Notes towards an optimal sampling strategy in dendroclimatology

Running title: Sampling strategies

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ABSTRACT

Though the extraction of increment cores is common practice in tree-ring research, there is no standard for the number of samples per tree, or trees per site needed to accurately describe the common growth pattern of a discrete population of trees over space and time. Tree-ring chronologies composed of living, subfossil and archaeological material often combine an uneven distribution of increment cores and disc samples. The effects of taking one or two cores per tree, or even the inclusion of measured radii from entire discs, on chronology development and quality remain unreported. Here, we present four new larch (*Larix cajanderi* Mayr) ring width chronologies from the same 20 trees in northeastern Siberia that have been independently developed using different combinations of core and disc samples. Our experiment reveals: i) sawing is much faster than coring, with the later not always hitting the pith; ii) the disc-based chronology contains less missing rings, extends further back in time and exhibits more growth coherency; iii) although the sampling design has little impact on the overall chronology behaviour, lower frequency information is more robustly obtained from the disc measurements that also tend to reflect a slightly stronger temperature signal. In quantifying the influence of sampling strategy on the quality of tree-ring width chronologies and their suitability for climate reconstructions, this study provides useful insights for optimizing fieldwork campaigns, as well as developing composite chronologies from different wood sources.

Keywords: Sampling design; disc samples; increment cores; climate signal; northeastern Siberia; missing rings

1. Introduction

Despite the near centennial-long tradition of our discipline (Douglass, 1928), and great advancements in between (Schulman, 1937; Fritts, 1976; Schweingruber, 1996), a common sampling strategy for dendrochronology does not exist. While this is partly related to the coexistence of different schools (mainly in Europe and the USA) and subdisciplines (including archaeology, biology, climatology, ecology and forestry), fieldwork is ideally adapted to fulfil project-specific requirements ranging from simple dating of artefacts and structures, to the more complex reconstruction of climate and estimation of biomass. Moreover, each sampling design represents a compromise between the 'more is always better', and the 'practicalities' related to logistics, permissions and resources allocated to a specific project. Disregarding some rules of thumb, there is still disagreement about the pros and cons of extracting one or more cores per tree, or even collecting disc samples, let alone the number of trees needed to develop a robust chronology. Moreover, as tree-ring evidence has become increasing influential in the climate change debate, the judgement, experience and skill of individual researchers is often critically questioned from outside the discipline (Mann et al., 2012).

Here, we address these issues by independently developing four ring width chronologies from the same 20 conifers growing in northeastern Siberia. Each step, from fieldwork, through sample preparation and chronology development, to the assessment of common growth variability and climate sensitivity, has been analysed with regard to the value obtained and the effort spent.

2. Material and methods

The study site is located within the forest-tundra ecotone in northeastern Siberia at 70°01'N, 147°35'E and 18 m a.s.l. (Fig. 1a). Annual mean temperature is -13.7° C, with the coldest and warmest months exhibiting -34.2° C in January to 9.7° C in July. Annual precipitation totals are 204 mm, of which 40% are falling between June and August (based on meteorological station readings from 1945-2016 in Chokurdakh; Yakutia). Cajander larch (*Larix cajanderi* Mayr) is the main forest species in this permafrost region (Abaimov, 2010), where the exceptionally low radial growth is predominantly controlled by summer temperatures (Briffa et al., 1998; Esper et al., 2010; Hellmann et al., 2016; Hughes et al., 1999; Vaganov et al., 1996).

Sampling of an undisturbed, uneven-aged Cajander larch stand on the first terrace of the Indigirka River was conducted in late July 2016 (Fig. 1a). Two 5 mm increment cores (A and B) were taken perpendicular to each other, at approximately 1.0-1.3 m stem height, from 20 healthy dominant trees, before the trees were felled to collect discs from the same stem positions. The core samples A1-20 and B1-20, as well as the disc samples D1-20, were independently processed by experienced dendrochronologists at three laboratories in Brno, Cambridge and Krasnoyarsk (Czech Republic, UK and Russia).

In Cambridge all cores were mounted and polished with sand paper of progressively finer grain size down to 800 grit and the A cores, without the benefit of the B cores, were then measured on a Velmex Tree Ring Measuring System with a resolution of 0.001 mm (Velmex Inc., Bloomfield, NY, USA). The re-sanded A cores and the undated B cores were then sent to Brno where the composite collection of cores, A and B were independently measured on a TimeTable device with a resolution of 0.01 mm (VIAS/SCIEM, Vienna/Brunn am Gebirge, Austria). Unlike in Cambridge the Brno operator had the advantage of having two cores from the same tree to aid the dating of all cores. The disc samples were exclusively processed and measured in Krasnoyarsk on a LINTAB measuring system (RINNTECH e.K., Heidelberg, Germany). In Krasnoyarsk the operator was permitted to select two ‘ideal’ radii for measurement, those without any obvious signs of disturbance, reaction wood, and zones of exceptionally supressed growth. Cross-dating was carried out at all three laboratories independently using the TSAP-win (Rinn, 2003), PAST4 (Knibbe, 2004) and verified with COFECHA (Version 6.02P; http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software) software.

Negative exponential functions and bi-weight robust means were used to produce a chronology from all the A cores (Core-A), the two per tree combination A and B (Core-AB), another single series chronology from just the B cores (Core-B), and all the Disc measurements (Disk) using ARSTAN (Version 44h3; http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software). Moving-window, inter-series correlation coefficients (Rbar) and the Expressed Population Signal (EPS; Wigley et al., 1984) are used to characterize each of the four chronology's performance on inter-annual to multi-centennial time-scales. To assess the climate sensitivity of the four chronologies between 1950 and 2015, monthly mean temperatures were extracted from the nearest, high-resolution CRU TS4.01 grid point (Harris et al., 2014).

3. Results

A total of 40 continuous ring width measurement tracks from the pith to bark were obtained from the disc samples D1-20 (Table 1; Fig. 1b). However, the A core from tree N107, could not be measured either in Cambridge or Brno, due to the large number of excessively narrow growth rings and the abundance of missing rings throughout most of the core. The Core-A chronology is 510 years long and covers the period 1506-2015, whereas the Core-B chronology is slightly shorter (1521-2015). The Disk chronology spans 518 years between 1499 and 2016 (Table 1). It should be noted that in the outer portions of all samples, the core-based chronologies suffer from declining sample replication towards the present due to a large degree of suppressed growth. Moreover, the first 30 years of the Core-A chronology is represented by one series (Fig. 1b). The mean segment length (MSL) of the 40 disc-based measurement series is 396 years, whereas the MSL of the 19 sample Core-A, and 20 sample Core-B chronologies is 52 and 29 years shorter, respectively.

The mean sensitivity of all four chronologies is statistically similar, ranging between 0.334 and 0.343, and demonstrating a high level of inter-annual variability (Table 1). Though all four chronologies reveal a sufficient amount of internal growth coherency (Table 1), the Rbar and EPS values of 0.377 and 0.908 are substantially lower for the Core-A chronology compared to the 0.427 and 0.960 of the Disk chronology (Fig. 1c, d).

The mean annual growth rates of all 20 trees are extremely low, varying between 0.17 and 0.18 mm, depending on the dataset (Fig. 2a). The year-to-year and longer-term fluctuations in both, the raw and standardized chronologies, are particularly similar when sample size exceeds four series in 1589 (Fig. 2a, b), which is also confirmed by the high moving inter-series correlations between the standard chronologies calculated over 30-year-long periods (Fig. 2b insert).

Of the total number of rings dated and measured, the Core-B dataset contains with 0.92% the highest proportion of missing rings (63 out of 6877), followed by the Core-A and Core-AB collection with 0.90% (63 of 6975) and 0.85% (115 of 13593), respectively (Fig. 2c). The lowest number of missing rings is found in the Disk dataset (0.51%, 81 of 15845). Missing rings were identified in 33 of the 39 core measurement series, and only in 18 of the 40 disc-radii. Up to 80% of the Core-A cores are missing the ring formed in 1680, 67% of the Core-B cores are missing 1580, 43% of the combined AB Cores are missing 1580, and only 25% of the dated radii from the Disk collection are missing the ring formed in 1801 (Fig. 2c). The maximal number of detected missing rings in a single core is 11 out of 427 (2.6% in the B core of tree N113). The overall number of years with missing rings per dataset ranges from 25-32.

The growth-climate response analysis reveals statistically significant positive correlation coefficients (r >0.6) between mean June temperatures and all four chronologies (Fig. 3). Relationships with all other monthly means, including previous autumn and winter conditions, are insignificant. Spatial field correlation coefficients of the Disk chronology indicate a high degree of explained June temperature variability from around 130-160° E and between 75-65° N.

4. Discussion and conclusions

Owing to the restricted region and species for which these results apply, we admit our findings cannot be arbitrarily extrapolated to all habitats. At the same time, this study emphasizes the immense value of having both, a high quality and quantity of individual tree-ring measurements. Although we are well aware that felling trees is not always possible and never desirable, for the relatively small trees in northeastern Siberia it is much faster than extracting cores, and time is a critical constraint for fieldwork in remote regions where logistics are not only challenging but also extremely expensive. Another advantage of discs is the certain presence of the pith, which is not always obtained when coring. Although some of the trees in our study were more than 500 years old, their stem diameter was less than 18 cm, which certainly facilitated getting close or even hitting the pith. However, the first decades of the core-based chronologies are less-well replicated than the disc-based chronology, which translates into an overall improved signal strength of the disk chronology. Avoiding the need for pith offset estimates further improves the application of composite detrending techniques (Esper et al., 2003). Another advantage of disc versus core samples is the opportunity to measure radial paths that circumvent compression wood and other anatomical features that would complicate cross-dating and obfuscate the detection of an optimal, climate-induced common growth behaviour. The extraction of two instead of one core per tree represents a fair compromise for retaining chronology quality, though requires more labour, both in the field (coring instead of felling) and laboratory (detecting missing rings). In fact, at least 77.5%. of all of the measured cores exhibit missing rings, whereas less than half of the measured disc radii contain missing rings. In addition to the higher tendency of missing the pith and more missing rings, the outmost part of some core samples could not be measured due to suppressed growth. Compared to the core-based records, the disc-based chronology yields an almost 25% longer June temperature reconstruction with an overall stronger signal-to-noise ratio.

In defence of collecting disc samples, we acknowledge they do provide the opportunity for additional studies that use bulk measures of wood material in destructive experiments including state-of-the-art wood anatomical and biogeochemical measurements, high-resolution, intra- and inter-annual density profiles, and isotopic ratios. Archived disc samples can also become a valuable resource for future generations with yet unknown – research questions, approaches and techniques, as well as providing material for international collaborations. However, compared to cores, the larger weight and size of disc samples is a disadvantage, both for transportation and storage, and it is obviously difficult to justify felling a *methuselah* for a single experiment.

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Author contributions

UB initiated and coordinated the study. AVK, AP, TK and MR measured the data, and AVK performed the analyses with input from UB and PJK. AVK wrote the paper together with UB and PJK. All authors provided critical discussion.

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Table 1. Chronology characteristics (MSL = mean segment length, MS = missing rings).

Series ID	N of series	Period	MSL, years	Mean sensitivity	Mean Rbar	Mean EPS	First year EPS>0.85/ N of series	Portion of MS
Core-A	19	1506-2016	367	0.343	0.377	0.908	1653/9	0.903
Core-B	20	1521-2015	344	0.338	0.416	0.918	1666/8	0.916
Core-AB	39	1506-2015	349	0.334	0.413	0.954	1628/11	0.845
Disc	40	1499-2016	396	0.336	0.427	0.960	1544/6	0.511

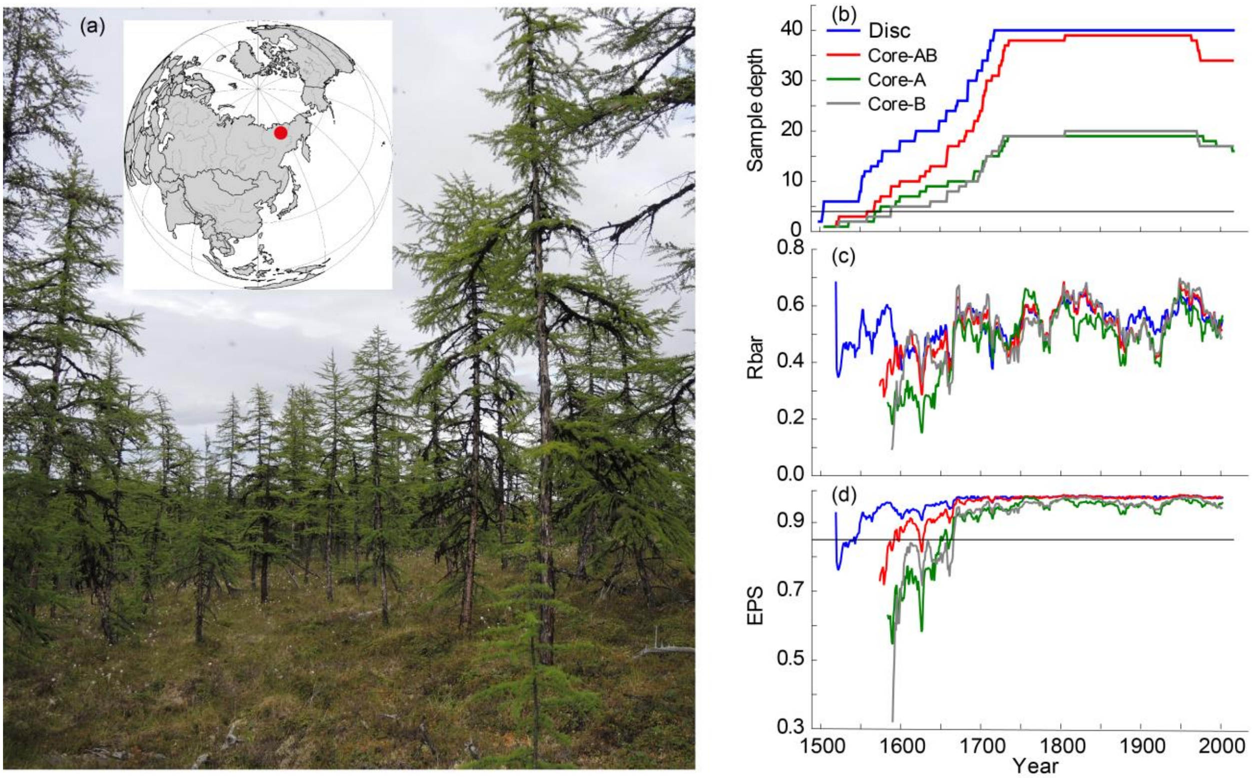
Note: Mean EPS was calculated as an average for 30-year periods shifted by 1 year when sampling depth ≥4.

Figure Captions

Fig. 1. (**a**) Photo of site with insert showing the location (red dot), (**b**) Temporal evolution of sample size in the four datasets, with the horizontal line indicating replication ≥4 series. 30-year moving (**c**) inters-series correlation coefficients (Rbar) and (**d**) EPS of the four chronologies, with the horizontal line corresponding an EPS of 0.85.

Fig. 2. (**a**) Raw and (**b**) standard chronologies of the four datasets, with the vertical lines highlighting the years in which sample size is ≥4 series, and the inset showing 30-year moving inter-series correlation coefficients of the four standard chronologies. (**c**) Percentage of missing rings in each of the four chronologies.

Fig. 3. Correlation coefficients of the four standard chronologies and monthly mean temperatures from previous year September to September of ring formation, calculated over 1950-2015. Correlation maps reveal the spatial domain of explained variability by those chronologies that capture the strongest (Disc) June temperature signal (*r* = 0.64).



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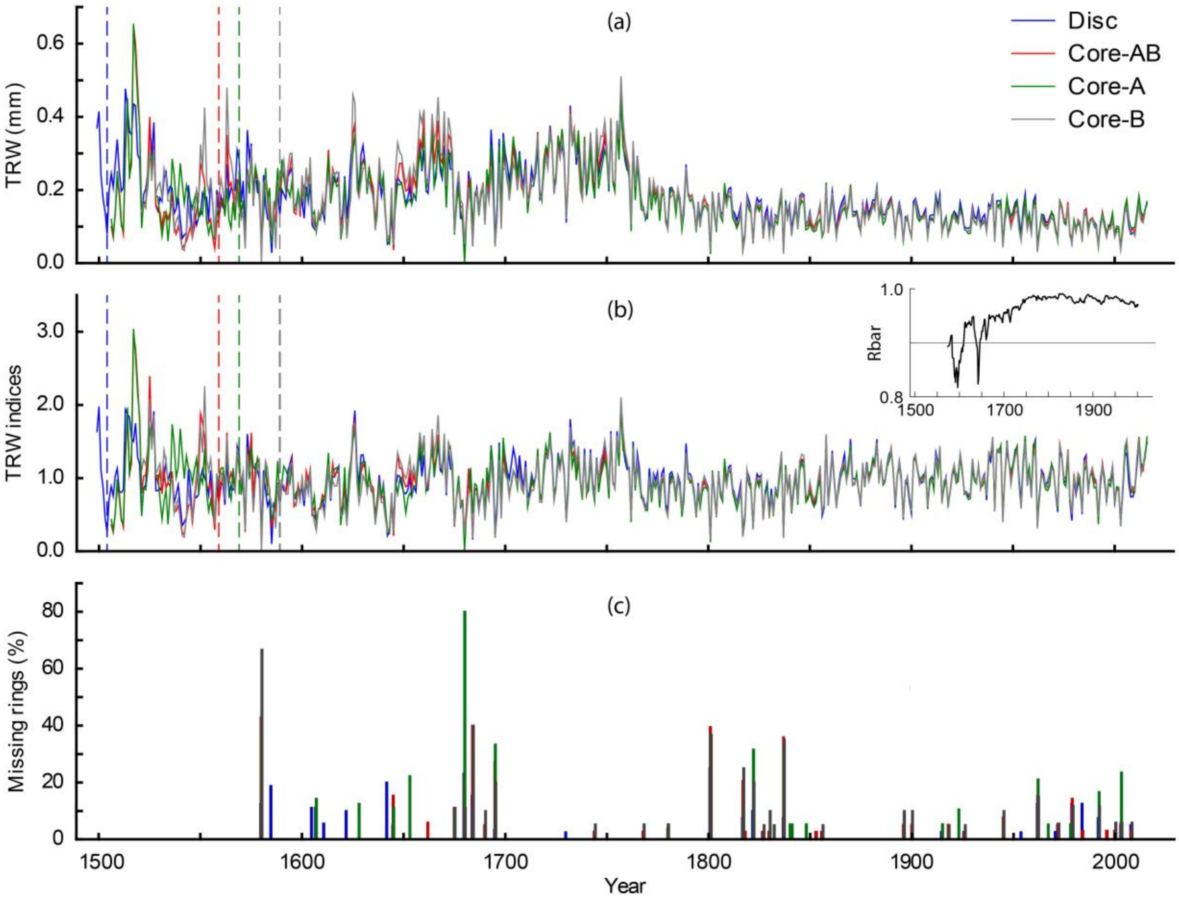

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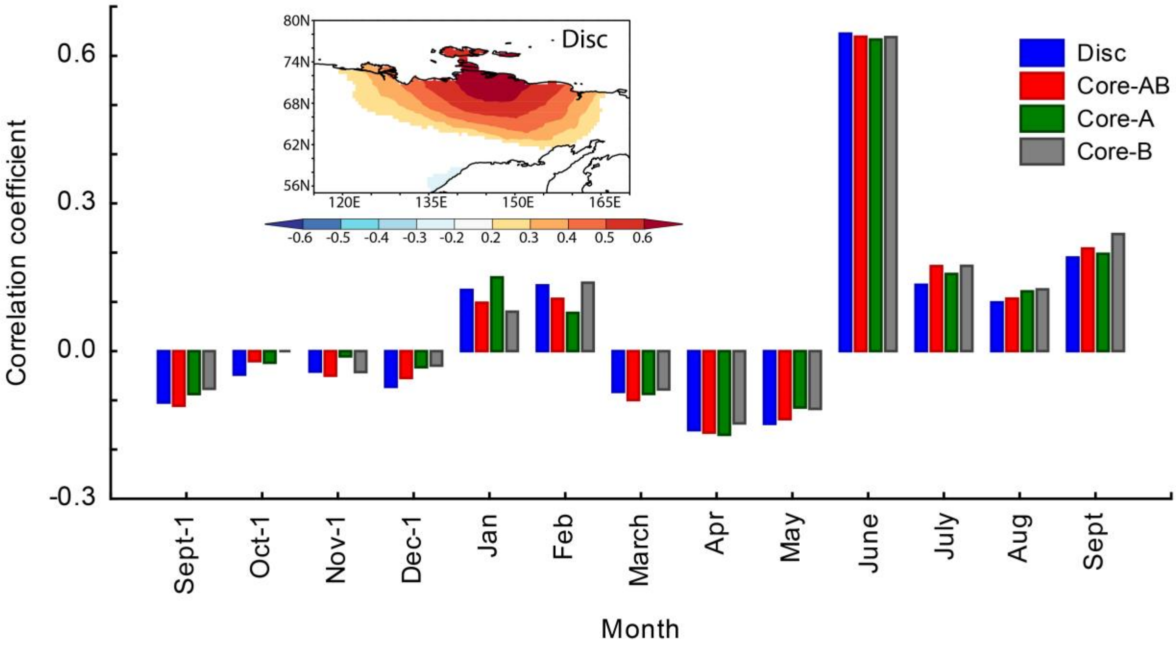

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