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# Combining the archives of nature and society: Tree rings and tithes

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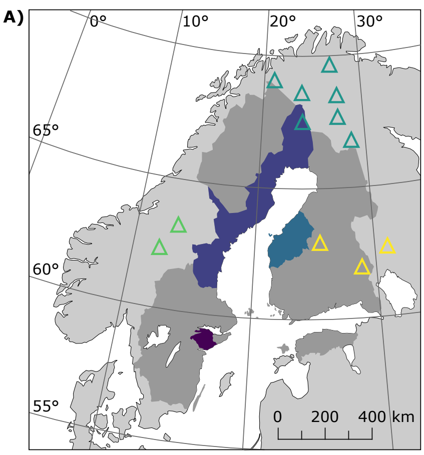
**Combining information from proxy materials stored in natural and man-made archives helps to gain a more comprehensive understanding of past climate-society relationships. This is demonstrated here with an example from tree-ring and tithe data from the 16th- to 17th-century Swedish Realm.**

The impacts of future climate change on agriculture form a crucial issue for food security. Valuable insights into this topic can be gained by studying the impacts of past climate on crop cultivation – not only in recent history, but also over past centuries. Use of only the most recent data increases the risk of addressing symptoms rather than deep-rooted causes (Adamson et al. 2018). Yet, such deeper historical dimensions are not extensively examined in the literature. This is likely because direct statistical data on climate and agricultural production become available mainly from the 19th century onwards. Nevertheless, for periods further back in time, we can use indirect, i.e. proxy, data to study the relationships between climatic and agricultural fluctuations. These proxy data can be found in either the "archives of nature", such as ice layers and tree rings, or in the "archives of society", composed of written documents. This article discusses some of the main issues in combining proxy data from both types of archives by presenting a case study on temperature and grain harvest fluctuations from the 16th- to 17th-century Swedish Realm (comprising roughly the area of modern-day Sweden, Finland, and Estonia).




## Proxies of temperature and grain yields

Meteorological data and countrywide agricultural statistics are both available from 19th-century Sweden and Finland. Analysis of these series has previously revealed that temperatures and yields of principal grains generally show positive and statistically significant correlations, with warmer conditions bringing higher yields (Holopainen et al. 2012; Huhtamaa et al. 2015). Prior to this "statistical era", the availability of crop-yield and instrumental temperature data decreases dramatically. For annual harvest data, some sporadic yield-ratio series are available from the 16th and 17th centuries. Yet these commonly indicate the yield ratios of manorial estates, i.e. the productivity of fields owned by the nobility. The great majority (>80%) of the population in Sweden and Finland were, however, peasants. Nevertheless, grain tithes can provide an alternative source to detect annual yield fluctuations. The tithe was a tax that every land-holding peasant was obliged to pay in the 16th- to 17th-century Swedish Realm. Although collection practices varied slightly across the kingdom, each peasant household, in general, was supposed to pay approximately 10% of their annual grain harvest as tithes. The tithes commonly consisted of roughly equal shares of barley and rye, but in the northernmost areas, the tithes were paid almost entirely in barley. Here we use tithe data from three old administrative areas: the province of Södermanland and the land of western Norrland in Sweden (Leijonhufvud 2001), and the province of southern Ostrobothnia in Finland (Huhtamaa and Helama 2017a).

In addition to using documentary evidence, crop yields and temperatures could be reconstructed using tree-ring data available from both countries (Fig. 1). Here we use maximum latewood density (MXD) chronologies of Scots pine (*Pinus sylvestris* L.) tree rings from Lapland (Matskovsky and Helama 2014), southern Finland (Helama et al. 2014), and Jämtland (Sweden; Gunnarson et al. 2011). All of these reconstructions explain around 60% or more of the total variance in the measured annual warm season temperatures. Furthermore, the Finnish MXD chronologies reliably indicate relative variations in grain yields in central and northern Finland (Huhtamaa and Helama 2017b).

## Tree rings and tithes

The years with strong drops in MXD-based growing season temperatures were found to match the years when all the tithe series indicated poor harvests. These years include 1587, 1601, and 1614 (Fig. 1). This suggests that although the harvest was influenced by local environmental conditions and man-made factors, at least during the years representing relatively average

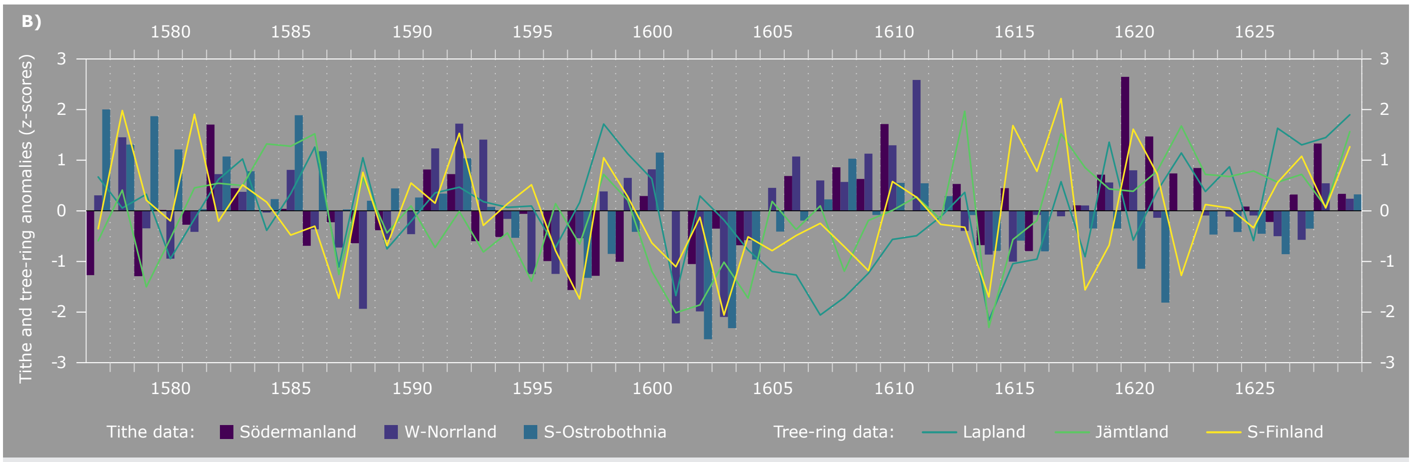
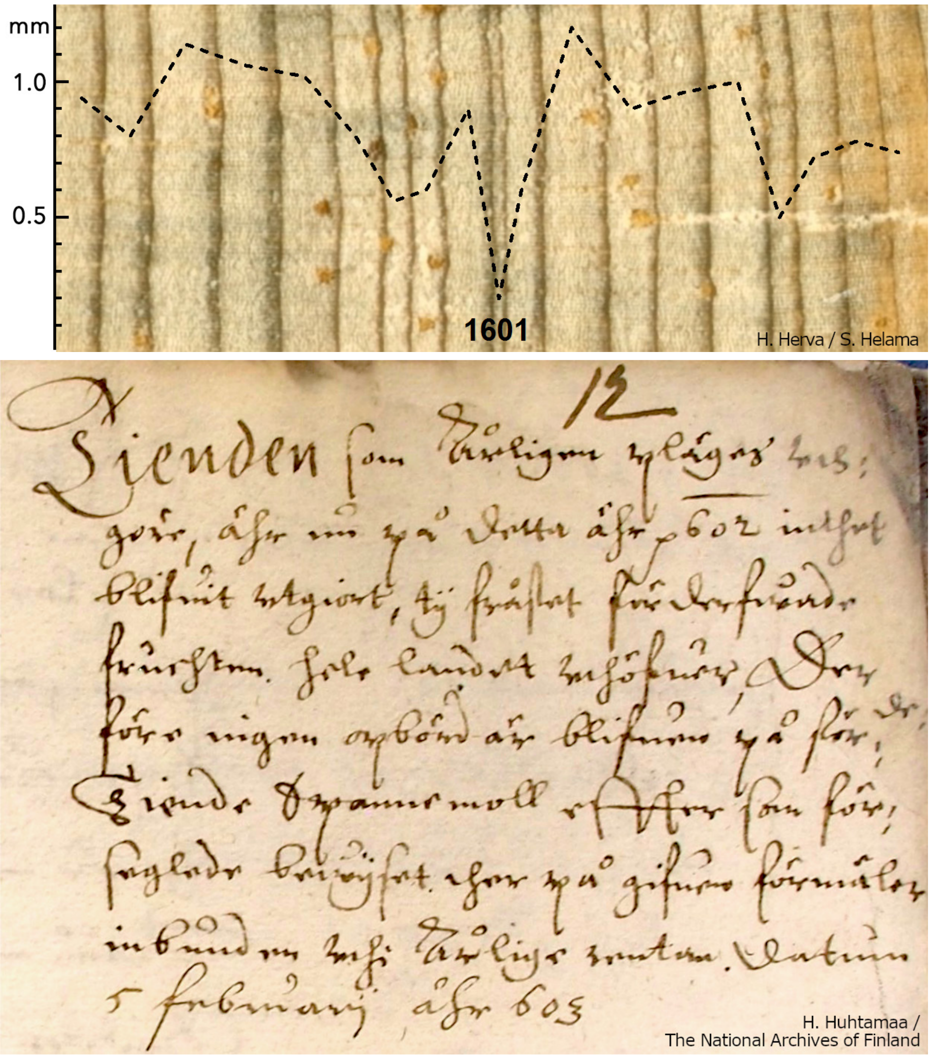



**Figure 1: (A)** Three historical districts for the tithe data (coloring) and the average sampling sites of the tree-ring data (triangles). The darker grey area illustrates the extent of the Swedish Realm in 1600. **(B)** Annual tithe variations and tree-ring reconstructed temperature variability (standardized over the period 1577–1629).




"The tithe that annually are due, are now for this year [1]602 not fulfilled, since the frost devastated the fruit [i.e. the crops]. The entire land therefore needs no taxation on the previously mentioned tithe grain as the sealed evidence tell within the bound [book of] annual rent. Date February 5 year [1]603."

**Figure 2:** The year 1601, evidenced in tree-ring samples from Finnish Lapland and written material from northern Finland. As the tithes were collected the following winter, the tithe year 1602 actually reflects the harvest year 1601.

climatic conditions, severe kingdom-wide harvest failures were likely driven by climate extremes. In this regard, the climatic "downturn" of 1601–1604 following the 1600 Huaynaputina volcanic eruption is especially visible in both types of data (Fig. 2). In fact, the 1601 harvest failure was so complete that in many provinces the authorities decided not to collect grain tithes at all (Huhtamaa and Helama 2017a).

Furthermore, the comparison of the MXD and tithe data reveals that harvests remained poor for at least one year after the year of poor harvest – even if climatic conditions would have supported higher yields (e.g. year 1588 in Fig. 1). The early modern Swedish Kingdom expected peasants to be self sufficient regarding seed grain. Thus, the harvest year following the crop failure remained poor as well, as only part (if any) of the fields could be sown due to empty grain stores. Consequently, insufficient preparedness to cope with large-scale crop failures, as well as inadequate seed grain storage, worsened the agricultural impacts.

The MXD measurements do not correlate as strongly with the 16th- to 17th-century tithe data as with the 19th-century yield data. This is hardly surprising, however, as the latter provide an indication of relative productivity fluctuations, whereas tithes can be more illustrative of the total quantities of grain harvest output. The total amount of taxed harvest may, in turn, have been influenced by several factors other than climate, such as the quantity and quality of seed grain, the size of the arable fields, and even the strictness of individual tax collectors. Moreover, the tithe series from Södermanland agreed least with the MXD-based temperature reconstructions (Fig. 1). This is likely due to the long distance between the province and MXD sites. Additionally, northern grain yields, like MXD, were more sensitive to the length and thermal conditions of the growing season than yields in southern Sweden, where winter temperatures and summer precipitation markedly influenced the harvest (Edvinsson et al. 2009).

## Discussion and conclusions

Data from both natural and man-made archives are needed when studying climate and grain harvest fluctuations in the era preceding official statistics. Meaningful comparisons require natural and written materials representing the same climate variables and similar spatio-temporal coverage and resolution. Thus, for example, temperature-sensitive tree-ring data from Sweden and Finland are not suitable to explore climate–harvest relationships in precipitation-sensitive agricultural areas further south. Moreover, when studying annual harvest fluctuations, the natural materials used for comparisons need to be dated to absolute calendar years to demonstrate inter-annual variability comparable to historical data. Among the different natural proxy types, only tree-ring chronologies are routinely converted to calendar years, making them directly comparable to historical data, with no need to speculate on dating issues.

The natural and man-made archives shown here (MXD and tithes, respectively) both serve as proxy materials, i.e. data indirectly indicative of past variations in climate and crop yields. In this sense, tree-ring data can be used to demonstrate climatic impacts on crop yields, whereas grain tithes indicate the quantity of the harvest. Additionally, when further information is needed, yield ratios, for example, can indicate the relative productivity variations and grain prices the fluctuations in grain availability. None of these different types of data alone provides us with a comprehensive picture of past harvest fluctuations. Combining these sources, however, provides us with a much more detailed understanding of the past.

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