SM3: Polar Urals region TRW and MXD analysis

PU1 Brief background history

On the eastern slope of the Polar Urals (Sob river basin) about 40 cuts from living trees of Siberian larch, growing at the upper tree-line ecotone, were collected in 1960-1962. These cross-sections were measured, cross-dated and ring-width averaged by calendar year without standardization. A ring-width chronology, 310 years long, was obtained, which showed significant differences in the magnitude of radial growth over time. This work showed that over the most recent 40 years there had been a very intense period of tree growth, evident even in old trees (Shiyatov, 1962). At that time, only a few cross-sections from dead trees (sub-fossil wood), preserved on the surface were sampled, but these samples were not dated. Samples collected before 1977 were used by D. A. Graybill and S. G. Shiyatov to build a new chronology with the intention of identifying the long-term fluctuations of tree growth and summer temperatures over the past millennium. For this purpose, 48 of the longest individual series were selected from among the living trees and 23 series from sub-fossil wood. The calculation of TRW indices for each individual series was produced by taking ratios of measured over "expected" ring width where expected values were given by a negative exponential function fit to the measurement series from each individual tree. The new chronology was used to reconstruct of June-July temperature for 1010 years. The important result of this work was to identify the close relationship between ring-width indices and observed summer temperatures. The presence of an extended warm period in the Middle Ages (11-13th centuries) and the subsequent cooling of climate from the 14th to 19th centuries were also inferred (Graybill and Shiyatov, 1992).

A focussed effort directed at sampling sub-fossil wood was made in 1977 on the south-eastern slope of Massiv Rai-Iz, where many wood remains were located slightly above the then tree line, indicating that during the relatively recent past, trees grew at higher hypsometric levels than at the time of sampling. The samples were taken from larch trunks and roots; 29 cross-sections from sub-fossil wood and 71 core samples from living trees. Ring-width measurements were standardized using the "corridor" method. The resulting chronology (spanning 960-1969 CE) was published in S.G. Shiyatov (1986). In 1983, on the south-eastern slope of massive Rai-Iz an altitudinal transect was established. It was 430 m in length, running from 280 to 340 m.a.s.l. This transect was located above the then current recent tree-line and here there were a large number of well-preserved remains of dead trees located within it. The location of each of 270 dead trees was mapped and cross-sections were taken at the base of trunk or root from each dead tree. Of these samples, those containing the greatest number of tree rings were selected for analysis. As a result, the Polar Urals chronology, using the "corridor" method, was extended back to 745 CE, and a corresponding reconstruction of summer temperatures was published (Shiyatov, 1995).

In July 1991, Fritz Schweingruber, Stepan Shiyatov and Russian colleagues extracted cores from living trees of spruce and larch from an area of mixed larch and spruce forest (66.52N, 65.38E, 250 m.a.s.l.). They also selected wood samples, previously obtained from dead larch trees found in the same area (Shiyatov 1986), some of which were from slightly higher (by up to 80m) altitudes. These samples were processed at The Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland, http://www.wsl.ch/index_EN (WSL) using

X-ray techniques to produce (among other parameters) tree-ring width (TRW) and maximum latewood density (MXD) data sets for the larch (Pou_la) wood samples (Schweingruber and Briffa 1996). A temperature reconstruction, for the period 914 to 1990 CE was produced from the Pou_la MXD and TRW measurement data, using RCS for the MXD in order to preserve long-timescale variance (Briffa et al. 1995) – see main text for further details. The Pou_la site data, both TRW and MXD, were discussed in a review paper (Briffa et al. 1996) which outlined problems relating to the preservation of long-timescale variance and, for the Polar Urals (referred to as Sob river), also discussed the potential effects of changes of mean tree-age and mean-elevation of samples through time as sources of potential bias.

In June 1999, in order to improve the replication of the sub-fossil (Pou_la) chronology, Fritz Schweingruber obtained further wood samples from the Ekaterinberg collection of dead, sub-fossil larch tree remnants (Shiyatov, personal communication) and a second larch data set (Polurula), again containing both TRW and MXD measurement series was produced. These data were archived in the Tree-Ring Data Bank in September 2000. Esper et al. (2002) produced a reconstruction of Northern Hemisphere mean annual temperatures using only the TRW data from the densitometric measurements from a network of sites around the Northern Hemisphere, from several different species, and this large data set included the Polar Urals larch data (Pou_la) and the more recently available Polurula larch data (see Table PU1). For the current work, the Institute of Plant & Animal Ecology, Russian Academy of Sciences, Ekaterinburg http://ipae.uran.ru/ provided further measurements of TRW and MXD from living trees updating the larch through to 2006 (Purlasi and Purlasi_sc). This material was measured at V.N.Sukachev Institute of Forest, Siberian Branch of Russian Academy of Sciences, Krasnoyarsk using procedures of X-ray densitometry similar to those used by Fritz Schweingruber at WSL. It was noticed (personal communication Alexander Kirdyanov) that there was a difference in the mean values of MXD measurements made in the different laboratories but using the same larch samples.

PU2 Assembling measurement data

It is necessary to test the validity of the dating and to test the various sub-sets of Polar Urals data for homogeneity and hence suitability for use with RCS. Crossdating was checked using statistical crossdating software and all series used were considered to crossdate correctly (results are provided in files "...Corr.prn" http://www.cru.uea.ac.uk/cru/papers/briffa2013qsr/). When acquired, some of the data-files were based on mean-tree series while others contained multiple core data for most trees. All core measurement series were averaged to produce mean-tree series throughout. Pith offset data, available for all series, were used in RCS processing (pith offset data are provided in files ".pth"). Summary reports for each site containing some basic statistics for each tree are provided in (...Stats.prn). The crossdating demonstrated that there is a strong common high-frequency signal in these trees.

Table PU1. Details of the Polar Urals sites used here including site name, altitude, grid locations, years spanned by data and species.

FILE	ALT	NORTH	EAST	START	END	SPECIES
Russ001	?	6600	6500	1541	1968	LASI
Pou_la	250	6652	6538	914	1990	LASI
Polurula	250	6652	6538	778	1892	LASI
Purlasi	185	6649	6535	1641	2001	LASI
purlasi_sc	185	6647	6530	1845	2006	LASI

Table PU2 – Some basic statistics for the Polar Urals data sets.

Indices created by standardising with a 30-year spline.
Corr - the mean correlation of each index series with the chronology (excluding that series).
Rbar - the mean inter index-series correlation.
MnRaw - the mean value of all measurements for the site.
File extension ".raw", ".trw" and ".rwl" indicate ring-width measurements
File extension ".mxd" indicates maximum latewood density measurements

File name	Cores	Start	End	Years	Rings	Corr	RBar	MnRaw
Larch								
russ001.rwl	21	1541	1968	428	4901	0.75	0.61	0.328
pou_la.raw	93	914	1990	1077	13929	0.78	0.66	0.476
pou_la_mod.raw	23	1631	1990	360	4059	0.84	0.73	0.434
pou_la_sub.raw	50	914	1744	831	7017	0.72	0.61	0.511
pou_la_stem.raw	47	914	1744	831	6627	0.72	0.62	0.484
polurula.raw	32	778	1892	1115	5361	0.68	0.54	0.655
polustem.raw	14	872	1892	1021	2334	0.64	0.58	0.430
purlasi.raw	34	1641	2001	361	7993	0.83	0.70	0.407
purlasi_sc.raw	24	1845	2006	162	2822	0.81	0.73	0.792
pou_la.mxd	93	914	1990	1077	13929	0.73	0.63	0.737
polurula.mxd	32	778	1892	1115	5361	0.63	0.60	0.759
purlasi.mxd	34	1641	2001	361	7993	0.78	0.65	0.831
purlasi_sc.mxd	24	1845	2006	162	2822	0.75	0.68	0.799

PU3 Samples from root collar and stem

The rings in the trunk of Siberian larch are generally concentric whereas the rings in the root-collar samples can vary considerably, being larger in the direction of a major root and smaller in directions between roots (Figure PU07). The allocation of material to individual roots will partly depend on mechanical strength requirements within the tree and growth can favour one root (direction) over several decades. Hence the dimensions of TRW measurements for one year taken in different directions from root-collar samples can be very variable. The Polar Urals sub-fossil samples arise from very detailed, long-term study at the tree-line (e.g. Shiyatov 1995, see also PU1). All wood samples (roots, stems and branches) found in the study area were measured. In a number of cases where the stems of trees had decayed, the measurements were taken from remnant root collars. The original samples selected for densitometric analysis (forming the Pou_la measurements data) were preferentially selected from stem samples collected in 1977 and 1983 by Stepan Shiyatov (see Figure PU06). A subsequent attempt to increase sample replication in the early, medieval period (a request from Schweingruber to Shiyatov in June 1999 for more samples) produced the so-called "update" data set, i.e. the Polurula data. These contained considerably more root-collar samples (see Figure PU05) than did the previous Pou_la data. While potentially much less prone to biased interpretation when processed using curve-fitting, effectively high-pass filter standardisation methods (see Figures PU01 and PU02), these samples represent systematically wider ring widths (see Shiyatov's message to Schweingruber in Figure PU06) and are not necessarily suitable for RCS processing which is designed to exploit temporal changes in the mean growth rates of trees (TRW) to generate long-timescale variance (see Figures PU03b and PU04c).

Figure PU01 - To test the medium-frequency signal the Pou-la and Polurula series were standardised using 100-year spline, signal-free standardisation. Mean indices are plotted separately for sub-sets of data (original sub-fossil, modern, and sub-fossil update) for TRW (a) and for MXD (b), with 10-year smoothing and thin lines showing <4 trees. These plots show consistency in the overlaps between original sub-fossil, sub-fossil update and modern samples at medium-frequency timescales (i.e. a few decades) for both TRW and MXD chronologies.

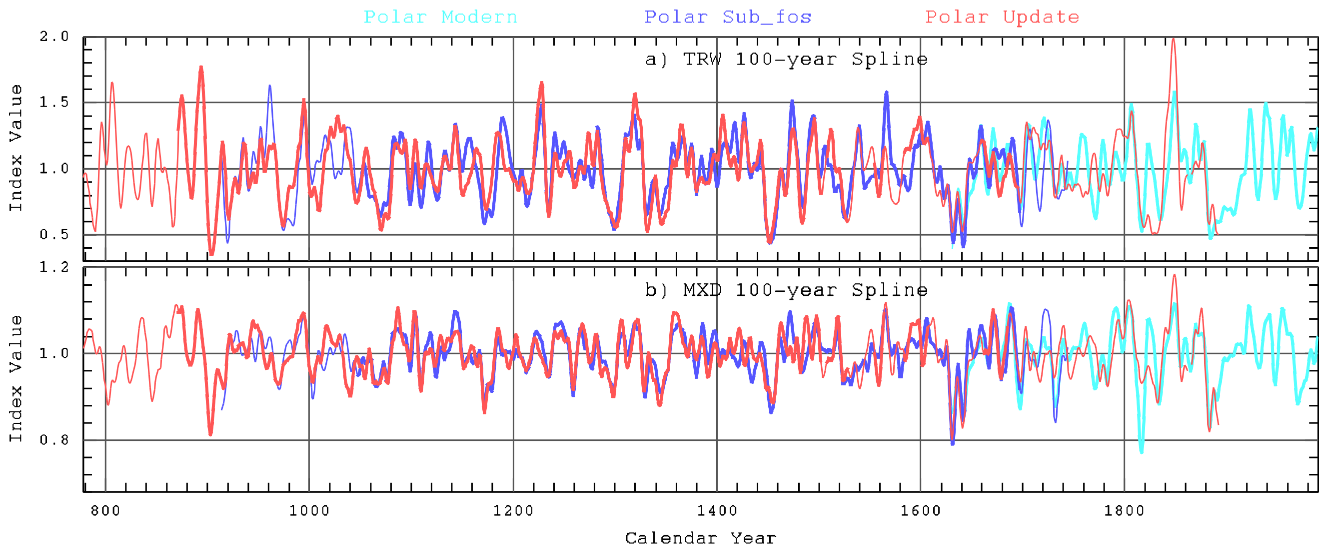


Figure PU02 - MXD and TRW processed separately. Indices created using 100-year spline, signal-free standardisation using all Pou_la and Polurula trees. Mean indices were calculated separately for Polar Urals sub-sets of data (modern, original sub-fossil, and sub-fossil update) and these were normalised over their common periods (see Table PU1) by subtracting the mean and dividing by the standard deviation. Mean values of MXD and TRW are compared for the Polar Urals sub-sets of data: modern (a), original sub-fossil (b), and sub-fossil update (c) with 10-year smoothing for display and thin lines for <4 trees. All sub-set samples produce similar signals from TRW and MXD at medium-frequency (a few decades) timescales within the limits of accuracy imposed by small sample counts. Sample counts over time are shown by grey shading. Poor correspondence between curves is associated with poor sample replication (see also SM6 describing time dependent chronology confidence levels).

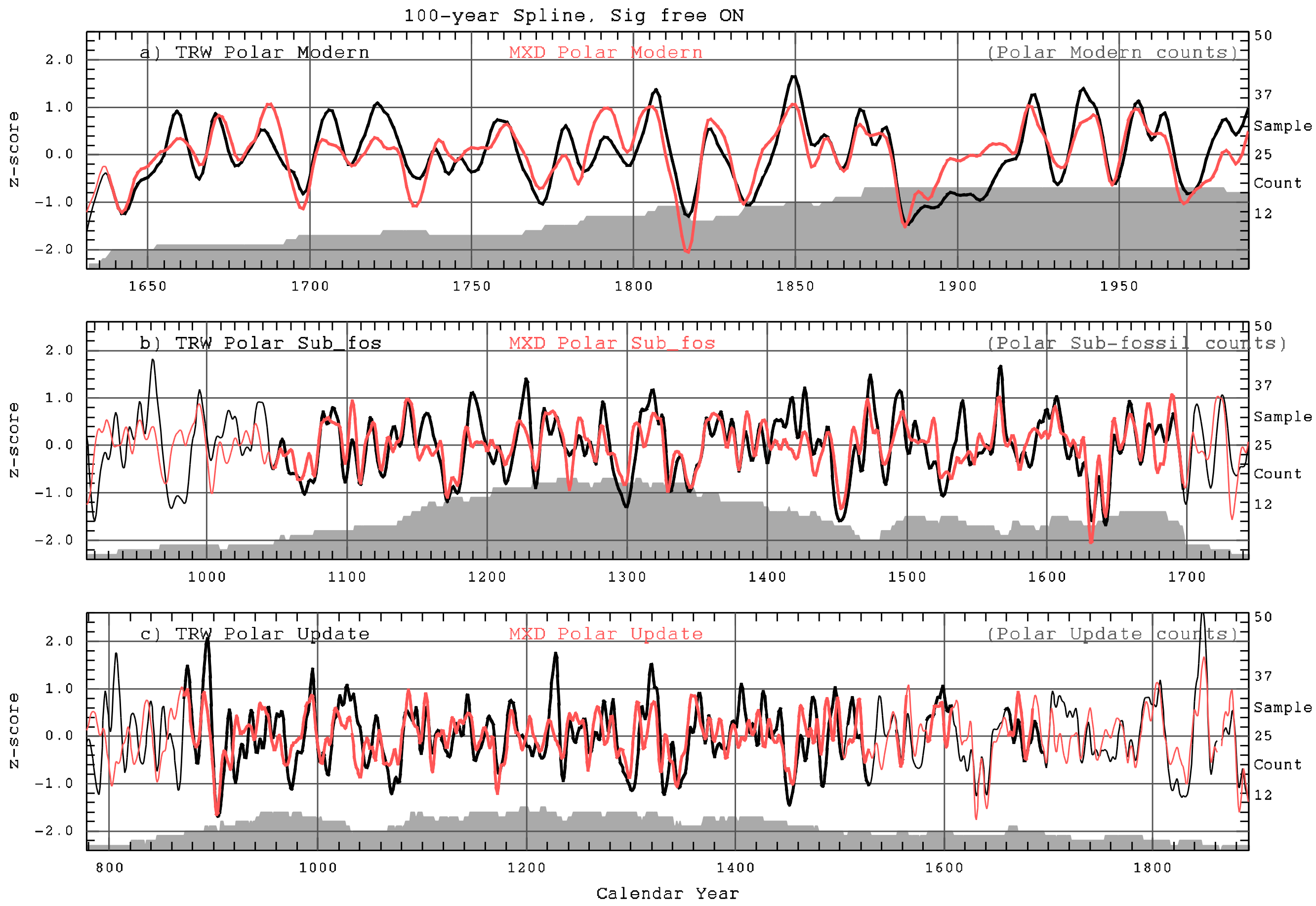


Figure PU03 – To examine the low-frequency signal, RCS is used to produce both TRW and MXD chronologies. The separate chronologies (living-tree, original sub-fossil, and sub-fossil update) were standardised individually using one-curve signal-free RCS for TRW (a) and MXD (b). The combined data set (Pou-la and Polurula) was also standardised using one-curve signal-free RCS producing separate sub-chronologies (original sub-fossil, modern, and sub-fossil update) for TRW (b) and MXD (d). Chronologies have been smoothed with a 50-year spline for display and thin lines show sample replication <4 trees. When standardised separately, each chronology will have a mean of approximately 1.0. When standardised together the overall chronology will have indices with mean 1.0 but when the resulting tree indices are averaged into separate sub-chronologies, these can have differing mean values. These figures show the inconsistency between the original and update sub-fossil samples. When chronologies were created using one-curve RCS (b) the chronologies can be seen to match in some periods but are very different in the periods circa 950 to 1150 and 1350 to 1550. The MXD chronologies have a better match than do the TRW but even here the equivalence is not as good as was demonstrated in their 100-year-spline standardised equivalents.

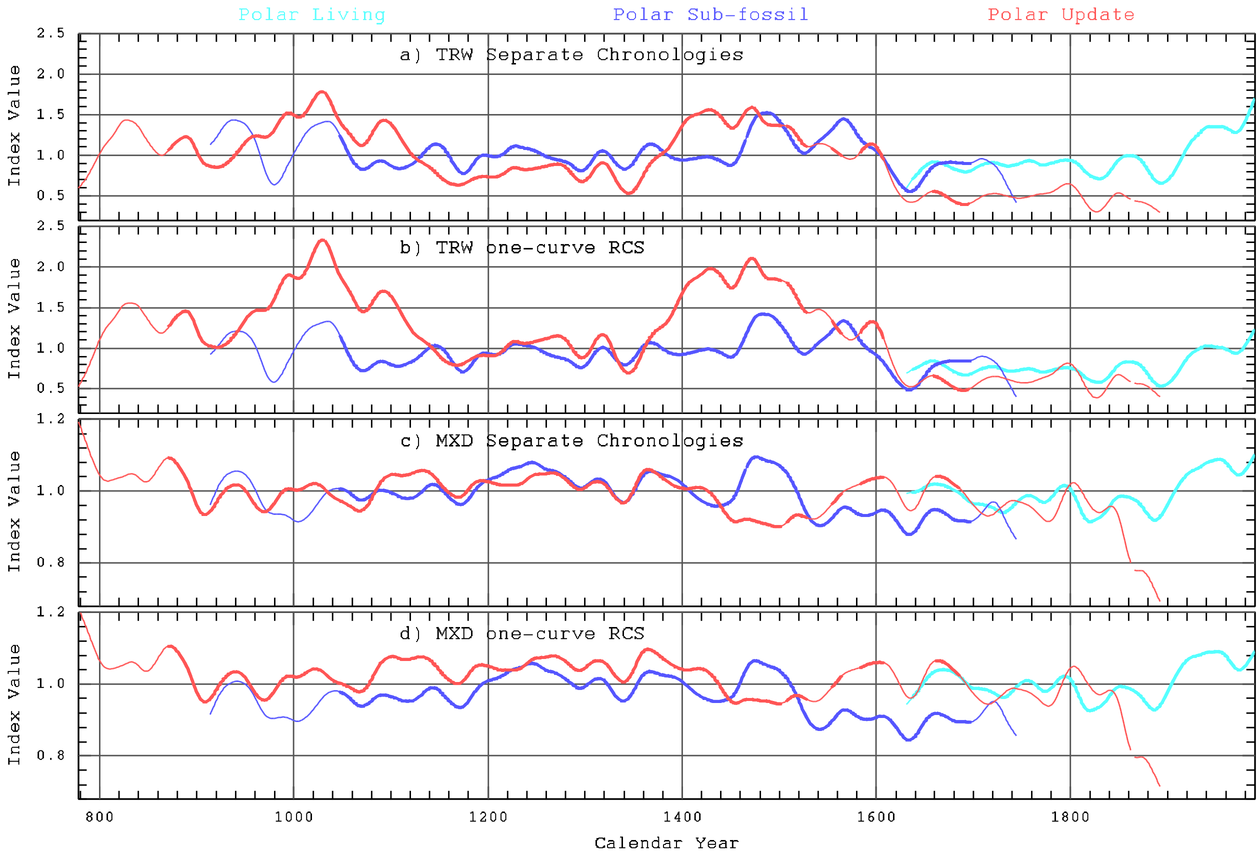


Figure PU04 – Polar Urals MXD and TRW processed separately. Indices created with one-curve, signal-free RCS using all samples (Pou_la and Polurula). Mean indices are plotted separately for sub-sets of data (modern, original sub-fossil, and sub-fossil update), with 10-year smoothing and thin lines showing <4 trees. MXD and TRW comparison for mean indices of the Polar Urals sub-sets of data: modern (a), original sub-fossil (b), and sub-fossil update (c). The pairs of series were normalised (by subtraction of the mean and division by the standard deviation) over their common periods (see Table PU1). The "modern" samples produce similar signals from TRW and MXD at low-frequency timescales, again within the limits of accuracy imposed by small sample counts. The original sub-fossil series match reasonably with the exception of the 16th century. For the sub-fossil "update" chronologies the extremely high index values of the TRW chronology in the 11th and 15th centuries are not present in the MXD. A re-examination of the original sample metadata revealed that the problems with the Polurula (and to a much lesser degree Pou_la) chronology appear to arise because a number of the samples were taken from the remains of root collars rather than tree stems. Sample counts are indicated by grey shading.

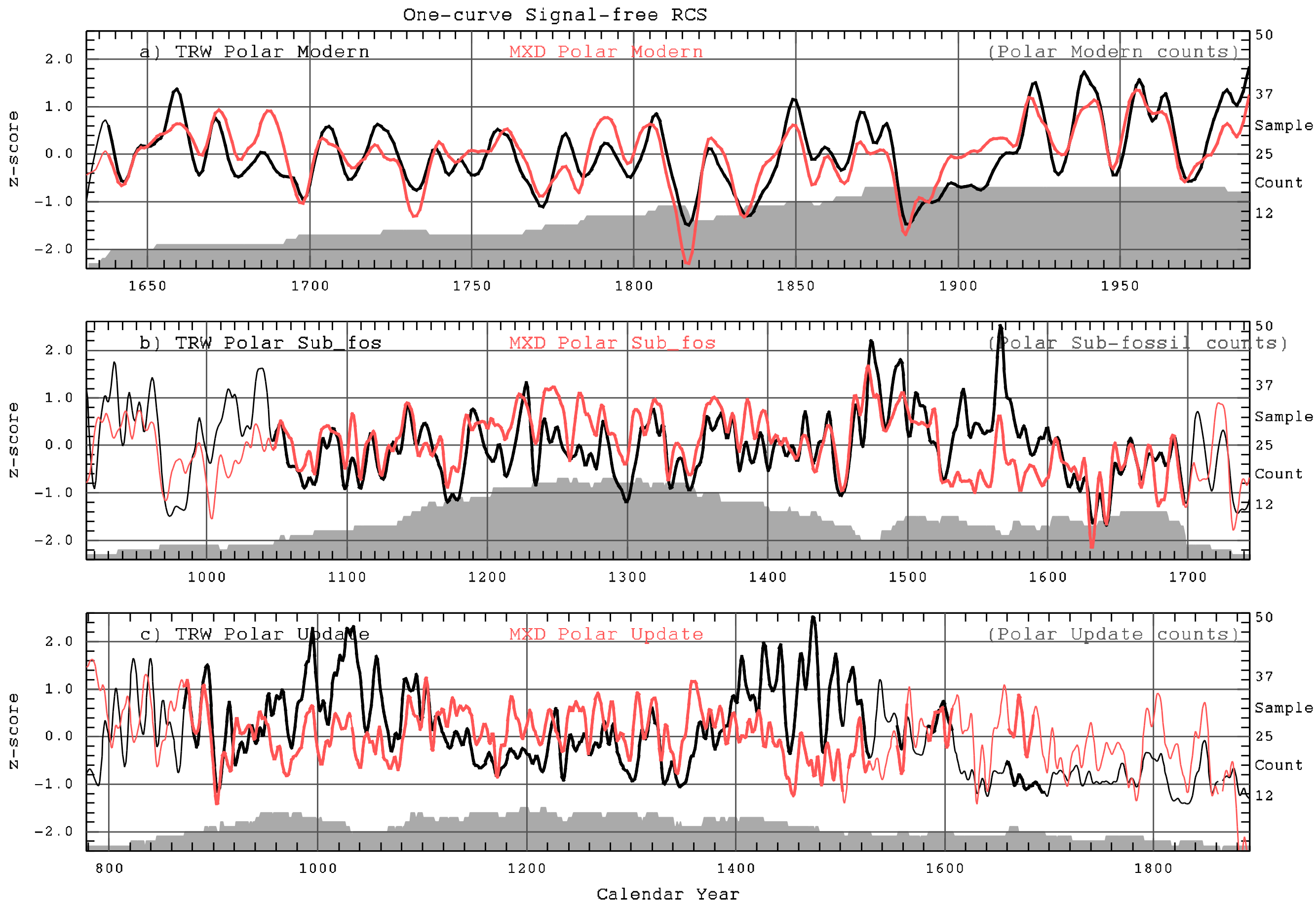


Figure PU05 – Identifications of the source of wood (stem or root collar) for the Pou_la chronology. The original caption read "*Samples from dead trees taken by Stepan Shiyatov in 1977 and 1983 at the upper tree-line (Polar Ural Mountains) which were measured (RW) and dated in Ekaterinburg and from these samples were taken wood along another radius and sent to Fritz Schweingruber*". Three Pou_la tree samples were from the root collar.

Code	Time interval, PM	Number of rings	Location of sampling
p-07	1572-1729	158	trunk
p-13	1042-1220	179	trunk
p-14	1091-1351	261	trunk
p-17	1108-1269	162	trunk
p-19	1092-1227	136	trunk
p-24	1479-1629	151	trunk
p-26	1018-1239	222	trunk
p-27	1086-1325	240	trunk
m-30	1019-1230	212	large root base
m-33	927-1108	182	large root base
m-34	1280-1429	150	trunk
m-37	1061-1269	209	trunk
m-38	1217-1465	249	trunk
m-39	1242-1508	267	large root base
m-43	1351-1608	258	large root base
m-44	1354-1566	213	large root base
m-45	1271-1542	272	trunk
m-47	1310-1565	256	trunk
m-49	1350-1576	227	large root base
m-50	1206-1415	210	trunk
m-51	983-1295	313	large root base
m-52	1466-1587	122	trunk
m-53	1579-1753	175	trunk
m-54	1570-1736	167	trunk
pm-204	1149-1326	178	trunk
pm-205	1244-1399	156	trunk
pm-206	1076-1368	293	large root base
pm-207	1049-1284	236	large root base
pm-221	1177-1429	253	trunk
pm-227	1111-1444	334	trunk
pm-229	1211-1506	296	trunk
pm-238	1493-1703	211	trunk
pm-246	1082-1221	146	trunk
pm-247	1552-1742	191	trunk
pm-255	1657-1817	161	trunk
pm-256	1656-1865	210	trunk
pm-259	1751-1904	154	trunk
pm-260	1573-1724	152	trunk
pm-270	931-1087	157	large root base
pm-275	861-1063	203	trunk
pm-286	893-1106	214	large root base
pm-290	911-1090	180	large root base

Figure PU06 – Scan of a Table contained in a letter (Stepan Shiyatov to Fritz Schweingruber dated June 1999) identifying the source of samples used to create Polurula TRW and MXD data as being either from the root collar or from the stem. Of 32 samples comprising the Polurula data 18 were from root-collar samples.

POLURULA

Filme 1121 A-F

Dear Fritz,

I am sending you 32 samples of dead trees obtained from the base of trunks and base of roots of Siberian larch which have been grown at the upper timberline in the Polar Urals. I tried to select more ancient material and material representing the 1400-1700th time interval. The chronology will be prolonged more than 170 years if these samples are suitable for density measurements. Unfortunately, more older wood is not well preserved. Short characteristics of these samples are below:

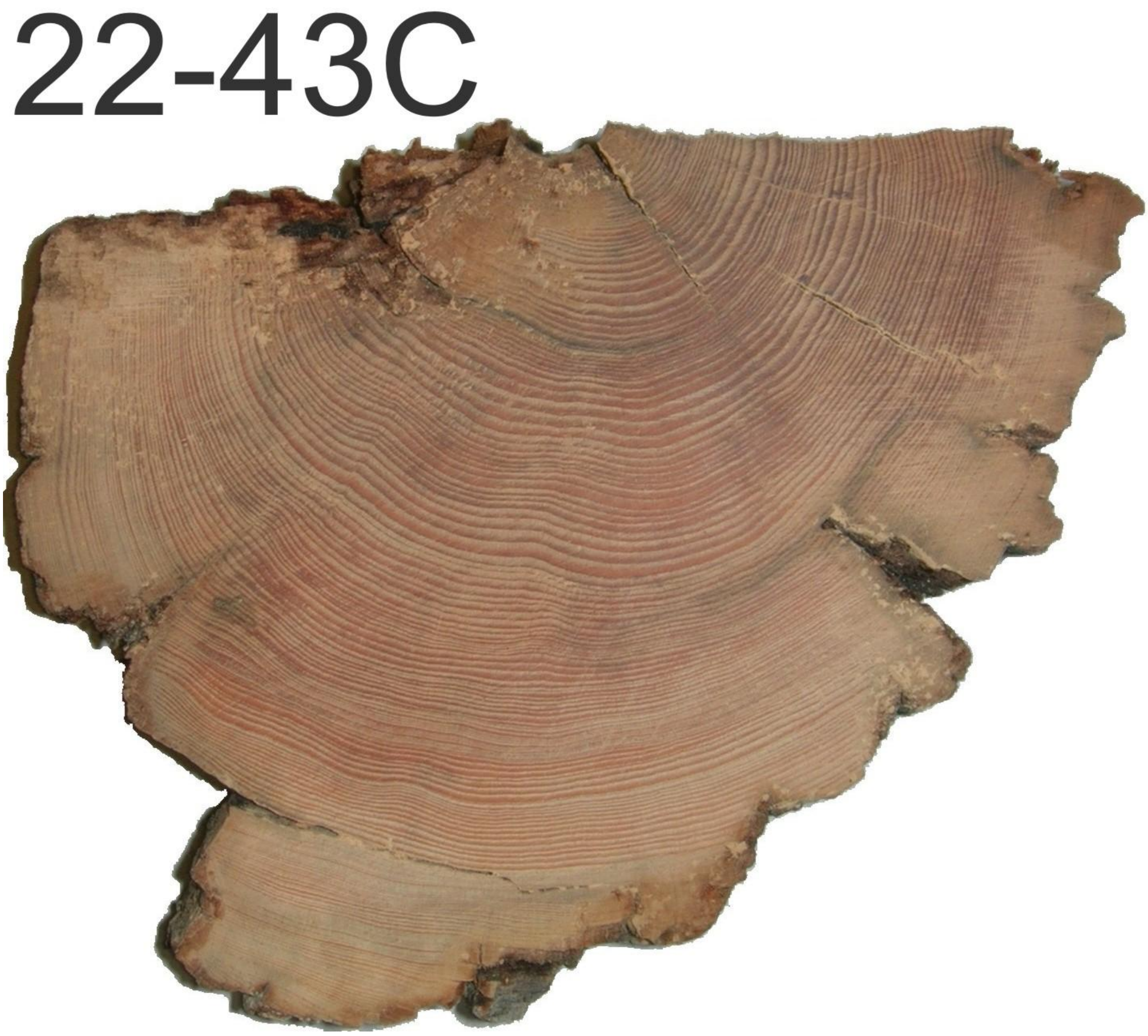
Anzahl Stücke

Codes	Part of tree	Time interval
pl1174	root	831-1146
pl1133	root	1194-1500
pm0303	root	1019-1230
pm2903	root	911-1090
pm0333	root	927-1108
pl1903	root	1069-1375
pm0433	root	1351-1608
pm2291	trunk	1211-1506
pm2041	trunk	1149-1326
pm2051	trunk	1244-1399
pm2271	trunk	1111-1444
pm2551	trunk	1657-1817
pm2561	trunk	1656-1865
pm2601	trunk	1573-1724
pm2591	trunk	1751-1904
pm2461	trunk	1082-1221
pm2381	trunk	1493-1703
pm2211 ref.	trunk	1177-1429
pm2471	trunk	1552-1752
pm0191	trunk	1092-1227
pm2863	root	893-1106
pm2703	root	931-1087
pm2133	root	840-989
pm2073	root	1049-1284
pm0393	root	1242-1508
pm2063	root	1076-1368
pm0443	root	1405-1566
pm0493	root	1350-1576
pl0694	root	800-935
pl0983	root	869-1029
pl0893	root	745-926
pm2751	trunk	861-1063

(PL0693) root 792-928

auch so beschriftet!

Figure PU07 Wood sample from the base of the stem of larch (*Larix sibirica* Ledeb.) from the Polar Urals. **22-43C** 66°49.07'N 65°33.94' E, 269 m.a.s.l., 1170-1412 CE. As sampling approaches the root the variation of ring-width measured along radii in different directions increases considerably.



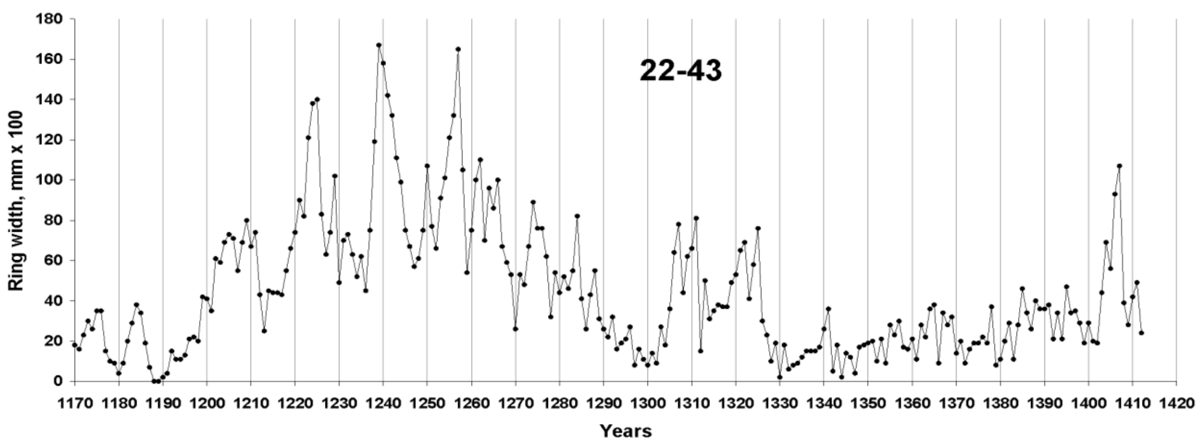


Figure PU08 – Polar Urals TRW tree indices (red are update samples from roots, blue are update samples from stems, green are original sub-fossil samples from stem, black are original sub-fossil samples from root, and cyan are the living-tree samples). Indices created with one-curve, signal-free RCS using all samples (Pou_la and Polurula). Each index series was replaced by its mean, a horizontal line (a) or smoothed with a 100-year spline (b). Total sample counts (grey shading) and the standard deviation of the mean value for each year are shown in (c). The larger values created by extreme values of root measurements show clearly anomalous periods in the 11th and 15th to 16th centuries. Ring growth in the root is frequently not circular and root-collar samples can be very variable (large or small rings) but tend to be larger for samples selected for MXD measurement. The high standard deviations, coupled with low sample counts, indicate large error levels in the 10th to 11th and 15th to 16th centuries for a chronology built using all of the Pou_la and Polurula samples.

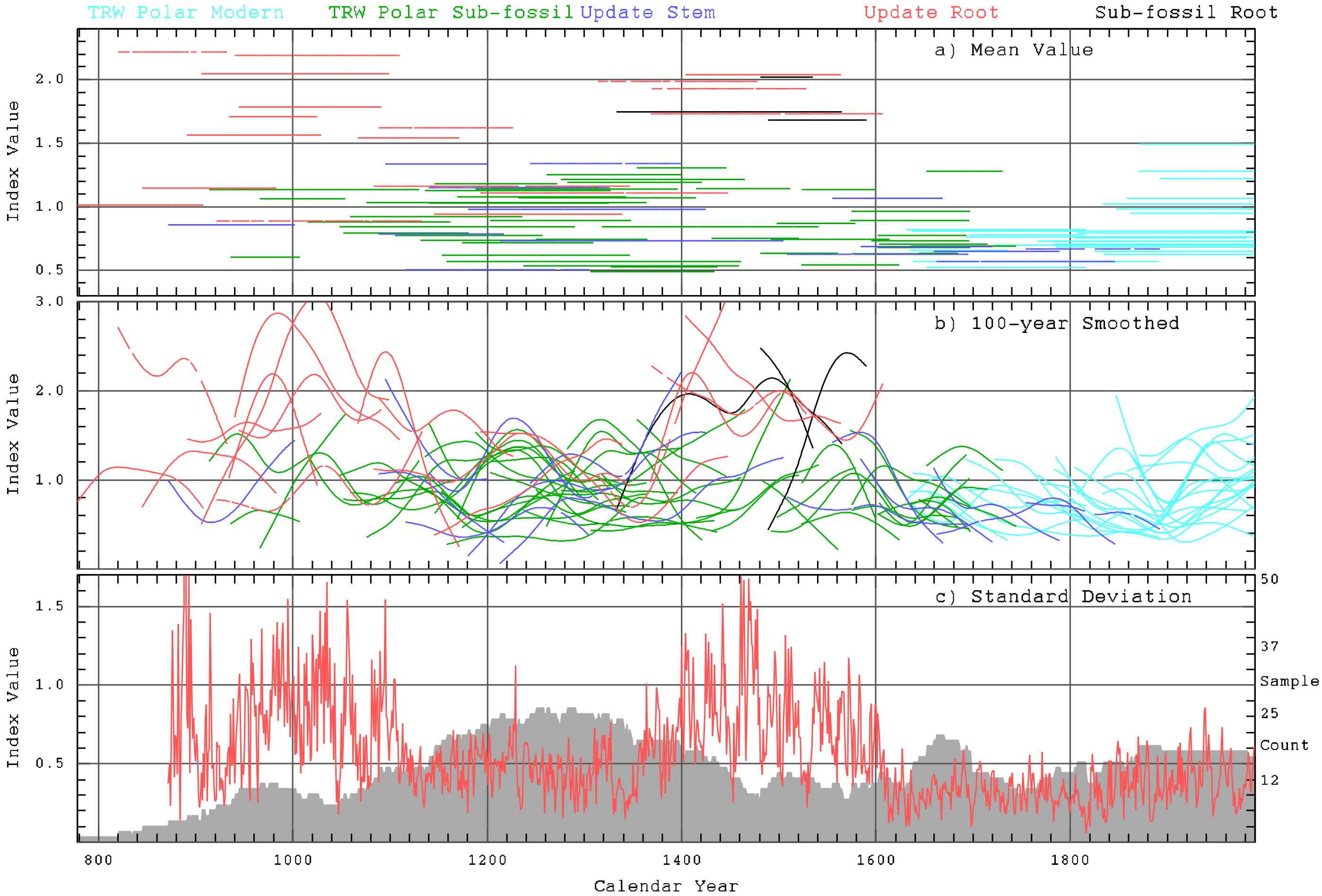
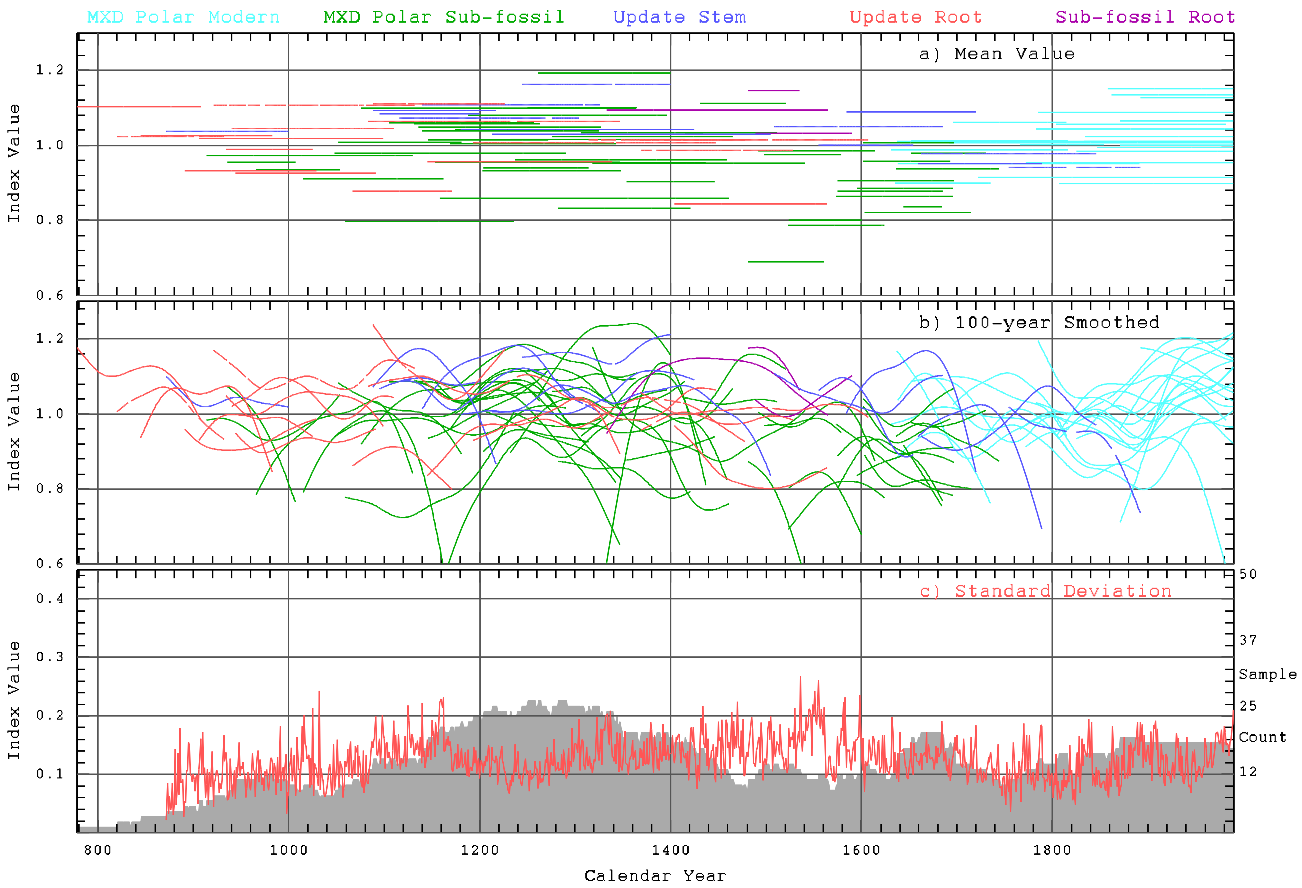


Figure PU09 Polar Urals MXD tree indices (red are update samples from roots, blue are update samples from stems, green are original sub-fossil samples from stem, black are original sub-fossil samples from root, and cyan are the living-tree samples). Indices created with one-curve, signal-free RCS using all samples (Pou_la and Polurula). Each index series was replaced by its mean, a horizontal line (a) or smoothed with a 100-year spline (b). The standard deviation for each year of the RCS chronology is shown in the lower figure. The values of root-collar samples are not noticeably different from those from the tree bole and the standard deviations are not unusual in those periods with larger counts of samples from root-collars.



PU4 Additional larch data

Figure P10 – This Figure is based on Polar Urals TRW data sets contained in separate files (Pou_la_mod, Pou_la_stem, Polustem, Purlasim, Purlasi_scm and Russ001). Firstly the data sets were standardised using 100-year spline, signal-free standardisation. The chronologies are shown in (a) which demonstrates a clear, common high-frequency signal. These were smoothed with a 10-year low-pass spline (b) to demonstrate the clear common, medium-frequency signal. The measurements from all of these sites were combined and processed together using one-curve, signal-free RCS. The mean values of tree indices for each site are plotted in (c). These were smoothed with a 10-year low-pass spline (d). The low-frequency chronologies are less coherent than the 100-year spline chronologies but still demonstrate a common low-frequency signal.

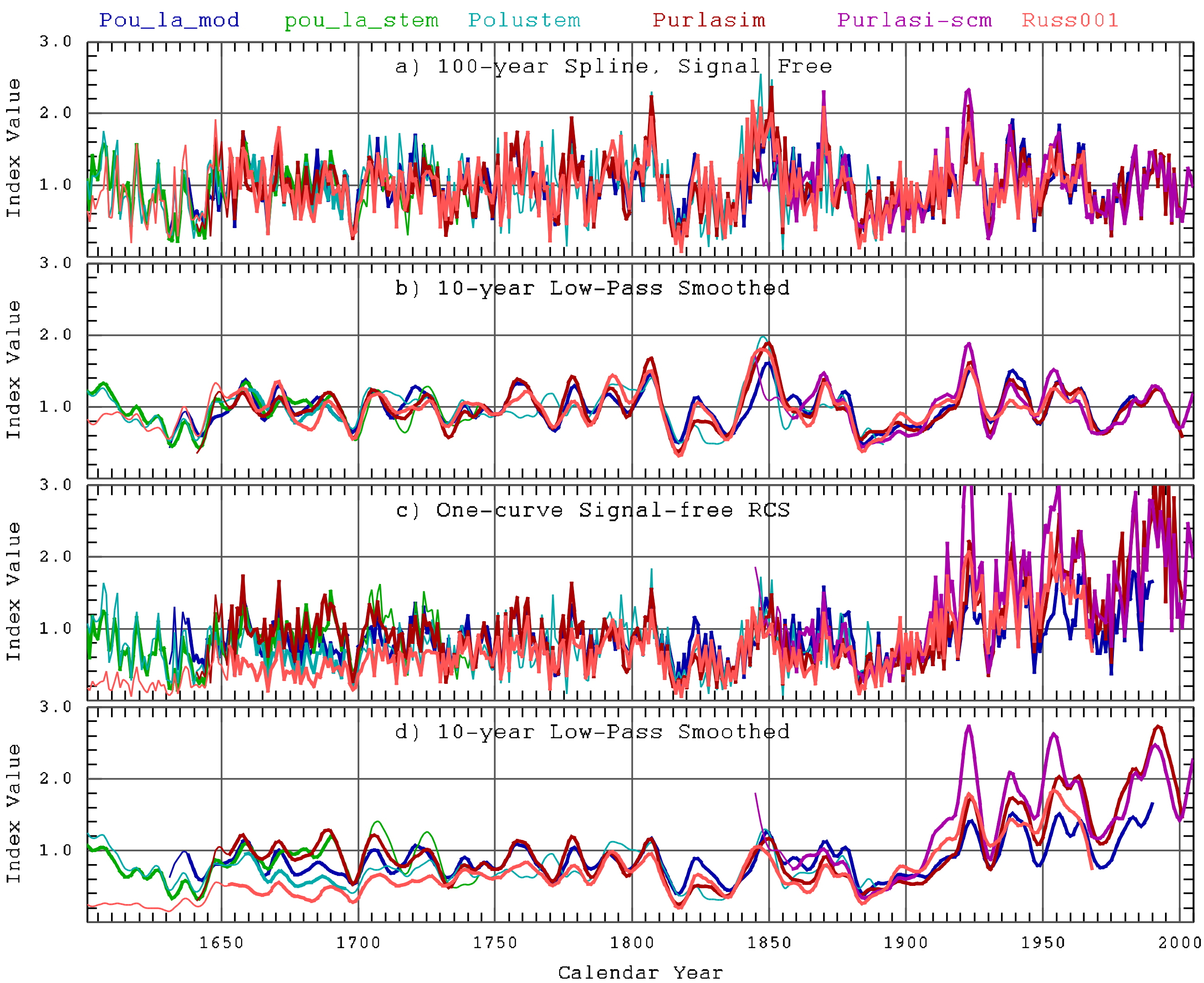


Figure PU11 – Chronologies constructed using adjusted MXD data from the Polar Urals (Pou_la_modadj.mxd, Pou_la_stem.mxd, Polurulaxadj.mxd and Purlaaxadj.mxd). Chronologies of the means of tree indices are shown separately for the averages of the "original" sub-fossil (green), the "update" sub-fossil (cyan), the original modern data (blue), and the additional modern data collections (brown and purple). The chronologies are constructed using all data and: (a) and (b) 100-year high-pass spline, signal-free standardisation; and (c) and (d) one-curve, signal-free RCS. Chronologies (b) and (d) were smoothed with a 10-year spline. Thin lines are used where tree counts are less than four. The low-frequency chronologies are less coherent than the 100-year spline chronologies but still demonstrate a common low-frequency signal.

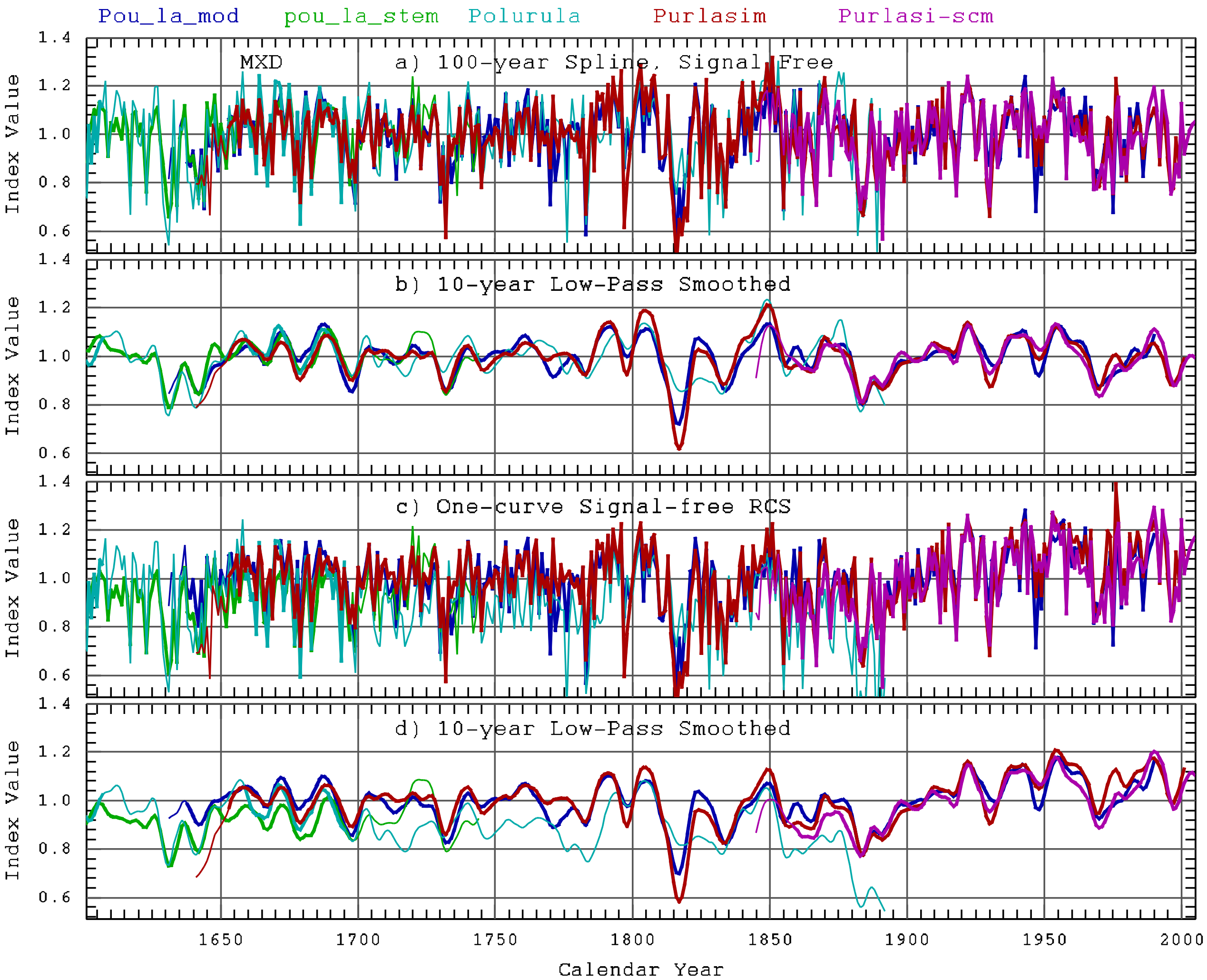


Figure PU12 – The RCS curves for each site (mean of signal-free measurements by ring age smoothed using an age related spline) are plotted for trees standardised using signal-free RCS using separate sites (a), one-curve RCS for all trees (b), and two-curve RCS for all trees (c). Thin lines show <4 trees. The RCS curves generated for separate chronologies show the relative growth rates of trees at each site, with Purlasim trees apparently the fastest growing. When using one-curve or two-curve RCS, the Purlasim signal-free RCS curve does not appear anomalous because of the removal of the common signal, which was large in the 20th century when most of the Purlasim rings grew.

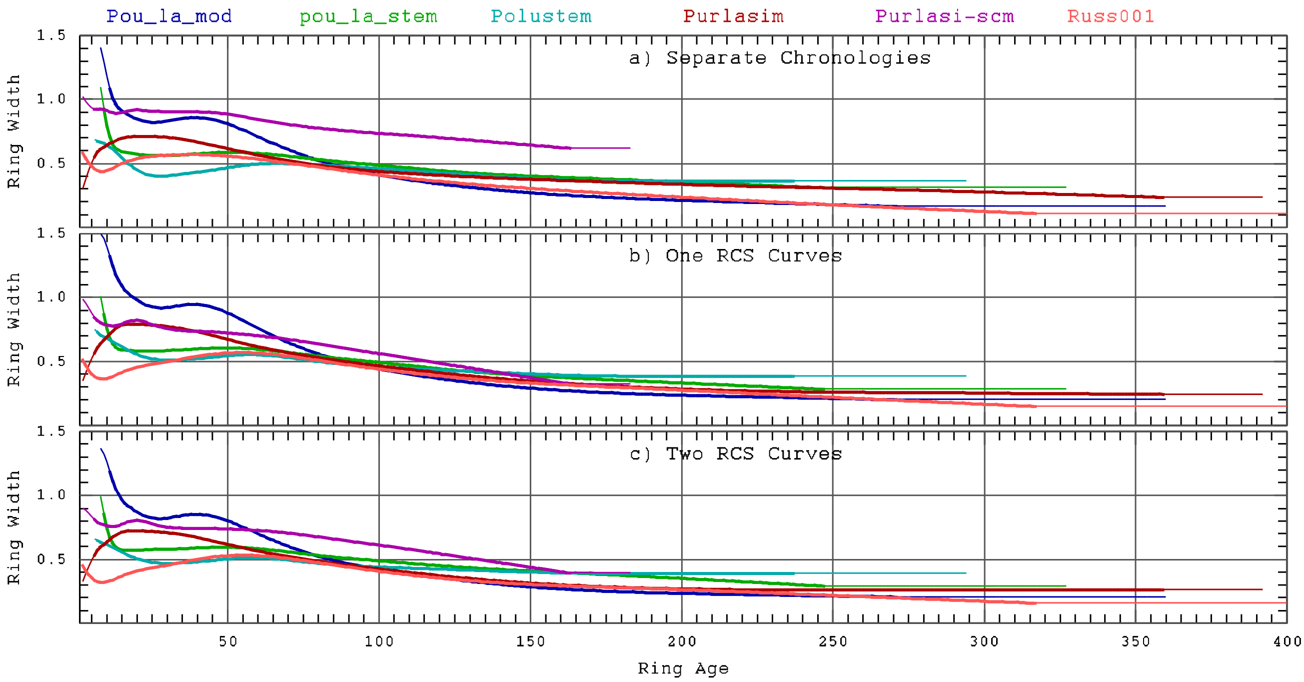
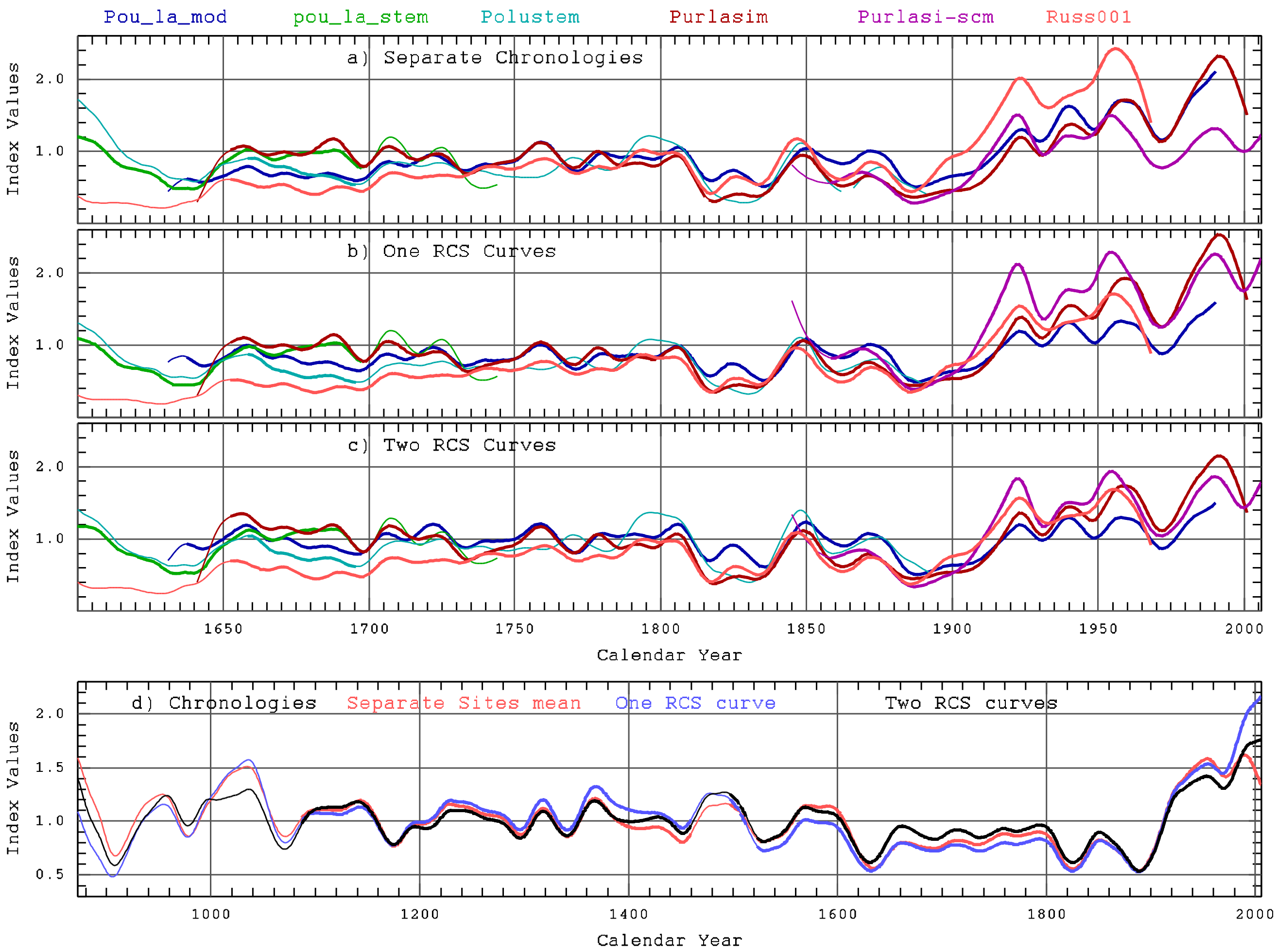


Figure PU13 – The chronologies for each site are plotted for trees standardised using signal-free RCS on each separate site (a), using one-curve RCS for all trees (b), and using two-curve RCS for all trees (c). Thin lines show <4 trees. The separate chronologies show the relative growth rates of trees at each site, with Russ001 trees showing slower initial growth and faster later growth relative to the other sites. When using one-curve or two-curve RCS, the early (pre 1750) parts of the Russ001 chronology are lower than the other chronologies while the later parts are similar.



Note that the data for Russ001 (for which there are only TRW) are not included in the current Polar Urals TRW chronology. They are samples from living trees which finish in 1969 and pith-offset data was not available for them. However they are included in Figures 11 to 13 to demonstrate their compatibility with the other Polar Urals TRW data shown above.

Figure PU14 – The sub-sample RCS curves of the Polar Urals MXD data (mean of signal-free measurements by ring age smoothed using an age related spline) are plotted for different RCS applications: using signal-free RCS separately applied to the data for each site (a), standardising all data using the same RCS curve derived from all trees (b), and using two-curve RCS for all trees (c). Thin lines show <4 trees. The sub-sample RCS curves show the relative density of trees at each site, with Pou_la_mod trees having higher density at young ring ages and lower density at old ring ages relative to the other site data sets. Using one-curve or two-curve RCS does not change this situation.

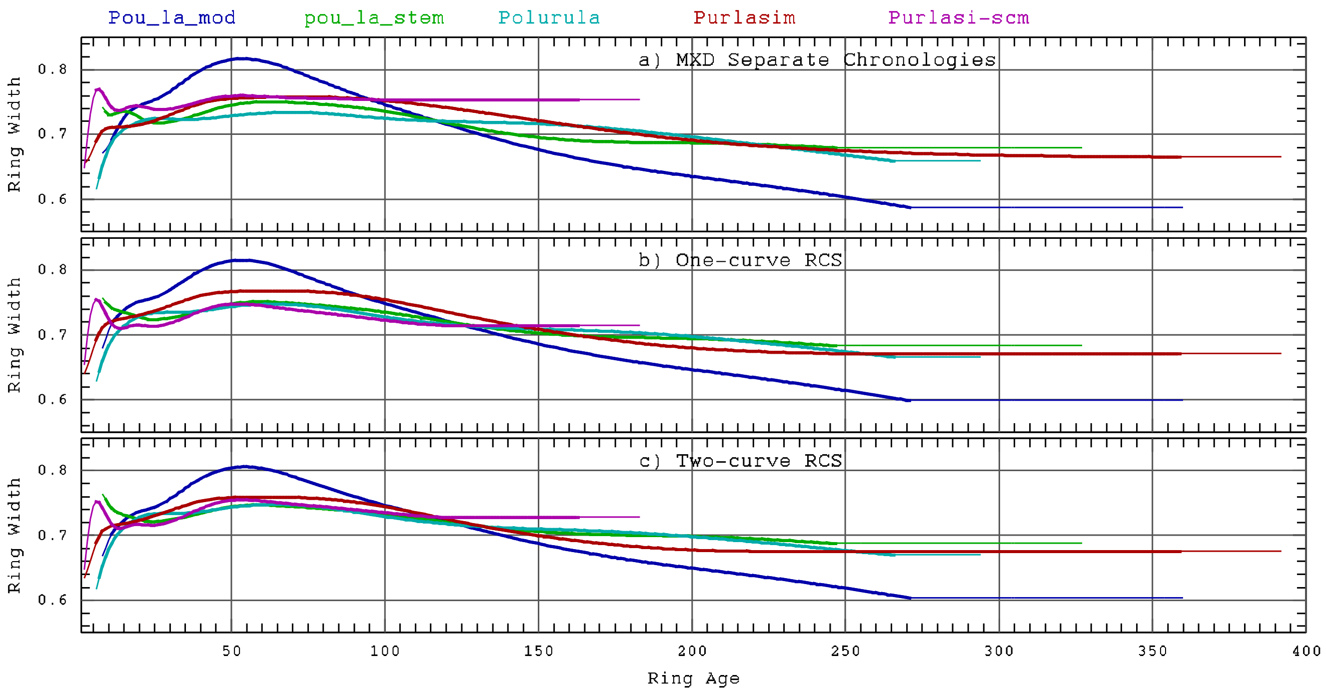


Figure PU15 – The MXD chronologies for each Polar Urals site are plotted for trees standardised using signal-free RCS on each separate site data set (a), using one-curve RCS for all Polar Urals MXD data (b), and using two-curve RCS for all Polar Urals MXD data (c). Thin lines show <4 trees. The separate MXD chronologies show similar low-frequency variance where sample counts are relatively high.

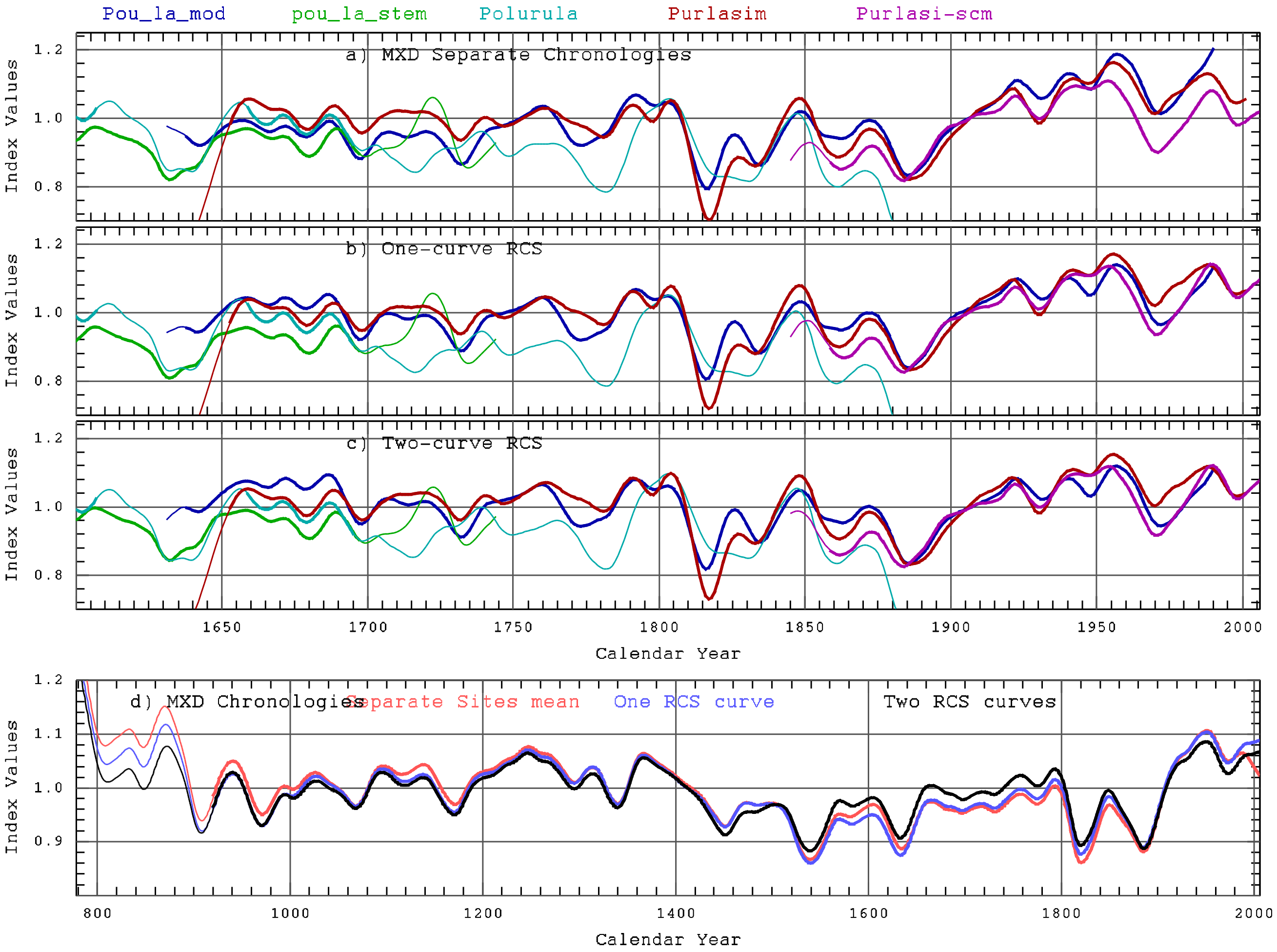


Figure PU16 The “Pou_la_mod.mxd” data have a distinctly differently shaped RCS curve to those of the other groups of Polar Urals trees (See Figure PU14, blue curve). Here, the “pou_la_mod” data are standardised as a single site dataset, with its own RCS curve (red). The other four Polar Ural sub-groups were combined and standardised using two-curve RCS. The count-weighted average of these separately standardised chronologies (pou_la_mod and others) is shown in black. All five sites were also combined and standardised using two-curve RCS (blue). Much of the difference will be due to modern sample bias where one-curve RCS is used (there are a few high-density, young trees in the “pou_la-mod” samples - see PU09). The use of two-curve RCS, applied to the Polar Urals dataset, mitigates the modern sample bias and so there is no requirement to process the Pou_la_mod.mxd data separately.