CARPATHIAN BASIN – THE WINNER OF THE LITTLE ICE AGE CLIMATE CHANGES: LONG-TERM TIME-SERIES ANALYSIS OF GRAIN, GRAPE AND HAY HARVESTS BETWEEN 1500 AND 1850

KARPATSKI BAZEN (PANONSKA NIZINA) – POBJEDNIK KLIMATSKIH PROMJENA MALOG LEDENOG DOBA: DUGOROČNA ANALIZA VREMENSKIH SERIJA BERBI ŽITA, GROŽĐA I SIJENA IZMEĐU 1500. I 1850. GODINE

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Summary

During the Little Ice Age, the climate became cooler in most of Europe, and the growing season shortened with a decline in the harvest of crops, which resulted in a general decline in living opportunities. However, the findings of the present study reveal that the situation in the Carpathian Basin was somewhat different. The results of our research suggest that Transdanubia, the most western one of the four macro-regions in the Carpathian Basin, was undoubtedly the greatest beneficiary of the wet climate of the Little Ice Age. The agricultural production of the Upper Hungary and the Great Hungarian Plain, as reflected by the indices I was using, was moderately positive. However, in Transylvania, the yields of grain and hay were below contemporary expectations. The diverse landscape certainly helped the Transdanubian macro-region to achieve excellent adaptability. The reason for its success may be that the lack of precipitation is the most critical bottleneck in the agriculture of the Carpathian Basin. The essential feature of the climate change brought about by the Little Ice Age in the Carpathian Basin was the increase in precipitation. Our findings show that it was the Little Ice Age, and especially its wet climate, that on average provided relatively favourable conditions for the balanced performance of agriculture in the Carpathian Basin in the long-term, in the Transdanubian region in particular. The wet climate played a crucial role in the low frequency of crop catastrophes in the 18th and 19th centuries. Moreover, the mosaic structure of traditional agriculture (arable and grazing land, orchards, vineyards, meadow farming and fishery) improved the resilience of local and regional economy in the Carpathian Basin. This diverse system characterized agriculture in the study area until the mid-19th century, making it more resilient than modern agriculture.

Keywords: climate history, environmental history, agrarian history, Little Ice Age, Carpathian Basin

Ključne riječi: povijest klime, povijest okoliša, agrarna povijest, Malo ledeno doba, Karpatski bazen (Panonska nizina)

INTRODUCTION

During the Little Ice Age, the climate became cooler in most of Europe, the growing season shortened with a decline in crops, resulting in a general decline in living opportunities.[1] However, the findings of our research suggest that the situation in the Carpathian Basin was somewhat different. The yields of three agricultural plants, grain, grapes and hay, were examined in the Carpathian Basin between 1500 and 1850. Regarding the time frame of our research, sufficient descriptive documentary sources were available in archives, providing data for climate reconstruction from the beginning of the 16th century, due to the spread of literacy and printing. The end of our research period is the mid-19th century because, with the spread of the meteorological station network, the importance of documentary sources in climate reconstruction decreased. Harvest reconstruction based on documentary sources reveals that the average grain and grape harvests were relatively favourable over the Little Ice Age, and only the yield of hay was below the expectations at the time. The present study examines these surprising findings in detail.

Regarding the scope of our investigation, it is essential to note that we focus exclusively on the relation between agricultural yields and weather; we do not analyze either the social effects of adverse yields or the subsistence crises and famines. The objective of our study is to explore the agricultural effects of the Little Ice Age climate in the Carpathian Basin. We examine the productivity of agriculture there, adopting the perspective of the Braudelian "longue durée"[2] for outlining the trends and frameworks of the agrarian time series in the Carpathian Basin, which may lay the groundworks for more detailed local and regional case studies addressing more specific issues.

REGIONAL CHARACTERISTICS OF THE LITTLE ICE AGE IN THE CARPATHIAN BASIN

The Little Ice Age was the last completed, and thus completely known, phase of climate change, which was, according to our present knowledge, the most significant global cooling during human history.[3] During the Little Ice Age, in the Carpathian Basin, the average temperature of summers did not differ significantly from those of the 20th century, but winters were more extended and colder. A much more reliable indicator of global cooling was the increase in precipitation, which primarily fell in the form of snow due to the long and cold winters.[4] The mainly wet climate appeared in the last decade of the 16th century and continued until the first years of the 19th century (see Figure 1). It is no coincidence, therefore, that in the 18th and 19th centuries it was water regulation that became the most critical environmental issue and programme of Hungarian modernization.

Another essential feature of the Little Ice Age in the Carpathian Basin was the modification of seasons. The four-season structure remained, but the duration of seasons changed during the intensive global cooling periods. For example, March became a winter month, and the River Danube would often be completely iced over until the middle or, occasionally, the end of the month.[5] June was exceedingly wet, serving as the basis for the folk forecast on the day of Medárd (8th June), which said that if it rained on that day, the weather would remain rainy for another 40 days.

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1 The most recent summary of climate history studies concerning the agricultural production during the Little Ice Age: Sam White, John Brooke, and Christian Pfister. 2018. "Climate, Weather, and Food." In: Sam White, Christian Pfister, and Franz Mauelshagen eds. *The Palgrave Handbook of Climate History.* Palgrave Macmillan, London: 331-354.

2 Fernand Braudel. 1969. Écrits sur l'histoire. Flammarion. Paris.

3 The most important general works about the Little Ice Age: Jean M. Grove. 2004. *Little Ice Ages: Ancient and Modern.* London: Routledge Publisher; Christian Pfister. 1999. *Wetternachhersage, 500 Jahre Klimavariationen und Naturkatastrophen 1496–1995.* Bern: Verlag Paul Haupt. 1999; Rüdiger Glaser. 2013. *Klimageschichte Mitteleuropas – 1200 Jahre Wetter, Klima, Katastrophen.*3. Auflage. WBG, Darmstadt; Sam White, Christian Pfister, and Franz Mauelshagen. 2018. *The Palgrave Handbook of Climate History.* Palgrave Macmillan, London.

4 Lajos Rácz. 1999. *Climate History of Hungary Since 16th Century: Past, Present and Future.* Pécs: Center for Regional Studies; Lajos Rácz. 2013. *The Steppe to Europe: An Environmental History of Hungary in the Traditional Age.* Cambridge: White Horse Press.

5 Lajos Rácz. 2016. "The Danube Pontoon Bridge of Pest-Buda (1767-1849) as an indicator and victim of the climate change of the Little Ice Age." *Global Environment* 9: 458-493.

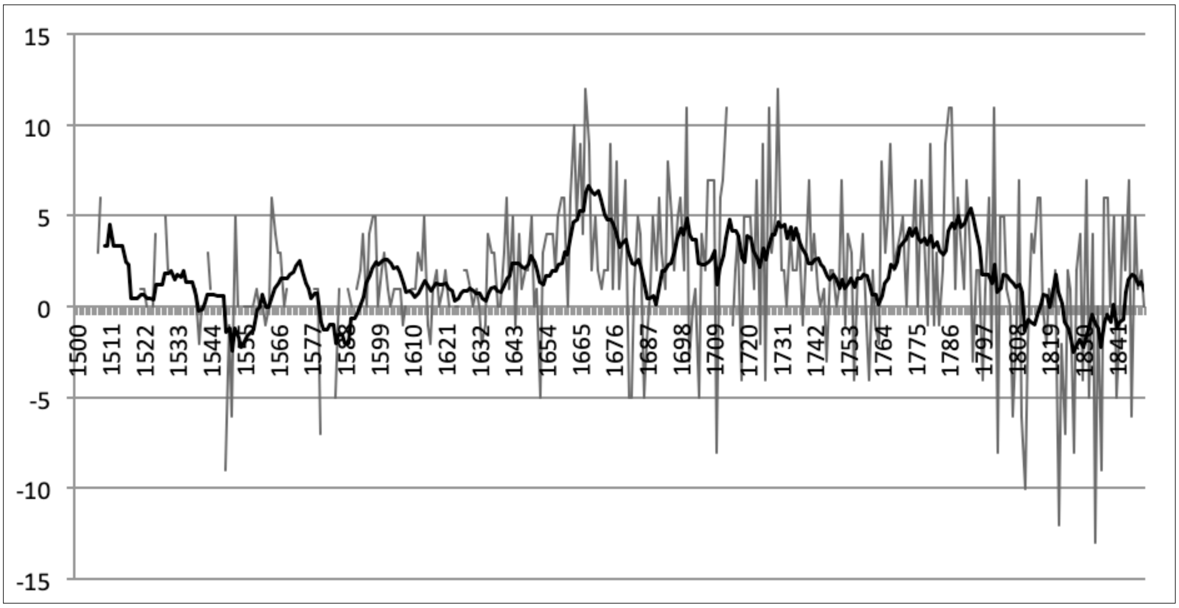

Figure 1. *Yearly precipitation time series (grey line) of the Carpathian Basin from 1500 to 1850 based on documentary sources, and its ten-year moving average (black line). The yearly climate history indices are derived from monthly indices that may range from +3 (very wet) to -3 (very dry), and the yearly indices may change between +36 and -36. Large absolute values of indices may signal weather anomalies, while values around 0 may also signal data deficiency. The indices of the time series are the author's research results. Data source: see footnote 19.*

We can distinguish five specific periods of climate deterioration during the Little Ice Age in the Carpathian Basin:

1. From the 14th century, a significant amount of data show that floodings became frequent. Findings in archaeological excavations also prove that villages on the Great Hungarian Plain and in some parts of Transdanubia were forced to move to higher altitudes in the early centuries of the Late Middle Ages.[6]
2. The weather turned colder and wetter at the turn of the 17th century.
3. The last third of the 17th century was the coldest period of the Little Ice Age globally, and the Carpathian Basin was no exception; the cold and wet climate started in the mid-17th century and lasted until the end of the first decades of the 18th century.[7]
4. Following the mostly mild 18th century, cold and wet weather returned between the 1810s and the 1840s.[8]
5. The last characteristic period of the Little Ice Age was the last third of the 19th century. (It is an exceptional misfortune that during water control works in Hungary, the managers of these works assumed the conditions of this extreme period to be ordinary.[9])

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[6] Zsolt Pinke, László Ferenczi, Gyula Gábris, Balázs Nagy. 2016. "Settlement patterns as indicators of water level rising? Case study on the wetlands of the Great Hungarian Plain." *Quaternary International.* 415: 204-215.; András Vadas. 2010. *Weather Anomalies and Climatic Change in Late Medieval Hungary: Weather events in the 1310s in the Hungarian Kingdom*. Saarbrücken: VDM Verlag.; Andrea Kiss, József Laszlovszky. 2013. "14th-16th-century Danube floods and long-term water-level changes in archaeological and sedimentary evidence in the Western and Central Carpathian Basin: An overview with the documentary comparison." *Journal of Environmental Geography* 6/3-4, 1-11.; Kiss Andrea. 2020. "A dynamic interplay of weather, biological factors and socio-economic interactions: late 15th-century-early 16th-century crises in Hungary". In: Andrea Kiss- Kathleen Pribyl (eds.): The Dance of Death in Late Medieval and Renaissance Europe. Routledge. 125-145.

[7] Lajos Rácz. 1999, 2013.

[8] Lajos Rácz. 2016.

[9] Zsolt Pinke. 2014. "Modernization and decline: an eco-historical perspective on regulation of the Tisza Valley." *Journal of Historical Geography.* 45: 92-105.

The present study focuses on the climate and environmental history of the Carpathian Basin (Figure 2). From a landscape geographic perspective, the Carpathian Basin is the most extensive macro-region of the central European basin area, well exceeding the dimensions of the Czech and the Vienna Basins. Its most prominent characteristic feature is that three-quarters of its 300,000 km^2 area is less than 500 m and half of it is less than 200 m above sea level. From a climate history aspect, it is of particular importance that the Carpathian Basin lies in the intersection of influences from three climatic regions: the continental, the oceanic and the Mediterranean climate zones. In this study, four macro-regions are differentiated in the Carpathian Basin: Transdanubia, the Great Hungarian Plain, the Upper Hungary region (roughly corresponding to present-day Slovakia) and Transylvania (a macro-region of Romania today).[10]

In Hungarian history, the beginning of the Early Modern Times was extremely difficult. The Hungarian royal army losing the battle at the city of Mohács against the Ottoman Empire in 1526 proved to be fatal; as a consequence of this, the history of the sovereign Kingdom of Hungary came to an end, and the country was divided into three parts. The central and southern areas of the country became part of the Ottoman Empire (1541); the northern and the western areas were integrated into the Central European Habsburg Monarchy with a partly independent status; in the east, the Transylvanian

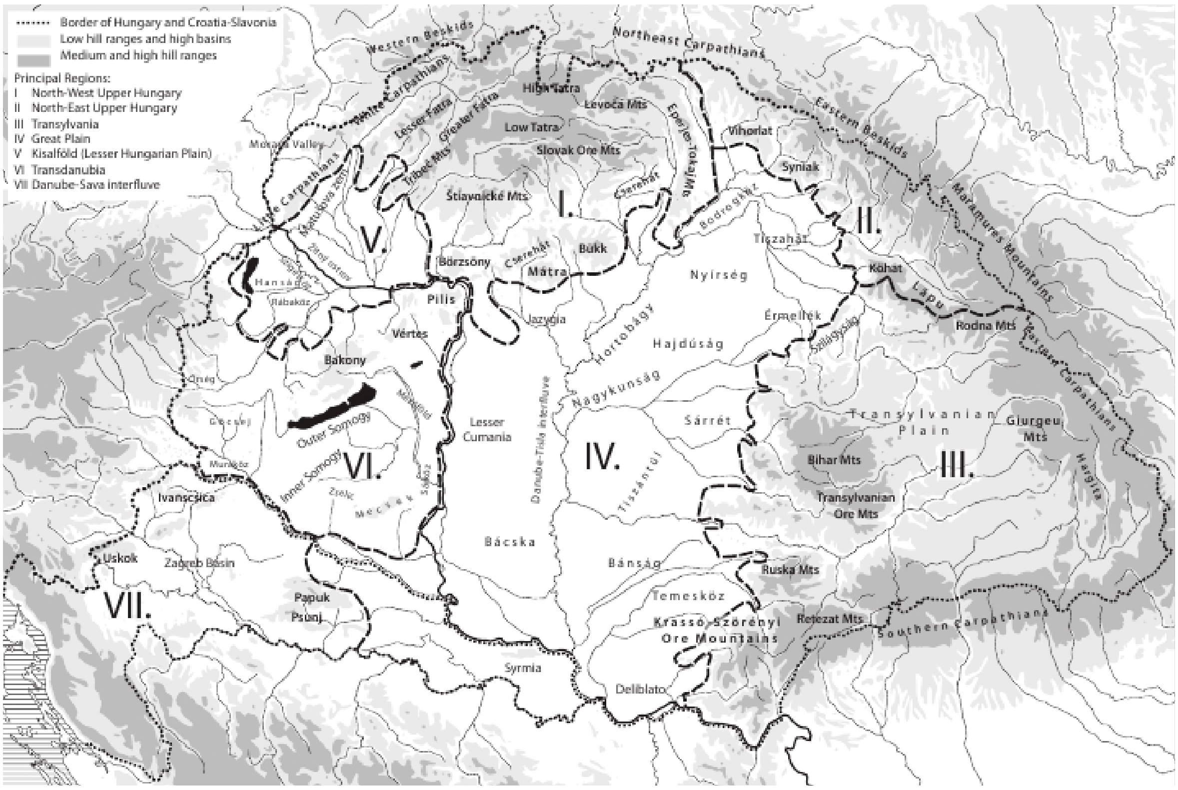

Figure 2. *Historical geography regions of the Carpathian Basin*. Four macro-regions: Transdanubia (VI), the Upper Hungary (I, II, V), Transylvania (III), the Great Hungarian Plain (IV) (Rácz, 2013: 29).*

* The mapped region VII, not dealt with in this study, actually includes not only the Danube-Sava interfluve, but also a further part of the Sava catchment, and a further section of the Dinaric Alps.

[10] Gábor Mezősi. 2017. *The Physical Geography of Hungary.* München: Springer Verlag.; Zoltán Dövényi. 2012. *A Kárpát-medence földrajza (The Geography of the Carpathian Basin).* Akadémiai Kiadó, Budapest.

Principality became a satellite state of the Ottoman Empire with limited self-governance (1570). Ensued by the success of the reconquest wars (1686-1699), the unity of the country was almost entirely re-established under the Central European Habsburg Empire. In the reunified Kingdom of Hungary, a rapid demographic and economic expansion took place during the 18th and the 19th centuries. However, in the first half of the 19th century, the feudal rules and institutions were a hindrance to growth. The growing crisis led to a series of reforms in Hungary in the 1820s (also referred to as the era of reforms) with the intention of modernizing the political and economic system.

CLIMATIC INFLUENCES ON AGRICULTURAL PRODUCTION DURING THE LITTLE ICE AGE IN CENTRAL EUROPE

Changes in weather greatly influenced the results of agricultural production throughout history. A key feature of the traditional age was that agricultural technology could compensate for unfavourable weather conditions for crops only to a limited extent.[11] Furthermore, due to the production limits of contemporary agriculture, four-fifth of the population had to work in agriculture as their primary occupation unless the agricultural shortage of a community could be compensated for by central command or through trade, which, however, could only be managed with considerable difficulty when weather and climate situations were unfavouarble.[12] Thus, the ratio of the local population that could make a living independent of current crop yields changed every year. In medieval and modern Europe, it was marginal agricultural areas that were the most severely impacted by the Little Ice Age. It is not surprising that climate and environmental history studies were mostly conducted in Scandinavia, Scotland and the countries of the Alpine region in the second half of the 20th century. It was the Swiss Heinz Wanner who introduced the concept of Little Ice Age-Type Events (LIATE) to describe the weather and climatic profile of the coldest periods.[13] In Switzerland, the most characteristic periods of the Little Ice Age were marked by the advance of glaciers, which was primarily caused by the increased frequency of long, snowy and cold winters along with cool and wet summers. Wanner's concept was further developed by Christian Pfister, professor of the University of Bern, who introduced the concept of Little Ice Age-Type Impacts (LIATIMP)[14] to describe weather situations which had the most adverse effects on contemporary agricultural production (Figure 4).

Along with Rudolf Brázdil, professor of the University of Brno, Christian Pfister examined the consequences of Little Ice Age-Type weather effects from the points of view of crop production and pasture farming. They claim that extended rainy periods during autumn, at the time of sowing, decrease both the size of arable land and the nitrogen content of the soil. Cold in March and April spoils the prospects of both grain harvest and grass yield. A wet midsummer has an unfavourable effect on the production of all food plants. Wet autumn, cold spring and wet midsummer occurring together in consecutive years can have severe economic and social consequences. Their extent depends on the damage mitigation ability of the economy and society. With all this knowledge, a model of crop disaster can be created for a given area.[15]

DOCUMENTARY SOURCES OF THE CLIMATE AND AGRICULTURAL HISTORY

11 Sam White, John Brooke, and Christian Pfister. 2018.

12 Pfister, Christian, Brázdil, Rudolf 2006. 'Social vulnerability to climate in the "Little Ice Age": an example from Central Europe in the early 1770s.' *Climate of the Past* 2: 115–129.

13 Wanner, Heinz 2000. 'Vom Ende der letzten Eiszeit zum mittelalterlichen Klimaoptimum.' In H. Wanner, D. Gyalistras, J. Luterbacher, R. Rickli, E. Salvisberg, C. Schmutz, S. Brönnimann (eds.). *Klimawandel im Schweizer Alpenraum.* Zürich. pp. 73–78.

14 Christian Pfister, Chantal Camenisch, and Petr Dobrovolný. 2018. "Analysis and Interpretation: Temperature and Precipitation Indices." In: Sam White, Christian Pfister, and Franz Mauelshagen, eds. *The Palgrave Handbook of Climate History.* Palgrave Macmillan, London: 115-130.

15 Pfister, Christian, Brázdil, Rudolf 2006.

Figure 3. *The weather impact of critical months, influencing crop and dairy farming in Switzerland and the Czech Republic. Italics: weather impacts that primarily affect the quantity of crops. Bold: weather impacts that primarily influence the quality of crops. (Pfister-Brázdil, 2006: 121)*

Critical months	Grain	Dairy forage	Wine
September–October	*Wet*	*Cold*	**Cold and wet**
March-April	*Cold*	*Cold*	*(Late frost)*
July-August	**Wet**	**Wet**	*Cold and Wet*

DATABASE OF THE CARPATHIAN BASIN

The most important collection of sources of Hungarian climate and environmental history research were compiled by climatologist Antal Réthly (1879-1975), the former head of the Hungarian Meteorological Service (and organizer of the Turkish Meteorological Service) with the active participation of chief archivist and Jesuit monk Flórián Holovics (1903-1988). Réthly's collections were published in three massive volumes,[16] and there is a debate in Hungarian climate history research whether Réthy's collections can be used as a source for climate reconstruction.[17] I consider Réthly's collections a useful database that requires careful content revision to eliminate unreliable data. I have been working with these volumes since the 1980s, revising the reliability of the information provided by the documentary sources, based on methods introduced by Christian Pfister and Hannes Schüle when compiling the Euro-Climhist data bank[18], and complemented this database with new archival findings. Finally, I have created a climate and environmental history database which contains sightly more than 270,000 pieces of elementary information about the climate and environmental history of the Carpathian Basin between 1500 and 1850.[19] The upcoming sections introduce some relevant examples of this source group.

Chronicles

During the early modern period, regional and urban chronicles proved to be useful sources for climate and environmental history. Transylvanian theologian and historian Máté Sepsi Lackó (1576-1633) wrote a history of Transylvania between 1520 and 1624.[20] The collection of Southern Transylvanian chronicles by Albert Bielz (1817-1898), which contains the German-language regional and urban chronicles of the Saxon cities of Transylvania, also has many references to whether events relevant for agriculture.[21] Another German-language chronicle by György Payr (1588-1651) and Mihály Payr (1620-1673) is the continuation of a chain of chronicles from Sopron.[22] The most important source of climate history

[16] Réthly Antal 1962. *Időjárási események* és *elemi csapások Magyarországon 1700-ig (Weather events and natural disasters in Hungary until 1700).* Budapest: Akadémiai Kiadó; Réthly Antal 1970. *Időjárási események* és *elemi csapások Magyarországon 1701-1800-ig (Weather events and natural disasters in Hungary between 1701-1800).* Budapest: Akadémiai Kiadó; Réthly Antal 1998. *Időjárási események* és *elemi csapások Magyarországon 1801-1900-ig (Weather events and natural disasters in Hungary between 1801-1900).* Budapest: Országos Meteorológiai Szolgálat.

[17] Andrea Kiss. 2009 "Historical climatology in Hungary: Role of documentary evidence in the study of past climates and hydrometeorological extremes." Időjárás: Quarterly Journal of the Hungarian Meteorological Service 113, no. 4: 315–339.; András Vadas. 2020. "The Little Ice Age and the Hungarian Kingdom? Sources and Research Perspectives." In: Martin Bauch and Gerrit Jasper Schenk, eds. *The Crisis of the 14th Century. Teleconnections between Environmental and Societal Change?* Berlin: De Gruyter. 263-279.

[18] Hannes Schüle and Christian Pfister. 1992. "Euro-Climhist – outlines of a Multi Proxy Data Base for investigating the climate of Europe over the last centuries." In: Brukhardt Frenzel. ed. *European climate reconstructed from documentary data: methods and results.* Stuttgart. 211-218.

[19] This database has been developed since 1985, and it provides the information background for my climate and environmental history research. The most important studies of mine are accessible on my Academia.edu account: u-szeged.academia.edu/LajosRácz.

[20] Sepsi Lackó Máté. 1857. *Sepsi Laczkó Máté krónikája (Chronicle of Máté Sepsi Laczkó).* Erdélyi Történelmi Adatok. Kolozsvár.

[21] Albert Bielz. 1862-63. *Beitrag zur Geschichte merkwürdiger Naturbegebenheiten in Siebenbürgen.* Nagyszeben.

[22] Heimler Károly. 1942. *Payr György* és *Payr Mihály krónikája: 1584-1700 (Chronicle of György Payr and Mihály Payr: 1584-1700).* Soproni krónikák II. Sopron.

from the Upper Hungary was the chronicle of Lőcse (now Levoča, Slovakia), by Gáspár Hain (1632-1687).[23]

Historia Domus and Diaries

Regarding the modern era, highly useful sources were the *Diaries* of Jesuit monasteries and the *Historia Domus* of Franciscan monasteries. Such were the Latin diaries of the Jesuit monasteries of Lőcse (now Levoča, Slovakia), and Kassa (now Košice, Slovakia) and the *Historia Domus* of the Franciscan monasteries in Gyöngyös, Eger, Mernye, Kecskemét and Jászberény.[24]

Manorial economic memoranda

Manorial economic memoranda compiled by economic clerks, also serve as valuable sources. Manorial clerks dealt with the efficiency of agricultural production primarily in these memoranda, having the general opinion that weather played the most crucial role everywhere.[25]

Personal notes

Another highly relevant source group of our climate and environmental history reconstruction was personal notes, which were available due to the spread of literacy from the second part of the 17th century. There are two types of personal notes that can be used as documentary sources: personal correspondence and personal diaries, authored by politician aristocrats, urban citizens, priests leading parishes and landed gentry, who paid considerable attention to weather and physical environment and wrote about market prices too.

Prime examples of these are the letters written by Counts Mihály Teleki[26] (1634-1690), Miklós Esterházy[27] (1582-1645) and Prince György Rákóczi II.[28] (1621-1660). Prince Imre Thököly's (1657-1705) military diaries are especially valuable sources of climate history of the Carpathian Basin.[29] One of the most valuable documentary sources of environmental history in the study area was the Transylvanian politician György Czegei Vass's (1644-1705) diary. György Czegei Vass started writing his memoranda in 1680 and continued to do so until his death in 1705.[30] László Zlinszky (1801-1862) was the first engineer and road director-general of Pest County, who started writing his diary in 1821, which was very rich in meteorological memoranda, and he kept writing entries until his death in 1862. Mihály Király, the reformed clergyman of the Transylvanian Egerebegy (now Agârbiciu, Romania), wrote his diary between 1823 and 1848, which is the most valuable documentary source for Transylvanian climate history research.[31]

Early newspapers

Since the 1770s, newspapers became increasingly essential sources for climate and environmental history reconstruction in the Carpathian Basin. The *Pressburger Zeitung*, the oldest newspaper in continuous publication in the press history of the Kingdom of Hungary, was founded in 1764 and in circulation until 1929. It was published in German in Pozsony (the Hungarian name of the city) or Pressburg (the German name of the city), which is now Bratislava, Slovakia; it is an excellent example of the multilingual and multicultural nature of Central Europe. The *Magyar Hírmondó* (Hungarian Newsletter) was published in Pozsony (now Bratislava, Slovakia) between 1780 and 1788, and this was the first news-

23 Hain Gáspár. 1910-13. *Hain Gáspár Lőcsei krónikája (Chronicle of Lőcse written by* Gáspár Hain). Lőcse.
24 Réthly Antal. 1962. 1970. 1998.
25 Bakács István. 1930. *Trautschon herceg regéci uradalmának terméseredményei a XVIII. században (Yields of the lordship of Regéc of Prince Trautschon in the eighteenth century).* Tanulmányok a magyar mezőgazdaság történetéhez 1. Budapest.
26 Gergely Sámuel. 1905-26. *Teleki Mihály levelezése I-VIII (Mihály Teleki's Correspondence).* Budapest.
27 Merényi Lajos. 1909. *Esterházy Miklós levelei Nyári Krisztinához 1624-1639 (Miklós Esterházy's Letters to Krisztina Nyári).* Történelmi Tár. Budapest.
28 Nagy Iván. 1877. *II. Rákóczi György levelei (György Rákóczi II's Letters).* Magyar Történelmi Tár XVII. Budapest.
29 Thaly Kálmán. 1868. *Thököly Imre naplói, leveleskönyvei és emlékezetes írásai 1686-1715 (Imre Thököly's diaries, letter-books and memorable writings: 1686-1715).* Pest.
30 Réthly Antal. 1962. 1970.
31 Réthly Antal. 1998.

paper in Hungarian. The *Magyar Kurír* (Hungarian Courier), printed between 1788 and 1834, was the most influential Hungarian newspaper published in Vienna. The *Ephemerides Budenses* was an exciting chapter in Hungarian press history between 1790 and 1793, because this newspaper was published in Latin, which was the official language of the country until 1843. The most influential newspaper in Hungarian was the *Hazai és Külföldi Tudósítások* (Domestic and Foreign Reports), published in Pest-Buda between 1806 and 1848. In general, these newspapers were published two times a week, and an overview of the meteorological-environmental conditions of settlements and areas can be obtained from their news, making them a pivotal source.[32]

THE METHOD OF QUANTIFYING DESCRIPTIVE DOCUMENTARY SOURCES OF CLIMATE AND ENVIRONMENTAL HISTORY

To identify the information possibly relating to climate and environmental history that can be used for systematic climate analysis, first, we had to organize the documentary sources according to topic, space and time, following the method standardized by Christian Pfister.[33] As the first step, explicit weather-related information, e.g. daily temperature, was separated from indirect information, e.g. the freezing or flooding of a river, and, from phenological data, relating to the natural environment and crops, e.g. blooming or ripening. In the temporal organization of the sources, five timeframes were set up: one day, ten days, a month, a season and a whole year. The levels of spatial organization of the data were the settlement or community, the county, the four macro-regions (Transdanubia, the Upper Hungary, Transylvania, and the Great Hungarian Plain), and, finally, the whole country. Following the method of weighted indices introduced by Christian Pfister, referred to as "Pfister Indices"[34] by Franz Mauelshagen, I quantified the information obtained from descriptive historical sources. The weather phenomena described by the sources were put on a scale where +3 corresponds to unusually warm and wet weather and -3 to extremely cold and dry weather. The creation of weather indices is a process that cannot be fully formalized mathematically, as several aspects have to be considered while assigning the relevant value (or one regarded as such). The most crucial element for weighting was the reliability of the source, but the interpretability of weather and duration of the described phenomenon also had to be taken into account. In this study, daily, ten-day, monthly, seasonal and yearly temperature and precipitation time series were created with reference to the settlements, counties and macro-regions of the Carpathian Basin and the whole country. In the case of grain, hay and grape harvest, the same method was used to quantify the qualitative documentary sources, but the spatial reconstruction was only performed for the macro-regions and the whole country. In this context, +3 meant excellent and -3 very poor harvest on this scale (Figure 4). Moreover, we attempted to define the countrywide character of grain, hay and grape yield by summing up the regional values. As we examined four macro-regions, results could vary between +12 (generally excellent yield) and -12 (crop disaster in the whole Carpathian Basin).

Figure 4. *Quantification scale for climate and agricultural documentary sources with the method of weighted indices.*

+3	extremely warm/wet/good
+2	very warm/wet/good
+1	warm/wet/good
0	Normal
-1	cold/dry/bad
-2	very cold/dry/bad
-3	extremely cold/dry/bad

32 Kókay György. 1979. *A magyar sajtó története I (History of the Hungarian Press I). 1705-1848.* Budapest

33 Christian Pfister. 1984. *Das Klima der Schweiz von 1525–1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft. Volume 1, Klimageschichte der Schweiz 1525–1860; volume 2, Bevölkerung, Klima und Agrarmodernisierung 1525–1860.* Bern: Paul Haupt.

34 Franz Matthias Mauelshagen. 2010. *Klimageschichte der Neuzeit, 1500–1900.* Darmstadt: Darmstadt Wiss. Buchges.

AGRICULTURAL PRODUCTION IN THE CARPATHIAN BASIN DURING THE LITTLE ICE AGE: GRAIN, HAY AND GRAPE HARVESTS

Grain

Wheat was the primary grain of the Carpathian Basin, while barley and rye appeared as additional cereals in colder and wetter areas. We have reliable documentary sources about grain harvests in the macro-regions of the Carpathian Basin since the 1620s only (Figure 5). In the examined three and a half centuries, there were years with catastrophic crop but, surprisingly, lasting periods of poor harvest never happened. Moderately weak crop periods, however, can be identified in the last third of the 16th century, in the mid-17th century, at the turn of the 18th centuries, and in the first half of the 19th century. However, it is worth noting that in the 18th century, from the 1720s onwards, grain harvests were relatively good in the Carpathian Basin until the end of the century.

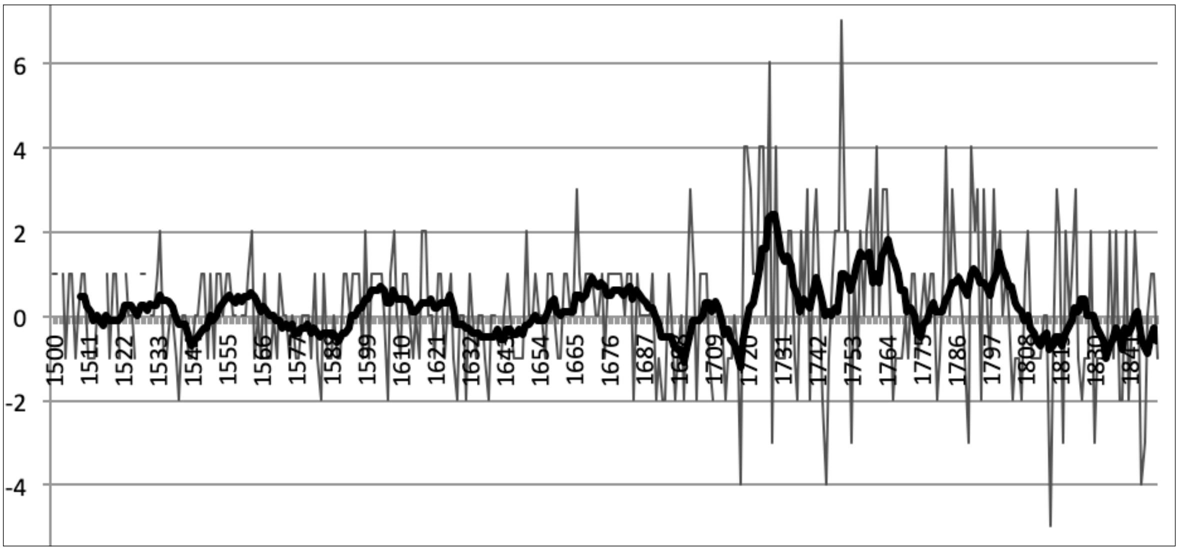

Figure 5. *Grain production (grey line) in the Carpathian Basin, and its ten-year moving average (black line). The values in the graph were calculated based on the time series of the four macro-regions (Transdanubia, the Upper Hungary, Transylvania, and the Great Hungarian Plain), and their values may vary between +12 and -12. The interpretation of large absolute values is unambiguous, but values around 0 may also reflect data deficiency.*

If we examine the macro-regions of the Carpathian Basin separately for 351 years (the macro-regional harvest indices may change between + and -1053), then the spatial differences of the generated data of grain productions show an exceptionally interesting regional distribution (Figure 6). In the Transdanubian macro-region, grain production was undoubtedly quite good during the Little Ice Age. In the other three macro-regions, the grain harvest indices scattered around the average. However, the negative values of the Hungarian Plain and Transylvania show that cereal production in the central, southern and eastern parts of the Carpathian Basin was the most susceptible to climate deterioration. Finally, positive harvest indices of the country derive from the high values of Transdanubia.

Figure 6. *Grain production in the macro-regions of the Carpathian Basin from 1500 to 1850; harvest indices may vary between + and -1053, indices for the Carpathian Basin as a whole between + and -4212.*

1500-1850	Grain harvest
Transdanubia	56
Upper Hungary	9
Transylvania	-7
Great Hungarian Plain	-3
Carpathian Basin	**55**

Grape

Concerning grape harvests, modern chroniclers noted not only the quantity of the fruit but the quality of wine too. The three and a half century-long wine harvest time series draw the most surprising picture. Unlike other Central and Western European sources, documentary sources reveal that the quantity and quality of wine in the Carpathian Basin was quite satisfactory in the country during the Little Ice Age (Figures 7 and 8). It is especially unexpected that in the 17th century, the coldest century in the Little Ice Age, the grape crop was on average good in the entire Carpathian Basin.

The grape-harvests were relatively favourable permanently in all of the macro-regions of the Carpathian Basin over the Little Ice Age. In terms of grape crop, Transdanubia was certainly the most successful macro-region. However, the qualitative indicators of wine were relatively good only in Transdanubia.

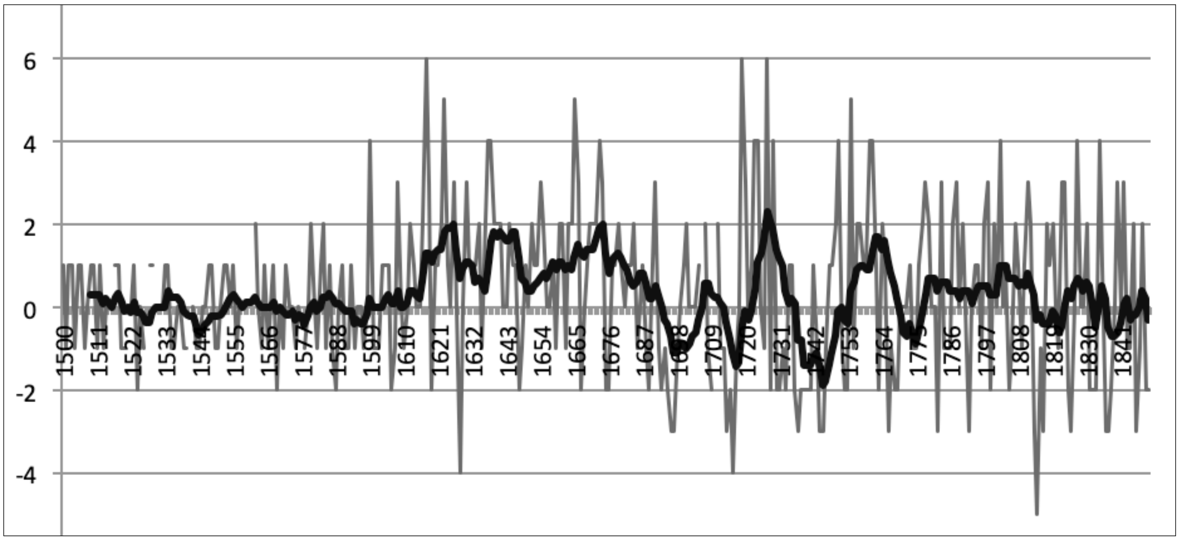

Figure 7. *Quantity (grey line) of grape crop in the Carpathian Basin, and its ten-year moving average (black line). The indices in the graph were calculated based on the time series of the four macro-regions (Transdanubia, the Upper Hungary, Transylvania, and the Great Hungarian Plain), and their values may vary between + and -12. The interpretation of large absolute values is unambiguous, but values close to 0 may also reflect data deficiency.*

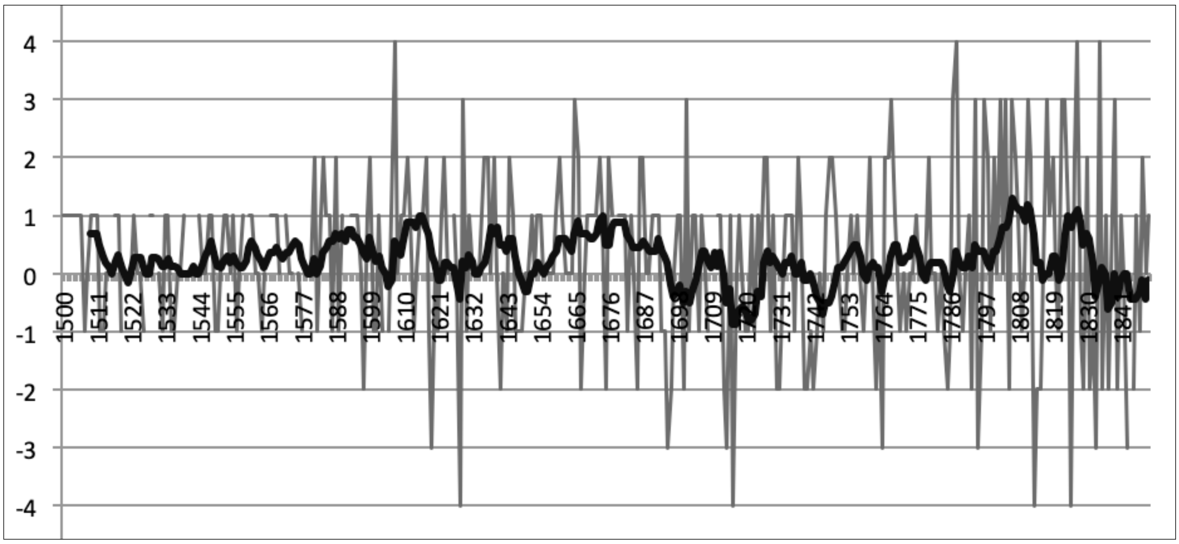

Figure 8. *Quality (grey line) of the grape crop in the Carpathian Basin, and its ten-year moving average (black line). The indices in the graph were calculated based on the time series of the four macro-regions (Transdanubia, the Upper Hungary, Transylvania, and the Great Hungarian Plain), and their values may vary between + and -12. The interpretation of large absolute values is unambiguous, but values around 0 may also reflect data deficiency.*

Indices of Transylvania and the Great Hungarian Plain moved around the average but on the positive scale, while those of the Upper Hungary were near to the average but on the negative side (Figure 9).

Figure 9. *Grape-harvests of macro-regions in the Carpathian Basin between 1500 and 1850, harvest quantity and quality indices may vary between + and -1053, indices for the Carpathian Basin as a whole between + and -4212.*

1500-1850	Grape quantity	Grape quality
Transdanubia	48	79
Upper Hungary	14	-8
Transylvania	14	4
Great Hungarian Plain	20	8
Carpathian Basin	**96**	**83**

Hay

The harvest of hay was the only agricultural yield during the Little Ice Age which permanently fell somewhat short of the expectations of the time, except for some decades in the 18th century (Figure 10). The crop of hay indices were on the negative scale in all of the macro-regions. At the same time, it is to be noted that in the Upper Hungary the long-term average of the yields of hay was the least poor (Figure 11).

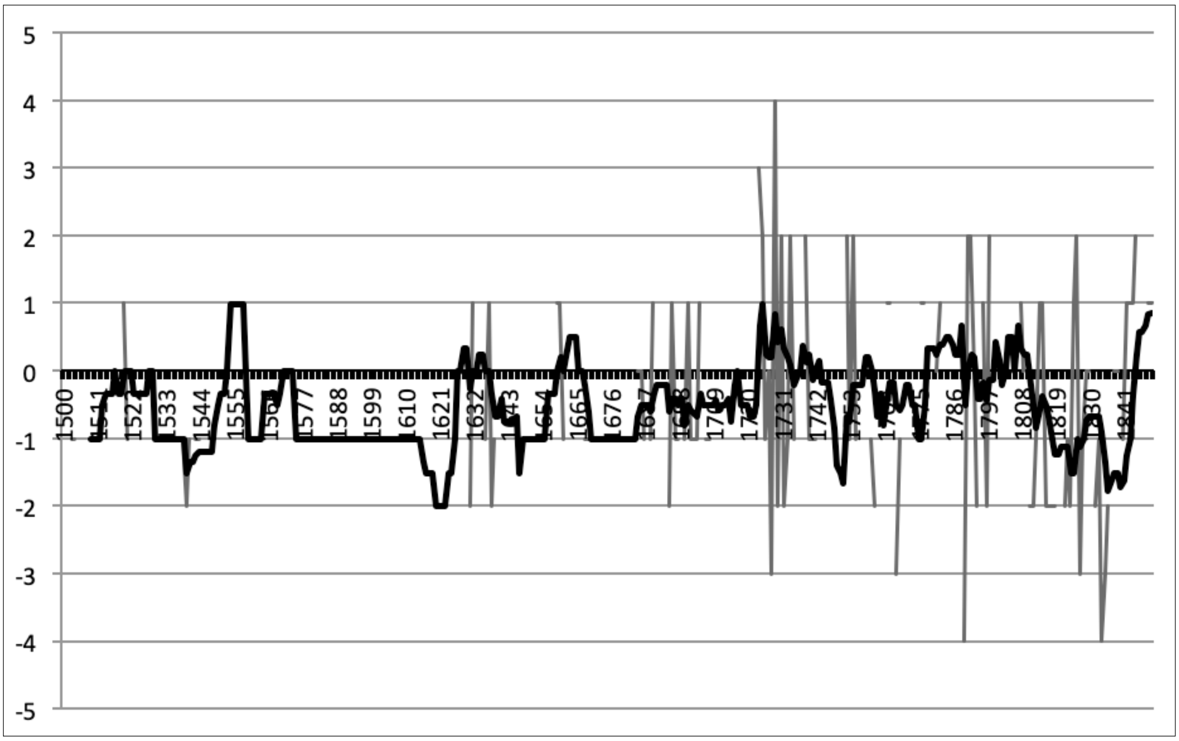

Figure 10. *Hay production (grey line) in the Carpathian Basin, and its ten-year moving average (black line). The values of the graph were calculated based on the time series of the four macro-regions (Transdanubia, the Upper Hungary, Transylvania, and the Great Hungarian Plain), and their values may vary between + and -12. The interpretation of large absolute values is unambiguous, but values around 0 may also reflect data deficiency.*

1500-1850	Hay harvest
Transdanubia	-17
Upper Hungary	-9
Transylvania	-20
Great Hungarian Plain	-17
Carpathian Basin	**-63**

Figure 11. *Hay production in macro-regions of the Carpathian Basin between 1500 and 1850, the harvest indices may vary between + and -1053, indices for the Carpathian Basin as a whole between + and -4212.*

CROP DISASTERS IN THE CARPATHIAN BASIN DURING THE LITTLE ICE AGE

The results of this study, based on time series data of grain, grape and hay harvests, indicate that the climate changes of the Little Ice Age did not cause a long-term deterioration in agricultural production in the Carpathian Basin. The following sections present how the frequency of crop disasters changed between 1500 and 1850. Crop disaster is defined as a situation where the harvest was recorded as rather poor in at least three of the four macro-regions of the Carpathian Basin (Figure 12).

Figure 12. *Years of grain, grape and hay crop catastrophes in the Carpathian Basin. The number of macro-regions affected is given in parantheses after each year.*

	Years
Grain	1718 (3), 1728 (3), 1745 (4), 1753 (3), 1790 (3), 1816 (4), 1820 (3), 1830 (3), 1845 (4), 1846 (3).
Grape quantity	1696 (3), 1697 (3), 1714 (3), 1716 (3), 1737 (3), 1744 (3), 1745 (3), 1766 (3), 1792 (3), 1813 (3), 1814 (4), 1816 (3), 1825 (3), 1836 (3), 1837 (3), 1846 (3).
Grape quality	1628 (3), 1695 (3), 1714 (3), 1716 (3), 1764 (3), 1795 (3), 1813 (4), 1825 (4), 1833 (3), 1843 (3).
Hay	1718 (3), 1728 (3), 1748 (3), 1768 (3), 1790 (4), 1827 (3), 1834 (4), 1835 (3).

Grain

In the examined three and a half centuries, we found a total of ten years in which grain yields were so poor in at least three macro-regions that we can speak of a crop disaster that affected the whole Carpathian Basin: 1718, 1728, 1745, 1753, 1790, 1816, 1820, 1830, 1845 and 1846. Ploughing and sowing were considerably hindered by wet October weather in five years: 1718, 1728, 1790, 1816 and 1845. As far as crop yields are concerned, the most significant determining climatic factor was that March became colder during the Little Ice Age. In 7 of the 10 poor yield years, March weather was considerably and characteristically cold in 1753, 1790, 1816, 1820, 1830, 1845 and 1846. Yield prospects were worsened by dry spring weather in 1718, 1728 and 1753, especially when the driest period was during May (in 1753, 1745, 1790, 1820 and 1846). Modern works of agronomy draw attention to the adverse effects of May storms on young plants, but according to historical sources, it is generally not storms but the accompanying hail that was the most damaging.

Grape

Grape harvests were analyzed separately with respect to the quantity and the quality of wine. *Modest quantity of wine:* In the examined three and a half centuries, we found sixteen years when grape harvests were small in quantity in the whole country: 1696, 1697, 1714, 1716, 1737, 1744, 1745, 1766, 1792, 1813, 1814, 1816, 1825, 1836, 1837, and 1846. The cold and wet spring weather impedes the development of grape. During the Little Ice Age, March, on several occasions, could be categorized as a winter month (1697, 1816, 1825, and 1846). Among the spring months, meteorological anomalies in April affected the quantity of wine the most, leading to a poor harvest. Anomalies in April were quite diverse; there were years with cold weather (1696, 1716, 1737, 1792, 1814, 1816, 1836, and 1846), but there were exceptionally wet (1696, 1737, 1766, and 1836) and unusually dry years as well (1744, 1792, 1813, 1825, and 1846). A cold May is especially harmful for the development of vegetation (1737, 1792, 1814, 1825, 1836, and 1837), and neither excessive precipitation (1745, 1814, and 1837) nor dryness (1825) is favourable for it. Cool (June: 1814, 1816, 1825, and 1837; July: 1696, 1813, 1816, 1825, and 1837), wet (June: 1814, 1816, 1825, and 1837; July: 1696, 1766, 1813, 1816, 1825, and 1837) or dry (June: 1836 and 1846; July: 1792, 1836, and 1846) June or July weather does not create favourabble conditions for the development of grape plants. At the end of summer, cool (1716 and 1813) and wet (1813 and 1825) weather delayed the ripening of grapes, while dryness caused other damages (1836 and 1846). The most significant threat to the ripening of grape and vintage was cold (September: 1816, 1745, and 1825; October: 1697, 1716, 1814, and 1825) and wet weather (September: 1792, 1813, and 1825; October: 1697,1792, and 1825), and lasting dryness (1836) in September and October.

Poor quality wine: Our data reveal ten vintages with poor quality throughout the country in the examined centuries of the Little Ice Age: 1628, 1695, 1714, 1716, 1764, 1795, 1813, 1825, 1833, and 1843. We have documentary sources about cold March weather (1695, 1764, 1795, 1825, 1833, and 1843), which delayed the starting of vegetation. In April, cold weather often coincided with extreme dryness (1716, 1813, and 1825), which sometimes continued in May (1825). May frosts were one of the most significant threats (1795, 1825, and 1843) to yield prospects. In the summer months, cold weather and extreme precipitation were the most significant threats to the development of grape. One of the essential features of the severe periods in the Little Ice Age was cold (June: 1695, 1764, 1825, and 1843; July: 1695, 1813, 1825, and 1843; August: 1716, 1813, and 1843) and wet (June: 1628, 1695, and 1825; July: 1628, 1695, 1813, 1825, and 1843; August: 1716, 1813, 1833, and 1843) June, July and August weather. In September, it was mostly cold (1695, 1716, 1825, 1833, and 1843) and wet (1695, 1813, 1825, 1833, and 1843) weather that could ruin yield prospects, but in one year, drought also caused problems (1795). In October, it was mostly cold (1716 and 1825) and wet (1764 and 1825) weather that caused problems in the last phase of ripening and vintage works.

Hay

In the examined three and a half centuries, there were eight disastrous years countrywide: 1718, 1728, 1748, 1768, 1790, 1827, 1834 and 1835. There was one poor hay year when no relevant historical sources are available about the weather (1790). However, we managed to obtain some essential phenological information from documentary sources of certain years which did not only mention the fact of poor crop yield but also gave a description of the weather. There were years when the mild spring weather caused considerable damage in the hay yield, as extensive flooding hindered grass growth (1728 and 1768). A permanently cold early spring could also worsen the prospects of hay yield (1748). A drought in May would predictably spoil the hay yield (1728, 1827 and 1834). This effect was even more adverse if a dry May was part of a more extended period of drought (1827 and 1834). Surprisingly, a very wet July (1768) and August (1728) could also result in the absence of aftergrass.

The weathering profile of harvest disasters in the Carpathian Basin

The worst enemy of soil preparation for autumn grains (ploughing and harrowing) has always been wet weather in modern Hungary (Figure 13). It is to be noted that 24-27,000 km^2 of the Carpathian Basin used to be a permanently or temporarily flooded area (mainly in the Great Hungarian Plain area)[35] and no agricultural work could be done in the wetlands. Thus, the areas flooded at the time of grain ploughing and sowing had to be abandoned by farmers. Furthermore, the flooded areas were also impassable,

Figure 13. *Weather effects in critical months influencing grain, grape and hay production in the Carpathian Basin. Italics: weather effects which primarily influence the quantity of harvest. Bold: weather effects which primarily influence the quality of crops.*

	Grain	Hay	Grape
October	*wet*		***cold, wet***
March	*cold*	*cold*	***cold, wet***
April			***cold, wet***
May	*dry, frost, hail*	*dry*	***cold, wet,*** *frost*
June	***hot, dry, wet***	**wet**	***cold, wet,*** *dry*
July	***wet***	*dry, wet*	***cold, wet,*** *dry*
August	***wet***	***dry, wet***	***cold, wet***
September			***cold, wet***

35 Dövényi Zoltán. 2012. *A Kárpát-medence földrajza (The Geography of the Carpathian Basin).* Akadémiai Kiadó, Budapest.

which made them valueless from a commercial point of view. A cold March, which is one of the most critical regional characteristics of the Little Ice Age in the Carpathian Basin, hindered the development of every kind of vegetation, thus worsening the yield prospects of both grains and hay. Dry weather in May could halt the development of plants, and frost and hail would damage germinating cereals. Both the quantity and the quality of grains ripening in June were decreased by both extremely hot and dry and extremely wet weather. For hay production, it was only wet weather in June that had an adverse effect, partially by making mowing more difficult, and also because rain would significantly decrease the nutritional value of the grass that had been mowed. Grain harvest in the Carpathian Basin mostly takes place in July and in the first half of August. Wet weather causes considerable damage in both the quantity and the quality of grain. According to agronomical and historical experience, aftergrass hay production can be spoiled by arid and wet weather alike. Cold weather unfavourably affects the grape harvest both from a quantitative and qualitative aspect in all seasons. Late spring frosts were especially harmful. Wet and dry weather decreased the quantity of wine throughout all seasons. Wet and dry spring weather was disadvantegous for the quality of wine. In summer and autumn, excessive precipitation had unfavourable effects on the quality of grape crop.

The most crucial difference between the Swiss-Czech and the Carpathian Basin harvest catastrophe model over the Little Ice Age is that, in the case of my study area, the role of precipitation is much more significant. In the Carpathian Basin, exceptionally wet or dry weather could cause more severe agricultural damages.

CONCLUSIONS

The environmental history reconstruction presented in this study reveals that there was no substantial decline in yields of grain, grape and hay in the Carpathian Basin during the Little Ice Age. Arable farming had rather satisfactory results in specific periods and regions there, unlike in other European regions, which suffered from climate deteriorations. In summary, the following factors may have contributed to the relative success of agriculture in the Carpathian Basin in the Little Ice Age:

Data deficiency. There were no data available about catastrophic harvest situations from the 16^{th}, and only some from the 17^{th} century. Further research may account for the deficiency of documentary sources.

Considerable regional differences. The results of the examination suggest that, out of the Carpathian Basin's four macro-regions, Transdanubia undoubtedly benefitted most from the wet climate of the Little Ice Age. The agricultural production of the Upper Hungary and the Great Hungarian Plain was moderately positive, but in Transylvania, the yields of grain and hay remained below contemporary expectations, and the average of the yields of the three agrarian cultures was also negative. The diverse landscape certainly contributed to the distinguished adaptability of the Transdanubian macro-region.

There were favourable effects of wet weather. The lack of precipitation is the most critical bottleneck in the agriculture of the Carpathian Basin. An essential feature of climate change brought about by the Little Ice Age in the study area was the increase in the quantity of precipitation. The findings suggest that the balanced performance of agriculture in the Carpathian Basin and the great success of Transdanubia could be attributed to geographical conditions, especially to the wet climatic conditions of the Little Ice Age. Wet climate played a crucial role in the low frequency of crop catastrophe situations in the 18^{th} and 19^{th} centuries (Figure 14).

Resilience was increased by mosaic farming. The mosaic structure of traditional agriculture (arable and grazing land, fruit garden, vineyard, meadow farming, and fishery) improved the resilience of local and regional economy in the Carpathian Basin. This diverse system characterized agriculture in the Carpathian Basin until the mid-19^{th} century, and the capacity of this farming system to mitigate natural hazards was much higher than in modern agriculture.

This study is the first synoptic and long term analysis of agrarian time series of the Carpathian Basin during the modern period of the Little Ice Age, and its most important finding is that agriculture in the

Figure 14. *Grain, grape and hay production in the macro-regions of the Carpathian Basin between 1500 and 1850, the harvest indices may vary between +4212 and -4212.*

	Grain	Grape quantity	Grape quality	Hay	Sum
Transdanubia	56	48	79	-17	166
Upper Hungary	9	14	-8	-9	6
Transylvania	-7	14	4	-20	-9
Great Hungarian Plain	-3	20	8	-17	8
CARPATHIAN BASIN	55	96	83	-63	171

Carpathian Basin tolerated the climatic changes of the Little Ice Age rather well. There remain a number of questions that still need to be addressed. In this study, I did not analyze the question of economic and social circumstances, because the main goal was to examine the direct impact of weather on agricultural production. The issue of harvest failure causing subsistence crisis or famine was not the subject of this study. However, I intend to consider this question in my further research.

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