4 Droughts in Historical Times in Europe, as Derived from Documentary Evidence

Rudolf Brázdil, Andrea Kiss, Ladislava Řezníčková and Mariano Barriendos

Abstract

Documentary evidence can provide high-resolution data pertaining to past droughts. This may include a wide range of sources, among them: narratives (annals, chronicles, memoirs); diaries kept by persons specifically interested in the weather; accountancy and economic-administrative archives; legal-administrative records; religious observances; letters; songs; newspapers and magazines; paintings and pictographic evidence; chronograms; epigraphic evidence; early instrumental meteorological observations; society and professional reports; and weather compilations. Most of these are generally available for many European countries. Such a variety of documentary information is sufficient to distinguish between the basic types of drought (meteorological, agricultural, hydrological and socio-economic) and reconstruct hydroclimatic conditions in the form of series of precipitation totals, drought frequencies and drought indices. This paper presents a European overview of existing documentary-based drought studies for the Mediterranean, western, central and eastern areas of Europe. Examples of outstanding European droughts are drawn from events of 1361, 1616 and 1718–1719 CE. The descriptions of European droughts and of human responses to them, pay particular attention to impacts on society, to perceptions of drought and to spiritual and ritual responses, as well as to the institutional/legal-administrative decisions and changes droughts have brought about. Perspectives for future research into historical droughts in Europe are also presented.

Keywords

Drought · Documentary data · Long-term variability · Impacts · Human responses · Europe

R. Brázdil (✉) · L. Řezníčková
Institute of Geography, Masaryk University, Brno, Czech Republic
e-mail: brazdil@sci.muni.cz

R. Brázdil · L. Řezníčková
Global Change Research Institute, Czech Academy of Sciences, Brno, Czech Republic

A. Kiss
Institute for Hydraulic Engineering and Water Resources Management, Vienna University of Technology, Vienna, Austria

A. Kiss
Department of Historical Auxiliary Sciences, Institute of History, University of Szeged, Szeged, Hungary

M. Barriendos
Department of History and Archaeology, University of Barcelona, Barcelona, Spain

J. Herget and A. Fontana (eds.), *Palaeohydrology*, Geography of the Physical Environment,
https://doi.org/10.1007/978-3-030-23315-0_4

4.1 Introduction

Droughts, together with floods, are one of the most extreme phases of the hydrologic cycle. However, "floods" may be clearly defined, while it is far more difficult to refer to "droughts" in a succinct and unambiguous way; a generally accepted definition of drought simply does not exist. They cannot be viewed as merely physical phenomena, but rather as "*the result of interplay between the natural event and the demand placed on a water supply by human-use systems*" (Wilhite and Pulwarty 2018, p. 18). Van Loon et al. (2016a, b, p. 3631) consider drought the result of "*complex interactions between meteorological anomalies, land surface processes, and human inflows, outflows, and* [water] *storage changes*". According to Svoboda and Fuchs (2018), drought is a normal, recurrent feature of climate that occurs in virtually all climatic zones.

A primary reason for drought is a reduction of precipitation in the given area compared to its "mean" or "normal" precipitation totals. This situation may occur in any place and at any time and lasts from weeks to months. Such "meteorological drought" may be enhanced by high temperatures, low relative humidity and higher wind speeds. Lack of precipitation may lead to shortages of water for growing plants, which is known as "agricultural drought". Similar effects and scale of influence may also occur in forests, be they ornamental, conservation sites or commercial. After extended meteorological drought, the deficiency in precipitation may be reflected in lack of water in streams, rivers, water reservoirs and any underground waters; such a situation constitutes "hydrological drought" (Mishra and Singh 2010 also reported in terms of "underground water drought"). The impacts of these droughts on society, and human responses to drought, may appear after some time in economic, social and political life, thus identified as "socio-economic drought" (Heim 2002; Wilhite and Pulwarty 2018).

A plethora of drought indices have been developed in order to describe droughts and their various environmental effects (e.g. Heim 2000, 2002; Svoboda and Fuchs 2018). Among them, the Standardised Precipitation Index (SPI) (McKee et al. 1993), Standardised Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al. 2010; Beguería et al. 2014) and the Palmer Drought Severity Index (PDSI) (Palmer 1965; Dai 2011) are the most frequently used. Since they are calculated from instrumental meteorological measurements of air temperature and precipitation, series of them for Europe may benefit from the relatively large number of long-term meteorological observations that have been made (e.g. Camuffo and Jones 2002; van der Schrier et al. 2007; Todd et al. 2013; Haslinger and Blöschl 2017).

There exist several different types of proxies that may serve to extend our knowledge of drought into the pre-instrumental period (see PAGES Hydro2k Consortium 2017). Documentary evidence is one of them, used as the basic source of data in historical climatology (Brázdil et al. 2005, 2010; White et al. 2018), and it plays an important role. Such information is derived from a range of written sources that offer high-resolution qualitative or quantitative data, concerning droughts and their impacts. These sources have been used to create long-term drought chronologies (e.g. Lyakhov 1984; Martín-Vide and Barriendos Vallvé 1995; Piervitali and Colacino 2001; Domínguez-Castro et al. 2008; Tejedor et al. 2018), sometimes combined with droughts from the instrumental period (e.g. Brázdil et al. 2013, 2016; Noone et al. 2017), and to investigate certain important past drought events in detail, including their human impacts and responses to them (e.g. Munzar 2004; Wetter et al. 2014; Kiss and Nikolić 2015; Roggenkamp and Herget 2015; Kiss 2017, 2019; Brázdil et al. 2019).

This chapter of the book presents the state-of-the-art in the study of the spatiotemporal variability of droughts, their impacts and responses to them in Europe (for the worldwide scale, *see* Brázdil et al. 2018). It describes the types of documentary sources that relate to droughts, the methods of drought reconstruction and long-term drought variability, providing examples of outstanding droughts, drought impacts and human responses. It gleans what can be

learned from historical droughts and applied to recent and future droughts, and finally formulates perspectives for future research into historical droughts.

4.2 Documentary Evidence

Documentary evidence consists of any material object that bears or contains any man-made information contemporaneous with the culture of its time (e.g. chronicle, manuscript, financial accounts, "books of memory") and structural records (on bridges, commemorative stones, etc.). Many such records may also contain information about the weather or related phenomena, including droughts. The main individual types of documentary sources are listed below. Each type is generally characterised with respect to the data within it, by references addressing such types of data, and finally by example(s) of records that serve to gather more a detailed idea of the context in which the information came into existence. The following main types of documentary evidence may be used for the study of droughts in Europe:

(i) **narrative sources**

Droughts and their impacts are among the climatic phenomena that appear in several types of narrative source (annals, chronicles, "books of memory" and inscriptions among them). Together, they constitute some of the main sources of documentary data in historical climatology. Records were kept to preserve memories of outstanding events or phenomena, particularly those that involved loss of human lives, material damage and possible socio-economic effects on society in general.

Examples The first annals of Novgorod (Russia) (*Novgorodskaya pervaya letopis starshego i mladshego izvoda*) reported a drought in AD 1471 (Shmakin et al. 2013, p. 53): "*So it was that in Novgorod District no droplet of rain fell out of the sky to the earth for the whole summer from the month of May to September, and* [from] *the heat of the sun all the earth and marshes dried up*. […] [The river] *Lovat' dried out because drought and doom were massive in that year*." The Congregational Church Book of Guestwick in the English county of Norfolk includes a drought in its record for 26 August 1719 (Kington 1980, p. 125): "[…] *sometime was set apart for prayer to seek God on account of the great heat and extreme drought. Such a summer for heat in the months of May, June, July and August was hardly known in the memory of any man living – the pastures scorched, the pits and ponds dried up, the poor beasts of the fields pining for want of water* […] *the season is very threatening for man and beast.* […] *Fevers and deaths* [have been] *many*".

(ii) **diaries**

Personal and private records often include some accounts of the weather, recorded by their keepers for a variety of reasons in ephemerides, calendars, work-related and personal diaries. Weather diaries were also kept, containing more-or-less systematic daily visual weather records (e.g. Symons 1891). These may be supplemented by detailed descriptions of certain weather extremes or by monthly or annual weather summaries in which, as well as short notes related to dry weather on individual days, longer drought episodes may be described.

Examples Gregorio Susanna, in his diary for 1760–1761 in Catanzaro (Italy) used his end-of-year record for 31 December 1760 to summarise drought impacts for that year (Diodato and Bellocchi 2011, p. 192): "*Food supplies have been very low because of the great drought that never seems to stop. Decimating all fruits, with grapes also destined to perish, and very little must and wheat and oil* […] *Drought has occurred because there has been no rain up to late December, the countryside is arid and bare of grass, and almost all the cattle are dead. Starvation threatens; much prayer is in order.* […]". The diary of Nicoll (1836, p. 138), a Scot living in Edinburgh, described the great summer

drought of 1654 (see also Dawson 2009): "*All this summer and harvest, in the year of Our Lord 1654, there occurred an exceedingly great drought though all parts of* [the region of] *Lothian, but especially around Edinburgh, where all the wells dried out, to the extent that the inhabitants could not get enough to process their food, and water could not be found. Despite this, all the west of the country, from Glasgow to the Rhinns of Galloway had rain and wet as usual, or more. All this time, and since, great drought* [has] *continued in all the wells of Edinburgh, and throughout the land of Lothian, so much so that the people of Edinburgh have been forced to venture out for a* [Scottish] *mile* [1.8 km] *before they can get any clean water, either for the brewing of ale or beer, or for cooking food in a pot*".

(iii) **financial and economic-administrative records**

Particular documents (mainly accountancy sheets and letters of application) prepared at various levels of governmental or state administration, which may obtain some drought-related information, are important financial and economic-administrative sources. One type of example may be found in documents related to the rebate of taxes, when agricultural production had been significantly damaged by hydro-meteorological extremes (e.g. Brázdil et al. 2012b), or requests for postponement of debt payment, tax exemption or financial support. Severe droughts could give rise to all of these.

Example The accounts covering the incomes of the bishop of Eger (Hungary) report the 1507 drought in these terms (Kovács 1992, p. 233): "*On the given date* [15 July 1507] *the above-mentioned tithes of the citizens of Heperyes* [Prešov, Slovakia] *were to be sold and leased for 84 fl.* [florins]*, as in this year a great drought destroyed their harvest* etc.*; from this* [sum] *they now render 42 fl., and the other 42 fl. is bound over to be rendered by the forthcoming St. Nicolas day* [6 December]".

(iv) **legal-administrative evidence**

Documentary sources recording the flow of "application–decision" between the various levels of public administration show a range of responses to the stresses produced by drought, exploring technical, legal alternatives to improve water resources.

Examples The Duke of Dalmatia gave permission to the Morlachs (the Black Vlach pastoral community) to stay within the territory of Trogir town until 24 April 1362 "[…] *because great drought and difficult times are now so threatening, and because of the tenderness of the lambs of the Morlachs, who are at present living at a great distance from their homeland, in order to avoid enormous loss* […]" (Smičiklas et al. 1915, p. 211). Another typical example comes from Spain. In Catalonia, after a long drought period, the Barcelona City Council authorities sent an official communication to the Kingdom Council on 28 August 1627 requesting authorisation to build a channel for river transfer from the River Llobregat to the Barcelona area to alleviate and diminish drought "*especially in times when heaven threatens the secrets of God with such droughts on earth*" (Dietari de l'Antic Consell Barceloní, vol. 10, p. 181).

(v) **religious sources**

Prayer and processions of religious entreaty are widespread and traditional religious responses to drought events. Typical of the Roman Catholic Church, they were organised to beseech God for rain (*pro pluvia* rogations) or for Him to stop wet/stormy periods (*pro serenitate* rogations), in order to avoid damage to agricultural crops. These processions were often mentioned in the records of local governments (Fig. 4.1). Particularly in the regions that were part of the


GOIGS
DE SANT
LLAURADOR, PATRÓ
LES SAGRADES RELÍQUIES DEL QUAL PERPINYÀ I EN L'ESGLÉSIA DE
Sa festa
Boixos d'En MARIAN RIBAS
A LLAOR
GALDERIC
DELS PAGESOS CATALANS
ES VENEREN EN LA CATEDRAL DE ST. PAU DEL CAMP, DE BARCELONA
16 octubre
Lletra i música del Mestre JOAN LLONGUERES
Puix que Déu son poder mostra, Galderic, amb els seus Sants, Beneïu la Terra nostra i els Pagesos catalans!
Per model Jesús prenieu en la vostra joventut. Cada sole que Vós obrieu, un camí amb nova virtut. Amb el Sol que us brilla al rostre feu madurs els fruits tardans. &
Llaurador com vostre pare, us va fer nostre Senyor. De bondats, la Verge Mare plantà en Vós bona llavor. A la llum que'l Crist us mostra convertiu vostres germans. &
Quan el Comte de Cerdanya sos gran temple edificà, del cos vostre, a la muntanya, les Relíquies va deixà. Vostra glòria al punt demostra, Déu, obrant miracles grans. &
En venir la maltempsada, gloriós Sant Galderic, de tempesta i pedregada sereu Vós el nostre abric. La fe viva serà el sostre; les pregàries, els pilans. &
Si la terra és endurida i l'eixut arriba al cor, que la pluja benaïda tot ho ablani amb sa dolçor. Feu que el plò ens amari el rostre perquè els precs no sien vans. &
Si'l bon Déu l'hora ens envia de la gran tribulació nostre empar i nostre guia siau sempre, brau Patró. Els camins, per voler vostre, tots se'ns tornin breus i plans. &
Feu la terra generosa i combleu nostres sembrats; l'olivera feu fruitosa i salveu nostres vinyats. L'abundor del poder vostre broilli en flors i fruits i cants. &
A tot mal declarant guerra, amb constància i sant anhel, conreant la nostra Terra, Vós sabéreu guanyar'l Cel. Gent d'arreu als peus se us postra deslliurada de tirans. &
Perquè ens guiï la llum vostra com fruit d'or que ens ve a les mans, Beneïu la Terra nostra i els Pagesos catalans!
V/ Ora pro nobis, beate Gauderice.
R/ Ut digni efficiamur promissionibus Christi.
OREMUS
Deus, qui beatum Gaudericum, confessorem tuum, contra pestilentiam et terræ sterilitatem protectorem dedisti, concede ut ejus meritis et intercessione a labe peccati liberemur in terris, et abundantia gloriæ tuæ fruamur in cælis. Per Christum Dominum nostrum... Amen.
Moderato.
Puix que Déu son poder mostra, Galde-ric, amb els seus Sants,
Tornada.
Be-ne-ïu la Te-rra nos-tra i els pa-ge-sos ca-ta-lans!
Mogut.
Per mo-del Je-sús pre-nì-eu en la vostra jo-ven-
-tut. Ca-da sole que Vós o-bri-eu un ca-mí amb nova vir-
-tut. Amb el Sol que us brilla al rostre feu madurs els fruits tardans.
2.ª ÈPOCA
L'escreix de la venda serà per a auxiliar els pobres vergonyants. Podrà informar el P. Antoni Maria de Barcelona, Església de la Mare de Déu de l'Ajuda, Barcelona.
Sèrie 2 P
Número
351
Octubre 1927
AMB LLICÈNCIA ECLESIÀSTICA

Fig. 4.1 "Goig" of St. Galderic the Farmer (1846 edition). St. Galderic was patron to Catalan farmers, with special focus on drought events in northern Catalonia (Spain). A "Goig" is a text for songs and prayers during rogation ceremonies. A public assistant took this sheet to ensure that the various songs and prayers appropriate to the ceremony were performed perfectly, to the letter (Anonymous 1927)

Hispanic Kingdom, such rogations have proven very useful proxies for droughts events (e.g. Martín-Vide and Barriendos Vallvé 1995; Barriendos 1997, 2005; Domínguez-Castro et al. 2008, 2010, 2012; Tejedor et al. 2018).

Example Barcelona City Council sent an official request to the Cathedral Chapter on 8 November 1715 to start drought rogation ceremonies: "*This day, the City Council of Barcelona sends the deputy of present House with a message to Most Illustrious Chapter of the Cathedral, pleading that, in view of the need for water for the farmland at the present time, an order be served to perform the usual rogations to obtain from God the grace to give us the water we need: And during the 10th day of the aforementioned month the Most Illustrious Chapter came to the present House, confirming to the Board of Illustrious*

Administrators that the Illustrious Chapter had accepted the request, and a 'Collecta pro pluvia' would be convoked and displayed, which is the first step usually taken by the Church" (Dietari de l'Antic Consell Barceloní, vol. 44, fol. 26).

(vi) letters

Letters of a private or institutional character contain information on droughts if a corresponding dry episode concerned the writer in some way. Such communications may contain not only information related to dry weather, but also already-observed impacts of droughts as well as a broader perspective and anticipated socio-economic consequences. An example of the systematic use of private correspondence for climate reconstruction is a paper made by Rodrigo et al. (1998), using Jesuit letters exchanged in Castille (Spain) in the 1634–1648 period, or precipitation reconstruction for Zafra (Spain) by Fernández-Fernández et al. (2015) based on weekly letters from 1750 to 1840.

Example Martin Škvorecký, an administrator at Pacov (Czech Republic), reported to Lady Zuzana Černínová in a letter dated 16 May 1638: "*God's* [harvest] *of winter rye and wheat becoming burned due to extremely hot and dry weather, spring grain similarly. If this continues* [any] *longer, everything in the fields will mature without profit. The grass also appears bad and cannot grow due to great drought*." (Teplý 1928, p. 105).

(vii) songs

Hydro-meteorological events involving loss of lives and great damage, as in the case of floods or flash floods, became themes for the folk songs and broadsheets of the marketplace and shopkeepers. Although drought is a phenomenon without such direct dramatic impacts and consequences, dry episodes also appeared in song form. For example, the severe drought of 1678 in Bohemia inspired the song "A Key to the Rain, or a New Song for a Time of Drought" (*Klíč od deště aneb Nová píseň v čas sucha*) by Václav Šťastný František Rambek, first published in Prague in 1678 and in a second edition a year later (Brázdil and Trnka 2015).

Example "A Song for Want of Rain" (*Píseň za déšť potřebný*), from a manuscript of Antonín Štěpán, a wealthy citizen of Pelhřimov (Czech Republic), consists of 28 verses and is of a supplicatory character. It related to a severe drought in 1790 (Martínková 2005). The second verse of the song provides an insight into its nature (ibid., p. 142): "*For the sake of Your thirst on your cross, have mercy, /Oh Lord, /Water the earth, because* [it] *is thirsty, for it has become cracked /And parched. /Due to this all the crops of the earth /For want of rainwater /*[they] *vanish and perish. /May God grant that* [they] *die not*".

(viii) newspapers and magazines

Weather and climatic extremes appear frequently in newspapers and magazines. Reports of droughts usually take the form of descriptions of the human hardships arising out of lack of water for various aspects of everyday life (reduced water sources, crop failure or bad harvest increases in prices, famine, etc.) or by expression of anticipated negative impacts in the near future. An example of the use of newspaper reports for creation of climate proxies appears as a paper by Gallego et al. (2008), and for compilation of droughts for the island of Ireland as a paper by Murphy et al. (2017).

Examples The French newspaper/journal *Mercure* (1615, pp. 414–415) published an article under the title "*Cold weather, hot weather, drought, and fire ruins this year* [1615] *in Germany & Hungary*". The Austrian newspaper *Wiener Zeitung* (No. 59, 24 July 1748, non-paginated) reported from a Poznań (Poland) correspondent, for 10 July 1748: "*The drought continues even further; it has not rained at all for four weeks, and the cereals of the ground in various areas are completely scorched.*" In 1790 in Vienna (Austria), "*After an almost three-month-long drought, on the 25th* [June] *a great thunderstorm occurred at 5 o'clock in the morning and the fertile but cold rain continued*

Fig. 4.2 A '*pro pluvia'* rogation procession in Paris during the drought of 1694 (Bibliothèque nationale de France, 62 C 2000L; see also Garnier et al. 2015)

for two days …" (*Wiener Zeitung*, No. 52, 30 June 1790, p. 1703).

(ix) **paintings and pictographic evidence**

Compared to the floods, windstorms and severe winters that usually attracted great public attention, droughts and their effects only seldom appear in paintings and pictographic evidence.

Examples Although pictures of processions appear quite often, those related directly to drought are very scarce. One of them is an image of a *pro pluvia* procession from Paris (France) related to drought in 1694 (Fig. 4.2). Another such rare example is a painting titled "Prayer in Time of Drought" by the Russian artist Grigoryi Grigorievich Myasoyedov (1834–1911), dated to between 1878 and 1881, which shows poor people praying for rain, one of the traditional responses to drought (see Fig. 4.8 in Brázdil et al. 2018).

(x) **chronograms**

Chronograms consist of records painted or carved into stone statues, walls or the timber of buildings, but also recorded in chronicles or other narrative sources, that commemorate any significant event (e.g. flood, drought) or years during which people have been heavily affected (e.g., loss of lives, damage). They were quite common in eighteenth-century western and central Europe and were frequently written in Latin or German verse. In a chronogram, selected letters are interpreted as Roman figures (in capital letters or in bold), indicating the year of an event.

Example Hieronymus Haura, a member of the Augustinian order in Brno (Czech Republic),

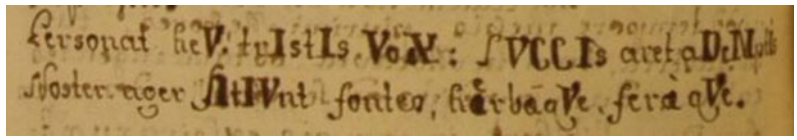

Fig. 4.3 Cut-out of chronogram related to drought in 1746 in the Czech Lands, from the chronicle of Hieronymus Haura

reported a drought of 1746 in his chronicle thus (Fig. 4.3): "Personat he**V**! tu**I**st**I**s **V**o**X**: S**V**C**C**I**s** aret a**D**e**M**pt**I**s /Noster ager s**I**t**IV**nt fontes, herbaeq**V**e, feraeq**V**e." (i.e. It resounds! Oh, woe betide, such a voice: The drought desiccated, it eats up our fields, the springs are thirsty, the plants and animals, too.) The year 1746 follows from the sum of the highlighted Roman figures: V + I + I + V + X + V + C + C + I + D + M + I + I + I + V + V + V (5 + 1 + 1 + 5 + 10 + 5 + 100 + 100 + 1 + 500 + 1000 + 1 + 1 + 1 + 5 + 5 + 5 = 1746) (Brázdil and Trnka 2015).

(xi) epigraphic evidence

Protrusions of bedrock located in river beds have been used as indicators of low-water levels, shown by corresponding year-marks (although the reliability of the marks has to be proved). As signs of long-term hydrological drought, often accompanied by bad harvests and subsequent shortages, they are also known as "hunger stones". Such stones have been reported, for example, for the River Elbe at Děčín (Brázdil and Kotyza 1995), for other places on this river (Elleder 2016) and for the River Danube at Budapest (Palotay et al. 2012).

Example Low-water levels in the River Rhine were recorded on the "Laufenstein" stone in Laufenburg (Germany/Switzerland) (Fig. 4.4a). Walter (1901) reports, as well as visible marks for the years 1541, 1750, 1823, 1858, 1891 and 1893 (Fig. 4.4b), a further four uncertain years: 1692, 1764, 1797 and 1848 (Pfister et al. 2006 consider three of them as correct, with a one-digit correction each: 1672 instead of 1692, 1714 instead of 1764, and 1767 instead of 1797).

(xii) early instrumental observations

Those instrumental meteorological observations that began before the establishment of national meteorological institutes to organise systematic

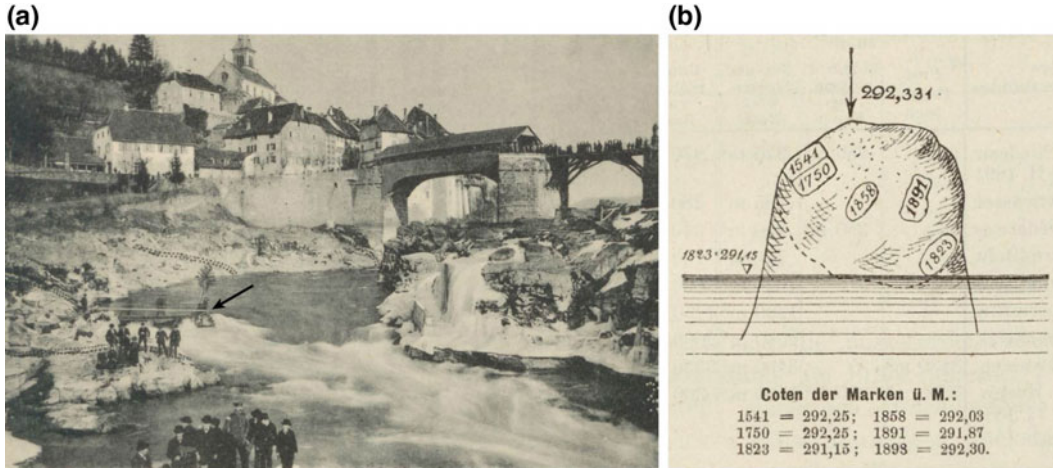

Fig. 4.4 **a** The "Laufenstein" stone (identified by arrow) on the River Rhine at Laufenburg (January 1891); **b** the water marks on "Laufenstein": heights in m asl (Walter 1901)

Sammlung
Von
Natur- und Medicin-
Wie auch
hierzu gehörigen Kunst- und Literatur-.
Geschichten,
So sich
An. 1717. in den 3. Sommer-Monaten
In Schlesien und andern Ländern begeben.
Welcher Gestalt nemlich:
1) Die Veränderung des Gewitters von Tage zu Tage und von Zeit zu Zeit. 2) Land- und Witterungs-Seuchen, von Monat zu Monat, nach dem Einfluß Lufft und Wetters. 3) Zu- und Mißwachs von Feld-Wald- und Garten-Früchten, auch allerhand animalischem Proventu, in allerley Ländern Europens von einer Jahrs-Zeit zur andern bemercket worden: Wie nicht weniger 4) was vor einzelne eclatante natürliche Begebenheiten am Firmament, in der Lufft, auf und unter der Erde, im Wasser, an Menschen und Vieh: auch 5) was vor neue physicalische und medicinische Erfindungen diese Zeit über hervorgebracht und bekant worden: und denn 6) was in re literaria Physico-Medica veränderliches vorgefallen.
Alles in ordentlicher Connexion und mit allerley Reflexions
Aus vielfältiger Correspondenz, und andern Relationibus, so wie grossen Theils aus eigener Erfahrung zusammen gelesen;
Und
Als ein Versuch ans Licht gestellet
Von
Einigen Breßlauischen Medicis.
Sommer-Quartal 1717.
Breßlau,
Bey Michael Hubert, M DCC XVIII.

Fig. 4.5 Title page of the first volume of the Breslau network series with meteorological observations for the summer quarter of 1717

observations in established formal station networks are generally considered "early instrumental observations". At the pan-European level, they arose out of the personal interests of certain individuals [e.g. the Medici Network organised by Grand Duke Ferdinand II de'Medici and his brother Prince Leopold in Italy, with measurements from 1654 to 1670 (Camuffo and Bertolin 2012), and the Breslau Network organised by the physician Johann Kanold in Breslau, recently Polish Wrocław, with published meteorological measurements in 1717–1730 (Fig. 4.5; e.g. Lüdecke 2010)] or some institutes or societies [e.g. *Societas Meteorologica Palatina*, organised by the German Scientific Society at Mannheim, with published meteorological measurements from 1781 to 1792 (Kington 1974)]. Early instrumental observations have been systematically elaborated, for example, for Poland (Przybylak 2010), the Czech Republic (Brázdil et al.

2012a), Portugal (Alcoforado et al. 2012) and Spain (Domínguez-Castro et al. 2014b). As well as measured temperatures and precipitation totals, they may also contain remarks or descriptions concerning dry weather or droughts.

Example With reference to the drought of 1718, reported from Budapest (Hungary) as one of places covered by the Breslau Network (Kanold 1719, p. 1162): "[…] *from the 14th of June, it was reported that, because of the great heat, misery was greatly aggravated there, and the fields and meadows were heavily distressed, so that the marshes and swamps dried out.* […] *because of the lack of water, people were obliged, with their cattle, to move partly to the* [River] *Danube and partly the* [River] *Tisza so that* [the animals] *would not die of thirst* […]."

(xiii) society and professional reports

Droughts and their impacts may also appear in the reports/publications of various learned and other societies engaged in agricultural and forestry production. Such publications became particularly widespread in Europe in the eighteenth–nineteenth centuries. For example, the I. R. Patriotic-Economic Society in Bohemia organised its own network of meteorological and phenological stations and published observations and annual reports of agricultural production (1822–1845), including forestry management reports as well from 1828 onwards (Brázdil et al. 2011; Bělínová and Brázdil 2012). Among individual professional reports, the paper "A note concerning the physical-meteorological causes of constant droughts in Murcia and Almería" by Manuel Rico Sinobas, published in Madrid in 1851, is one example of a professional report, possibly the first scientific approach to drought in Spain, considering not only atmospheric processes, but also deforestation impacting on soil moisture, land use changes, etc.

Example A recent drought is reflected in a report of the French "*Société royale de medicine*" in Paris for 18 September 1781 (Réflexions 1781, p. 1): "*Diseases have occurred in the capital and its surroundings which, although not an epidemic proper, have nevertheless acquired a somewhat general character, which must be attributed to the heat and excessive drought that have made this season remarkable especially for* [we] *"Medics" whose role is to compare the phenomena that nature presents to us with the changes which these phenomena produce,* [and] *present to us in our system*".

(xiv) weather compilations

Although such compilations cannot be treated as a separate source type, their widespread application renders as it is necessary to mention such data and text collections in some detail. There exists quite a long tradition of collecting and publishing weather-related (including drought-related) reports in Europe. Particularly worthy of mention are the compilations by Weikinn (1958–2002) for Europe and by Buisman (1995–2006) for the Low countries. Because these compilations gather data from historical sources of varying quality, usually without critical evaluation of sources, their practical use may be biased, producing misleading or even erroneous results (for criticisms of compilations see e.g. Bell and Ogilvie 1978). Even compilations prepared with a source-critical approach (e.g. Malewicz 1980; Alexandre 1987) may require additional source analysis.

In order to preserve documentary data, usually collected at national levels, then prepare them for the analysis using computers, as well as to make them accessible to further researchers, some databases (also containing drought-related information) have been created in Europe. Among the foremost are the Euro-Climhist database, started by C. Pfister in Bern (Switzerland) (http://www.euroclimhist.unibe.ch) and the Tambora database, started by R. Glaser in Freiburg (Germany) (https://www.tambora.org; Riemann et al. 2015).

4.3 Methods of Drought Reconstruction

4.3.1 Interpretation of Droughts from Documentary Data

As partly follows from examples of reporting drought in documentary sources (see Sect. 4.2), the following indicators of individual types of drought may be found in documentary evidence (see also Brázdil et al. 2018):

(i) **meteorological drought**

Meteorological drought is indicated by reports describing, for example, a lack of rain, drought, dry weather, hot and dry weather, periods without rain, "rain that hardly moistened the soil", "rain needed", drought "beyond living memory" and dust on the roads.

(ii) **agricultural drought**

The occurrence of agricultural drought is made evident, for example, by information related to complete failure of crops or bad harvests, lack of seed, lack of feed for livestock, cracked earth, dried-out pastures, limited availability of straw, conditions impossible for soil cultivation or sowing (Fig. 4.6), tearing grain by hand rather than reaping, the occurrence of outbreaks of caterpillars, mice and other pests or damage to crops.

(iii) **hydrological drought**

The occurrence of hydrological drought can be derived, for example, from information reporting low-water levels in rivers and the appearance of hunger stones, standing and/or green water in rivers, crossing large rivers "barefoot" or with wagons, springs, wells, fountains, brooks, streams and fish cultivation ponds drying out, lack of water for people and animals, sale of water, watermills out of operation, cessation of river transport or lack of water for extinguishing fires.

(iv) **socio-economic drought**

Among the indicators of socio-economic drought that may appear in documentary evidence are, for example, information concerning bad harvests, food shortages, price rises (grain and other

Fig. 4.6 Drought had a negative influence not only on the growth of field crops, but also on soil cultivation (ploughing, sowing): a ploughman by Matouš Ornys z Linperka in the Třebenice hymn book, 1577–1578 (*Photo* O. Kotyza archive)

crops), poverty, debt, distress, famine, requests for tax reduction, administrative measures, raised awareness of alleged witchcraft and other rain-related ritual practices, human mortality, disease, epidemics, emigration, fires consuming both buildings and forests and the sale of livestock at well below normal market prices. However, because of the intrinsic complication of this suite of effects, the triggers of drought and its role in socio-economic processes or phenomena have to be clearly indicated or proved.

The overview of basic drought-related documentary sources in Sect. 4.2 makes it clear that work with such evidence requires a careful and critical approach to the collection, interpretation and elaboration of drought information from prevailingly qualitative data. The following steps appear the most important: (i) use of information about drought-related events experienced by the author of the records (primary sources); (ii) a critical approach to documentary sources with respect to their origin (contemporary or non-contemporary; local or foreign) and the contemporaneous socio-economic situation; (iii) temporal and spatial cross-checking of various data; (iv) careful meteorological interpretation and analysis of the evidence available, supported by knowledge of recent climatic patterns in the area studied (for more details see, for example, Brázdil et al. 2005, 2010).

4.3.2 Drought Reconstructions

A range of statistical approaches to quantitative climatic reconstruction (particularly for temperatures and precipitation) have been applied in historical climatology in recent decades. For some time, these were targets for a degree of criticism from scientists not involved in the historical-climatological community. This changed when standard palaeoclimatological methods of climate reconstruction began to be applied to historical-climatological research (see e.g. Leijonhufvud et al. 2008, 2010; Dobrovolný et al. 2009, 2010).

Three types of documentary-based reconstructions of dry patterns, drought characteristics and drought indices may be categorised:

(i) **series of precipitation indices**

Series of precipitation indices may be employed to analyse drier and wetter periods. Depending on the density and quality of the documentary evidence, appropriate precipitation indices may be created. For example, a 3-degree scale may classify months as dry (−1), normal (0) or wet (1), while a 7-degree scale may break down as extremely dry (−3), very dry (−2), dry (−1), normal (0), wet (1), very wet (2) and extremely wet (3). Seasonal (winter DJF, spring MAM, summer JJA, autumn SON) or annual values are obtained as sums of indices for the corresponding months (e.g. Pfister 1992). Applying standard palaeoclimatological methods, series of precipitation indices may then be used for reconstruction of precipitation totals (e.g. Dobrovolný et al. 2015).

(ii) **series of drought frequency or drought proxies**

Various approaches have been used to create series of drought frequencies and drought proxies:

- combination of several consecutive months classified as dry, very dry or extremely dry (e.g. at least two such consecutive months were considered as a drought episode by Brázdil et al. 2013)
- Drought Rogation Index, taking into account the five levels of drought intensity/duration according to the hierarchical system of religious rogation ceremonies (e.g. Martín-Vide and Barriendos Vallvé 1995; Barriendos 1997)
- Drought Index (DI): DI = 1 for meteorological drought associated with agricultural drought in at least in two places (central-southern Italy), otherwise DI = 0; if at least three successive months could be classified as DI = 1, this is considered a drought year (Diodato and Bellocchi 2011).

(iii) **series of drought indices**

Reconstructed monthly series of mean temperatures and precipitation totals for the same area can be further used for calculations of series of drought indices. Temperature series for central Europe (Dobrovolný et al. 2010) and precipitation series for the Czech Lands (Dobrovolný et al. 2015) were used to calculate series of seasonal, summer half-year and annual SPI, SPEI, Z-index and PDSI from AD 1501 onwards for the Czech Lands by Brázdil et al. (2016). Further, phenological series sensitive to drought can be used for calculation of drought indices, as has been demonstrated for April–August SPEI reconstructed from grape harvest dates for the Bohemian wine-growing region from AD 1499 onwards by Možný et al. (2016).

4.4 Droughts in Historical Times in Europe

4.4.1 Spatiotemporal Overview of the Long-Term Variability of Droughts

The results of long-term spatiotemporal variability of droughts, based either fully or partly on documentary evidence, are summarised below by European region. The northern Europe region is not included due to a current absence of documentary-based, long-term drought series.

4.4.1.1 The Mediterranean

Although several series of precipitation indices or precipitation totals have been reconstructed for the Mediterranean (Rodrigo et al. 1995, 1999; Diodato 2007; Rodrigo 2008; Rodrigo and Barriendos 2008), *pro pluvia* rogations remain the basic source of information for Spain (e.g. Tejedor et al. 2018) and also, in part, for Portugal (Fragoso et al. 2018) and Italy (Piervitali and Colacino 2001). Drought fluctuations in the Mediterranean may be described in terms of different types of documentary-based, drought-related series:

(a) annual values of the weighted Drought Rogation Index for the Catalonian coast of north-eastern Iberia, 1501–1860 (Martín--Vide and Barriendos Vallvé 1995; Oliva et al. 2018)
(b) annual Drought Weighted Index Sums (DWISs) for central-southern Italy, 1501–2000 (Diodato and Bellocchi 2011)
(c) a series of 50 *pro pluvia* processions in Erice, Western Sicily, 1565–1915 (Piervitali and Colacino 2001).

It follows from Fig. 4.7 that it is difficult to find any common features in the series of decadal fluctuations of Mediterranean droughts employed, a factor reflected in statistically insignificant correlation coefficients among all three series. Some coherence is apparent for the driest decades between 1541 and 1570 in Spain, based on rogation indices (Fig. 4.7a) and Italian DWISs; in Italian series, the decades 1541–1550 and 1791–1800 were the driest (Fig. 4.7b). On the other hand, four *pro pluvia* processions occurred in Western Sicily in 1661–1670, while in the other decades, their frequency was between zero and three (Fig. 4.7c).

The drought information appearing in Fig. 4.7 may be extended back to before AD 1500 by surviving Byzantine documentary sources for the eastern Mediterranean and the Middle East. Based on these, Telelis (2008) detected a higher frequency of droughts (at least two dry events of extended duration per decade as inclusion criterion) in AD 360–390, 530–580, 690–720 and 1090–1200 for the temperate semi-arid regions, in AD 320–340, 390–420, 450–480, 510–560, 600–630, 740–770, 1040–1070, 1130–1200 and 1290–1320 for the desert region, and in AD 560–590, 740–790, 1020–1050, 1070–1110 and 1140–1160 for the Mediterranean regions. Domínguez-Castro et al. (2014a), analysing 11 Islamic chronicles with high temporal and spatial resolution for Iberia in the AD 711–1010 period, identified three severe droughts in 748–754 (drought reported each year), 812–823 (droughts with long famines) and 867–879 (droughts with references to famine).

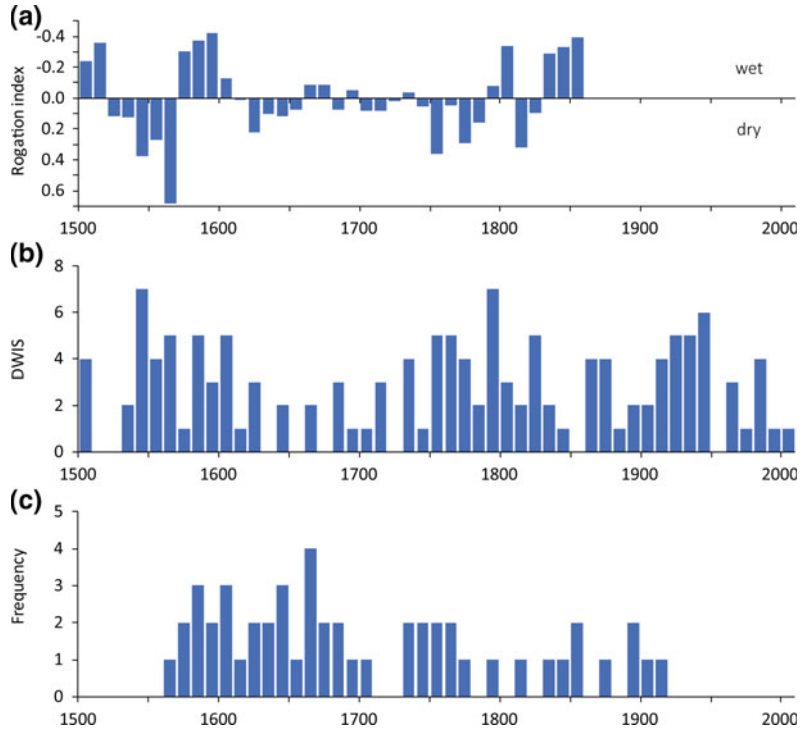

Fig. 4.7 Fluctuations in decadal values of drought-related series in the Mediterranean: **a** means of the weighted Drought Rogation Index for the Catalonian coast of north-eastern Iberia, 1501–1860 (Martín-Vide and Barriendos Vallvé 1995; Oliva et al. 2018); **b** Drought Weighted Index Sums (DWISs) for central-southern Italy, 1501–2000 (Diodato and Bellocchi 2011); **c** frequency of *pro pluvia* processions in Erice, Western Sicily, 1565–1915 (Piervitali and Colacino 2001)

4.4.1.2 Western Europe

Drought patterns for the past millennium in western Europe are covered by a number of types of documentary-based, drought-related series:

(i) annual frequencies of unusually dry JJA months in western Europe derived from various chronicle sources, 1000–1419 (Alexandre 1987)

(ii) "precipitation scores"—dry patterns identified for England by monthly scores of −2 (slightly more dry than normal) and −3 (particularly dry), although with many missing data (June and July are the most complete), 1200–1439 (Ogilvie and Farmer 1997)

(iii) a series of 40 droughts for the UK and 68 droughts for the Ile-de-France region (Paris and surroundings), 1500–2014, with severity classified according to the Historical Severity Drought Scale (HSDS), graded from 1 to 5 (Garnier 2019)

(iv) a drought catalogue for the island of Ireland represented by SPI-12 values (based on documentary data before 1850), 1765–2015 (Noone et al. 2017).

As Fig. 4.8a–b indicate, each of the three decades with the highest frequencies of dry JJA months in series for western Europe and England agree in 1371–1380 and 1411–1420 and differ in 1241–1250 (only western Europe) and 1301–1310 (only England). While frequencies of droughts in the UK from AD 1500 fluctuate only between zero and two (Fig. 4.8c), droughts for the Ile-de-France region indicate a very distinct peak between 1691 and 1740 (with five droughts in 1701–1710 and four in the following decade), but no such events are apparent in the subsequent 30 years after 1740 (Fig. 4.8d). SPI-12 values for the island of Ireland (Fig. 4.8e) indicate that the 1801–1810 decade was the driest, followed by another drier period between 1831 and 1860. Correlation coefficients among all the five series analysed are statistically non-significant.

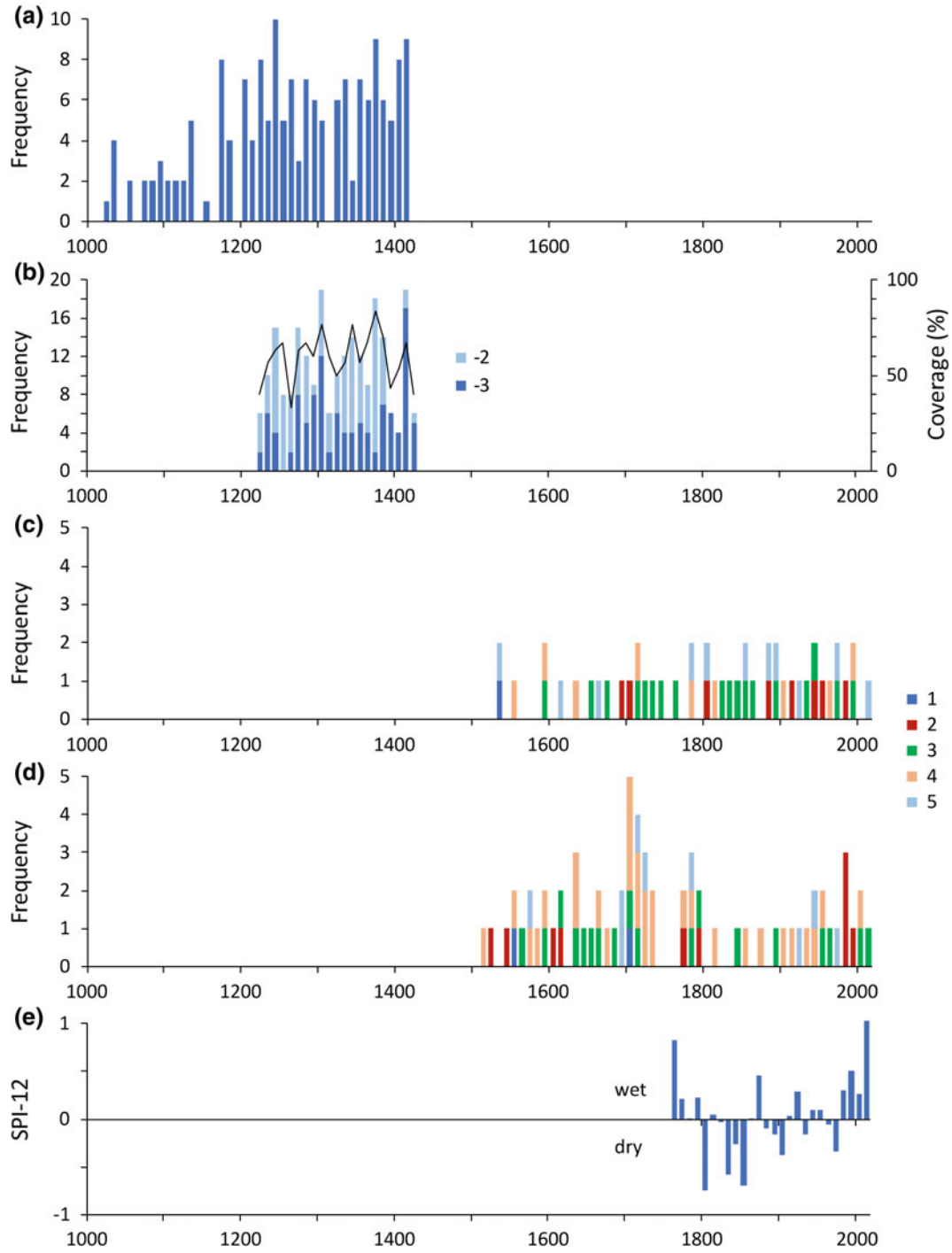

Fig. 4.8 Fluctuations in decadal values of drought-related series in western Europe during the past millennium: **a** frequencies of unusually dry JJA months, western Europe, 1000–1419 (Alexandre 1987); **b** frequencies of months with "scores" −2 and −3 corresponding to dry patterns (columns), UK, 1221–1430 (Ogilvie and Farmer 1997) with percentage coverage of totally interpreted months (line); **c** frequency of droughts with respect to their severity according to HSDS (1: absence of rainfall, 2: locally low waters, 3: general low waters, 4: severe low-water marks and 5: exceptional drought), UK, 1500–2014 (data derived from Garnier 2019); **d** the same, Ile-de-France region, France, 1500–2014 (data derived from Garnier 2019); **e** means of SPI-12, Ireland, 1765–2015 (Noone et al. 2017)

4.4.1.3 Central Europe

Drought patterns for the past 500 years in central Europe may be covered by several types of drought-related series:

(i) monthly precipitation indices series derived from documentary data for Germany, 1501–1850, and reconstructed seasonal and annual precipitation totals since AD 1501 (Glaser 2001, 2008)
(ii) monthly precipitation indices series derived from documentary and instrumental data for Switzerland, 1550–2003 (Pfister 1999, extended)
(iii) seasonal, summer half-year and annual series of drought indices (SPI, SPEI, Z-index and PDSI) for the Czech Lands, AD 1501–2017 (Brázdil et al. 2016, extended)
(iv) April–August SPEI series for the Bohemian wine-growing region, Czech Lands, 1499–2012 (Možný et al. 2016).

Documentary-based, drought-related series in central Europe, represented by reconstructions for Germany, Switzerland and Czech Lands (Fig. 4.9), show slight coherence, expressed by statistically significant correlation coefficients only between German and Czech summer half-year SPEI ($r = -0.34$) and the two Czech series ($r = 0.58$). The decade of 1811–1820, with the highest frequency of precipitation indices indicating dry patterns (from dry to extremely dry) in Germany (Fig. 4.9a) also exhibits the highest frequency for Switzerland (Fig. 4.9b), where 1661–1670 also appears with the same frequency. However, two subsequent decades with higher frequencies in Germany (1771–1780, 1791–1800) disagree with those in Switzerland (1661–1670, 1821–1830). Droughts expressed by SPEI for the Czech Lands dominate in the pre-instrumental period in 1721–1730 for the Czech summer half-year (Fig. 4.9c), while for April–August SPEI in Bohemia, the equivalent period is 1531–1540. Droughts in both decades also appear in other Czech (Bohemian) series, but are less intense. A higher frequency of droughts in the last decades of the eighteenth century and at the beginning of the nineteenth century in Germany corresponds to drier patterns expressed by SPEI in the both Czech series.

4.4.1.4 Eastern Europe

The non-chernozem European part of the former Soviet Union was addressed by Lyakhov (1984), who presented frequency of extremely dry and wet MAM–JJA seasons for 30-year intervals from the thirteenth century to 1980. Nine extremely dry seasons appeared in 1351–1380, 1831–1860 and 1891–1920, eight in 1201–1230 and seven in 1411–1440, 1801–1830 and 1951–1980. In contrast, only one extremely dry season each was recorded for the 1231–1260 and 1771–1800 periods (Fig. 4.10a). A compilation containing a thousand-year history of unusual natural events in the Russian Lands and western Europe from Russian written sources by Borisenkov and Pasetskiy (1988) appeared after Lyakhov's paper, later extended back to the fifth century BC (Borisenkov and Pasetskiy 2002). But lack of territorial focus in listed drought events (*zasucha*) complicates critical use of their presented drought chronology. More recently, Shmakin et al. (2013) presented documentary-based droughts over the Eastern European Plain during the eleventh–nineteenth centuries, classifying them into three categories, with 29 droughts in category 1 (local droughts without described impacts), 31 droughts in category 2 (regional droughts with described impacts) and 16 droughts in category 3 (drought in several regions with described heavy impacts). The highest frequency of droughts was found in 1861–1890 with seven dry episodes. Several 30-year periods without any drought or with one–two droughts may reflect insufficient density of documentary sources available (Fig. 4.10b). Besides significantly smaller number of droughts in Shmakin et al (2013) compared to Lyakhov (1984), both series are not statistically significant correlated.

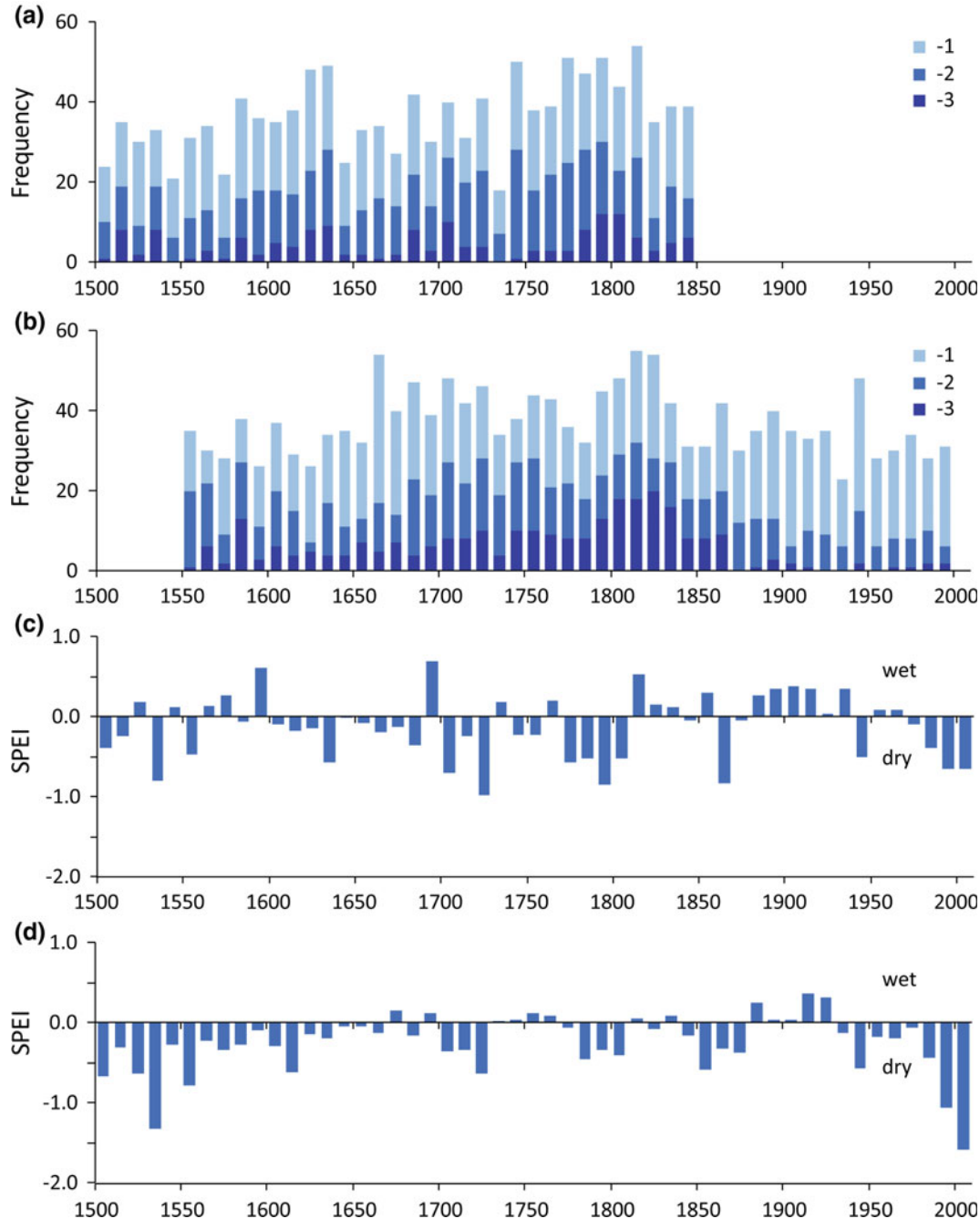

Fig. 4.9 Fluctuations in decadal values of drought-related series in central Europe during the past 500 years: **a** frequency of precipitation indices expressing dry patterns (−1 dry, −2 very dry, −3 extremely dry), Germany, 1501–1850 (Glaser 2001, 2008); **b** same as (**a**) for Switzerland, 1551–2000 (Pfister 1999); **c** means of summer half-year SPEI in the Czech Lands, 1501–2010 (Brázdil et al. 2016); **d** means of April–August SPEI in Bohemia, Czech Lands, 1501–2010 (Možný et al. 2016)

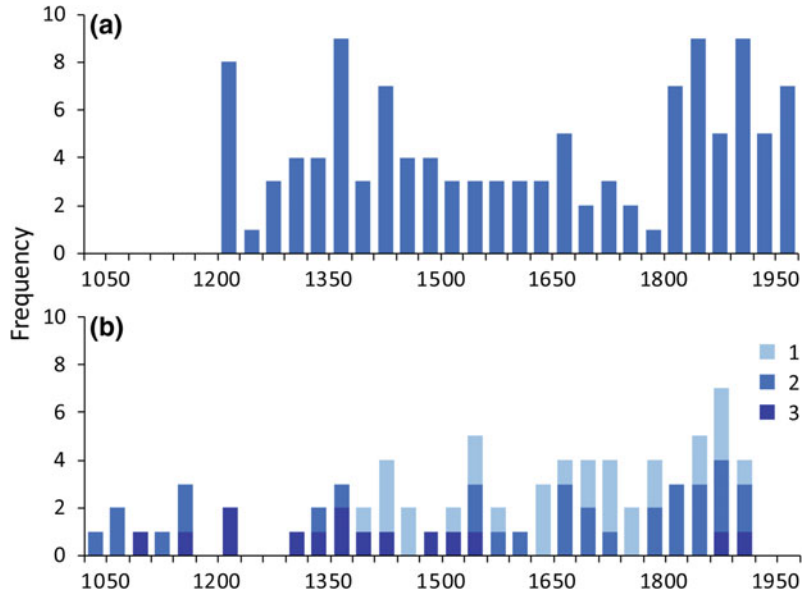

Fig. 4.10 Fluctuation of 30-year frequency of droughts in eastern Europe during the past millennium: **a** Non-chernozem European part of the former Soviet Union, 1201–1980 (Lyakhov 1984); **b** Eastern European Plain, eleventh–nineteenth century, the last column only 1891–1900 (Shmakin et al. 2013). Key: 1—local droughts without described impacts, 2—regional droughts with described impacts, 3—drought in several regions with descriptions of severe impacts

4.4.2 Examples of Outstanding European Droughts in the Past

Using documentary evidence, and judging by their meteorological character and impacts, many past drought events have been identified as extreme or outstanding at national levels. On the European scale, this is especially true of the year 1540, which Wetter et al. (2014) used to coin the term "megadrought" for long and intense dry patterns deducible from rich documentary evidence in western and central Europe. Also, identified as a very warm year (Wetter and Pfister 2013), it has been compared with the patterns of a far more recent extreme year in 2003 (e.g. Orth et al. 2016; Pfister 2018). The year 1473 was also described as an outstandingly warm and dry year by Camenisch et al. (2019). Without repeating the facts related to these events, some further examples of outstanding European droughts are described in brief below.

4.4.2.1 Drought in 1361

Although 1360 and 1362 might have been to some extent dry, the most important drought occurred in England in 1361 (Pribyl 2017). In Liège (Belgium), the year 1361 was characterised by a great drought, although the wine vintage was good (but heat and dry weather had already been reported there in 1360). A good wine vintage was also noted for Fosses in northern France. Early ripening of fruit and grapes, as well as an early vintage took place in France (e.g. Bordeaux, Metz), Germany (e.g. Konstanz) and also northern Italy (e.g. Bologna). In the southern German areas, Austria, Poland, Silesia and Hungary, great heat and drought resulted in moderately bad cereal harvests. The excessive summer heat also reached the Baltic Sea area (e.g. Bremen) in 1361, followed by abundant rainy spells later (Alexandre 1987).

Several contemporary sources reported a major drought event for 1361 in central Europe. A hot and dry summer occurred in Silesia and

Poland, where drought together with frequent thunderstorms and frost in June combined to produce a bad harvest. Quite bad grain harvests caused by drought were also reported from Austria, Bohemia and Hungary, with increases in prices. This situation caused particular difficulties in the food supply as, for example, in Vienna (Malewicz 1980; Brázdil and Kotyza 1995; Rohr 2007; Kiss and Nikolić 2015; Kiss 2017). These factors contributed to shortages and famine continuing through to 1362; these resulted, for example, in an instruction from the Czech king and Emperor Charles IV to collect any excess of grain into community granaries in Bohemia (but rather for military purposes), and even to the prohibition of grain export from the Hungarian and Croatian kingdoms (Brázdil and Kotyza 1995; Kiss and Nikolić 2015). In central Dalmatia, significant confrontation had to be resolved in March 1362, when the Morlachs, far from their homelands, received—rather exceptionally—permission from the Duke of Dalmatia to use the lands of Trogir town, in view of the great drought (see Sect. 4.2, point (iv)). Similarly, excessive drought-related problems were mentioned along the French Mediterranean coastline, where religious processions of entreaty for rain were organised in mid-April and early May at Nimes (see Alexandre 1987; Kiss and Nikolić 2015).

4.4.2.2 Drought in 1616

In the Netherlands, JJA of 1616 was described as much hotter and drier than usual; in some areas with devastating hail at the end of June and with destructive fires in, among other places, Amsterdam (Buisman 2000). In Germany, a dry episode started in mid-April of 1616 and continued over JJA; this drought led to a very bad haymaking season and an inferior harvest of cereals. Phenological phases started much earlier than usual (e.g. the vintage was a month early) and the wine was very good. Many fires broke out (e.g. Buisman 2000; Glaser 2008, 2013). Glaser (2008) classified MAM as mild and dry, JJA as very hot and extremely dry and SON as dry. No rain fell between 6 June and 30 July in Switzerland and the grass perished; Pfister (1999) classified both these months as extremely warm and extremely dry.

Dry patterns also prevailed in the Czech Lands (Brázdil et al. 2019). For example, no rain was recorded between 3 April and 31 July in Louny in north-western Bohemia and the drought continued into SON. Documentary sources reported significant drought impacts: shortages of water; lack of water to drive watermills, which forced people to travel great distances to grind their grain; very bad grain harvests; great heat; dried-up rivers and the River Vltava "stinking" at Prague and more. Extreme drought in 1616 in the Czech Lands is commemorated by a low-water mark on the 'hunger stone' in the River Elbe at Děčín, while a printed sermon by the Reverend Daniel Philomates the Elder spoke of a 100-year drought (Fig. 4.11). Similarly, JJA in Hungary was long and very hot, with great drought. Apart from a significant drop in water levels, frequent thunderstorms and fire events, the cereal harvests and the haymaking were very bad, but vine and fruit harvests were better. Mice and starlings appeared in abundance, while many people died of dysentery (e.g. Kovács 1995).

Of only a general character is information about the 1616 JJA drought in Latvia (Tarand et al. 2013) and of intense heat and severe droughts in Istria, where many people fell ill and livestock died (Ogrin 2002). A great drought followed by famine also occurred in the European part of Russia (Shmakin et al. 2013; Yurchenkov 2014). Droughts in 1616, as in 1615, also occurred in the various parts of England, but it appears that their severity did not reach the level of the intense drought of 1612 (Jones et al. 1984; Pribyl and Cornes 2019). Significant drought, which destroyed harvests, has already been mentioned regarding Germany and Hungary in 1615 (*Mercure*, 1615, pp. 414–415).

4.4.2.3 Drought in 1718–1719

In the Netherlands, August 1718, as well as the entire JJA period (as in 1719) were among the hottest and driest for many years (Buisman 2006). Drought and low-water levels were also reported in France (again, as in 1719); a great

Fig. 4.11 Two surviving records of the extreme severity of the 1616 drought in the Czech Lands: **a** a mark on the hunger stone located in the River Elbe at Děčín-Podmokly, 1904 (*Photo* O. Kotyza archive); **b** a printed sermon by the Reverend Daniel Philomates the Elder related to the 1616 drought (Collection of the National Museum, Prague)

(accidental) fire broke out in late April along the River Seine in Paris (Kanold 1719). In 1718, very warm and dry weather set in as early as April–May in eastern Austria. In JJA, with extended sweltering weather, crops perished, the earth was cracked, forest fires occurred, and wells, springs, rivers, brooks and lakes dried up (Strömmer 2003). Records from Germany speak of a hot and very dry JJA with damaging consequences, making particular mention of the soil cracking. Warm weather continued into September; the wine was considered good (Glaser 2008). According to documentary evidence from the Czech Lands, MAM and JJA were very dry, leading to considerable consequences. For example, the grain harvest was very bad, resulting in shortages and increases in prices; low-water levels, even rivers drying out, put some watermills out of operation, forcing people to go great distances to mill (Brázdil and Kirchner 2007). In Switzerland, a warm and dry period started on 20 May and continued, with a degree of interruption in the last third of October, until the end of November. However, Pfister (1999) classified only July as very dry and September as extremely dry. In Slovenia, the year of 1718 was described as hot and dry with shortages in the coastal zone (the Piran area). Agricultural crops, grapes and olives perished due to dry weather, leading to causing heavy losses (Ogrin 2002). Great heat and drought were also reported from Volhynia (today's south-eastern Poland, south-western Belarus, and western Ukraine), Podolia (today's west-central and south-western Ukraine and north-eastern Moldova) as well as the southern Romanian principality Valachia (Kanold 1718). In the southern part of the Carpathian Basin, in the Temesvár/Timişoara (SW Romania) the rivers and swamps dried up, and the excessive heat and drought reportedly continued until early November in the area of present-day Slovakia (Kanold 1720). Severe heat and drought were reported also in Italy. Excessive heat and drought also prevailed in JJA and early SON in Scandinavia (Kanold 1720).

Great heats and extreme droughts in 1719 from May to August were mentioned in the Norfolk county in England with scorched pastures, dried-up pits and ponds and lack of water for livestock (see Sect. 4.2, point (i); Kington 1980). In eastern Austria, MAM and JJA of this year were characterised by very warm weather and great drought. Grass and cereals perished utterly, summer crops were very bad, the grapes were harvested extraordinarily early and trees blossomed two or three times in some places (Strömmer 2003). Outstanding periods of heat and drought prevailed in JJA in Germany. In Brandenburg, for example, no rain fell in the

eight weeks leading up to 20 August; rivers such as the Oder had ran very low indeed; forest fires broke out; an already poor bad grain harvest was exacerbated by an overabundance of mice in the fields. Warm and dry weather continued during SON (Glaser 2008). In Switzerland, only scant precipitation fell from mid-March to 20 June, not even enough to moisten the soil. April, May and June were classified as very dry. Periods of heat in July were broken by thunderstorms, but August was again interpreted as very warm and extremely dry. Wells dried up and people were forced to travel great distances for water and milling (Pfister 1999).

Reports for 1719 from the Czech Lands speak of great periods of heat and drought in JJA, with serious consequences: problems with milling due to lack of water, bad harvests of grains and flax, dry grass in the pastures, etc. Matters were serious enough at the end of August for processions of entreaty for rain to be organised in Uherské Hradiště (Brázdil and Kirchner 2007). In Hungary, very dry and hot weather prevailed from April (at the latest) throughout JJA, with devastating hailstorms reported all over the country in June. While low waters were already occurring in some areas in MAM, many large bodies of water dried up in SON, leading to shortages, although the period was already wetter in certain areas. The cereal harvest was scant or completely lost. The drought, and its consequent food shortages, hunger and even famine, was at its worst in Transylvania (e.g. Csáki 2010) and in the southern part of the Carpathian Basin, but similar drought-related problems were also reported from Croatia and Serbia (Kanold 1719). Due to an exceptionally poor hay harvest, people moved, together with their cattle to the great rivers, i.e. the Danube and the Tisza. An infamous witchcraft trial, directly associated with the great drought, started in Szeged in the same year (Kanold 1719; Petrovics 2005). In Latvia, the drought was so extraordinary that bushes and tussocks dried out to their very roots and the water in the River Daugava was so low that it was possible to drive carts through it in many places (Tarand et al. 2013).

4.5 Drought Impacts and Societal Responses

Because many impacts and responses of droughts were already generally reported in Sects. 4.3.1 and 4.4.2, this section concentrates particularly on the major topics: in which ways drought affected society and how society responded on the effects of this major natural hazards in the mediaeval and early modern period.

4.5.1 Impacts of Drought on Society

Apart from the primary shortage or lack of appropriate drinking water for human consumption and for domestic animals, probably the most important problems arose in agricultural activities. It was particularly the lack of (appropriate) rainwater in the periods crucial for the vegetation growth. Further, intriguing factors for the agriculture during drought were heat waves and the higher frequency and intensity of destructive convective events (thunderstorms, hails, torrential rains, heavy winds). The negative effects of drought could be different under various climatic conditions. While in central and eastern Europe or the Mediterranean, a drought usually meant bad cereal harvest (wheat, barley, rye, oat) and played an important role in the development of dearth and famine, for example, in England, it was mainly the oat and barley that suffered, whereas wheat yields were usually above average, and a drought year typically did not mean a famine year (e.g. Jones et al. 1984; Brázdil and Kotyza 1995; Ogrin 2002; Glaser 2013; Pribyl 2017). However, all over Europe, droughts were accompanied by weaker legume harvests and bad hay harvests. In western and west-central Europe drought was usually followed by good quality and good or normal quantity grapevine and fruit; towards the east, also depending on the conditions of the preceding period, droughts were accompanied by low quantity of wine and fruit (e.g. Brázdil and Kotyza 1995; Glaser 2013; Camenisch 2015). Apart from bad harvest, dried-up soils were more difficult to plough.

Trees during drought also dried up in increasing numbers that sometimes concerned also fruit trees (e.g. Ogrin 2002; Pribyl 2017). The negative impact of bad harvest due to drought was in some cases strengthened by inflexible taxation, for example, by the special food taxes for the army as in 1717 in Transylvania (Csáki 2010).

Drought also resulted in great problems in animal husbandry and pastoral communities: the lack of drinking water in parallel to the bad hay harvest and the dried-up pastures caused a great stress for domestic animals, especially for the young ones, all over Europe. Drought years were often accompanied by the mass losses of domestic animals caused partly by the lack of appropriate water and fodder, but also due to the easily spreading diseases what the underfed, weakened animals were much more prone to than in normal years (e.g. Ogilvie 1990; Bellon 1996; Ogrin 2002; Kiss 2009; Cullen 2010; Gómez-Baggethun et al. 2012; Kiss and Nikolić 2015; Pribyl 2017; Fragoso et al. 2018). The lack of water and excessive heat not only affected the animals themselves, but generally also dairy production, i.e. milk and milk products (e.g. Gómez-Baggethun et al. 2012; Gerrard and Petley 2013). When referring to domestic animals, less obvious cases also have to be taken into consideration. For example, excessive heats and droughts negatively affected bees and bee-products, but regarding cultivated vegetation the same is true for some of the important drought-sensitive vegetables such as cabbage which, in a preserved form, was usually a main source of vitamin supply in wintertime (Kiss 2019).

Animal invasions during and after the drought period often increased the stress caused by drought, mainly affecting the anyway bad harvests. Although locusts (Fig. 4.12) are usually associated with drought, apart from areas where locusts stayed and nested for years (e.g. in Hungary—Kiss 2009), their invasion usually occurred in the affected parts of Europe after grain harvest time, and their impact was spatially restricted (Rohr 2007; Brázdil et al. 2014). Additionally, other pests such as birds, caterpillars, mice and hamsters (e.g. Brázdil et al. 2008, 2018; Pribyl 2017; see also Sect. 4.4.2.2) might have also accompanied drought events that further decreased harvest outcomes.

The shortage of drinking water, lack of cereals and other drought-related circumstances resulted in high prices, malnutrition, higher child mortality, dearth and famine in human population, and favoured the renewed occurrence, spread and increase of certain diseases such as dysentery or plague (e.g. Behringer 1999; Xoplaki et al. 2001; Ogrin 2002; Telelis 2008; Glaser 2013; Yurchenkov 2014; Noone et al. 2017; Fragoso et al. 2018). However, drought years were usually not followed by food shortage and famine in England (Pribyl 2017).

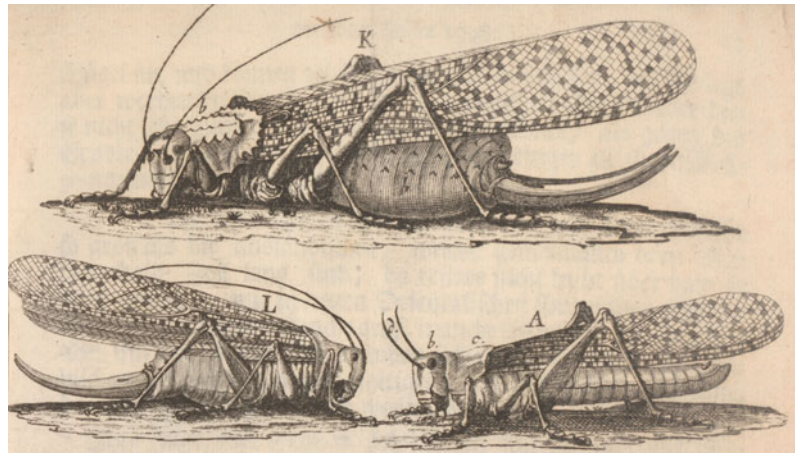

Fig. 4.12 Historical illustration of locusts showing female and male adults migratory locusts (section from a figure in Kundmann 1748)

Drought strongly affected energy production: due to lack of water, mills could not grin that further increased the high prices of flavour and bread. Not only bad or very bad harvests, but also the transport of heavy bulk food (grain) became more difficult as the rivers were hardly navigable due to low-water levels (e.g. Brázdil and Kotyza 1995; Garnier 2010; Glaser 2013; Garnier et al. 2015; Kiss and Nikolić 2015). During the most severe droughts, large rivers became passable on foot that greatly weakened the natural defence of fortifications and country borders; as a consequence, military conflict zones were more prone to violent conflicts, swift raids over large areas, military campaigns and wars (Kiss and Nikolić 2015; Kiss 2017). Furthermore, drought led to unemployment, social unrest and conflicts, and frequent legal disputes over water resources and land boundaries (e.g. Kiss 2005; Gómez-Baggethun et al. 2012; Grau-Satorras et al. 2016).

Prolonged droughts and heats were often accompanied by accidental fire events. Although most reports are usually related to the fires in settlements with special emphasis on towns, wildfires were also recorded on numerous occasions. While in the famous drought years such as 1473 and 1540 forest fires were widespread in large regions of central Europe, bushfire near Antwerp and "soil" fire in Poland were also reported from time to time (e.g. Ogrin 2002; Gerrard and Petley 2013; Wetter et al. 2014; Brázdil et al. 2018; Camenisch et al. 2019). Especially in urban areas, the most typical house building material was partly or entirely wood; only the rich could afford to build houses mainly of stone (or brick). During droughts, the occurrence of devastating fire had a much higher probability that could threaten large part of a town (e.g. London fire in 1666—Garrioch 2016). However, even before the development of systematic fire protection in cities, certain fire prevention measures were often taken in account to avoid fire. For example, in Hamburg, a certain amount of water had to be stored between houses for the case of incidental fire during the 1718 or 1719 drought (Kanold 1719).

Migration was a further important, indirect consequence of severe droughts, either talking about short- or long-term leave or emigration. The migration of pastoral communities, due to the lack of water and fodder were forced temporarily to drive their animals towards areas that were less prone to water shortage, namely to large water bodies, rivers or lakes, is a typical example. During prolonged drought, this was also a practice among individuals with large herds of animals, who usually returned home when vegetation revived after drought (e.g. Kanold 1719; Kiss and Nikolić 2015; Grau-Satorras et al. 2016). Another, much more severe type of migration took place when people, urged by hunger, after selling all their valuable properties for buying food, were forced to leave their homes and try to find food and living elsewhere (e.g. Kanold 1719; Bellon 1996; Csáki 2010; Noone et al. 2017; Fragoso et al. 2018).

4.5.2 Social Responses

4.5.2.1 Perception, Spiritual and Ritual Approaches

Although drought was also understood as a natural/environmental phenomenon in pre-industrial societies, spiritual causative believes were, in parallel, associated with destructive drought phenomena. Drought, similar to other destructive natural hazards, was often considered, especially in the Middle Ages, as the scourge of God for the sins of humans. And although the practice of public prayers, rogations, processions, pilgrimages in times of drought, asking God and the intervention of specific saints are known also from some other parts of Europe (e.g. Brázdil and Kotyza 1995; Gómez-Baggethun et al. 2012; Gerrard and Petley 2013; Camenisch 2015; Kiss and Nikolić 2015; Williams 2016; Fragoso et al. 2018; Mrgic 2018), the most systematic contemporary documentation and recent scientific analyses of these events are known in particular from Spain and Italy (e.g. Martín-Vide and Barriendos Vallvé 1995; Barriendos 1997, 2005; Piervitali and Colacino 2001; Domínguez-Castro et al. 2008, 2010, 2012; Tejedor et al. 2018). Among other significant natural hazards affecting human

societies, drought also influenced long-term spiritual responses, for example, the development of regular prayers and processions, change of the local patron saint or establishment of new parishes (e.g. Grau-Satorras et al. 2016). For example, in France, Saint Godeberta of Noyon, Saint Honorius of Amiens, Saint Angadrisma of Beauvais, Saint Solange of Bourges and Saint Trophimus of Arles were specific saints to pray to avoid drought (Gerrard and Petley 2013).

On the other hand, in mediaeval, but especially in early modern times, drought was also believed to be related to demonic forces. These believes, especially in times of high socio-economic and political vulnerability, more often led to the accusation of people for drought-related magic and witchcraft. Whereas the main period of witch-hunting in western and central Europe was in the sixteenth–seventeenth centuries and weather-related accusations were much more rare in the Middle Ages, the importance of droughts and related extremes in the accusation of witches (as weather-makers) was already notable in mediaeval eastern Europe (e.g. Russia or Ukraine) (Zgutam 1977; Worobec 1995; Behringer 1999; Pfister 2007; Levack 2016). In most other parts of Europe witch accusations (Fig. 4.13) intensified from the sixteenth century onwards, when harvest failure due to weather effects formed connection between agricultural crisis and witchcraft (e.g. Behringer 1997, 1999; Pfister 2007). The theories reflecting the intervention of supernatural powers existed parallel in time: for example, during a witch accusation of 1718 in Hungary, drought was mentioned by some of the trial witnesses as the God's scourge, while others gave the testimony that witches took away the rain or dew and/or sold it to Turkish witches (Reizner 1899). Frequency of witch accusations was intensified particularly during political and socio-economic instability and it was related not only to drought or other weather-related extremes (e.g. Behringer 1999; Petrovics 2005; Pfister 2007).

Fig. 4.13 Execution of three witches on 4 November 1585 in Baden (Switzerland) (Zentralbibliothek Zürich, Collection of Johann Jakob Wick, Ms F 33, fol. 277r)

4.5.2.2 Institutional/Legal-Administrative Decisions and Changes

Numerous methods were applied to solve immediately the shortage of (drinking) water: one solution was to allocate and utilise new water supplies, for example, deepen the existing wells or dig new (deeper) wells in time of drought, while often the transportation of freshwater to a greater distance was, to some extent, another feasible solution (e.g. Brázdil and Kotyza 1995; Dawson 2009; Glaser 2013; Grau-Satorras et al. 2016). In times of water shortage and low-water levels, the utilisation of wetlands and inundation areas intensified: these areas could still provide fodder for the animals even in times when very bad hay harvests caused by drought made significant problems. Additionally, wet pastures were sometimes ploughed and temporarily turned into arable land (e.g. Kiss 2005).

As for the solution of short-term food shortage and dearth, increased cereal import might provide some auxiliary help (e.g. Rohr 2007; Keene 2011). Charity was another, broadly applied immediate reaction of individuals and communities that gained special importance in the time of scarcity, often induced by drought throughout mediaeval and early modern period, until modern times (e.g. McRee 1993; Boa 2012; Gerrard and Petley 2013). In most cases, however, documentary evidence reports mainly administrative decisions. A widespread form of easing the drought-driven stress was tax reduction and/or partly or entirely postponing tax payment for later times, or release tax depths for more public works (e.g. Gerrard and Petley 2013; Brázdil et al. 2018; Fragoso et al. 2018; Kiss 2019).

Some legal-administrative provisions were organised on the state level: the prohibition of cereal (legume, vegetable) export abroad was used especially in the Middle Ages as an important tool to decrease the negative effects of (threatening) food shortage, partly or mainly caused by drought. Public granaries, usually ordered and maintained by the sovereign, on a local–regional level further served the purpose of grain distribution to the locals in need (e.g. seed for sowing). Although granaries were most widespread from the eighteenth century, for example, in France, Portugal, Prussia and the countries of the Habsburg Empire, in some cases, they were already mentioned in the Middle Ages, too (Black 1990; Brázdil and Kotyza 1995; Domínguez-Castro et al. 2012; Gómez-Baggethun et al. 2012; Glaser 2013; Kiss 2017).

Apart from short-term administrative responses, beyond the above-mentioned response types, several long-term changes and developments served to decrease social vulnerability towards drought on community level. Among these long-term solutions, for example, the selection of drought-resistant main cultivated plants was one of the many important issues. However, drought-related legal decisions, water access rights, new water reservoirs and water diversions, the development and maintenance of irrigation systems particularly in the Mediterranean, organised and maintained by the local and municipal administration, also played a crucial role on community level. Another problem to be solved on the community level during droughts was water quality, regular maintenance and monitoring (e.g. Grau-Satorras et al. 2016).

4.6 Perspectives for Future Research into Historical Droughts in Europe

Dai (2013) reported a possible future increase in the frequency and severity of drought episodes attributable to recent global warming. Naumann et al. (2018) analysed future drought conditions corresponding to global warming of 1.5, 2 and 3 °C compared to pre-industrial times: they pointed out a progressive and significant increase in drought frequency, particularly in the Mediterranean, most of Africa, western and southern Asia, Central America and Oceania, even five or even ten times higher than at present. Drought projections for the twenty-first century indicate that the Mediterranean, a consistent drought-prone region of Europe, is one of the most endangered areas (e.g. García-Ruiz et al. 2011; Seager et al. 2014). However, indications from other parts of Europe signal that drought may also become a serious natural extreme on a far wider scale (Spinoni et al. 2018).

Because future estimates of droughts are primarily based on projections of climate models, it would appear quite important to possess detailed knowledge of droughts from the past, i.e. from the pre-instrumental as well as instrumental periods. A wealth of documentary evidence related to droughts in Europe has facilitated the collation of much important information concerning the spatiotemporal variability and impacts of historical droughts, from which we may learn much that is relevant to recent droughts as well as their future projections in the context of anthropogenically enhanced global warming. Recent and projected future droughts can be confronted in terms of their frequency, severity, spatial extent, human impacts and responses in times of clearly prevailing natural forcing. The study in hand demonstrates the importance of studying drought frequency and severity with respect to regional differences in Europe. As well as events of broad territorial extent, there are also episodes at regional and sub-regional scales that may have impacts just as severe.

Brázdil et al. (2018), giving a worldwide overview of drought studies from documentary sources, indicated certain key points for future drought research which remain valid, with some of them also extending to Europe:

(i) Compilation of long-term drought series combining documentary and instrumental data for the study of the long-term spatiotemporal variability of droughts, a particularly pressing matter in countries currently lacking drought series, or for which these are only incomplete.
(ii) Use of documentary data for the reconstruction of series of generally used drought indices based on reconstructed temperatures and precipitation or documentary-based biophysical series.
(iii) Comprehensive analysis of past major droughts in order to estimate the potential impacts of extreme droughts for current and future societies.
(iv) Comparison of documentary-based droughts with those derived from other high-resolution proxies to improve understanding of past drought episodes.
(v) Communication with climate modellers as to way in which to use knowledge of documentary-based droughts in past model simulations and in future drought projections.
(vi) Interdisciplinary cooperation with scientists in a wider range of fields to establish what lessons may be learnt from drought management practices in the past, with the future in mind.

These points are also related to, or may be supplemented by, the topical questions raised by multidisciplinary drought research for the first quarter of the twenty-first century, as formulated by Trnka et al. (2018). The present contribution strongly indicates that the use of documentary data has great potential for the study of historical droughts with important and relevant implications for the better understanding of recent and future droughts in Europe.

Acknowledgements Rudolf Brázdil acknowledges the support of Czech Science Foundation, project ref. 17-10026S. Andrea Kiss acknowledges financial support from the Austrian Science Funds, project ref. I 3174. Ladislava Řezníčková was supported by "SustES – Adaptation strategies for sustainable ecosystem services and food security under adverse environmental conditions" project ref. CZ.02.1.01/0.0/0.0/16_019/0000797. Mariano Barriendos acknowledges support from the Spanish Ministry of Economy and Competition, programme I + D + i, funding project CLIMED, ref. CGL2015-69985-R. We would like to thank the following individuals and institutions: for provision of data, N. Diodato (Benevento), C. Murphy and S. Noone (Kildare), C. Pfister (Bern) and V. V. Popova (Moscow); for providing us with figures and permission with their publication—Fig. 4.2, Bibliothèque nationale de France, Paris, Figs. 4.6 and 4.11a, O. Kotyza (Litoměřice), Fig. 4.11b, the National Museum, Prague and Fig. 4.13, Zentralbibliothek, Zürich; for further assistance with this manuscript, Jaak Jaagus (Tartu), Neil Macdonald (Liverpool) and Kathleen Pribyl (Norwich). Tony Long (Svinošice) helped work up the English. We also thank anonymous referee for valuable critical comments.

References

Alcoforado MJ, Vaquero JM, Trigo RM, Taborda JP (2012) Early Portuguese meteorological measurements (18th century). Clim Past 8:353–371. https://doi.org/10.5194/cp-8-353-2012

Alexandre P (1987) Le climat en Europe au Moyen Âge. Contribution à l'histoire des variations climatiques de 1000 à 1425, d'après les sources narratives de l'Europe occidentale. Éditions de l'École des Hautes Études en Sciences Sociales, Paris

Anonymous (1927) Goigs a llaor de Sant Galderic llaurador, patró dels pagesos Catalans (Prayers and songs in honour of Saint Galderic the Farmer, patron of all Catalan farmers). Arnau-Ors i Bartrés, Barcelona

Barriendos M (1997) Climatic variations in the Iberian Peninsula during the late Maunder Minimum (AD 1675–1715): an analysis of data from rogation ceremonies. Holocene 7:105–111. https://doi.org/10.1177/095968369700700110

Barriendos M (2005) Climate and culture in Spain. Religious responses to extreme climatic events in the Hispanic Kingdoms (16th–19th century). In: Behringer W, Lehmann H, Pfister C (eds) Kulturelle Konsequenzen der "Kleine Eiszeit" – Cultural Consequences of the "Little Ice Age". Vandenhoeck & Ruprecht, Göttingen, pp 379–414

Beguería S, Vicente-Serrano SM, Reig F, Latorre B (2014) Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. Int J Climatol 34:3001–3023. https://doi.org/10.1002/joc.3887

Behringer W (1997) Witchcraft persecutions in Bavaria. Popular magic, religious zealotry and reason of state in early modern Europe. Cambridge University Press, Cambridge

Behringer W (1999) Climatic change and witch-hunting: the impact of the Little Ice Age on mentalities. Clim Change 43:335–351. https://doi.org/10.1023/A:1005554519604

Bělínová M, Brázdil R (2012) Meteorologická pozorování c. k. Vlastenecko-hospodářské společnosti v Čechách v letech 1817–1847 (Meteorological observations of I. R. Patriotic-Economic Society in Bohemia in the years 1817–1847). Meteorol Zpr 65:13–22

Bell WT, Ogilvie AEJ (1978) Weather compilations as a source of data for the reconstruction of European climate during the medieval period. Clim Change 1:331–348. https://doi.org/10.1007/BF00135154

Bellon T (1996) Beklen. A nagykunsági mezővárosok állattartó gazdálkodása a XVIII-XIX. században (Beklen. Animal husbandry of the towns in Greater Cumania in the 18–19th centuries). Karcag Város Önkormányzata, Karcag

Black J (1990) History of Europe. Eighteenth century Europe 1700–1789. Macmillan, New York

Boa K (2012) Az 1863–1864. évi aszály és ínség Békés megyében (The 1863–1864 drought and dearth in Békés County). Fons 19:161–199

Borisenkov YP, Pasetskiy VM (1988) Tysyatcheletnaya letopis neobytchaynykh yavleniy prirody (A thousand-year history of unusual natural events). Mysl, Moskva

Borisenkov YP, Pasetskiy VM (2002) Letopis neobytchaynikh yavleniy prirody za 2.5 tysyatcheletiya (V v. do n.e.–XX v. n.e.) (A chronicle of unusual natural events for 2.5 millennia (5th century BC–20th century AD)). Gidrometeoizdat, Saint-Petersburg

Brázdil R, Kirchner K (eds) (2007): Vybrané přírodní extrémy a jejich dopady na Moravě a ve Slezsku (Selected natural extremes and their impacts in Moravia and Silesia). Masarykova univerzita, Český hydrometeorologický ústav, Ústav geoniky Akademie věd České republiky, v.v.i., Brno, Praha, Ostrava

Brázdil R, Kotyza O (1995) History of weather and climate in the Czech Lands I. Period 1000–1500. Zürcher Geographische Schriften 62. ETH Zürich, Zürich

Brázdil R, Trnka M (eds) (2015) Sucho v českých zemích: minulost, současnost, budoucnost (Droughts in the Czech Lands: Past, present and future). Centrum výzkumu globální změny Akademie věd České republiky, v.v.i., Brno

Brázdil R, Pfister C, Wanner H et al (2005) Historical climatology in Europe—the state of the art. Clim Change 70:363–430. https://doi.org/10.1007/s10584-005-5924-1

Brázdil R, Kiss A, Luterbacher J, Valášek H (2008) Weather patterns in eastern Slovakia 1717–1730, based on records from Breslau meteorological network. Int J Climatol 28:1639–1651. https://doi.org/10.1002/joc.1667

Brázdil R, Dobrovolný P, Luterbacher J et al (2010) European climate of the past 500 years: new challenges for historical climatology. Clim Change 101:7–40. https://doi.org/10.1007/s10584-009-9783-z

Brázdil R, Bělínová M, Rožnovský J (2011) Phenological observations made by the I. R. Bohemian Patriotic-Economic Society, 1828–1847. Theor Appl Climatol 105:71–81. https://doi.org/10.1007/s00704-010-0373-9

Brázdil R, Bělínová M, Dobrovolný P et al (2012a) Temperature and precipitation fluctuations in the Czech Lands during the instrumental period. Masaryk University, Brno

Brázdil R, Chromá K, Valášek H, Dolák L (2012b) Hydrometeorological extremes derived from taxation records for south-eastern Moravia, Czech Republic, 1751–1900 AD. Clim Past 8:467–481. https://doi.org/10.5194/cp-8-467-2012

Brázdil R, Dobrovolný P, Trnka M et al (2013) Droughts in the Czech Lands, 1090–2012 AD. Clim Past 9:1985–2002. https://doi.org/10.5194/cp-9-1985-2013

Brázdil R, Řezníčková L, Valášek H et al (2014) Past locust outbreaks in the Czech Lands: do they indicate particular climatic patterns? Theor Appl Climatol 116:343–357. https://doi.org/10.1007/s00704-013-0950-9

Brázdil R, Dobrovolný P, Trnka M et al (2016) Documentary and instrumental-based drought indices for the Czech Lands back to AD 1501. Clim Res 70:103–117. https://doi.org/10.3354/cr01380

Brázdil R, Kiss A, Luterbacher J et al (2018) Documentary data and the study of past droughts: a global state of the art. Clim Past 14:1915–1960. https://doi.org/10.5194/cp-14-1915-2018

Brázdil R, Dobrovolný P, Trnka M et al (2019) Extreme droughts and human responses to them: the Czech Lands in the pre-instrumental period. Clim Past 15:1–24. https://doi.org/10.5194/cp-15-1-2019

Buisman J (1995–2006) Duizend Jaar Weer, Wind en Water in de Lage Landen. Vol. 1, to 1300 (1995); Vol. 2, 1300–1450 (1996); Vol. 3, 1450–1575 (1998); Vol. 4, 1575–1675 (2000); Vol. 5, 1675–1750 (2006). Uitgegeverij Van Wijnen, Franeker

Camenisch C (2015) Endlose Kälte. Witterungsverlauf und Getreidepreise in dem Burgundischen Niederlanden im 15. Jahrhundert. Schwabe, Basel

Camenisch C, Brázdil R, Kiss A et al (2019) Extreme heats and droughts of 1473 and their impacts in Europe in context of the early 1470s. Reg Environ Change, in review

Camuffo D, Bertolin C (2012) The earliest temperature observations in the world: the Medici Network (1654–1670). Clim Change 111:335–363. https://doi.org/10.1007/s10584-011-0142-5

Camuffo D, Jones P (eds) (2002) Improved understanding of past climatic variability from early daily European instrumental sources. Kluwer Academic Publishers, Dordrecht

Csáki Á (2010) Szárazság és pestis Háromszéken 1717–1720-ban (Drought and plague in Háromszék [Hargita county, Romania] in 1717–1720). Acta Siculica 2010:277–287

Cullen JK (2010) Famine in Scotland: The 'Ill Years' of the 1690s. Scottish Historical Review Monograph, Edinburgh University Press

Dai A (2011) Characteristics and trends in various forms of the Palmer Drought Severity Index (PDSI) during 1900–2008. J Geophys Res 116:D12115. https://doi.org/10.1029/2010JD015541

Dai A (2013) Increasing drought under global warming in observations and models. Nat Clim Change 3:52–58. https://doi.org/10.1038/nclimate1633

Dawson A (2009) Do foul and fair a day. A history of Scotland's weather and climate. Birlinn, Edinburgh

Diodato N (2007) Climatic fluctuations in southern Italy since the 17th century: reconstruction with precipitation records at Benevento. Clim Change 80:411–431. https://doi.org/10.1007/s10584-006-9119-1

Diodato N, Bellocchi G (2011) Historical perspective of drought response in central-southern Italy. Clim Res 49:189–200. https://doi.org/10.3354/cr01020

Dobrovolný P, Brázdil R, Valášek H et al (2009) A standard paleoclimatological approach to temperature reconstruction in historical climatology: an example from the Czech Republic, A.D. 1718–2007. Int J Climatol 29:1478–1492. https://doi.org/10.1002/joc.1789

Dobrovolný P, Moberg A, Brázdil R et al (2010) Monthly and seasonal temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500. Clim Change 101:69–107. https://doi.org/10.1007/s10584-009-9724-x

Dobrovolný P, Brázdil R, Trnka M et al (2015) Precipitation reconstruction for the Czech Lands, AD 1501–2010. Int J Climatol 35:1–14. https://doi.org/10.1002/joc.3957

Domínguez-Castro F, Santisteban JI, Barriendos M, Mediavilla R (2008) Reconstruction of drought episodes for central Spain from rogation ceremonies recorded at the Toledo Cathedral from 1506 to 1900: a methodological approach. Glob Plan Change 63:230–242. https://doi.org/10.1016/j.gloplacha2008.06.002

Domínguez-Castro F, García-Herrera R, Ribera P, Barriendos M (2010) A shift in the spatial pattern of Iberian droughts during the 17th century. Clim Past 6:553–563. https://doi.org/10.5194/cp-6-553-2010

Domínguez-Castro F, Ribera P, García-Herrera R et al (2012) Assessing extreme droughts in Spain during 1750–1850 from rogation ceremonies. Clim Past 8:705–722. https://doi.org/10.5194/cp-8-705-2012

Domínguez-Castro F, de Miguel JC, Vaquero JM et al (2014a) Climatic potential of Islamic Chronicles in Iberia: extreme droughts (AD 711–1010). Holocene 24:370–374. https://doi.org/10.1177/0959683613518591

Domínguez-Castro F, Vaquero JM, Rodrigo FS et al (2014b) Early Spanish meteorological records (1780–1850). Int J Climatol 34:593–603. https://doi.org/10.1002/joc.3709

Elleder L (2016) The Hunger stones: a new source for more objective identification of historical droughts. EGU General Assembly, Vienna, Austria, 17–22 Apr 2016, EGU2016-14986

Fernández-Fernández MI, Gallego MC, Domínguez-Castro F et al (2015) The climate in Zafra from 1750 to 1840: precipitation. Clim Change 129:267–280. https://doi.org/10.1007/s10584-014-1315-9

Fragoso M, Carraça MGD, Alcoforado MJ (2018) Droughts in Portugal in the 18th century—a study based on newly found documentary data. Int J Climatol 38:5522–5541. https://doi.org/10.1002/joc.5745

Gallego D, García-Herrera R, Prieto R, Peña-Ortiz C (2008) On the quality of climate proxies derived from newspaper reports—a case study. Clim Past 4:11–18. https://doi.org/10.5194/cp-4-11-2008

García-Ruiz JM, López-Moreno JI, Vicente-Serrano SM et al (2011) Mediterranean water resources in a global change scenario. Earth Sci Rev 105:121–139. https://doi.org/10.1016/j.earscirev.2011.01.006

Garnier E (2010) Bassesses extraordinaires et grandes chaleurs. 500 and de sécheresses et de chaleurs en France et dans lespays limitrophes. La Huille Blanche 4:1–17. https://doi.org/10.1051/lhb/2010039

Garnier E (2019) Historic drought from archives: beyond the instrumental record. In: Iglesias A, Assimacopoulos D, Van Lanen HAJ (eds) Drought. Science and policy. Wiley, Hoboken, pp 45–67

Garnier E, Assimacopoulos D, van Lanen HAJ (2015) Historic droughts beyond the modern instrumental records: an analysis of cases in United Kingdom, France, Rhine and Syros. DROUGHT-R&SPI, Technical Report No. 35

Garrioch D (2016) 1666 and London's fire history: a re-evaluation. Hist J 59:319–338. https://doi.org/10.1017/S0018246X15000382

Gerrard CM, Petley DN (2013) A risk society? Environmental hazards, risk and resilience in the later Middle Ages in Europe. Nat Hazards 69:1051–1079. https://doi.org/10.1007/s11069-013-0750-7

Glaser R (2001) Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen. Primus Verlag, Darmstadt

Glaser R (2008) Klimageschichte Mitteleuropas. 1200 Jahre Wetter, Klima, Katastrophen. 2. Auflage. Primus Verlag, Darmstadt

Glaser R (2013) Klimageschichte Mitteleuropas. 1200 Jahre Wetter, Klima, Katastrophen. 3. Auflage. Primus Verlag, Darmstadt

Gómez-Baggethun E, Reyes-García V, Olsson P, Montes C (2012) Traditional ecological knowledge and community resilience to environmental extremes: a case study in Doñana, SW Spain. Glob Environ Change 22:640–650. https://doi.org/10.1016/j.gloenvcha.2012.02.005

Grau-Satorras M, Otero I, Gómez-Baggethun E, Reyes-García V (2016) Long-term community responses to droughts in the early modern period: the case study of Terrassa, Spain. Ecol Soc 21:33. https://doi.org/10.5751/ES-08232-210233

Haslinger K, Blöschl G (2017) Space-time patterns of meteorological drought events in the European Greater Alpine Region over the past 210 year. Water Resour Res 53:9807–9823. https://doi.org/10.1002/2017WR020797

Heim RR (2000) Drought indices. A review. In: Wilhite DA (ed) Drought: a global assessment. Hazards Disaster Series, vol I. Routledge, New York, pp 159–167

Heim RR (2002) A review of twentieth-century drought indices used in the United States. Bull Am Met Soc 83:1149–1165. https://doi.org/10.1175/1520-0477-83.8.1149

Jones PD, Ogilvie AEJ, Wigley TML (1984) Riverflow data for the United Kingdom: reconstructed data back to 1844 and historical data back to 1556. CRURP 8. Climate Research Unit, Norwich

Kanold J (1718–1720) Sammlung von Natur- und Medicin-, wie auch hierzu gehörigen Kunst- und Literatur-Geschichten. Michael Hubert, Breslau

Keene D (2011) Crisis management in London's food supply, 1250–1500. In: Dodds B, Liddy CD (eds) Commercial activity, markets and entrepreneurs in the Middle Ages: essays in honour of Richard Britnell. Boydell & Brewer, pp 45–62

Kington J (1974) The Societas Meteorologica Palatina: an eighteenth-century meteorological society. Weather 29:416–426. https://doi.org/10.1002/j.1477-8696.1974.tb04330.x

Kington B (1980) Searches for historical weather data: appeals and responses. Weather 35:124–134. https://doi.org/10.1002/j.1477-8696.1980.tb04731.x

Kiss A (2005) Utilization of the inundation area at Lake Fertő before regulation works: example of Sarród and its surroundings. Acta Geographica 38:39–49

Kiss A (2009) Historical climatology in Hungary: role of documentary evidence in the study of past climates and hydrometeorological extremes. Időjárás 113:315–339

Kiss A (2017) Droughts and low water levels in late Medieval Hungary II: 1361, 1439, 1443–4, 1455, 1473, 1480, 1482(?), 1502–3, 1506: documentary versus tree-ring (OWDA) evidence. J Environ Geogr 10:43–56. https://doi.org/10.1515/jengeo-2017-0012

Kiss A (2019) Anatomy of a great drought in late medieval Hungary. the drought of (1506–)1507 and its multiannual socio-economic consequences in a Central-European context. Reg Environ Change, in review

Kiss A, Nikolić Z (2015) Droughts, dry spells and low water levels in Medieval Hungary (and Croatia) I: the great droughts of 1362, 1474, 1479, 1494 and 1507. J Environ Geogr 8:11–22. https://doi.org/10.1515/jengeo-2015-0002

Kovács PE (1992) Estei Hippolit püspök egri számadáskönyvei 1500–1508 (The Account Books of the Bishop of Eger, Ippolito d'Este). Heves Megyei Levéltár, Eger

Kovács JL (1995) Faut Márk és Klein Menyhért krónikája. – Die Chronik des Marx Faut und Melchior Klein. 1526–1616. Sopron város történeti forrásai – Quellen zur Geschichte der Stadt Ödenburg. C sorozat 1. kötet – Reihe C Band 1. Soproni Levéltár – Burgenländischen Landesregierung, Sopron – Eisenstadt

Kundmann JC (1748) Anmerckungen über die Heuschrecken in Schlesien von dem Jahre 1748. Johann Jacob Korn, Breßlau

Leijonhufvud L, Wilson R, Moberg A (2008) Documentary data provide evidence of Stockholm average winter to spring temperatures in the eighteenth and nineteenth centuries. Holocene 18:333–343. https://doi.org/10.1177/0959683607086770

Leijonhufvud L, Wilson R, Moberg A et al (2010) Five centuries of Stockholm winter/spring temperatures reconstructed from documentary evidence and instrumental observations. Clim Change 101:109–141. https://doi.org/10.1007/s10584-009-9650-y

Levack BP (2016) The witch-hunt in early modern Europe, 4th edn. Routledge, London

Lüdecke C (2010) Von der Kanoldsammlung (1717–1730) zu den Ephemeriden der Societas Meteorologica Palatina (1781–1792). Meteorologische Quellen zur Umweltgeschichte des 18. Jahrhunderts. In: Popplow M (ed) Landschaften agrarisch-ökonomischen Wissens: Strategien innovativer Ressourcennutzung in Zeitschriften und Sozietäten des 18. Jahrhunderts. Waxmann, pp 97–119

Lyakhov ME (1984) Klimatitcheskiye extremumy v tsentralnoy tchasti yevropeyskoy territorii SSSR v XIII–XX vv (Climatic extremes in the central part of the European USSR in the 13th to the 20th centuries). Izvestiya Akad Nauk SSSR – Ser Geogr 6:68–74

Malewicz HM (1980) Zjawiska przyrodnicze w relacjach dziejopisarzy polskiego średniowiecza (Natural events in reports by the historians of Medieval Poland). Ossolineum, Wrocław

Martínková L (2005) Paměti pelhřimovských měšťanů z přelomu 18. a 19. století. Filip Ignác Dremsa & Antonín Štěpán (Memoirs of the burghers of Pelhřimov from the end of the 18th century and the start of the 19th. Filip Ignác Dremsa & Antonín Štěpán). Moravský zemský archiv v Brně – Státní okresní archiv v Pelhřimově, Pelhřimov

Martín-Vide J, Barriendos Vallvé M (1995) The use of rogation ceremony records in climatic reconstruction: a case study from Catalonia (Spain). Clim Change 30:201–221. https://doi.org/10.1007/BF01091842

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time steps. In: Preprints, 8th Conference on Applied Climatology. Anaheim, 17–22 Jan 1993, pp 179–184

McRee BR (1993) Charity and gild solidarity in late Medieval England. J British Studies 32:195–225. https://doi.org/10.1086/386030

Mishra AK, Singh VP (2010) A review of drought concepts. J Hydrol 391:202–216. https://doi.org/10.1016/j.jhydrol.2010.07.012

Možný M, Brázdil R, Dobrovolný P et al (2016) Drought reconstruction based on grape harvest dates for the Czech Lands, 1499–2012. Clim Res 70:119–132. https://doi.org/10.3354/cr01423

Mrgic J (2018) Intemperate weather in violent times—narratives from the Western Balkans during the Little Ice Age (17–18th centuries). Cuadernos de Investigación Geográfica 44:137–169

Munzar J (2004) Extreme droughts in Central Europe in the preinstrumental period. Morav Geogr Rep 12:13–23

Murphy C, Noone S, Duffy C et al (2017) Irish droughts in newspaper archives: rediscovering forgotten hazards? Weather 72:151–155. https://doi.org/10.1002/wea.2904

Naumann G, Alfieri L, Wyser K et al (2018) Global changes in drought conditions under different levels of warming. Geophys Res Lett 45:3285–3296. https://doi.org/10.1002/2017gl076521

Nicoll J (1836) A diary of public transactions and other occurrences, chiefly in Scotland from January 1650 to June 1667. T. Constable, Edinburgh

Noone S, Broderick C, Duffy C et al (2017) A 250-year drought catalogue for the island of Ireland (1765–2015). Int J Climatol 37:239–254. https://doi.org/10.1002/joc.4999

Ogilvie AEJ (1990) Climatic changes in Iceland A.D. c. 865 to 1598. Acta Archaeologica 61:233–251

Ogilvie A, Farmer G (1997) Documenting the medieval climate. In: Hulme M, Barrow E (eds) Climates of the British Isles. Present, past and future. Routledge, London, pp 112–133

Ogrin D (2002) Dry and wet years in submediterranean Slovenia from the 14th to the mid-19th century. Acta Univ Palacki Olomuc, Fac Rer Nat – Geographica 37:55–62

Oliva M, Ruiz-Fernández J, Barriendos M et al (2018) The Little Ice Age in Iberian mountains. Earth-Sci Rev 177:175–208. https://doi.org/10.1016/j.earscirev.2017.11.010

Orth R, Vogel MM, Luterbacher J et al (2016) Did European temperatures in 1540 exceed present-day records? Environ Res Lett 11:114021. https://doi.org/10.1088/1748-9326/11/1/114021

PAGES Hydro2k Consortium (2017) Comparing proxy and model estimates of hydroclimate variability and change over the Common Era. Clim Past 13:1851–1900. https://doi.org/10.5194/cp-13-1851-2017

Palmer WC (1965) Meteorological drought. Office of climatology research paper 45. U.S. Weather Bureau, Washington

Palotay M, Mindszenty A, Kopecskó K, Poros Z (2012) Az Ínség-kő geológiája (Geology of the dearth-stone). Földtani Közlöny 142:243–250

Petrovics I (2005) Witch-hunt in Szeged in the early eighteenth century. In: Szeghyová B (ed) The role of magic in the past. Learned and popular magic, popular beliefs and diversity of attitudes. Pro Historia, Bratislava, pp 108–116

Pfister C (1992) Monthly temperature and precipitation in central Europe 1525–1979: quantifying documentary evidence on weather and its effects. In: Bradley RS, Jones PD (eds) Climate since A.D. 1500. Routledge, London, pp 118–142

Pfister C (1999) Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen (1496–1995). Paul Haupt, Bern

Pfister C (2007) Climatic extremes, recurrent crises and witch hunts: strategies of European societes in coping with exogenous shocks in the late sixteenth and early seventeenth centuries. Medieval Hist J 10:33–73. https://doi.org/10.1177/097194580701000202

Pfister C (2018) The "Black Swan" of 1540. Aspects of a European megadrought. In: Leggewie K, Mauelshagen F (eds) Climatic change and cultural transition in Europe. Leiden, Brill, pp 156–194

Pfister C, Weingartner R, Luterbacher J (2006) Hydrological winter droughts over the last 450 years in the Upper Rhine basin: a methodological approach. Hydrol Sci J 51:966–985. https://doi.org/10.1623/hysj.51.5.966

Piervitali E, Colacino M (2001) Evidence of drought in Western Sicily during the period 1565–1915 from liturgical offices. Clim Change 49:225–238. https://doi.org/10.1023/A:1010746612289

Pribyl K (2017) Farming, Famine and Plague. The impact of climate in late Medieval England. Springer, Cham

Pribyl K, Cornes R (2019) Droughts in medieval and early modern England. Part 2: Impacts. Weather (in press)

Przybylak R (2010) Instrumental observations. In: Przybylak R, Majorowicz J, Brázdil R, Kejna M (eds) The Polish climate in the European context: an historical overview. Springer Science + Business Media B.V., pp 129–166

Réflexions lues dans la séance tenue au Louvre, par la société royale de médecine, le 18 septembre 1781: sur la nature de la Constitution de cette année, & le traitement des maladies qu'elle a occasionnées à la fin. Ph.-D. Pierres, Impr., Paris, 1781

Reizner J (1899) Szeged története (History of Szeged), vol 4: Chartulary, Szeged Szabad Királyi Város közönsége, Szeged

Riemann D, Glaser R, Kahle M, Vogt S (2015) The CRE tambora.org—new data and tools for collaborative research in climate and environmental history. Geosci Data J 2:63–77. https://doi.org/10.1002/gdj3.30

Rodrigo FS (2008) A new method to reconstruct low-frequency climatic variability from documentary sources: application to winter rainfall series in Andalusia (Southern Spain) from 1501 to 2000. Clim Change 87:471–487. https://doi.org/10.1007/s10584-007-9312-x

Rodrigo FS, Barriendos M (2008) Reconstruction of seasonal and annual rainfall variability in the Iberian peninsula (16th–20th centuries). Glob Plan Change 63:243–257. https://doi.org/10.1016/j.gloplacha.2007.09.004

Rodrigo FS, Esteban Parra MJ, Castro DY (1995) Reconstruction of total annual rainfall in Andalusia (Southern Spain) during the 16th and 17th centuries from documentary sources. Theor Appl Climatol 52:207–218. https://doi.org/10.1007/BF00864044

Rodrigo FS, Esteban Parra MJ, Castro-Diez Y (1998) On the use of the Jesuit order private correspondence records in climate reconstructions: a case study from Castille (Spain) for 1634–1648 A.D. Clim Change 40:625–645. https://doi.org/10.1023/A:1005316118817

Rodrigo FS, Esteban-Parra MJ, Pozo-Vazquez D, Castro-Díez Y (1999) A 500-year precipitation record in Southern Spain. Int J Climatol 19:1233–1253. https://doi.org/10.1002/(SICI)1097-0088(199909)19:11%3c1233:AID-JOC413%3e3.0.CO;2-L

Roggenkamp T, Herget J (2015) An extreme drought in the year 69 AD on Lower Rhine. A quantitative reconstruction. Z Geomorph 59(Suppl 3):99–109. https://doi.org/10.1127/zfg_suppl/2015/S-59205

Rohr C (2007) Extreme Naturereignisse im Ostalpen. Naturerfahrung im Spätmittelalter und am Beginn der Neuzeit. Böhlau Verlag, Köln

Seager R, Liu H, Henderson N et al (2014) Causes of increasing aridification of the Mediterranean region in response to rising greenhouse gases. J Clim 27:4655–4676. https://doi.org/10.1175/JCLI-D-13-00446.1

Shmakin AB, Chernavskaya MM, Popova VV (2013) "Velikaya" zasucha 2010 g. na Vostochno-Evropeyskoy Ravnine: istoricheskiye analogi, cirkulyacionnyye mekhanismy (The Great drought of 2010 in the eastern European plain: historical analogues, circulation mechanisms). Izvestiya RAN – Ser Geogr 6:41–57

Smičiklas T, Kostrenčić M, Laszowski E (1915) Codex Diplomaticus Regni Croatiae, Dalmatiae et Slavoniae – Diplomatički zbornik Kraljevine Hrvatske, Dalmacije i Slavonije, vol 13. Tisak Dioničke Tiskare, Zagreb

Spinoni J, Vogt JV, Naumann G et al (2018) Will drought events become more frequent and severe in Europe? Int J Climatol 38:1718–1736. https://doi.org/10.1002/joc.5291

Strömmer E (2003) Klima-Geschichte. Methoden der Rekonstruktion und historische Perspektive. Ostösterreich 1700 bis 1830. Franz Deuticke, Wien

Svoboda MD, Fuchs BA (2018) Handbook of drought indicators and indices. In: Wilhite DA, Pulwarty RS (eds) Drought and water crises. Integrating science, management, and policy. CRC Press, Taylor & Francis Group, Boca Bayton, pp 155–207

Symons GJ (1891) Merle's MS. Considerationes temperiei pro 7 annis. Per Magistrum Willelmum Merle, socium domus de Merton. The earliest known journal of the weather. Kept by The Rev. William Merle, rector of Driby, Lincolnshire. 1377–1344. E. Stanford, London

Tarand A, Jaagus J, Kallis A (2013) Eesti kliima minevikus ja tänapäeval (Estonian climate: past and present). Tartu Ülikool, Kirjastus

Tejedor E, de Luis M, Barriendos M et al (2018) Rogation ceremonies: a key to understand past drought variability in northeastern Spain since 1650. Clim Past Discuss. https://www.clim-past-discuss.net/cp-2018-67/

Telelis I (2008) Climatic fluctuations in the Eastern Mediterranean and the Middle East AD 300–1500 from Byzantine documentary and proxy physical paleoclimatic evidence—a comparison. Jahrbuch der Österreichischen Byzantinistik 58:167–208. https://doi.org/10.1553/joeb58s167

Teplý F (1928) Martina Škvoreckého, úředníka na Pacově, hospodářská korespondence z dob války třicetileté (1630–1642) (Financial correspondence of Martin Škvorecký, a clerk at Pacov, from the time of the Thirty Years' War, 1630–1642). Nákladem Ministerstva zemědělství Republiky československé, Praha

Todd B, Macdonald N, Chiverrell RC et al (2013) Severity, duration and frequency of drought in SE England from 1697 to 2011. Clim Change 121:673–687. https://doi.org/10.1007/s10584-013-0970-6

Trnka M, Hayes M, Jurečka F et al (2018) Priority questions in multidisciplinary drought research. Clim Res 75:241–260. https://doi.org/10.3354/cr01509

van der Schrier G, Efthymiadis D, Briffa KR, Jones PD (2007) European Alpine moisture variability 1800–2003. Int J Climatol 27:415–427. https://doi.org/10.1002/joc.1411

Van Loon AF, Gleeson T, Clark J et al (2016a) Drought in the anthropocene. Nat Geosci 9:89–91. https://doi.org/10.1038/ngeo2646

Van Loon AF, Stahl K, Di Baldassarre J et al (2016b) Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches. Hydrol Earth Syst Sci 20:3631–3650. https://doi.org/10.5194/hess-20-3631-2016

Vicente-Serrano SM, Beguería S, López-Moreno JI (2010) A multi-scalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index—SPEI. J Clim 23:1696–1718. https://doi.org/10.1175/2009JCLI2909.1

Walter H (1901) Ueber die Stromschnelle von Laufenburg. Vierteljahrsschrift d. naturf. Ges. Zürich 46:232–263 (see also: Inaugural-Dissertation, Zürich)

Weikinn C (1958–2002) Quellentexte zur Witterungsgeschichte Europas von der Zeitwende bis zum Jahre 1850. Hydrographie. Teil 1 (Zeitwende–1500), Teil 2 (1501–1600), Teil 3 (1601–1700), Teil 4 (1701–1750), Teil 5 (1751–1800), Teil 6 (1801–1850). Akademie-Verlag, Berlin

Wetter O, Pfister C (2013) An underestimated record breaking event. Why summer 1540 was likely warmer than 2003. Clim Past 9:41–56. https://doi.org/10.5194/cp-9-41-2013

Wetter O, Pfister C, Werner JP et al (2014) The year-long unprecedented European heat and drought of 1540—a worst case. Clim Change 125:349–363. https://doi.org/10.1007/s10584-014-1184-2

White S, Pfister C, Mauelshagen F (eds) (2018) The Palgrave handbook of climate history. Palgrave Macmillan, London

Wilhite DA, Pulwarty RS (2018) Drought as hazard: understanding the natural and social context. In: Wilhite DA, Pulwarty RS (eds) Drought and water crises. Integrating science, management, and policy. CRC Press, Taylor & Francis Group, Boca Bayton, pp 3–20

Williams H (2016) Saint Geneviève's miracles: art and religion in eighteenth-century Paris. French Hist 30:322–353. https://doi.org/10.1093/fh/crv076

Worobec CD (1995) Witchcraft beliefs and practices in prerevolutionary Russian and Ukrainian villages. Russ Rev 54:165–187. https://doi.org/10.2307/130913

Xoplaki E, Maheras P, Luterbacher J (2001) Variability of climate in meridional Balkans during the periods 1675–1715 and 1780–1830 and its impact on human life. Clim Change 48:581–614. https://doi.org/10.1023/A:1005616424463

Yurchenkov V (2014) Impact of natural conditions on the regional historical development (based on the example of the Mordovian Land of the XVIIth century). In: Božić S (ed) History and geography: meetings and permations. Geography Institute Jovan Cvijić (SASA), Institute of Recent History of Serbia, Institute of Slavic Studies (RAS), Belgrade, pp 583–594

Zgutam R (1977) Witchcraft trials in seventeenth-century Russia. Amer Hist Rev 82:1187–1207