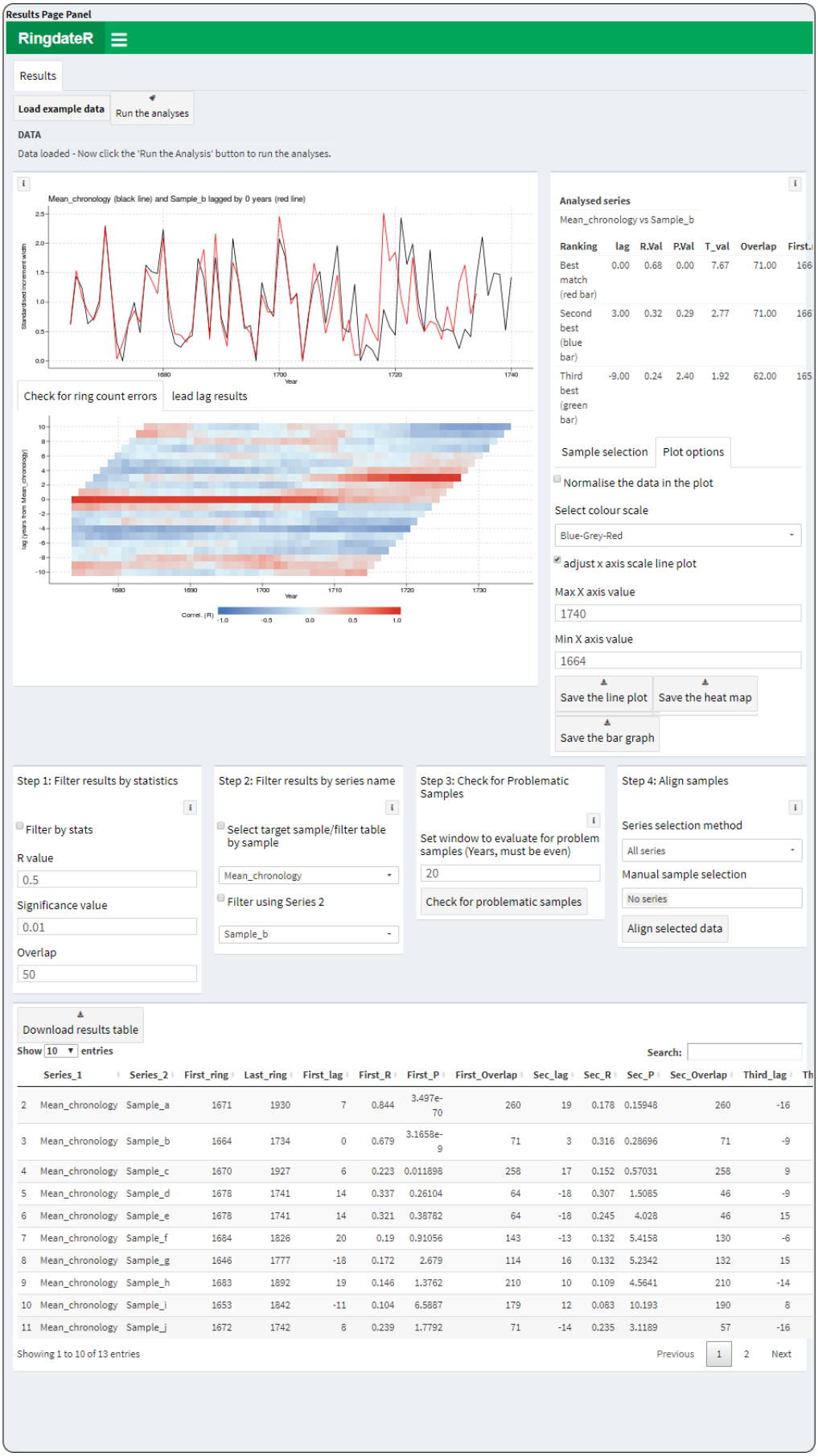


Fig 12: Example plots demonstrating the correlation characteristics of two pairs of measurement time series that have been flagged as containing potential problems. A1 and A2) Line plots of the two respective pairs of measurement time series. B1 and B2) Running correlation heat maps between the two respective 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 on 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. It is then possible to jump straight to the “Full Heat Map” page. For comparison against a chronology, it is required that the “Chronology Analysis Mode” is selected on the Starting Point page.

Note the full heat maps do not centre to the lag with the best possible crossdate. However, the menus displayed below the plot can be used to refine the x- and y-axis or the colour scale.

Interactive panel 7: An interactive panel on the “Full Heat Map” page.

Aligning Data

Samples that strongly match and thus likely crossdate can be aligned with one another.

Before aligning the data, whilst on the "Results" page, the user must apply the statistical filters (Fig. 13 Step 1), select a target sample (Fig. 13 step 2) and perform the problem sample check (Fig. 13 step 3).

In the menu in the Step 4 (Fig. 13), users then have the option to align: i) All samples – aligns all samples that pass the significance tests in comparisons against the target sample; ii) All samples, excluding problematic samples – aligns all samples that pass the significance tests minus samples flagged with potential problems; or iii) Manual sample selection – User can manually select samples to align as long as they pass the significance tests. It should be noted that only samples that pass the significance tests against the target sample can be aligned. 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 where the results of aligning the data are then displayed.

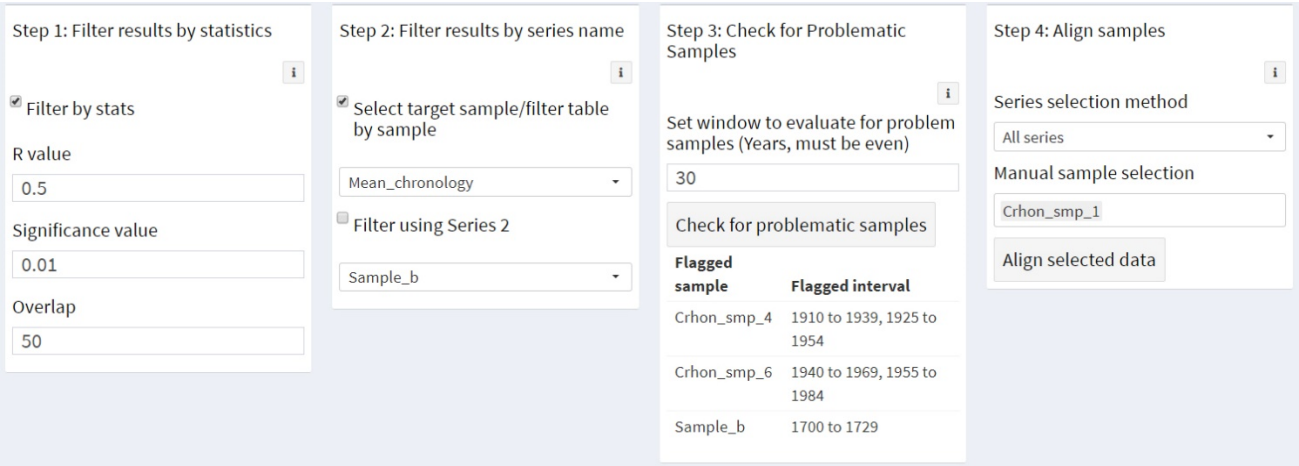


Fig 13: The menus from the "Results" page highlighting that time series can be aligned once the statistical filter is applied, the target sample selected, and the problem checker run. The "Align samples" menu allows users to define which samples are aligned: All samples – aligns all samples that pass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

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 provides tools to evaluate the strength of the common signal in the aligned data. This is done by calculating the average of all possible pairwise correlations among the series aligned (Rbar) and the expressed population statistic (EPS), which is a measure of common signal that is a function of Rbar and sample depth (Fig. 14). Both the Rbar and EPS statistics are running and 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 aligned dataset.

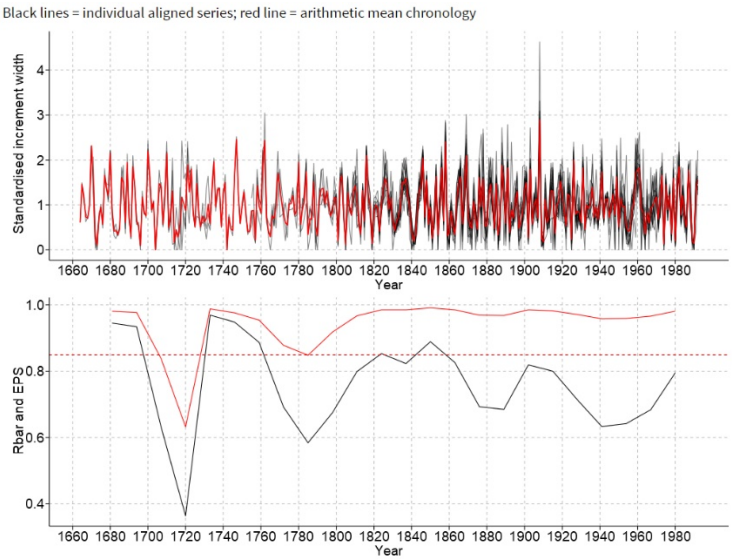


Fig 14: A line plot of the detrended measurement time series (black lines) plotted with their arithmetic mean (red line). B) A plot of the running Rbar and expressed population statistics (EPS); red and black lines, respectively. The dashed red line marks the 0.85 EPS threshold.

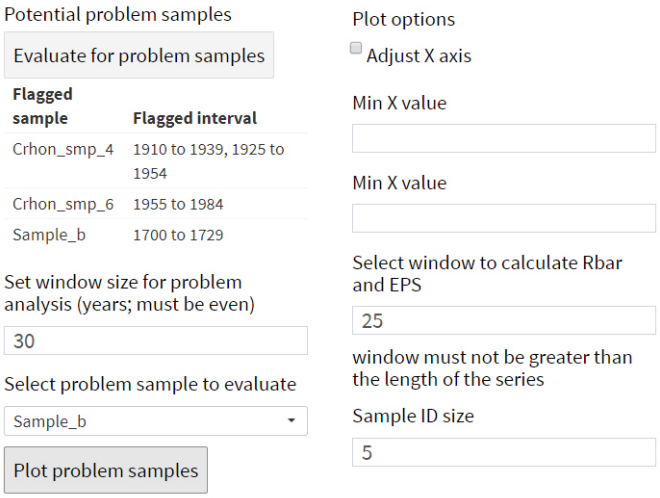


Fig 15: Options for performing a secondary check for problematic samples. An options menu for modifying the line plots and modifying the window used for calculating the EPS and Rbar statistics.

In addition to the Rbar and EPS statistics, RingdateR evaluates the mean correlation between each sample and the average of all others. 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 in the dataset.

The “Sample Depth Plot” tab on the “Aligned data” page generates a plot showing the span of each timeseries that has 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 shown with black lines.

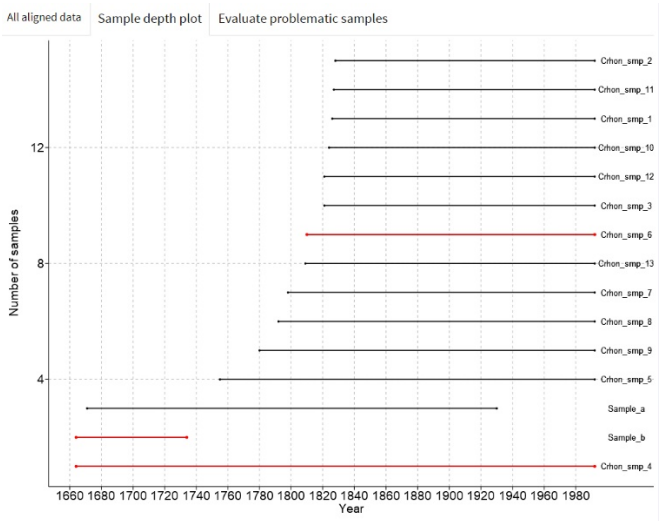


Fig 17: Plot showing the span of each aligned series in the dataset. Samples identified as having potential problems are shown with red lines. Samples that do not contain problems are shown with black lines.

Secondary Problem Sample Check

The “Aligned Data” page provides the option to perform a secondary problem sample check in which any problematic measurement time series can be compared against the mean of only those samples that do not contain potential problems (e.g. Fig. 18).

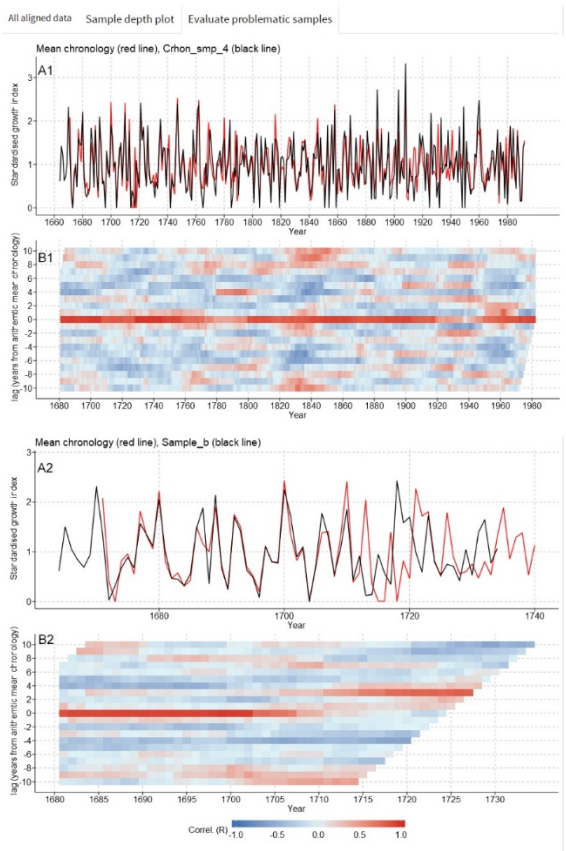
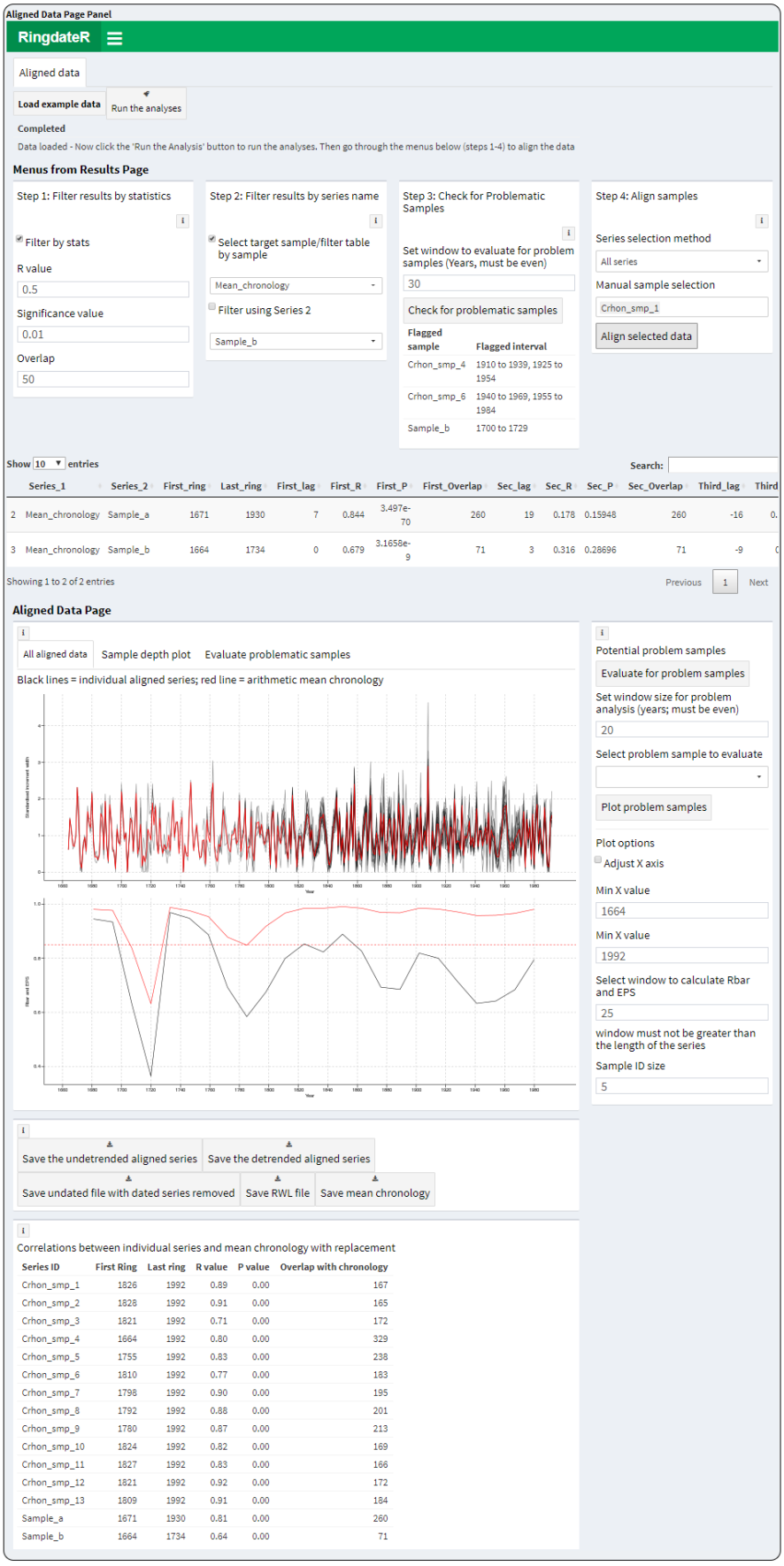


Fig 18: Example plots of two pairs of measurement time series that have been flagged for potential problems. A1 and A2) Line plots of the two pairs of measurement time series. B1 and B2) Running correlation heat maps between the two pairs of measurement time series. The analyses plotted in B1 contains strong positive correlations between the two measurement time series at zero-year lag. However, there are two intervals with low correlation. This drop in correlation is sufficient to flag this sample. However, correlations in adjacent lags are low indicating that this sample likely does not contain problems, but may be experiencing natural variability due to suppression, competition, or disturbance. The heat map plotted in B2 shows a likely frame shift due to three missing rings, reflected by a strong shift in peak correlation from zero year lag to a lag of three years. As in all cases of potential dating problems, the original sample should be visually re-examined to verify the dating problem.



Interactive panel 8: An interactive panel on the "Aligned Data" page. Note the menus at the top of the interactive panel originate from ther "Results page".

Saving data and outputs

Export buttons are located throughout the application and allow data and plots to be saved. All saved files are automatically saved to the default 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