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Early nineteenth century drought in east central Sweden inferred from dendrochronological and historical archives

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ABSTRACT: Scots pine tree-ring width data and entries from a farmer's diary were combined to assess early nineteenth century drought in east central Sweden. Tree-ring data were used to reconstruct drought, in the form of the standardized precipitation index (SPI), back to 1750. Daily weather observations in the farmer's diary were translated to temperature and degree of drought for each growing season from 1815 to 1833. During this period, Scots pine growth was constantly below average, and radial growth in 89% of the years between 1806 and 1832 indicated dry summers. Within the same period, severe drought was reported in the diary during several years. Although individual summers have been drier before and after this period, the record suggests that 1806 to 1835 was the longest continuous drought in the last 250 yr, possibly even the last 300 yr. Furthermore, this event seems to have been of regional extent, as indicated by meteorological, historical and tree-ring data from northern and central Europe. The present study showed that a combination of dendrochronological and historical records yields more useful information about past droughts, in terms of impact and long-term context, than one or the other of these sources can provide alone.

KEY WORDS: Early nineteenth-century drought · Tree-ring data · Farmer's diary

1. INTRODUCTION

Multi-century temperature reconstructions have increased our understanding of past climate variability and set twentieth century warming in a historical context. This is a necessity when assessing the anthropogenic impact on climate and modeling future climate scenarios (Mann & Jones 2003). However, there is still a great need to gather high-resolution precipitation data since precipitation changes are expected to accompany increasing temperatures. Indeed, precipitation over northern Europe has increased by 10 to 40% in the twentieth century (IPCC 2001). In Scandinavia, changes in the precipitation pattern have become evident over the past few decades (Hanssen-Bauer & Førland 1998), changes that will likely have considerable impacts on marine and terrestrial ecosystems (Crawford 2000). However, in Scandinavia most precipitation increase related to climate change is not expected during summer; climate simulations indicate considerably drier summers in the future (Swedish Regional Climate Modelling Programme, SWECLIM; www.smhi.se/sweclim/). In southern Sweden, short periods of drought usually occur in connection with blocking high pressures in spring and early summer, but if high temperatures and low precipitation prevail, they may extend well into late summer.

Summer droughts can have devastating impacts on the natural environment by reducing water availability and by increasing pollution levels, which may affect human health (IPCC 2001). Agriculture and water sup-

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ply are 2 economic sectors that may be most severely affected by exceptional summer heat and drought. An increased frequency of hot, dry summers is likely to reduce tree growth and thus affect timber yield and quality. Reduced tree vigor may favor outbreaks of pathogens, and hot and dry conditions can trigger forest fires. To set the expected changes into a longer-term context, we need to know about past precipitation/drought variability, and in order to reach beyond the meteorological observations, climate proxies such as tree rings and historical records must be used.

The annual growth of trees living close to their limit of distribution respond to climate variability with changes in their tree-ring pattern and hence provide annually resolved climate information. Trees growing at high altitudes or latitudes, where the growing season is short and cool, may provide temperature information, whereas trees growing in arid or semi-arid regions may provide information about precipitation and/or drought. Because of large spatial coverage and high-resolution climate output, tree-ring data is a widely used climate proxy. For instance, most recent high-resolution reconstructions of hemispheric or global temperatures have included tree-ring data (see Briffa et al. 2004). In addition, a large number of assessments of past precipitation and/or drought variability on local to regional scales have been made using tree-ring data (e.g. Yuan et al. 2001, Ni et al. 2002, Touchan et al. 2003). However, these have been based on trees from arid environments.

Due to the high-latitude location of Sweden, the yearly growth of conifers in large parts of the country reflects summer temperatures (e.g. Grudd et al. 2002, Gunnarson & Linderholm 2002), but in the southern parts the influence of precipitation increases (Linderholm et al. 2002). However, the climate in Sweden will never approach that of arid or semi-arid areas (because of its proximity to the North Atlantic Ocean and its high latitude), so the precipitation signal in tree-ring data from southern Sweden will not be as strong as the temperature signal in tree rings from northern Sweden. This has previously been highlighted in an analysis of the relationship between Scots pine growth and temperature/precipitation in Tyresta National Park, east central Sweden (Linderholm et al. 2004). These authors showed that, in general, May-June precipitation had a dominating (positive, R = 0.43) influence on pine growth, but that June-July temperatures also influenced (negative, R = –0.30) growth (Linderholm et al. 2004). This is due to the fact that pine growth in this area is influenced by both early summer precipitation and temperature. It would be difficult to reconstruct one of these parameters alone, but since it has been shown that narrow Scots pine tree rings generally were formed in dry and warm years, tree-ring data from this area may yield useful information on past summer drought.

Historical climate records, such as diaries, rarely span long coherent periods as other climate proxies do, but, despite small uncertainties in time and place, they are valuable complements to paleoclimatological studies (Pfister 1995). More importantly, they give a unique insight into the impact of climate events on humans. Internationally, historical records have been used in climate research for decades (e.g. Lamb 1977, Glaser et al. 1999, Pfister et al. 1999a, Shabalova & van Engelen 2003). Documentary climate information may contain direct weather observations or indirect observations, such as descriptions of parameteororological phenomena (drought, forest fires etc.) and phenological data (e.g. Pfister et al. 1999a). Daily weather records, in the form of diaries or notebooks, are especially useful sources of information for reconstruction of climate (Pfister et al. 1999b, Nordli 2001, Brazdil et al. 2003, Slonosky 2003). In Sweden, few studies of past climates have utilized documentary evidence (Retsö 2002, Molin 2003), despite the existence of a wealth of historical sources, which may provide useful climate information.

Ideally, the combination of several historical and natural climate archives could provide an excellent opportunity to reconstruct, as well as assess, impacts of past climate variability. In the present study, we analyze 2 independent climate proxies, dendrochronological and historical records, to evaluate summer drought in east central Sweden in the early nineteenth century. Tree-ring data of Scots pine *Pinus sylvestris* L. from Tyresta National Park are used to attempt to reconstruct summer drought for the last 250 yr, and daily entries about the weather in a farmer's diary from Smådalarö, close to Tyresta, are used to interpret summer drought in 1815 to 1833. The drought reconstruction from tree rings provides a long-term perspective on drought variability beyond the records of weather observations, while the diary entries place the early nineteenth century drought in a human context.

2. MATERIALS AND METHODS

2.1. Study area. Tyresta National Park (59° 11′ N, 18° 16′ E) is located ca. 20 km southeast of Stockholm in east central Sweden (Fig. 1). This natural forest lies in an area where flat plateaus of bedrock outcrops and valleys and lakes, oriented in a N–S direction, dominate the irregular landscape. The thin soil layer mainly consists of glacial till, and mires and bogs occupy ca. 10% of the national park. On higher elevations, where soil cover is very thin or even absent, Scots pine forests dominate, while in valleys and on slopes, where

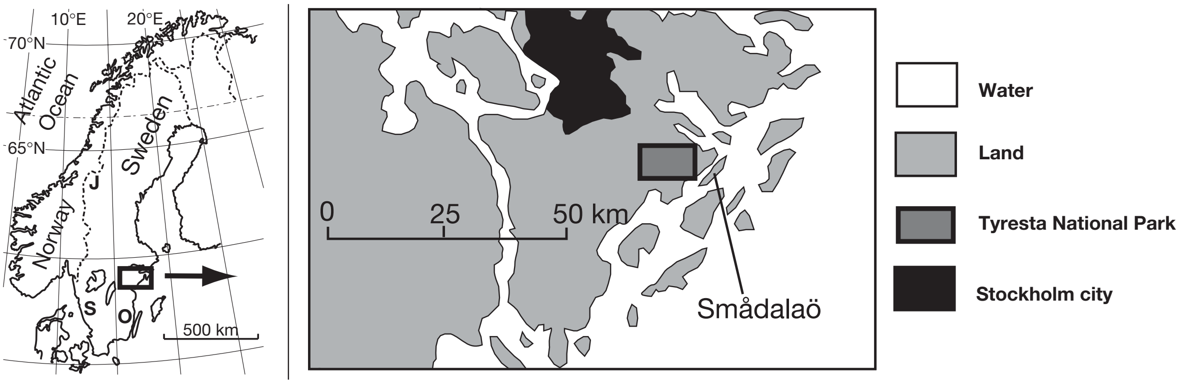


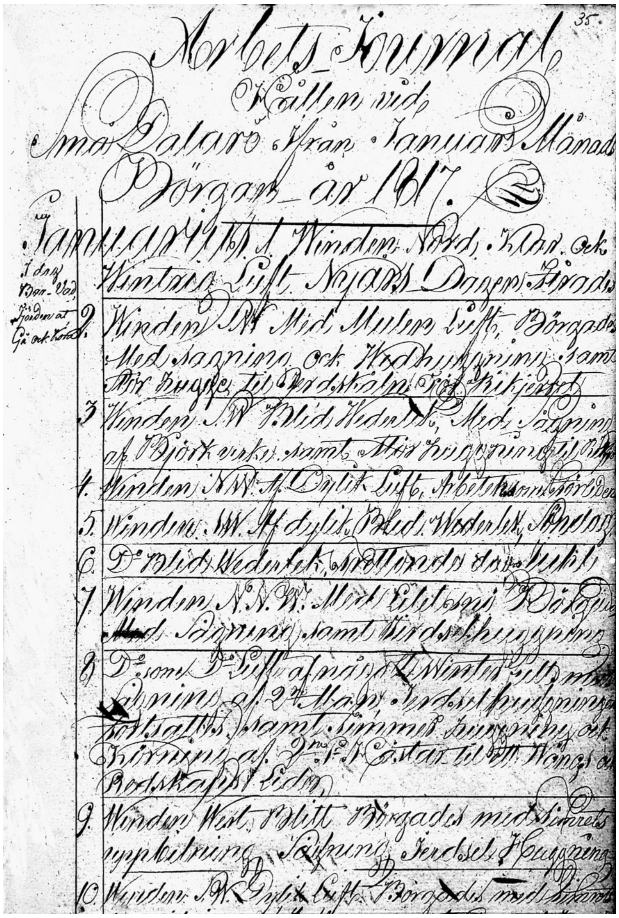
Fig. 1. Map of the study area in east central Sweden. Samples from Scots pines were collected in Tyresta National Park and the farmer's diary comes from Smådalarö, just east of the national park

soils are deeper, Norway spruce is dominant. Mean January and July temperatures at Stockholm, the closest meteorological station with a sufficiently long record, are –2.8 and 17.1°C respectively, and mean annual precipitation is 540 mm (1961–1990, Swedish Meteorological and Hydrological Institute, SMHI).

2.2. Tree-ring data. Two sites for sampling Scots pine tree-ring data were selected, 1 km apart, from open, natural and undisturbed Scots pine stands on the upper part of ridges and rocky outcrops at 55 to 60 m above sea level. One of the basic principles in dendrochronology is that trees growing at their limit of distribution are especially responsive to climate conditions (e.g. Fritts 1976). Since we were interested in a proxy for drought, the sampling sites with an extremely thin or absent soil layer were selected so that the trees were likely subjected to moisture deficit in spring and summer (Linderholm et al. 2004). Two samples from each tree were collected using an increment borer at a height of ca. 1.3 m. Samples were taken from within 50 by 50 m sample plots, including old as well as young trees. The samples were prepared according to the methods described by Stokes & Smiley (1968), and annual tree-ring widths were measured with a precision of 1/100 mm. When synchronous, the 2 measured radii were averaged into 1 tree-ring curve for each tree. All curves were quality checked using COFECHA software (Holmes et al. 1986), which verifies cross dating among tree-ring series and indicates possible dating or measurement problems. Of the sampled trees, 21 were used to build a master chronology for Tyresta. To enhance and extract the climatic signal in the tree-ring data, standardization was performed: the age-associated trend in tree growth was estimated and removed by fitting a negative exponential curve, regression line or, when no age trend was present, a straight line to each tree-ring series and then dividing the ring widths by the fitted curve (Fritts 1976). This procedure reduces each ring-width series to a series of dimensionless indices with a mean of 1.0, which allows the resultant standardized values of individual trees to be averaged together into a mean-value function, or master chronology, by adjusting the series for differential growth rates due to various tree ages and differences in the overall rate of growth (Lindholm 1996). Standardization was performed using ARSTAN software (Holmes et al. 1986). ARSTAN produces a set of master chronologies; in this study, the ARS chronology, which contains maximum low-frequency variability (Holmes et al. 1986), was used.

2.3. Drought indices. To calibrate our drought reconstruction we used monthly drought indices from the standardized precipitation index (SPI), a drought climatology calculated on a 0.5° grid over the European region 35 to 70° N and 35° E to 10° W for the period 1901 to 1999 (Lloyd-Hughes & Saunders 2002). A deficit of precipitation impacts soil moisture, stream flow, reservoir storage, and ground water level, etc., on different time scales. To quantify precipitation deficits on multiple time scales McKee et al. (1993) developed the SPI, the transformation of a precipitation time series into a standardized normal distribution. The SPI is computed by fitting a probability density function to the frequency distribution summed over the time scale of interest, separately for each month and location in space, and then transformed into the standardized normal distribution (Lloyd-Hughes & Saunders 2002). Using SPI, drought is classified from extremely wet ($SPI \geq 2$) to extremely dry ($SPI \leq -2$). We used SPI data for all months of the 1901 to 1999 period for the 0.5° × 0.5° cell centered over latitude 59° 25′and longitude 17° 75′.

2.4. Reconstructing drought. To assess the relationship between Scots pine growth and drought, correlations were computed between annual tree-ring width data (standardized, ARS version) and monthly SPIs. In order to incorporate the effect of drought on tree growth of the previous fall and winter drought as well as conditions during the growth season, the period of analysis covered October of the preceding year to September of the growth year. Correlation analysis was performed over the entire length of the drought climatology (1901 to 1999). In addition, climate in a specific year may affect tree growth in one or more subsequent years (Fritts 1976), so growth of the 2 years following ring formation was included in the analysis. Since annual Scots pine growth is mainly influenced by climate in the growing season, and references to drought in the farmer's diary generally are made during the same season, our aim was to reconstruct June–August drought. To reconstruct drought back in time, a simple regression model was used where the tree-ring data (growth year plus 1 subsequent year) were predictors and averaged June–August drought indices the predictand. The model was initially calibrated using half of the available data, i.e. 1901 to 1949, withholding the remaining data for verification. The procedure was then reversed, calibrating the model on 1950 to 1999 and verifying it on 1901 to 1999. The final model, derived from regression over the full period 1901 to 1999, was used to reconstruct summer drought back to 1750. The end date was decided by the Expressed Population Signal (EPS) criterion (Briffa & Jones 1990), where a chronology is regarded as reliable when EPS >0.85. The Tyresta tree-ring chronology was considered reliable from 1750 onwards, when the sample depth (i.e. number of trees) exceeded 7 trees.



Arbets Journal
Hållen vid
Småa Dalarö ifrån Januari Månads
Början år 1817.

Fig. 2. Extract from the farmer's diary. Entries from January 1817 are shown. Courtesy of National Maritime Museums, Stockholm, Sweden

2.5. The farmer's diary. The farmer's diary from Smådalarö (Fig. 1) was written by Anders Berg (1784 to 1835) between 1814 and 1835. In the diary, Berg describes daily work at the farm, but also makes comments about the weather, e.g. wind, cloudiness, relative temperature and precipitation (Fig. 2). From March 1815 through April 1834 there are almost daily weather observations. Only wind observations are objective (directions), while the other weather observations are subjective. However, weather is strongly related to life at the farm. Occasionally, single events can be used as weather indicators, e.g. the observation from 29 March 1819 that an employee, who took an unauthorized night leave, fell through thin ice and drowned, which indicates a period of warm and spring-like weather during late winter. Precipitation is important to a farmer, and especially dry spells are recorded; there are often prayers in the diary during droughts and, when the rain finally arrives, God is praised, as seen in the following extracts of the diary:

> '15 June 1822: Wind SW. Rain and storm, work at various indoor chores, wagons prepared along with clearing of the road (note in margin: Today the Lord bestowed us with rain after a persistent drought.)'
>
> '25 June 1823: Wind S. Cloudy and rain to answer the wish of man after a long drought by the Hand of the Lord. Various indoor chores were done. Clear once more in the afternoon (note in margin: Today the Lord bestowed us with a beautiful rain.)'
>
> '18 June 1824: Wind SE. Storm, with random clouds, Kohlkjerret meadow was turned by spade by all hands, except two men who finished the steps. At 4 o'clock in the afternoon, God bestowed us with rain that kept coming until 3 o'clock the following morning (note in margin: Today in the afternoon God bestowed the earth with rain after a long drought.)'

2.6. Interpreting the diary. The Smådalarö farmer's diary is a combination of weather observations and comments, and the content changes through time, sometimes being detailed, while at other times very little is written down. Some sections of the diary are missing; parts of months are missing on 6 occasions: 1 to 19 April 1815, 20 to 31 March 1817, 1 to 13 April 1817, 10 to 30 November 1817, 1 to 13 December 1817, and 11 to 31 October 1818, so the records from ca. 15 d have represented the full calendar month. Since no direct temperatures were recorded, the subjective estimations of Berg needed to be transformed into actual measurements. To make this transformation, all data in a specific weather category were grouped and ranked: wind strength (from calm to storm), temperature (from warm to strong cold) and precipitation (ranging from rain to snow) and general weather observations (Table 1). In addition, all entries containing general weather observations (e.g. timing of ice break up and phenological observations) provided additional information for the reconstructions.

To create a temperature record, daily data for each month were checked and evaluated for Days 1 to 15 and 16 to 30 (or 31) using data in the weather categories. For temperature, weather conditions associated with 0°C (e.g. observations of freezing or thawing) during the cold season were identified and temperatures were progressively estimated from the diary entries in ±2.5°C steps from that base level. The temperatures were first averaged for each 15 d period and then averaged for each month. To assess the accuracy of the estimations, the monthly average was again checked against the written observations in the specific month and also against the estimated temperature and weather conditions of the preceding and following months. Finally, the reconstructed temperatures were compared to the observations in the general observations category, such as forest fires or early summer frost. No attempt was made to estimate actual amounts of precipitation, but all precipitation events and their duration as well as the type of precipitation were recorded. Temperature estimates and precipitation indications were used together for reconstructing summer drought. In addition focus was put on all entries concerning drought, lack of rain and strong heat during the summer. Five categories, or degrees, of drought were estimated: 5 = very wet with rain throughout the summer; 4 = wetter than usual but with rain-free periods; 3 = normal conditions without any written comments on either rain or drought; 2 = drier than normal, but not extreme, with shorter spells of drought and occasional rain and 1 = severe drought. Finally, to validate the reconstructed degree of summer drought between 1815 and 1833, it was compared to the temperature and precipitation records from Stockholm.

Table 1. Weather types from Anders Berg's diary used to reconstruct climate 1815 to 1833. The most frequently used weather designations were arranged according to their relative strength (after Molin 2003). The category 'general weather' contains descriptions of the weather and was used to confirm the temperature and precipitation reconstructions. Note that the weather types have been more or less directly translated from the Swedish diary entries

Wind	Temperature	Precipitation	General climate
Calm	Warmth	Some rain	Beautiful weather
Slight wind	Some warmth	Rain	Clear
Beautiful wind	Spring warmth	Some snow	Half clear/scattered clouds
Wind	Spring cold	Snow	Thick air
Half storm/ hard wind	Some cold	Flying snow	Misty
Storm	Some frost		Partly covered skies
	Strong frost nights		Covered skies
	Cold		Rainy
	Strong cold		Some relief (in rain)
			Clearing skies
			Some winter
			Mild
			Drought

3. RESULTS

3.1. Tree-ring data

The standardized Tyresta tree-ring width chronology displayed high variability on inter-annual to decadal time scales (Fig. 3). However, between 1810 and 1835, tree growth was below average for the longest consecutive period throughout the record. This growth anomaly was especially conspicuous, since it was preceded and followed by periods of extremely favorable growth. A look at the actual growth (unstandardized) in 1800 to 1850 shows that a marked decrease in growth was recorded in most trees between 1810 and 1835, and yearly radial growth of <0.1 mm was occasionally found (Fig. 4), which is considered to be very low, even for xeric site trees in the region (Linderholm et al. 2002).

The correlation analysis illustrated that, in the twentieth century, Scots pine growth was significantly correlated to the SPI in June and July (Fig. 5). Additional positive (not significant) correlation with August SPI suggested that summer (June–August) drought could be reconstructed back in time using our tree-ring data. The calibration/verification statistics (Table 2) show that the relationship between SPI and tree growth was rather stable throughout the twentieth century. However, using tree-ring data only, ~24 % of the variance in the observed SPI variability could be explained. When reconstructed SPI values are plotted against the observed ones, it is clear that although there is in general fair agreement between the 2 records (R = 0.49), the reconstruction fails to capture the full range of inter-annual variability in the observed record, especially some of the very dry (e.g. 1901, 1911, 1955, 1969, 1975) or very wet (e.g. 1903, 1916, 1956, 1961, 1998) years (Fig. 6a). The relationship between reconstructed and measured SPI was particularly low around 1920, in the 1950s and in the 1980s. However, good agreement in the first half of the twentieth century, especially regarding the dry years, suggested that a reconstruction of SPI back in time would yield useful information about past droughts, and consequently the SPI was reconstructed back to 1750.

The full reconstruction (Fig. 6b) disclosed a considerable variability among the years, especially before 1900. There are a few periods where negative SPI is sustained for a few years, notably in the twentieth century. However, the early part of the nineteenth century stands out, not because of specifically dry years (according to the reconstruction several years before and after that period were drier), but because of the long time span with negative SPI years; between 1810 and 1833 only 2 years out of 24 could be characterized as wet, i.e. 92% of the years were dry during that period. Throughout the reliable part of the record, the 5 driest years were found in 1763, 1801, 1833, 1861 and 1871.

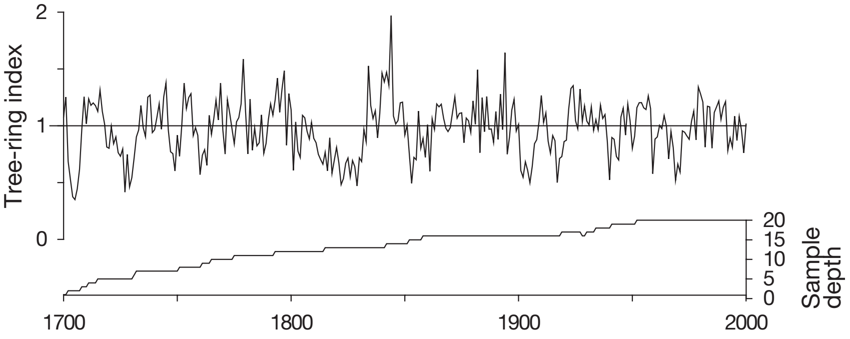


Fig. 3. Standardized Tyresta tree-ring width chronology. Lower line indicates sample depth, i.e. number of trees, over time. The chronology is considered reliable from 1750, when the number of trees is ≥7

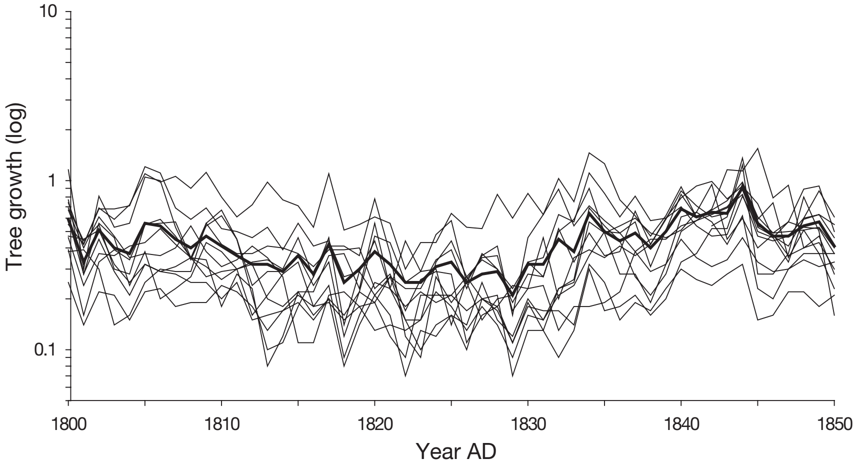


Fig. 4. Tree growth (unstandardized) for each tree in 1800–1850. Thick line represents the average of all series. Note the logarithmic scale

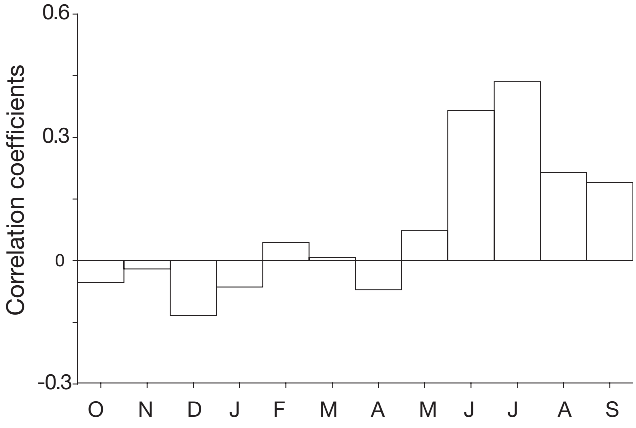


Fig. 5. Correlation between the Tyresta Scots pine tree-ring width chronology and the standardized precipitation index (SPI) from October prior to the growth year to September of the growth year in 1901–1999

Table 2. Calibration and verification statistics for the reconstruction of summer (June–August) standardized precipitation index (SPI). Sign test: comparison of correct to incorrect signs for estimated and actual data; TRW_t: tree-ring width (standardized) in the year of growth; TRW_{t+1}: tree-ring width in the following year; *significant at 0.05 level

Calibration period	1901–1949	1950–1999	1901–1999
Verification period	1950–1999	1901–1949	
Calibration			
Variance explained	0.29	0.24	0.24
Verification			
Variance explained	0.21	0.24	
Reduction of error	0.17*	0.21*	
Sign test			
Correct	30	36*	
Incorrect	20	13	
Regression weights			
TRW_t	2.21	2.32	2.20
TRW_{t+1}	−0.82	−1.16	−1.20

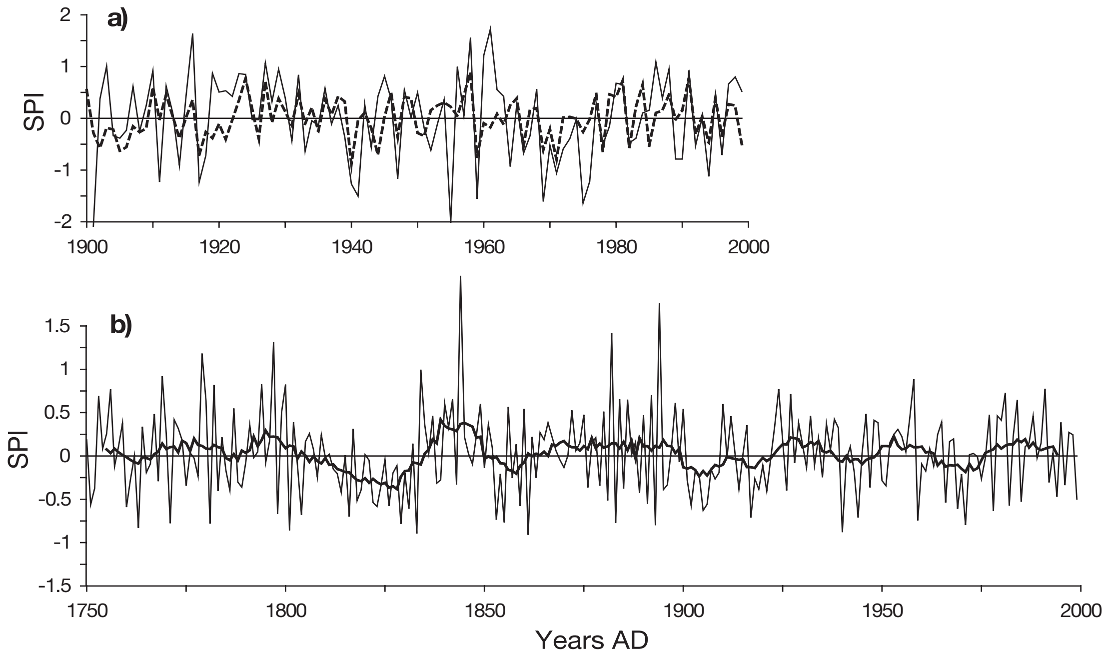


Fig. 6. (a) June–August SPI reconstructed from tree rings (dashed line) plotted against the observed SPI record in the twentieth century. (b) Reconstruction of June–August SPI back to 1750

3.2. The farmer's diary

Using the farmer's diary, summer drought was estimated for the period 1815 to 1833 (Fig. 7). Within this period, 4 summers of extreme drought (1 on our drought scale) were found: 1816, 1818, 1819 and 1826. The summers of 1817, 1822 to 1824 and 1829 were dry, but not extreme (2 on our drought scale), while the remaining summers must be considered to have been normal in terms of dryness. Only 1 yr was considered anomalously wet: 1832. To make an independent verification of the drought reconstruction from the farmer's diary, it was plotted against normalized June–August temperature and precipitation from the Stockholm record of observations (Fig. 7a,b). The relationship between estimated drought and temperature was strong (R = –0.74), while the correlation with precipitation was lower (R = 0.51). Furthermore, agreement was stronger between estimated drought and the tree-ring index (R = 0.59) than with the reconstructed SPI (R = 0.48, Fig. 7c,d). The low correlation between estimated drought, as inferred from the diary entries and reconstructed SPI, is mainly due to a drier end in the SPI record compared to that of the diary drought estimation.

4. DISCUSSION

The relationship between tree growth and drought, expressed as SPI, was found to be rather weak, since only ~24 % of the variability in measured SPI could be explained by the tree-ring data. From Fig. 6a it is clear that the tree-ring models fail to capture some of the very dry or wet years. It is not surprising that the tree-ring models cannot capture the very wet years, since in general the growth–climate relationship is more consistent for the formation of narrow rings (dry years) than for the formation of wide rings (wet years). This is because stressed trees respond more strongly to climate than trees growing under favourable conditions (Travis et al. 1990). Thus, it was more unexpected that the tree-ring models failed to capture the very dry years, as indicated by low observed SPI values in 1901, 1911, 1941, 1955, 1964, 1969, 1975–1976 and 1989–1990. A look at June–August total precipitation and mean temperature (from Stockholm) in those years shows that precipitation was below normal (1900 to 2000 average) in all years except 1941, and well below normal in 1901 and 1955; temperatures were above normal in 1901, 1955, 1941, 1955, 1976, 1989 and 1990, and very high in 1969 and 1975. However, it should be taken into consideration that these are averages for the whole season. In some of these years, the warm and dry months occurred in July and August, and most precipitation came in June (1901, 1955 and 1976). Consequently, a very dry and warm July or August could yield a low SPI for the entire season when averaged together with less extreme months. Quite possibly, Scots pine in Tyresta would also be able to withstand a dry late summer, provided that they had sufficient

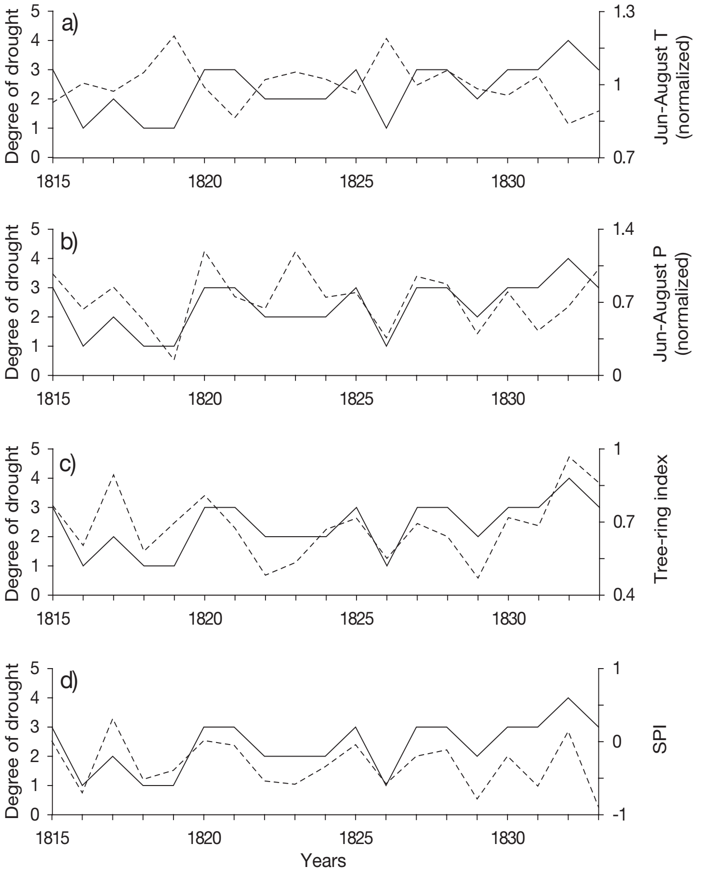


Fig. 7. Summer drought index 1815–1833 reconstructed from the farmer's diary (solid line), where 1 is extremely dry and 5 extremely wet, plotted against (a) normalized Stockholm June–August mean temperatures (T, dashed line), (b) normalized Stockholm June–August total precipitation (P, dashed line), (c) Tyresta tree-ring index (dashed line), and (d) reconstructed SPI (dashed line)

water available during the early stages of the growing season.

Furthermore, occasional responses of low growth to drought by Scots pine in southern Sweden may be attributed to the sensitivity of these trees to both temperature and precipitation during the growing season, and that the relative influence on pine growth of these 2 climate variables may vary depending on the general climate conditions (Linderholm 1999, Linderholm et al. 2004). For example, the effect of a summer with low precipitation may not be as severe on pine growth provided that summer temperatures are low. Furthermore, the effect of winter climate, e.g. temperatures, thickness of snow etc., or climate of the previous summer, may also affect growth in the following growing season. In 1954 and 1974, the years before low SPI (dry) summers, summer precipitation was well above normal, and in the winters and springs of 1901, 1911, 1969, 1975 and 1990, precipitation was above normal, while in 1941 the winter months were wet. Thus, it is possible that even in a dry summer there may be enough water stored in voids and cracks of the bedrock, where the pines spread their roots, for the trees to grow at close to normal rates if precipitation was high during winter and spring.

Despite the shortcomings of our SPI reconstruction, the generally good agreement with the observed data (especially in the early 1900s) together with the co-variability on decadal time scales between the 2 records suggest that it may be used as a proxy for past dry summers. Thus, in general, a period of low growth corresponds to dry conditions. However, it should be kept in mind that the tree-ring data could not capture the long period of below zero SPI in the late 1960s to mid-1970s very well. Furthermore, since only 24 % of the variance in observed SPI was explained by the tree-ring data, it is likely that some of the low growth years were considerably drier than the reconstruction suggests. Another factor to be taken into consideration is the SPI itself: it is based on gridded data, and thus may not fully represent the true conditions at a specific site. Trees will respond to the conditions at the site where they are growing, and the impact of drought will likely be highly variable depending on the local topography, soils etc.

The method used in this study to translate diary notes into temperature and drought might not be considered to be fully objective. One of the fundamental issues when interpreting a farmer's diary is to understand what the farmer means when he writes that a day is 'hot' or 'cold', i.e. how the entries should be translated regarding degrees Celsius, amounts of rain or degree of drought. Thus, it is necessary to build a 'mental relationship' with the keeper of the diary, and consequently, the longer and more detailed the record, the better. Furthermore, knowledge of the local climate in the area must be considered as a prerequisite for interpretation, e.g. what weather conditions can be expected in late spring or during summer in the area, so that the notes can be put into a climatic context. Nevertheless, the result of this study is encouraging, and since there is a wealth of historical records in Sweden which have not previously been considered for studies of past climate, we hope that the successful use of historical documents as indicators of past climate can inspire further research in this particular area.

One obvious way to verify our results was by comparing them to the existing long meteorological records from Stockholm. However, it should be noted that the quality of the precipitation record prior to 1900 has previously been questioned (Eriksson 1981). Regardless of whether the precipitation record has been over- or underestimated, a dramatic decrease in summer precipitation was evident in 1810 to 1835 (see Linderholm et al. 2004). In addition, summers seem to have been relatively warm during the first half of the nineteenth century (Moberg et al. 2002). Still, in a later study, Moberg et al. (2003) concluded that summer temperatures were probably positively biased prior to 1860. Nevertheless, the inter-annual variability in both temperature and precipitation records is most likely close to the truth, so a comparison of the diary drought reconstruction to normalized meteorological observations was considered to be valid.

From this study, it is clear that Scots pine tree-ring data cannot give reliable, high resolution (i.e. inter-annual) information about past droughts in east central Sweden. Furthermore, when reconstructing drought (or precipitation) from a farmer's diary, it is difficult to answer the question of how dry the drought is, as documented by the nineteenth century farmer, in relation to today's climate. Consequently, alone neither of these proxies can provide adequate information on past droughts. However, by combining the 2 sources, this can be achieved. A farmer's diary gives a detailed description of the duration and impacts of droughts, and thus the severity of a drought can be assessed. In contrast, tree-ring data can set a period of drought in a longer time context.

Together tree growth and the farmer's diary advocate dry and warm summers during the early part of the nineteenth century. Coinciding increases in Scots pine growth in the central Scandinavian Mountains (Gunnarson & Linderholm 2002), where pine growth is favored by warm and dry summers, implies that dry and warm summers occurred over most of Scandinavia. However, summer temperatures in Tornedalen, northern Sweden, were not unusually high (Klingbjer & Moberg 2003). In a reconstruction of summer temperatures for western Europe, Schweingruber et al. (1991) suggests that, in general, temperatures during 1810 to 1835 were high for large parts of the area, and summer temperatures in the Low Countries rose quite dramatically during this period (Shabalova & van Engelen 2003). Low summer precipitation during this period has been observed throughout Europe (Jones 2001), and together with Lamb's (1995, p. 251) description that 'The 1820s and 1830s introduced a return to greater warmth in Britain and Europe, and were distinguished, particularly in the 1820s, by genial warm springs and autumns', it suggests that this was a period of change in summer climate affecting not only Sweden, but large parts of Europe. In Finland, the early nineteenth century does not seem to have been particularly dry (Helama & Lindholm 2003), so it is possible that warm and dry summers were a feature in southern and central Scandinavia and central Europe.

5. CONCLUSION

A prolonged drought in the early nineteenth century in east central Sweden was assessed by combining dendrochronological and historical data. The radial growth of Scots pine was used to reconstruct summer drought (in the form of SPI) for the past 250 yr. Although the relationship between reconstructed and observed drought was occasionally weak in the calibration/verification period, it was proposed that Scots pines could be used as proxies for drought since they responded to dry summers with low growth. The tree-ring data suggested that dry summer conditions lasted for almost 2 decades between 1810 and 1835, the longest period in the past 250 yr. Independent from the tree-ring data, daily weather observations from a farmer's diary were used to infer summer drought between 1815 and 1833. Comparison with the Stockholm observational record suggested that both reconstructions captured summer conditions during that particular period. This study showed that combining 2 proxies of drought may yield useful information about past droughts that one or the other of these sources cannot give alone. A farmer's diary can provide a detailed description of the duration and impacts of droughts in a short period of time, while tree-ring data can set a period of drought in a longer time context.

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