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THE "MANY FRAGMENTS CURSE:" A SPECIAL CASE OF THE SEGMENT LENGTH CURSE

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ABSTRACT

The "many fragments curse," a special case of the segment length curse, occurs in dendrochronology when time series are broken into fragments, either because of missing part of a sample (e.g., a rot pocket) or when a section of ring growth cannot be crossdated (e.g., a section with extremely suppressed growth and/or many rings absent). We exorcise this curse by inserting values to connect fragments of measurements. This technique permits fitting a single detrending curve to the connected series and thus preserves the low-frequency variance contained in the entire series. Inserted values are discarded after detrending and do not otherwise affect calculations of final composite chronologies. As an example from junipers sampled at a site in Qinghai Province, China, 66 of 117 increment cores have nondatable sections of wood and one core has a gap of rotten wood between dated fragments. After connecting fragments by inserting values and then detrending, the chronology constructed from connected fragments has stronger century to multicentury scale variation than the chronology constructed from separate fragments. This approach is adapted to the library of computer programs developed for dendrochronological research under the auspices of the International Tree-Ring Data Bank.

Der "viele Fragmente Fluch," ein Spezialfall der Segment-länge Fluch, entsteht in der Dendrochronologie wenn Zeitreihen in Fragmente zerteilt werden, entweder wegen ein fehlender Teil der Probe (z.B. ein verfaultes Abschnitt) oder wenn eine Sektion des Ringwachstums nicht synchroniesiert werden kann (z.B. eine Sektion mit ekstrem unterdrücktem Wachstum und/oder viele fehlende Jahrringe). Wir beschwören diesen Fluch bei der einführung von Zahlen-werte um die fragmentierten Messungen zu verbinden. Diese Technik erlaubt eine einzelne "detrending curve" zu der entsprechende Reihe anzupassen, wobei die niederfrequenzliche Varianz in der gesamten Serie bewahrt wird. Eingeführte Wehrte werden nach dem "detrending" kassiert und beeinflussen anderswo nicht die endlichen zusammengesetzten Chronologien. Als ein Beispiel von eingesammelten Wacholder in einer Lokalität in der Quinghai provinz, China, hatten 66 von 117 Bohrkerne Sektionen mit nicht datierbares Holz und ein Kern hatte eine Unterberechung von verfaultes Holz zwischen datierte Fragmente. Nach dem verbindem der Fragmente bei Einführung von Zahlen-wehrte und danach "detrending," hatte die von der verbundenen Fragmente konstruierte Chronologie eine bessere Varianz als die von der seperaten Fragmente konstruierten Chronologie, da der Massstab über mehrere Jahrhunderte ging. Diese Metode ist der Bibliothek von Computerprogramme angepasst, entwickelt für dendrochronolgische Untersuchungen in der Regie von der International Tree-Ring Data Bank.

La "fragmentation multiple" est un cas particulier de morcellement qui apparaît en dendrochronologie lorsque les séries temporelles sont brisées en fragments, soit qu'une partie de l'échantillon est absente (par ex, une zone décomposée), ou lorsque une série de cernes ne peut pas être synchronisée (par ex, quand une section montre une croissance extrêmement réduite ou que de nomhreux cernes sont absents). Nous remédions à ce problème en insérant des valeurs qui connectent les fragments de mesures. Cette technique permet de lisser une courbe de détente à la série rattachée et qui de cette manière, préserve la variance de basse fréquence contenue dans la série entière. Les valeurs inserées sont éliminees après suppression de la tendance et n'affectent aucunçment les calculs de la chronologie composite finale. Comme exemple, nous utilisons des genévriers prélevés dans le site de la Province de Qinghai en Chine, 66 des 117 échantillons n'étaient pas synchronisables, et l'un d'eux montrait une zone de bois pourri entre des séries datables. Après avoir connecté les fragments en y insérant les valeurs, puis en détendant la série, la chronologie construite à partir des fragments rassemblés montre une variation centenaire ou multicentenaire plus forte que la chronologie construite à partir de fragments séparés. Cette approche est adaptée à la librarie de programmes développée pour la recherche dendrochronologique sous les auspices de l'International Tree-Ring Data Bank.

INTRODUCTION

Interpretation of low-frequency variation of composite tree-ring chronologies is constrained by the phenomenon referred to as the "segment length curse," which arises because the longest period of recoverable information in a composite chronology is limited by the lengths of individual series being analyzed (Cook et al. 1995). When age trends in tree-ring data are removed using either a modified negative exponential curve or a least-squares regression line (Fritts et al. 1969), variation of periods equal to or longer than the series itself is removed (Cook et al. 1990). In reality, variation of periods as short as one-third the series length is lost when using these detrending strategies (Cook et al. 1995). For example, a chronology built from detrended series spanning 1,000 years is not likely to retain variation at periods longer than about 333 years, even if lower-frequency variation is present in the measured data and might be attributable to environmental factors controlling ring growth.

The segment length curse is compounded when individual series of tree-ring data are broken into fragments. Tree-ring time series can be fragmented when part of a sample is missing (e.g., a rot pocket or a break) or when a section of ring growth cannot be crossdated (e.g., a section with extremely suppressed ring growth and/or many rings absent, possibly consecutively). A tree-ring series spanning 1,000 years that is broken into crossdated fragments spanning 150 years would retain variation of periods up to only about 50 years after detrending using either modified negative exponential or regression line fits. A chronology built from such fragmented series would be weak in low-frequency variance because of the segment length curse. Another ramification of fragmented series is that there are "ends" within the series, possibly resulting in end-effect problems, in which values at the ends of series are poorly estimated during detrending, throughout fragmented series. We call this problem the "many fragments curse," which is distinct from, yet contributes to, the segment length curse.

EXORCISING THE MANY FRAGMENTS CURSE

After measuring the crossdated fragments of a sample, the many fragments curse can be exorcised by numerically connecting the measured fragments. This permits fitting a single detrending curve to the connected series, thereby preserving any low-frequency variance contained in the entire series. Two approaches to numerically connecting fragments of measured data depend on whether all the wood is present for undated gaps in the sample:

1. If all the wood of a sample is present, but dating is intermittent because of sections of rings that cannot be crossdated (e.g., with excessively suppressed growth), measured ring widths of crossdated fragments can be connected by replacing the undatable rings with a mean value, i.e., the length (millimeters) of the undated gap divided by its time span (years). The result is a continuous time series over the entire time span of the sample. Application of this approach is limited to total ring width, as other tree-ring variables, such as partial ring widths (Schulman 1942), ring densities (Schweingruber 1990), various image analyzed variables (Park and Telewski 1993; Sheppard et al. 1996), elemental concentrations (Lewis 1995), and isotopic ratios (Leavitt 1992), do not allow measurement of the numerator with which an average value can be estimated.
2. If dated fragments are separated by gaps of wood that are missing (e.g., rotten or lost) or if variables other than total ring width are being analyzed, measured values of dated fragments may be connected by replacing the lost rings with a value equal to the average of several rings before and after the missing wood.

In both approaches, the inserted values do not reflect actual year-to-year variations in ring growth and therefore should be discarded after detrending. Every value of a composite chronology should be computed using detrended values of only measured rings of crossdated series without using any inserted values.

EXAMPLE: QINGHAI JUNIPER, CHINA

We encountered the many fragments curse in tree-ring collections of junipers *(Juniperus* sp.) in Qinghai Province, China. The primary objectives of that paleoenvironmental study are to reconstruct past climate using total ring width of juniper and to interpret past climatic variation, especially at the multicentury temporal scale. We ultimately crossdated (Stokes and Smiley 1968) most cores, but the crossdating was quite challenging, and a substantial number of samples have sections where ring growth is severely suppressed and not crossdatable.

As an example, 117 cores were collected from 59 trees growing at Shenge (Table 1), and 66 of those cores have nondatable sections of rings while one core has a gap of absent wood between dated fragments. After crossdating, we measured total ring widths of only the crossdated fragments, resulting in 243 separate time series — over twice the number of cores that were collected. The median time span (years) of the measured series is just over one-third that of the cores. A majority of the measured fragments span less than 300 years (Table 1), the minimum time span necessary to realistically retain century-scale variation after detrending. If these fragments were left separate, very low-frequency variation that might otherwise exist in the final standard chronology after detrending (Fritts 1976) would be removed because of

Table 1. Pertinent statistics of the juniper tree-ring collection (59 trees sampled) of Shenge (37° 00' N, 97° 48' E, 3900 m asl), Qinghai Province, China.

	Separate Fragments	After Connecting Fragments
Number of measured time series	243	117
Median time span of measured series (years)	260	726
Percent of measured series with less than 300 years	60	2

the segment length curse (Cook et al. 1995), and much of the collection would not be suitable for interpreting multicentury scale paleoenvironmental variation. For this collection to suit that objective, the fragments of each core should be connected.

Two examples illustrate the analysis of samples with undatable sections between dated and measured fragments. Core 1 spans 1,034 years with five crossdated fragments (Figure 1A, light line) that are separated by sections of ring growth that are too suppressed to crossdate. Detrending the crossdated fragments separately (Figure 1A, medium lines) results in five index series that retain little multicentury scale information (Figure 1B, cubic smoothing spline [Cook and Peters 1981]), even though low-frequency variation is visible in the measurement series (Figure 1A). We divided the length of each undatable section by its time span to estimate the average ring width (rounded to the nearest 0.01 mm. year $^{-1}$, the level of precision of our measuring device) for the section. We inserted the mean value into the measurement file for all years of the section (Figure 1A, horizontal lines). We then estimated a single detrending curve (Fritts et al. 1969) for the connected series (Figure 1A, heavy lines), discarded the inserted values for each undatable section, and divided actual measured values by their respective predicted values from the detrending curve to derive annual indices. This detrending process resulted in five index series (Figure 1C), just as before (Figure 1B), but these series retain the low-frequency variation (Figure 1C, smoothing spline) that is visible in the measurement series (Figure 1A).

Core 2, our juniper sample that is fragmented as a result of a gap of rotten wood between datable fragments, spans 1,056 years with two crossdated fragments (Figure 2A, light line). Detrending the crossdated fragments separately (Figure 2A, medium lines) results in two index series that display end-effect problems in the middle of the time span (Figure 2B, near A.D. 1600) due to underestimating the inner ends of each fragment (Figure 2A). We inserted the average value of the ten rings before and the ten rings after the gap for all years of the gap (Figure 2A, horizontal line). We then calculated a single detrending curve for the connected series (Figure 2A, heavy line), discarded the inserted values for the undatable gap, and divided actual measured values by their respective predicted values from the detrending curve. This detrending process resulted in two index series (Figure 2C), just as before (Figure 2B), but these index series do not display the end-effect problems near A.D. 1600.

DISCUSSION

Several salient points should be noted about the many fragments curse:

1. The severity of the many fragments curse varies with the proportion of fragmented series in a tree-ring collection and the extent to which those series are fragmented. In our Shenge juniper example, with over half the cores fragmented and a median fragment length one-third the median length of connected series, the many fragments curse noticeably diminishes the low-frequency component of the standard chronology. In comparison to the chronology constructed from connected fragments (Figure 3, solid line), the chronology constructed from separate fragments (Figure 3, dashed line) has a reduced amplitude of century scale variation and no multicentury scale variation.
2. The inserted values of an extremely suppressed, undatable section of rings (our first approach) may result in underestimation of dated rings adjacent to the undatable section during detrending. While this effect may be disconcerting, it can also be viewed

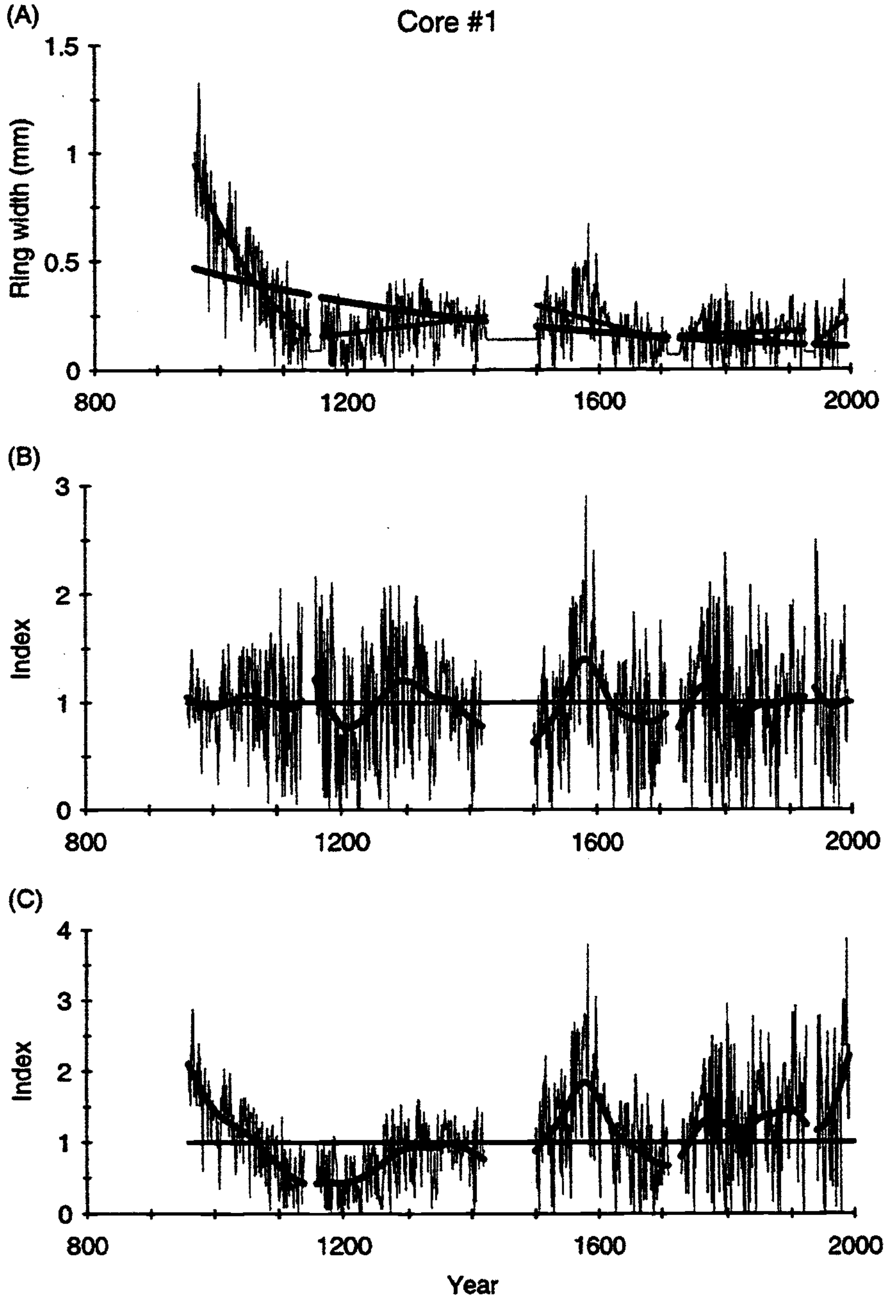

Figure 1. Core 1, a fragmented series with undatable wood between dated fragments. (A) ring measurements with horizontal lines between dated fragments representing inserted values (light line), separate trends (medium lines), and connected trends (heavy lines); (B) index series of fragmented series (light lines) with cubic smoothing splines (heavy lines); (C) index series of connected fragments (light lines) with spline curves (heavy lines).

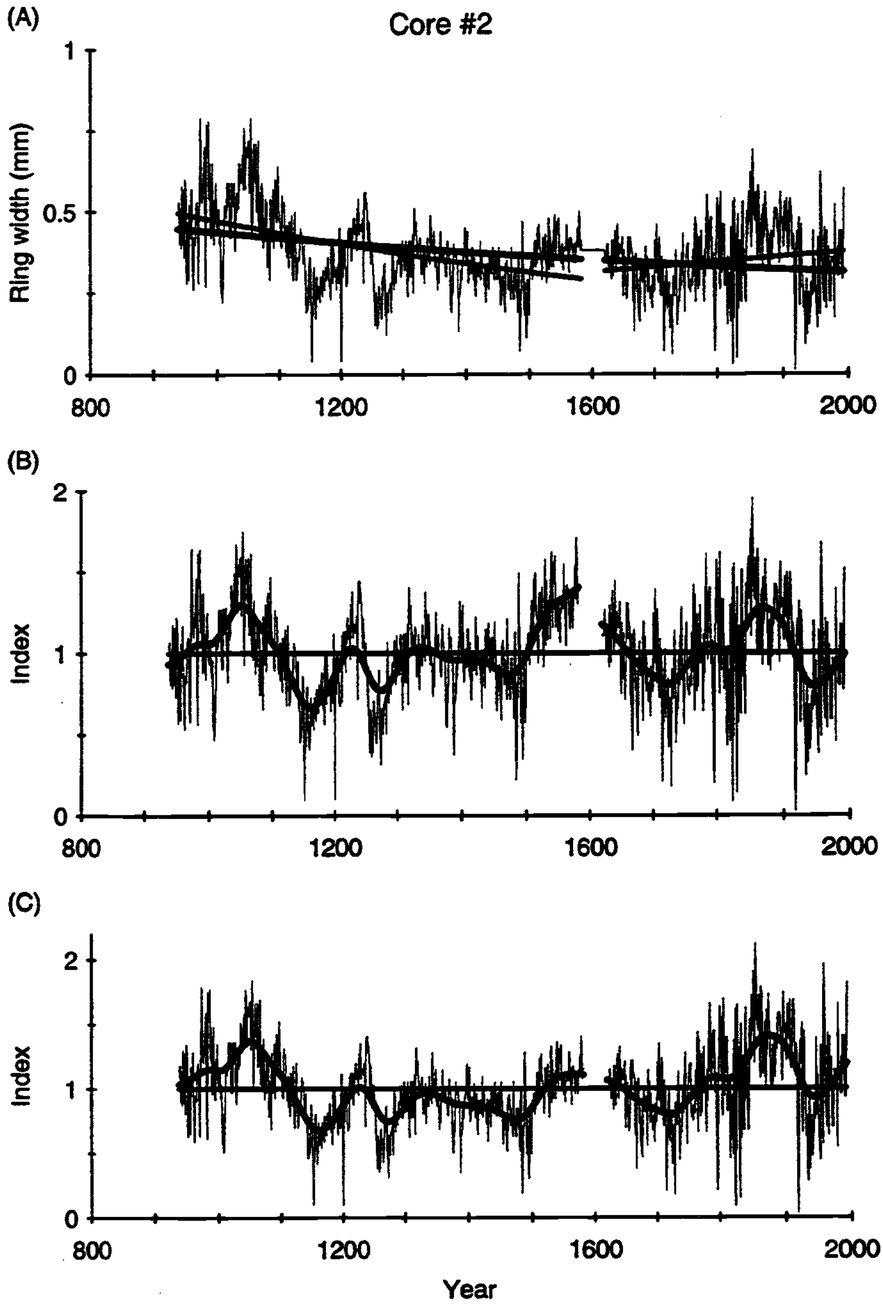

Figure 2. Core 2, a fragmented series with wood missing from between dated fragments. (A) ring measurements with horizontal lines between dated fragments representing inserted values (light line), separate trends (medium lines), and connected trends (heavy lines); (B) index series of fragmented series (light lines) with cubic smoothing splines (heavy lines); (C) index series of connected fragments (light lines) with spline curves (heavy lines).

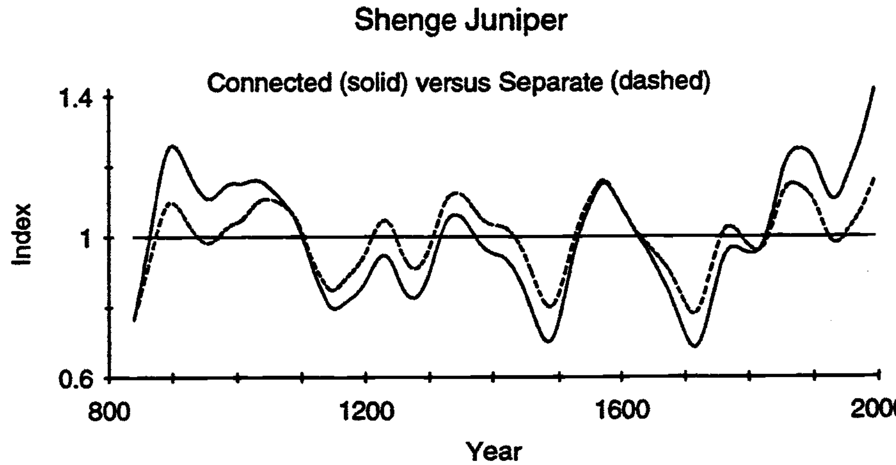

Figure 3. Smoothed chronologies of Shenge juniper constructed from detrended ring-width series with fragments connected (solid line) and from fragments detrended separately (dashed line).

as acknowledging a reality — extremely suppressed ring growth for a period of time — that should be part of the analysis and interpretation of the data. If it were valid to ignore that reality, inserting a missing data code, rather than an estimated value, would suffice for connecting dated fragments to preserve low-frequency variation after detrending.

3. Even after connecting fragments, researchers may still determine *a posteriori* that the detrending of a connected series is inadequate. For example, it could be argued that the first few centuries of the connected Core 1 are grossly misfit by the modified negative exponential curve (Figure 1A), and that some other detrending strategy might be more appropriate. Nonetheless, modified negative exponential detrending succeeded in the sense that it resulted in an index series with a mean and variance that can be considered weakly stationary with respect to its full time span of 1,034 years (Figure 2C). Regardless of the detrending strategy, if low-frequency variation is synchronous across most of the individual index series of a tree-ring collection, that variation will be expressed by the composite standard chronology (Sheppard 1993). Conversely, if low-frequency variation is not synchronous across most of the individual index series, it will not survive the averaging step of developing composite tree-ring chronologies (Cook 1985). As always, variation (at all frequencies) in a composite chronology should be cautiously interpreted for time periods that are poorly replicated.
4. Time series of actual values should be roughly stationary around gaps for our approach to exorcising the many fragments curse to be valid. If the mean and variance of the pregap fragment differ dramatically from that of the postgap fragment, connecting those fragments would not be justified and the fragments should probably be detrended separately (Blasing et al. 1983). As is true with most time-series analysis, plotting measurement series with their detrending curves is strongly recommended — if not necessary — when analyzing a tree-ring collection beset with fragmented series.

5. An obvious question exists when inserting values to connect fragments: How many years of a gap may be bridged with inserted values without compromising the quality of the true information in the series? Simple rules probably cannot cover all possible uses of connecting fragments, but gaps should certainly be short relative to the length the series would have been if it were not fragmented. Furthermore, the number of measured values before and after a gap that are used to estimate a mean value for a gap of no wood (our second approach) may also differ from case to case depending on trends of measured values adjacent to the gap. Again, a simple rule probably cannot cover all possible scenarios of this problem.
6. Other, more elegant approaches exist to exorcise the many fragments curse, including smoothing spline techniques that allow for fine tuning the frequency of variation retained in detrended series (Cook and Peters 1981). Our approach, however, is adapted to the current library of computer programs developed for dendrochronological research under the auspices of the International Tree-Ring Data Bank (Grissino-Mayer et al. 1996). In particular, within the module CRN of the Program DPL (or CRONOL), which is used to compute tree-ring chronologies, five or more consecutive identical values in a tree-ring measurement series are considered to be inserted values, not actual measurements. After the detrending curve specified by the user is computed and fitted to the entire series, the inserted values are discarded and the chronology is computed.

CONCLUSIONS

The many fragments curse has undoubtedly influenced past dendrochronological research, and it will presumably continue to affect research as dendrochronologists study growth of trees in increasingly marginal sites where ring growth may not always be crossdatable. As a special case of the segment length curse, fragmentation could eliminate an otherwise appropriate tree-ring collection from being applied to studies of very low frequency environmental change, which is commonly an important scientific objective of paleoenvironmental research (Rind and Overpeck 1993). By connecting crossdated fragments of tree-ring measurements with inserted values, detrending full-length time series, and discarding inserted values after detrending, this approach to exorcising the many fragments curse takes full advantage of the low-frequency information of tree-ring growth, which may then be interpreted for paleoenvironmental information.

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