Adaptation before Anthropogenic Climate Change:

A Historical Perspective on Adaptation to Droughts in Terrassa (1600-1870s, NE Spain)

PhD Dissertation

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Summary

Although anthropogenic climate change is a relatively recent phenomenon, throughout history human societies have adapted to climate variability, climatic extremes, and gradual climate changes. Thinking historically about climate change can contribute to develop more comprehensive models that explain general principles governing the dynamic relations between society and climate. In this dissertation, I explore two ways in which historical accounts could engage with research on the human dimensions of climate change. First, I draw on debates and analytical frameworks from current climate change research to study past adaptation processes. Particularly, I classify past adaptation strategies using taxonomies developed to understand current adaptation, explore adaptation at multiple levels, and revisit the debate about the multiple causes that drive (past and present) adaptation. Second, I develop a historical approach that can be useful to situate current adaptation processes into a broader perspective. Particularly, I apply a long-term perspective to visualize how and explain why diverse adaptation strategies distinctly manifest over long periods of time.

The empirical analysis is presented in three chapters that examine how a local community, the municipality of Terrassa (NE Spain), adapted to climatic extremes (i.e., recurrent droughts) during the period between the seventeenth and late nineteenth centuries. The first empirical chapter aims a) to understand and document how preindustrial communities experienced and collectively responded to droughts over long periods of time and b) to uncover non-climatic contemporary threats and processes that helped shape adaptive responses. The chapter systematically investigates the typology, timing, and context of drought responses in the village of Terrassa between 1600 and 1715 showing that this early modern community adopted a mixture of symbolic, institutional, and infrastructural responses to cope with recurrent droughts. Responses documented changed over time, significantly decreasing since the first third of the sixteenth century. I explain this pattern discussing how mounting public debt and successive wars could have limited the range of available response options.

The second empirical chapter aims to understand multi-level adaptation to climatic extremes in preindustrial societies. To do so, I use archival material to reconstruct and classify the set of strategies to cope with recurrent droughts used at the community and the household levels during the early modern period. Results show that peasant families developed a wider range of strategies than communities, although many strategies from both levels overlapped. The findings suggest that multilevel analysis is critical to understand the diversity of adaptation strategies developed in preindustrial societies. The chapter also discusses the methodological caveats that remain when using archival sources to understand past human adaptation to climate.

The last empirical chapter addresses the implications for climate adaptation of the socio-environmental transformations associated with the transition from the early modern period to industrialization. Specifically, the chapter documents how adaptation to droughts changed in the study area during the period between 1600 and 1870s, when the village of Terrassa turned into an industrial city. To contextualize and historicize the changes documented, I discuss how long-term changes in water governance regimes in Catalonia and governance actors beyond the local council could have conditioned local adaptation to drought.

Resum

El canvi climàtic antropogènic és un fenomen relativament recent, però al llarg de la història les societats humanes s'han adaptat a la variabilitat climàtica, als extrems climàtics, i als canvis climàtics graduals. Pensar històricament sobre el canvi climàtic pot contribuir a desenvolupar models més complets que expliquin els principis que governen les relacions dinàmiques entre clima i societat. En aquesta tesi doctoral, exploro dues maneres en què la mirada històrica es pot enllaçar amb la recerca sobre les dimensions humanes del canvi climàtic. En primer lloc, parteixo dels debats i els marcs analítics desenvolupats a partir de la recerca sobre el canvi climàtic actual per tal d'estudiar els processos adaptatius passats. Concretament, classifico les estratègies d'adaptació passades emprant taxonomies desenvolupades per comprendre l'adaptació actual, exploro l'adaptació a múltiples nivells, i torno a visitar el debat sobre les múltiples causes que impulsen l'adaptació (passada i present). En segon lloc, desenvolupo una aproximació històrica que pot ser útil per tal de situar els processos adaptatius actuals en una perspectiva més àmplia. Específicament, aplico una perspectiva a llarg termini que permet visualitzar com i explicar per què les estratègies d'adaptació es manifesten de manera diferent durant llargs períodes de temps.

L'anàlisi empíric d'aquesta tesi doctoral es presenta en tres capítols que examinen com una comunitat local, el municipi de Terrassa (NE Espanya), s'adapta als extrems climàtics (i.e., les sequeres recurrents) durant el període comprès entre el segle XVII i finals del segle XIX. El primer capítol empíric té per objectius a) entendre i documentar com les comunitats pre-industrials experimentaven i responien col·lectivament a les sequeres durant llargs períodes de temps, i b) posar en relleu quines amenaces i processos contemporanis no-climàtics condicionaven les respostes adaptatives documentades. Aquest capítol investiga de manera sistemàtica la tipologia, la cronologia, i el context de les respostes a les sequeres desenvolupades a la vila de Terrassa entre 1600 i 1715, mostrant com aquesta comunitat de l'Època Moderna va adoptar una mescla de respostes simbòliques, institucionals, i en infraestructures per tal de fer front a les sequeres recurrents. Les respostes documentades van canviar al llarg del temps, reduint-se de manera significativa a partir del primer terç del segle XVII. En aquest article, explico aquesta tendència discutint com el deute públic creixent i les guerres successives van poder limitar la gamma d'opcions de resposta disponibles.

El segon capítol empíric té per objectiu entendre l'adaptació multi-nivell als extrems climàtics en societats pre-industrials. Per tal d'assolir aquest objectiu, faig ús de material arxivístic per reconstruir i classificar el conjunt d'estratègies per fer front a les sequeres recurrents desenvolupades a nivell de comunitat i a nivell domèstic durant l'Època Moderna. Els resultats mostren com les famílies pageses van desenvolupar una gamma més àmplia d'estratègies que no pas les comunitats, tot i que moltes estratègies dels dos nivells se sobreposaven. Aquests resultats suggereixen que l'anàlisi multi-nivell és crucial per tal d'entendre la diversitat d'estratègies d'adaptació desenvolupades en societats pre-industrials. El capítol també discuteix quins són els límits metodològics alhora d'utilitzar fonts arxivístiques per tal de comprendre l'adaptació humana al clima durant el passat.

El darrer capítol empíric tracta sobre les implicacions de les transformacions socio-ambientals associades amb la transició de l'Època Moderna a la industrialització sobre l'adaptació al clima. En concret, el capítol documenta com l'adaptació a les sequeres va canviar a l'àrea d'estudi durant el període comprès entre 1600 i 1870s, quan la vila de Terrassa es va convertir en una ciutat industrial. Per tal de contextualitzar i historitzar els canvis documentats, discuteixo com els canvis a llarg termini en els règims de governança de l'aigua a Catalunya i altres agents de governança diferents de l'Ajuntament van poder condicionar les adaptacions locals a la sequera.

CHAPTER I

Introduction

1. Background

Anthropogenic climate change is a relatively recent phenomenon.[1] However, humans have experienced climate variability, climatic extremes, and gradual climate changes since pre-historical times (White 2012). As anthropogenic climate change exacerbates (IPCC 2014), and considering that *Homo sapiens* has long coexisted with major changes in climatic conditions (Brooke 2014, Latorre et al. 2016), the scientific community has started to emphasize the value of past experiences to cope with present climatic extremes and change. McIntosh, for instance, argued that "*by ignoring the great laboratory of millennia of responses to environmental change, we condemn ourselves to reinventing a very complex wheel in the face of one of humanity's greatest challenges*'' (McIntosh et al. 2000:3).

The analysis of historical analogies and examples, together with longitudinal analyses with a deep historical perspective can contribute to develop more comprehensive models that explain past socio-ecological interactions, historical legacies, and general principles of the dynamic relationships between society and climate change (Adger et al. 2003, Chakrabarty 2009, Ford et al. 2010, Steen-Adams et al. 2015, Parsons and Nalau 2016). Moreover, as pointed by McNeill (2008:45), the record of the past can be relevant to imagine the future, because ultimately climate change will be felt locally and regionally, as it happened during past climatic anomalies. Yet, while acknowledging the potential of the study of the past, scholars also highlight that the past should be reconstructed with caution, and possibly using empirically grounded studies that avoid climate (neo)determinism and over simplistic extrapolations in terms of the present and future implications (Butzer and Endfield 2012, Hannaford et al. 2014, Endfield 2014).

[1] There is still some debate about the onset of climate change and the overall geological epoch of the Anthropocene (see Lewis and Maslin 2015). The last IPCC indicates that the effects of anthropogenic greenhouse emissions have been the dominant cause of observed global warming since the second half of the twentieth century (Stocker et al. 2013, IPCC 2014). Advocates of the early Anthropocene hypothesis (the so-called Ruddiman hypothesis) defend that human effects on climate started earlier, especially triggered by the expansion of Neolithic agriculture (Ruddiman 2003, Kaplan et al. 2011, Ruddiman et al. 2015 and 2016). Recent paleoclimatic studies show how climate change is observed later than global warming onset. In Europe, for example, warming probably started by mid-nineteenth century, whilst climate change signals exceeding the range of climate variability did not emerge until the 1990s (Abram et al. 2016).

In the last two decades, two lines of research have aimed to historicize climate change.[2] On the one hand, historical climatologists and paleo-climatologists have reconstructed recent and remote climate dynamics. On the other hand, an emerging body of literature has started to focus on past human experiences and responses to changing climatic conditions. Below, I briefly describe the main contributions of these two lines, especially focusing on research addressing the last 500 years.

Climate reconstructions have progressed enormously since the early 2000s due to three important methodological developments within the field of historical climatology. First, historical climatological databases have improved their geographical and temporal resolution by revising existing databases and developing new ones (Brázdil et al. 2005). Second, the information from these databases has been processed though sophisticated statistical methods of standardisation, calibration and verification in order to develop more robust climate reconstructions (Brázdil et al. 2010). And third, researchers and research groups have developed networks of scientific cooperation and exchange, sharing data and creating synergistic research outcomes (Pfister 2010). All these efforts have contributed to build more precise chronologies and climate dynamics models, which allow to better understand the geographical variability of climatic anomalies, to identify the drivers (so-called climate "forcings") of such anomalies, and to define more accurately long processes of gradual climate change such as the Little Ice Age or the Medieval Warm Period (Brázdil et al. 2005, Jones 2008, Mann et al. 2009, White 2012). Therefore, historical climatology as well as other paleoclimatic sciences have provided significant insights into climate change science. Probably the most important insights in this regard are the establishment of baselines contextualizing the magnitude of today's observed changes in climate and the improvement of climate models to integrate past evidence when determining likely future climates (Crowley 2000). Despite all these advancements, improving interdisciplinary collaboration among climate modellers, paleo-climatologists, and social and cultural historians continues to be a critical challenge in this field (Bràzdil et al. 2010, Izdebski et al. 2016).

Several scholars, mostly from Europe, have tried to widen the traditional scope of historical climatology beyond the reconstructions of physical climate. In this sense, they have defined

[2] In fact, some studies have the inverse goal: rather than historicize climate, they aim to "climatize" history, in other words, to bring climate into human history (e.g. White 2011). The two aims are not incompatible and can be inserted into broader calls of environmental history to both think historically about socio-ecological systems and to re-interpret the past taking into account the environment (McNeill 2003).

historical climatology "*as a research field situated at the interface of climatology and (environmental) history, dealing mainly with documentary evidence and using the methodology of both climatology and history*" (Brázdil et al. 2010:8-9).[3] They claim that, by reducing humans to weather observers, the histories of climate can overshadow human agency in dealing with climate variability, extremes and changes (Pfister 2010, Allan et al. 2016). In this regard, works on historical climatology, the literature on disasters, as well as numerous studies from the humanities and the social sciences have proposed a **human history of climate** that helps to better understand the complex and historically changing relations between society and climate. A human focus is, indeed, indispensable if historical accounts aim to inform and engage with research on the human dimensions of climate change (hereafter HDCC).[4]

In a literature review on the historiography of climate change, Carey (2012) divided this second set of human-focused climate history contributions into three sub-fields. The first sub-field concentrates on the study of social **impacts, vulnerabilities, and adaptations** to past climatic variability and anomalies. Such pioneering works often focus on social responses to abrupt changes and climate extremes such as hurricanes (e.g. Shwartz 2015), droughts, or floods (e.g. Gil-Guirado et al. 2016), rather than assessing gradual processes such as the Little Ice Age (e.g. White 2011). While growing, studies on this line remain unevenly developed across countries and periods. Despite this fragmented evidence, this literature has helped to understand the inter-twinned factors that operate in the dynamic interaction of societies with climate extremes (e.g., Adamson 2014) and climate variability (e.g. Hannaford and Nash 2016). In addition, this literature also provides empirically-based examples of (mal)adaptation to climate changes. For instance, the case of witch-hunting during the sixteenth and the seventeenth centuries in central Europe, associated to climatic extremes and the Little Ice Age, informs of the possibility that responses to climate change end up exacerbating the suffering of marginalized groups (see Behringer 1999, Pfister 2007). Moreover, some of these studies help to understand the historical processes that have created certain geographies of vulnerability to

[3] The three objectives of this broader historical climatology developed very unevenly over the last 40 years are: (a) reconstructing of weather and climate prior to the modern instrumental period, (b) investigating the vulnerability of past economies and societies to climatic extremes and natural disasters, and (c) exploring discourses on climate (Pfister 2010; Brázdil et al. 2005, 2010).

[4] The notion of the human dimensions of climate change (HDCC) or human dimensions of global environmental change (HDGEC) originally referred to the study of societal impacts, adaptation, and vulnerability to these changes. Yet, broader and critical perspectives on this initial notion, as well as alternative terms, exist in the literature (e.g., Aspinall 2010, Mearns and Norton 2010, ISSC and UNESCO 2013, Castree et al. 2014).

climate (e.g. Endfield 2008). Indeed, these histories can contribute to understand current vulnerability to climate extremes. For example, settlement patterns help to explain increasing flood damages and the failure of past prevention infrastructures in rapidly urbanizing areas (Messerli et al. 2000).

Some future challenges in the research sub-field on vulnerabilities, social impacts of, and adaptations to past climatic variability and extremes are i) to expand the time ranges of studies in order to capture long-term patterns likely invisible at shorter frames; ii) to connect findings from past periods with findings from more recent periods, especially from the nineteenth and twentieth centuries; iii) to link historical analyses with the contributions from disaster studies; and iv) to examine the differential capacities to adapt, suffer, and recover from climate extremes across social, ethnic, and gender groups (Pfister 2010, Carey 2012, Carey et al. 2014). This dissertation addresses some of these research needs. In particular, I develop a long-term perspective of community responses to drought in the period 1605-1710 (Chapter II) that is later inter-twinned in a longer narrative ending at the second half of the nineteenth century, which also addresses the changing adaptations to droughts in the transition period to modern societies (Chapter IV). Gender and social inequalities are also considered in several sections of the three empirical chapters, although such aspects are not the main focus of this dissertation.

The second and third sub-fields identified by Carey (2012) focus on the representations of climate. The second sub-field is concerned with the **cultural constructions of climate** and intends to engage with cultural history to understand how societies and social groups perceive and represent climate (e.g. Quénet 2012, Veale et al., 2014, Culver 2014, Hall and Endfield 2016). Moreover, they aim to understand how climate perceptions changed over time and how they are conditioned by historically changing worldviews (see for instance the Special Issue in *Environment and History* edited by Lübken and Mauch in 2011, or the book edited by Janku et al. 2012). Debates about scientific and **traditional knowledge on climate** have also benefited from the historical lens. In this regard, the studies in the third sub-field aim to understand the relationships between the different sources of climate knowledge, how ideas and knowledge on climate relate to power structures that support certain political agendas, and how different social groups have used this knowledge over time (Fleming 2010, Carey 2012). As today's perceptions of climate change, such contested discourses, ideas and representations of climate, have shaped people's actions and therefore their adaptation choices. For instance, during the drought occurred in New Zealand in the 1906-1907, different views on rain clashed, and thus while farmers used both prayers and experiments of rain-making to cope with the impacts of drought, the emerging professional meteorologists

criticized the rain-making experiments as unscientific and amateurish (Beattie 2004). Importantly, these two sub-fields are related with the first one, because beliefs, values, perceptions, discourses, and knowledge mediate how people have reacted to climate changes in the past (Gómez-Baggethun et al. 2012, Pillatt 2012a).

Although historical climate-society relations provide relevant lessons for understanding the human dimensions of (current) climate change, three challenges remain critical when developing a cross-fertilization between climate change research and climate histories. First, historical accounts should bear in mind that modern climate change is different from previous changes in climate in at least four aspects: its speed, its global scale, the uncertainty it generates, and the human responsibility (Füssel 2007, McNeill 2008). The speed of change and the uncertainties regarding anthropogenic climate change are probably the most novel aspects, at least from recent human history. Regarding the spatial scale, it is worth noticing that despite the fact that climate change affects the whole Earth, its impacts manifest and are therefore felt and responded to at the local and regional levels (see Section 2.3), as occurred in past climate extremes. For this reason, some scholars argue that historical analyses are especially relevant for climate change debates when they focus on climate extremes regularly experienced in the past, that will likely become more frequent with climate change. As pointed by McNeil (2008:43), "*such* [climate-related] *shocks have been part of the ordinary experience of most generations until very recently. The most serious were epidemics and droughts - both of which climate modellers anticipate will become more likely in a greenhouse world*". Thus, in this dissertation, I focus on climatic extremes, particularly drought, because they mattered in past and would likely play an important role on future climate change scenarios (see Section 4.2).

The second challenge lies in avoid hasty conclusions derived from climatic interpretations of human history intended to provide direct lessons for current climate change challenges (Butzer and Endfield 2012). White (2011) warns against the logic of post hoc (*post hoc ergo propter hoc*, i.e. “after this, therefore because of this”). In other words, the fact that climatic and social events coincide or follow one another in time does not imply a causal relationship (see a similar reflection from archaeology in McGhee 1981). For this reason, White (2011) defends that historic interpretations should reasonably explain how and why different climatic and non-climatic documented events are related. To address this challenge, in this dissertation I developed a contextualized archival research which contributed to situate and explain the relationships among the recorded facts (see Section 4.4).

The third challenge is that climate histories willing to engage with HDCC scholarship should recognize not only the "hot concepts" used in this literature (e.g. resilience, vulnerability, adaptation), but also the plurality of perspectives they embrace. To follow the eclectic literature on the HDCC is not easy due to i) its interdisciplinary nature (for an account of the challenges related to interdisciplinary communication in HDCC research see Nielsen and D'haen 2014), ii) the particularity of each case study (see proposals for strengthening comparative analysis in Vogel and Henstra 2014), and iii) the difficulty of finding accurate systematic literature reviews (see the different views on reviews in Lorenz et al. 2014 and Fogelman and Basset 2014). Furthermore, the definitions, approaches, and the ways to classify and evaluate the key concepts in current HDCC research are often ambiguously used or weakly problematized in historical studies, and consequently historical studies are poorly integrated with current debates on climate change or global environmental change (for some exceptions see Orlove 2005, Fraser 2007, Endfield 2008, Adamson 2014, Kelso and Vogel 2015, Hannaford and Nash 2016). This dissertation addresses this gap by selecting HDCC concepts and frameworks to analyse the past while recognizing some of the limits and necessary simplifications that this entails. The next three sections develop this point further.

2. State of the art

2.1. The challenges of adaptation to climate change

The failure to reach international agreements on effective climate change mitigation policies as well as the growing evidence that climate change is already impacting our societies have fed the idea that we need to adapt, at least to the unavoidable impacts of climate change (Wigley 2005, Hare and Meinshausen 2006). In the last (fifth) report of the Intergovernmental Panel on Climate Change (IPCC), adaptation is defined as "the process of adjustment to actual or expected climate and its effects" (Noble et al. 2014: 838). Indeed, adaptation has a prominent role in this report. Many chapters of the second working group cover adaptation and the report incorporates twelve new terms associated with it such as 'adaptation constraint' and 'ecosystem-based adaptation' (Simonet 2015). Both the understanding of adaptation and the political priority to adapt have evolved across the successive reports of IPCC (1990-2014) and the climate change policies derived from them (Schipper 2006, Simonet 2015). During this process, researchers have developed and debated several approaches and definitions of adaptation to climate change. In the following paragraphs, I present three critical aspects of this expanding body of literature: the pluralism of conceptions, the difference between adjustment and transformation, and the debate on the causality of adaptation.

The notion of adaptation has been approached from different theoretical, analytical, and disciplinary traditions. The semantic history of the concept reflects such interdisciplinary nature. "Adaptation" (to the environment) was popularized in the nineteenth century after the Darwinist theory of evolution. From the biological domain, "adaptation" was soon converted into a trans-disciplinary term, exported to disciplines as distant as psychology, geography, or anthropology (Simonet 2010). Likewise, the current literature on adaptation to climate change is characterized by theoretical pluralism. Some scholars approach adaptation from a systemic perspective, while others prefer the theories of action. In the systemic approach, multiple states, complex interactions, as well as the possible feedbacks and trade-offs of adaptation strategies have a prominent role (e.g. Nelson et al. 2007). In contrast, action-oriented studies focus on the social agency of the involved actors, highlighting the actors' differential roles and power, intentionality and goals, as well as the relationships among them (e.g. Eisenack and Stecker 2012). The literature on hazards traditionally approached adaptation based on the stimulus-response model, i.e. purposeful adjustments to bio-physical hazards chosen by rational individuals after evaluating a range of possibilities. In turn, political ecologists approached it as a social process whereby people do not freely choose among different

adaptation options, but remain conditioned by structural factors that differentiate them socially (Basset and Fogelman 2013, for a recent critical perspective see Watts 2015). Some authors claim that such pluralism and lack of consensus regarding the concept may lead to semantic vagueness and ambiguity (Simonet and Fatoric 2016). As explained in the first section, existing pluralism challenges the communication between HDCC research and the histories of climate-society relationships. To propel dialog and cross-fertilization, the empirical chapters of this dissertation use widely known definitions and classifications of adaptation from the climate change literature to study past adaptation patterns. In the conclusion, I discuss some of the pros and contras of this decision (Chapter V).

In recent years, two contrasting views regarding adaptation have been debated: adjustment and transformation. Advocates of the adjustment perspective suggest that adaptation should recover and remain within the existing system or underlying framework (i.e. incremental adaptation), whereas transformation scholars claim that adaptation requires changing the prevailing system (Park et al. 2012, Kates et al. 2012, Feola 2015). This debate evocates an old political discussion between maintaining the *status quo* through a limited set of gradual reforms, versus transforming social, economic and power structures through a revolutionary process. Some researchers have also identified an intermediate position in the climate change literature, labelled as "transicionists" or "reformists" (Pelling 2011, Bassett and Fogelman 2013). This position seeks to alter the rules that create vulnerability to build adaptive capacity within the prevailing system. Nowadays, most research on climate change as well as the last IPCC report recognizes the adjustment/transformation debate, although there is still certain ambiguity between the terms, which often remain poorly defined (O'Brien 2012, Lonsdale et al. 2015). Furthermore, to the best of my knowledge, this terminology has scarcely been infused into historical studies (see Parsons and Nalau 2016 for an exception), although reflections about the collapse of ancient civilizations and the structural transformations occurred in the past could provide new insights into this debate. Without going deep into the debate, I address it in the third empirical chapter of this dissertation (Chapter IV).

Finally, researchers are also concerned with the understanding of what triggers human societies to adapt. In this regard, several authors criticize that the literature on adaptation to climate change only accounts for climatic factors (e.g. Smit et al. 2000), although people do not simply adapt to climate changes, but to multiple stressors and threats that can be inter-twinned (Nielsen and Reenberg 2010, Young 2010; see also the double-exposure approach proposed in Leichenko and O'Brien 2008). The reluctance to climatic determinism is significant in the humanities in general, and therefore also among historians (e.g. McCann 1999). While

this attitude has started to prevent the use of mono-causal explanations of climate-society relationships, it also explains why many historians refuse to tackle climate as a significant factor in explaining historical events (Pfister 2010). A priority of this PhD dissertation is to bring new light about the historically changing factors and inter-twinned processes that shaped past adaptations to climate, beyond climate per se. Specifically, I address the role of recurrent threats in pre-industrial societies such as wars and public debt (Chapter II), as well as the influence of slow pace processes such as the changes in water governance regimes on shaping adaptation to drought during "modernization" (Chapter IV). The role of internal characteristics, such as the different degrees of integration into the market economy by households, in conditioning past adaptation is discussed in Chapter III.

2.2. Existing frameworks to analyse adaptation processes

As currently understood, the notion of "adaptation" refers both to a process (i.e., a series of actions undertaken to adapt) and its outcome (i.e., the resulting successful situation in which the actors can better live or cope with the stressor) (Simonet 2010). This dissertation focuses and develops the processual dimension of adaptation. In other words, it considers that human adaptation cannot be fragmented into single strategies, but has to be understood as a set of co-constituting social processes, dynamic and historically-contingent (see a social sciences perspective in Wolf 2011). In previous literature, two existing approaches provide some tools to explore the temporal dimension of adaptation processes, namely the 'adaptive cycles' and the 'adaptation pathways'.

Adaptive cycles highlight the idea of cyclic patterns of change in complex systems. The notion originally provided a framework to explain the dynamics of ecological and resource management systems (Holling 1986), but was later widened to describe the role of disturbance and change in social-ecological systems (Holling and Gunderson 2002). The metaphor of the adaptive cycle is based on observed patterns of change in various types of systems, from lakes to national economies (Walker et al. 2004). The cycle is composed of four recognizable phases, which usually follow one to another in sequence: a) renewal (reorganization in which innovation and new opportunities are possible), b) growth (slow accumulation of resources), c) conservation (resources become increasingly locked up), and d) release (chaotic collapse) (see Fig. 1.1a).

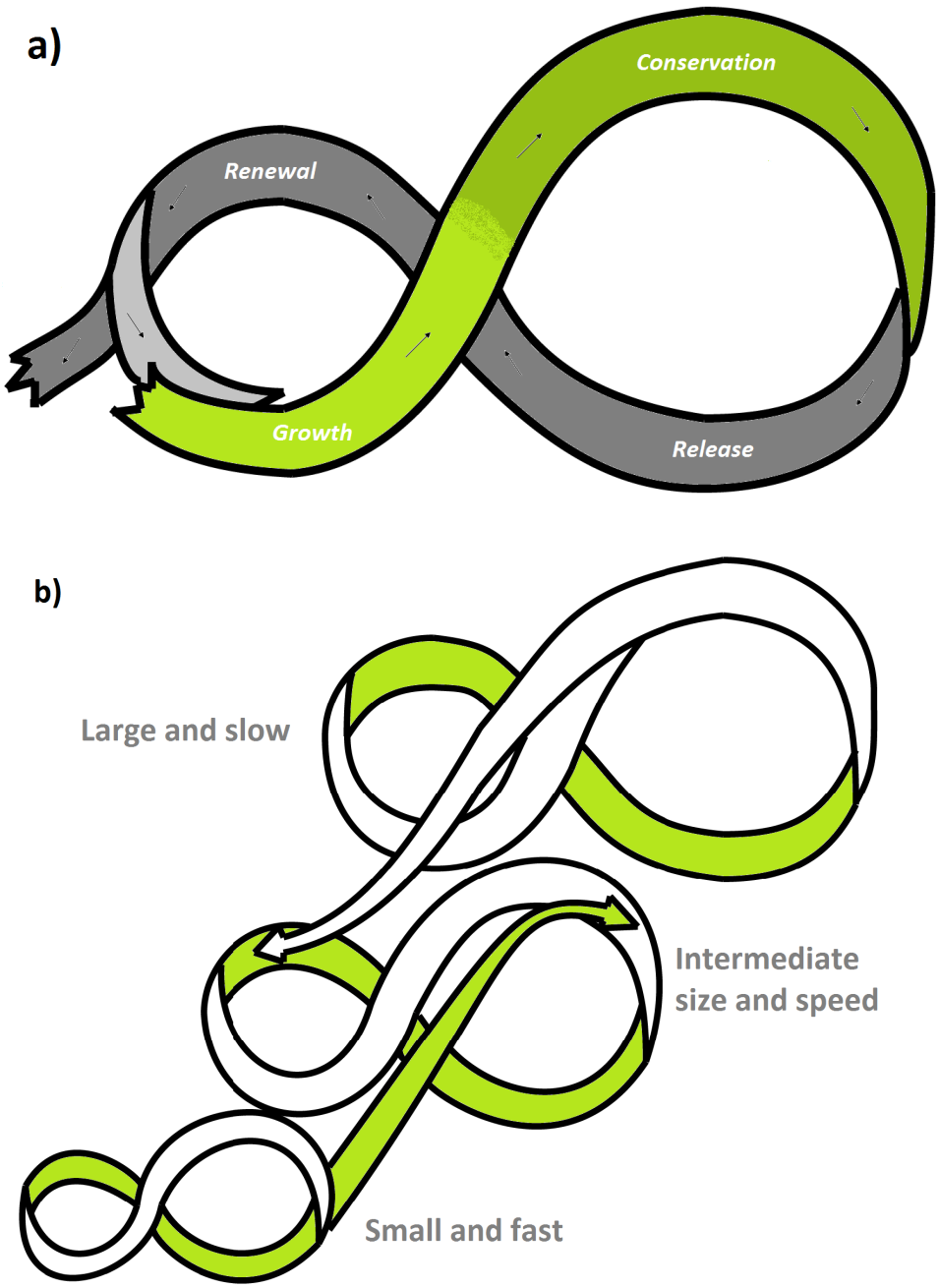

Figure 1.1. Adaptive cycle (a) and cross-scale linkages among adaptive cycles, i.e. panarchy (b) in socio-ecological systems. Source: adapted from Chapin et al. 2009.

The heuristic model termed "panarchy" describes interactions among adaptive cycles operating at different temporal and spatial scales (Holling et al. 2002, see Fig. 1b). Over long temporal scales, adaptive cycles can also appear sequentially chained (Fig. 1.2). For instance, the recent history of water management in the Everglades (south-eastern US) has been divided into four distinct eras: a) water drainage of wetlands for urban and agricultural development (1903-1947), b) implementation of public works to prevent flood damage (1948-1970), c) attempts to restructure management institutions to deal with water shortages and flood problems (1971-1982), and d) attempts to restore the ecosystem (1983-2000s)

(Gunderson et al. 2002, Gunderson and Light 2006). Each management era illustrates a separate adaptive cycle with its phases of renewal, growth, conservation, and release. Researchers studying longer management periods have also applied the four-phase heuristics to explain complex histories such as the management of Galapagos´ socio-ecological systems from the sixteenth century to the present (González et al. 2008, Fig. 1.2) or water institutional regimes in southern Spain from late eighteenth century to the present (Méndez et al. 2012).

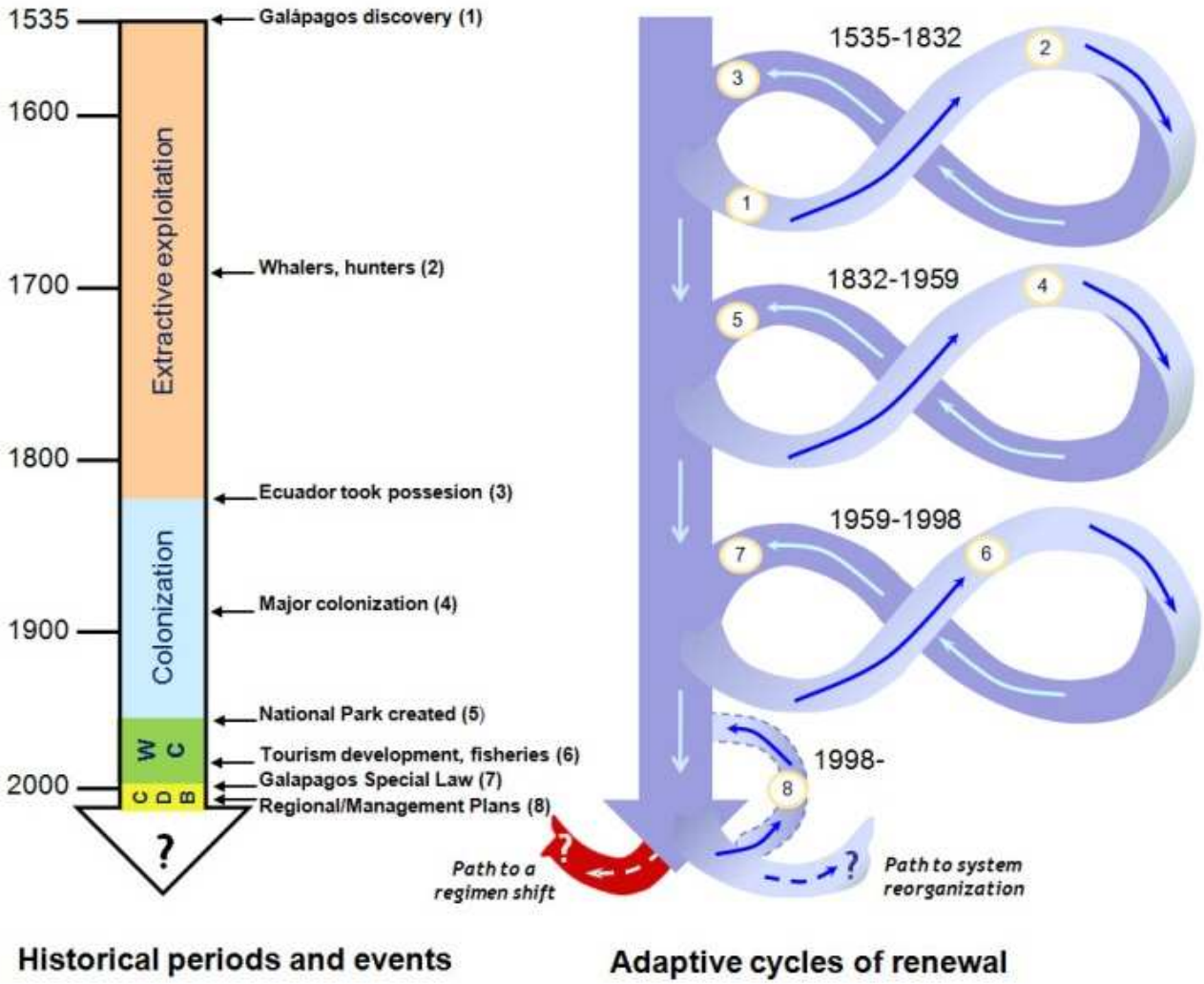

Figure 1.2. Successive iterations of adaptive cycles. Example from the management of socio-ecological systems between 1535-2000s in Galapagos islands (González et al. 2008).

In this dissertation, I use this framework to approach water governance regimes shaping processes of adaptation to drought (Chapter IV).

The second tool to approach long-term adaptation processes is known as **adaptation pathways** (see Fig. 1.3). The concept of 'pathways' was originally discussed in the literature on

economics, sociology, and geography, which also coined the term of path-dependency to refer to the inability of certain systems to evolve in ways that are not constrained by past developments (Martin and Sunley 2006). In the literature on climate change, the notion of adaptation pathways has been mainly used as a metaphor to visualize the processes, sequences, or series of adaptation decisions over time (e.g., Haasnoot et al. 2013, Maru et al. 2014; see Fig. 1.3). Planning desirable routes for climate adaptation policies is an example of an application of the concept of adaptation pathways (e.g. Tanaka et al. 2015).

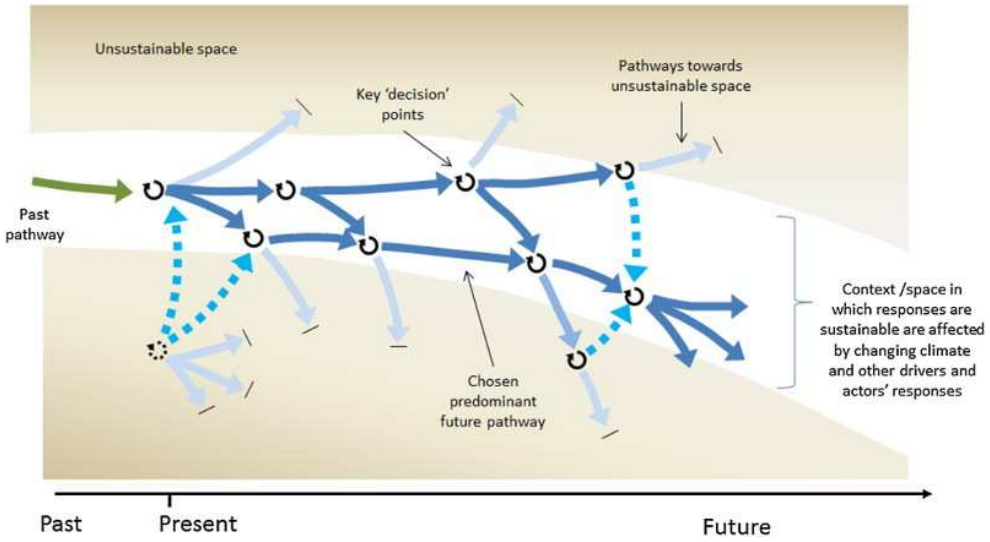

Figure 1.3. Adaptation pathways (Fazey et al. 2016). Note: dark blue arrows represent different possible routes that could be taken; black circle arrows represent decision points; light blue arrows lead to maladaptive dead-ends; dashed blue arrows represent more-or-less transformative pathway segments; and the green arrow (before present) represents historical pathways. The background represents the context in which pathways emerge, with the unshaded background space in which responses to change and adaptation are considered to be socially and environmentally sustainable. The boundary of this space changes due to changes in climate, environmental, or socio-economic conditions.

It has been argued that the "adaptation pathways" can be used not only as a decision-oriented tool, but also as an analytical tool that allows capturing issues such as the importance of the historical context, path dependencies, or the broader pathways of societal change in which adaptation processes are embedded (Wise et al. 2014). In this sense, a pioneering study exploring past adaptation pathways has revealed the existence of different pathways occurring at the same time at the individual, the household, and the community levels, and the role of historical legacies and continuities in shaping adaptation pathways (Fazey et al. 2016).

In this dissertation, I do not explicitly apply adaptation pathways to visualize the series of adaptation decisions documented over the study period. However, I do use some key concepts from this approach, such as path dependencies, to explain the analysed adaptation processes.

2.3. Governing adaptation: a multilevel perspective

This dissertation focuses on the temporal dimension of adaptation to climate. Yet, it also recognizes that adaptation is planned and implemented at certain spatial and organizational scales (Adger et al. 2005, Reyes-García et al. 2016). In this section, I review current discussions on local adaptation and the proposals found in the literature for multilevel governance. I also explain how this thesis addresses the issue of the organizational scale.

Numerous studies argue that adaptation to climate change is highly context-specific due to the local nature of the manifestations of and the vulnerabilities to climate change (Holling 1997, Berkes and Jolly 2001, Cutter et al. 2008, Sheppard et al. 2011, Pyhälä et al. 2016). Thus, while climate change is a global phenomenon, current and future adaptation to its impacts might mainly operate at national, regional, and particularly, local levels. In fact, place-based factors such as the local environment, the socio-economic context, or the available local knowledge play a key role in shaping adaptation processes (Naess 2005, Crabbé and Robin 2006, Roberts 2008). Consequently, local governments increasingly appear as key actors in the pursuit of successful climate change adaptation strategies (Rosenzweig et al. 2010, Hunt and Watkiss 2011).

However, when referring to the decision-making behind adaptation programs rather than to their implementation, some researchers disagree on the "localness of adaptation" (see recent reviews in Preston et al. 2013 and Nalau et al. 2015). These studies argue that adaptation to climate change is a responsibility that should be shared by all levels of government. Indeed, they prove how local adaptation does not take place in isolation, but remains embedded within a broader multilevel context, whereby local policy choices are influenced, fostered or hindered by decisions taken at other governance levels (Urwin and Jordan 2008, Amundsen et al. 2010, Mukheibir et al. 2013, Graham and Mitchell 2016). Moreover, some scholars defend that successful adaptation also requires cooperation with non-governmental actors including civil society organizations and businesses (Adger et al. 2005, see Fig. 1.4). Despite this growing literature on multilevel governance of climate adaptation, some authors have pointed out that the appropriate scale of action, the division of tasks, and the spaces of cooperation among governmental and non-governmental actors remain unclear (Gupta 2007, Adger et al. 2009).

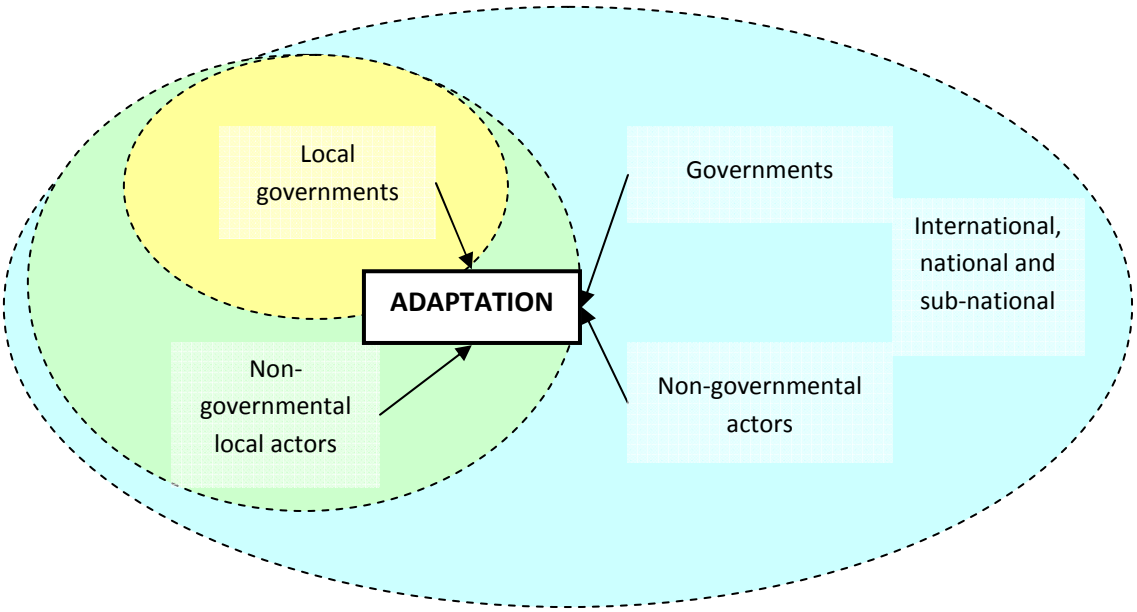

Figure 1.4. Different views on the levels of responsibility for climate adaptation: local government of adaptation (yellow); local governance of adaptation (green); multi-level governance of adaptation (blue). Source: own elaboration.

The levels and systems of governance at which adaptation to climate change can be most effective is a matter of discussion in the literature, and historical analyses can shed new light into how adaptation decisions were made over time and how we get to current systems. Few studies have explicitly examined how past, or small-scale societies, have adapted to climate variability and extremes across different levels of social organization (for some exceptions see Bankoff 2009, Endfield 2012, and Reyes-García et al. 2016), which is probably partly explained because of the difficulty of recovering and linking historical records produced simultaneously at multiple levels of decision-making. Moreover, many historical sub-disciplines focus on particular scales of analysis. For instance, historians of environmental politics usually take the nation-state as their unit of analysis (McNeill 2003). In this dissertation, I investigate the extent to which past local adaptation was embedded in a multilevel context during the early modern period (Chapter III) and I discuss the changing influence of governmental and non-governmental actors in local adaptation over the transition to "modern" societies (Chapter IV).

3. Research aims and questions

The general aim of this dissertation is to provide a historical background to climate change adaptation by empirically examining how past societies adapted to climate extremes.

The specific aims of this dissertation are:

- To advance the conceptual understanding of the long-term patterns of adaptation to local manifestations of climate extremes;
- to uncover the complexities of adaptation to climate extremes in pre-industrial and early industrial societies by approaching them through a long-term, multi-level, and multiple-stressors perspective;
- to develop methodologies that allow to bring archival-based analyses of past adaptation to research on the human dimensions of climate change;
- to present a case study using the historical approach and methods to document adaptation to climate extremes over the transition to "modern" societies; and
- to discuss the potential contribution, as well as the limits, of historical studies for understanding adaptation challenges posed by anthropogenic climate change.

These aims are addressed in the three empirical chapters of this dissertation (Chapters II-IV). Specifically, each chapter addresses research questions linked to the abovementioned research aims:

- Chapter II: How did pre-industrial communities experience and respond to climate extremes over long periods of time? To what extent other non-climatic contemporary threats and processes co-shaped their responses?
- Chapter III: How did pre-industrial societies adapt to climate extremes across different levels of social organization? What methodological challenges do we face when reconstructing past human adaptation to climate from archival sources?
- Chapter IV: How and why adaptation to climate extremes changed in the transition to "modern" societies? To what extent did environmental governance regimes condition adaptation patterns? How did multiple governance levels and stakeholders differently shape local adaptation to climate extremes?

4. Research design and methods

Each of the three empirical chapters includes a 'case study' or 'study site' section, as well as specific sections detailing the methodology used for the analysis presented in the chapter. Here I explain key decisions made in order to design this research, and I provide an overview of the study site, the chronology, and the climate extreme studied.

4.1. Study area

This research was conducted in the municipality of Terrassa, a city nowadays integrated in the Barcelona Metropolitan Region (Catalonia, NE Spain, Fig. 1.5). Past communities of Terrassa left detailed traces about their changing relations with climate extremes, which makes of Terrassa an excellent empirical ground for the purposes of this research. Indeed, as I wanted to address long-term changes in local adaptation practices, I had to focus on a society regularly challenged by climate extremes (see Section 4.2). The area where the municipality is located is prone to climate-driven extremes, particularly droughts and floods (see waterscape and climate description below). In addition, Terrassa has optimal records on local responses to climate extremes in terms of availability, quality, and accessibility of long-term documentary series (see Section 4.4). Finally, Terrassa remained a medium town until 1877, when it received the title of city. This means that the sources to be analysed had a manageable level of bureaucratic complexity in the study period (1600-1870s), while, at the same time, illustrate socio-climatic relations with a satisfactory level of detail.

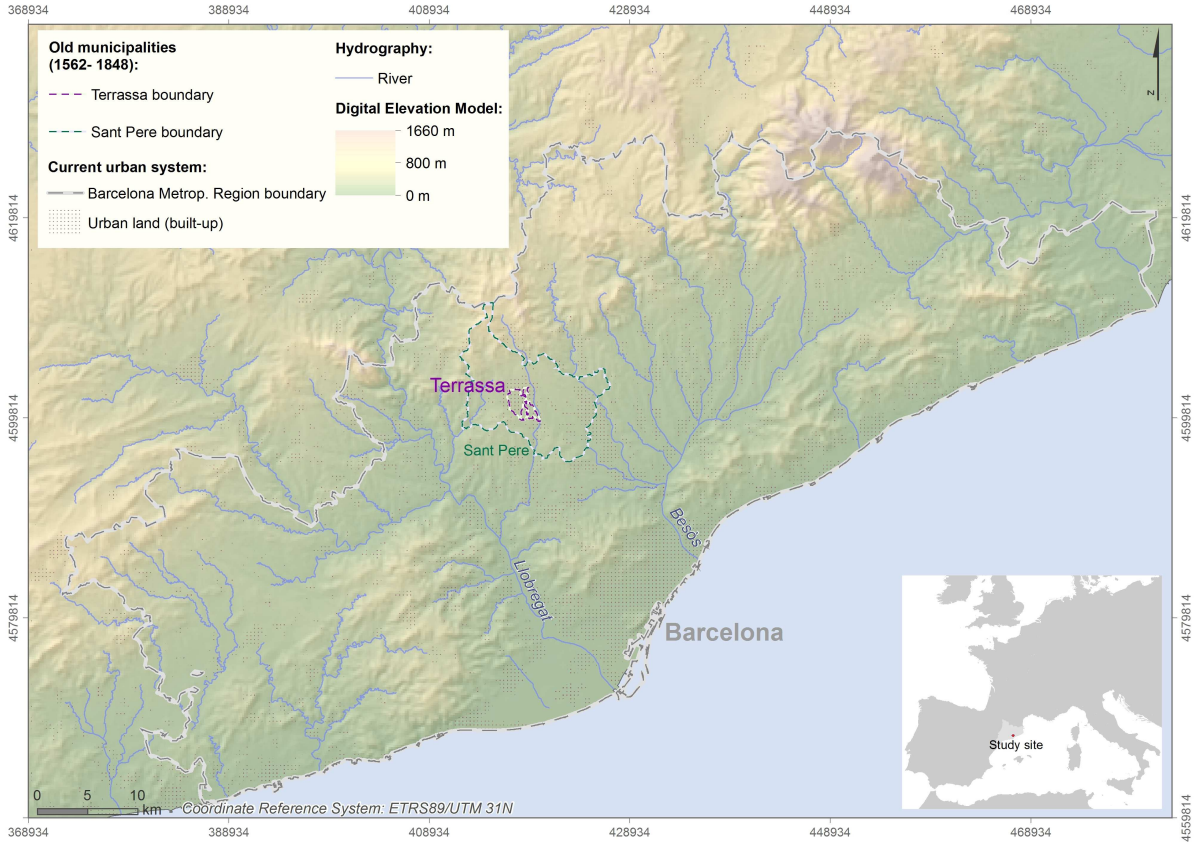

Figure 1.5. Map of the study area. Source: own elaboration based on data from *Instituto Geográfico Nacional* (2009), *Institut Cartogràfic de Catalunya* (2016), and *Agència Catalana de l'Aigua* (2010). In the study period the current municipality of Terrassa was divided in two municipalities: Sant Pere and Terrassa.

Waterscape and climate

With 215.121 inhabitants, Terrassa is today the fourth largest city in Catalonia and an important sub-centre of the Metropolitan Region of Barcelona (Font 2004, Idescat 2017). Until the early twentieth century, the municipality of Terrassa remained significantly small (see Table 3.1, Chapter III) but with the annexation of the neighbouring agrarian village of Sant Pere in 1904, the boundaries expanded to the current area of 70.2 km^2 (Idescat 2017). The city is located in the *Vallès* valley, between the Catalan littoral and the pre-littoral ranges. Due to geological and climatological reasons, the area lacks permanent water flows. Thus, local water resources are limited to temporary streams and aquifers. Temporary streams configure a dense network flowing to the Llobregat and the Besòs river basins (see Fig. 1.5). In medieval times, the fertile beds of such temporary streams were intensively used for cultivation (Ruiz 2011). Today, some of them remain under cultivation with garden plots (Grau-Satorras 2012). However, during the twentieth century, the larger temporary streams and those crossing the city were regulated, diverted, or channelled underground to reduce the vulnerability to flash floods that had caused catastrophic damages in the past (Thorndycraft et al. 2006, Oller et al. 2011, Llasat et al. 2016a). Regarding the aquifers, there are two relatively important groundwater bodies in the north-eastern area of Terrassa. The first groundwater body flows through sedimentary Quaternary materials accumulated in the valley (ACA 2004a). Its natural surface discharge creates springs and contributes to the flow of the temporary streams. This aquifer was exploited intensively through underground water mines by the local water company *Mina Pública d'Aigües de Terrassa* (hereafter MPAT) since the 1840s (Fig. 1.6). The second important groundwater body is deeper than the first one and is located at the Triassic sedimentary rocks from the lower slopes of the pre-littoral range (ACA 2004b), in the north of the Terrassa municipality. Its exploitation, led by the same water company, began in the 1870s (see Fig. 1.7). The two groundwater bodies are still being exploited today.

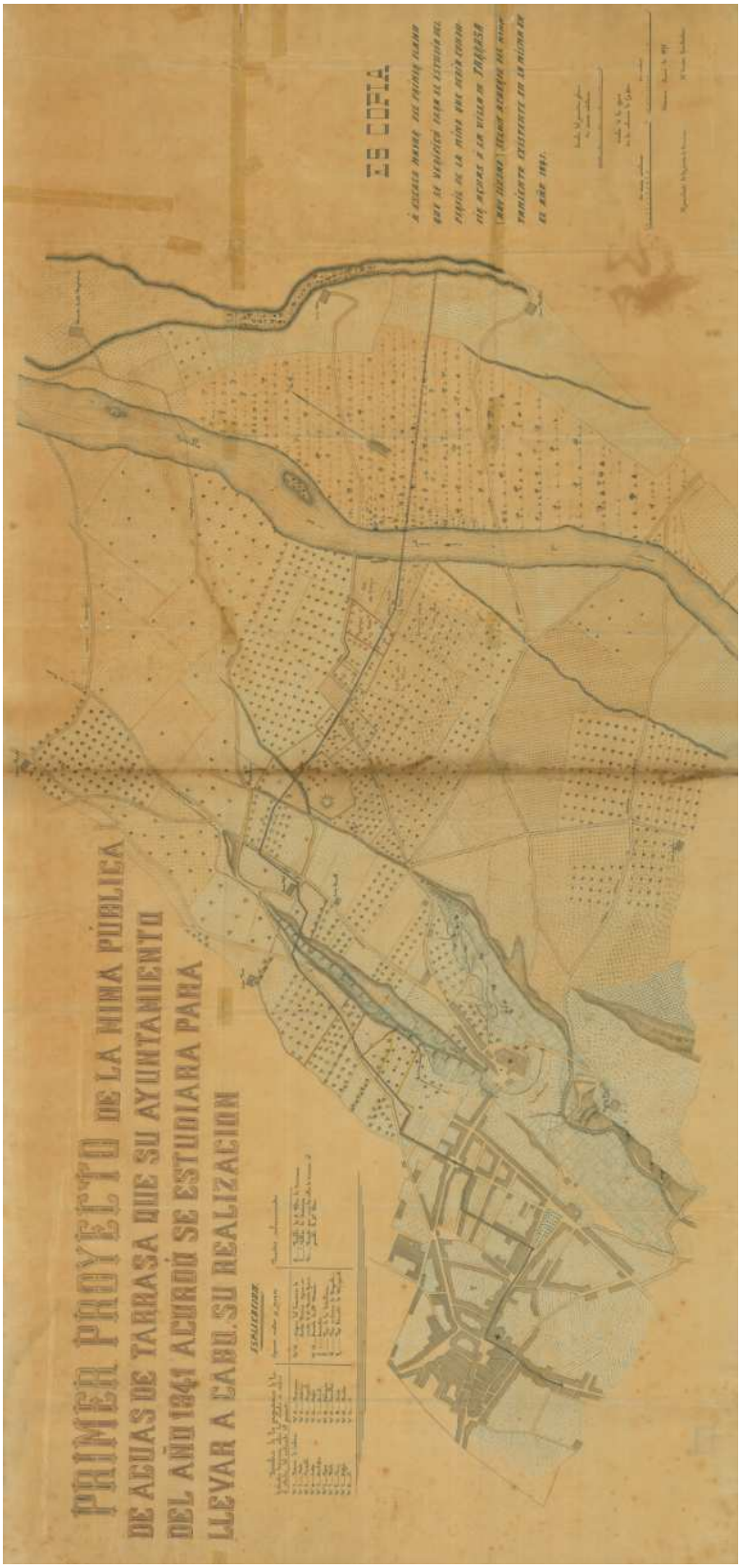

Figure 1.6. Map of the first water mine planned and built in 1841 by the local water company *Mina Pública d'Aigües de Terrassa* to exploit the Quaternary aquifer (copy from 1898). Note: the mine is represented by a tight blue line beginning in the village (left), crossing the northern fields of Sant Pere (centre), and ending at a water stream (right). Source: ACVOC-AHT, Collection ACVOC90-250 MPAT S.A., exp. UI P 57/21. Reprinted with the kind permission of the ACVOC-AHT.

Figure 1.7. Map of the water mines planned and built by the water company to exploit the northern aquifer (1873). Note: the principal mine is represented by a tight blue line beginning in the village (bottom). The mine divides into the east (first fork) and the west (second fork). The planned mines are represented in red. Source: ACVOC-AHT, Collection ACVOC90-250 MPAT S.A., exp. UI P 47/34. Reprinted with the kind permission of the ACVOC-AHT.

The climate of Terrassa lies between littoral and continental Mediterranean climates (Arisó 1982). Annual average temperatures are relatively high (16 °C, according to OEST 2016) and seasonal fluctuations are buffered by the proximity to the Mediterranean Sea (Martín-Vide et al. 2008). The annual average precipitation (576.3 mm, period 1923-2015; data from Prohom and Salvà 2011 and MPAT 2016) is close to the midpoint that divides dry and humid climates in Spain (600 mm). However, precipitation patterns are marked by an important summer deficit and high inter- and intra-annual irregularity (Fig. 1.8 and Fig. 1.9; Prohom and Salvà 2011).

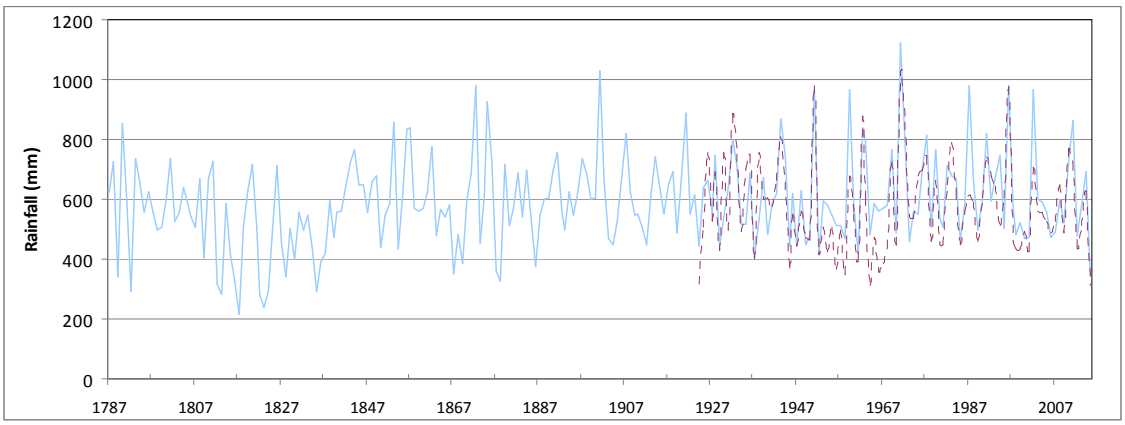

Figure 1.8. Annual rainfall series in Barcelona from 1787 to 2015 (blue line) and Terrassa from 1923 to 2015 (dashed red line). Source: own elaboration based on data from Prohom et al. (2016), Prohom and Salvà (2011), and MPAT (2016).

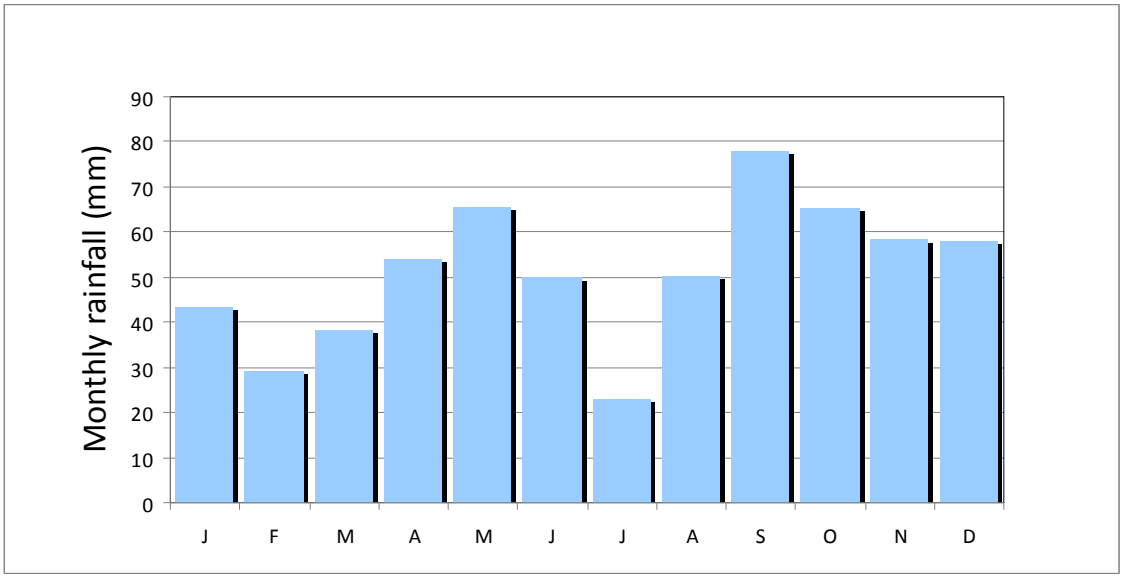

Figure 1.9. Monthly average precipitation in Terrassa. Source: own elaboration with data from MPAT (2016), during the period 1971-2000.

Precipitation irregularity and lack of permanent surface waters led to periodic water supply problems and high vulnerability to droughts in the area. As this dissertation shows, such problems increased with water demand growth in the eighteenth century and were critical in the nineteenth century, when Terrassa became a wool industry centre and experienced a large urban population growth. The first solution to face this crisis was to expand the network of underground water mines. Yet, by the end of the nineteenth century water mines could only provide between 2000 - 3000 m^3 per day.[5] In addition, the expansion of underground mines encountered physical (and legal) limits, resulting on acute conflicts of jurisdiction of groundwater resources with neighbouring municipalities (Larrosa 1992, Garganté 2012). By the end of the nineteenth century, the local water company, together with the industrial elites, projected another plan to exploit the water resources of the local valley: a reservoir called the *Pantà de la Xuriguera,* which was inaugurated in 1902. However, the reservoir was not well designed and failed to supply a constant and sufficient flow of water to fulfil the demands of the expanding city (Pastallé and Solé 2002, see Fig. 1.10).

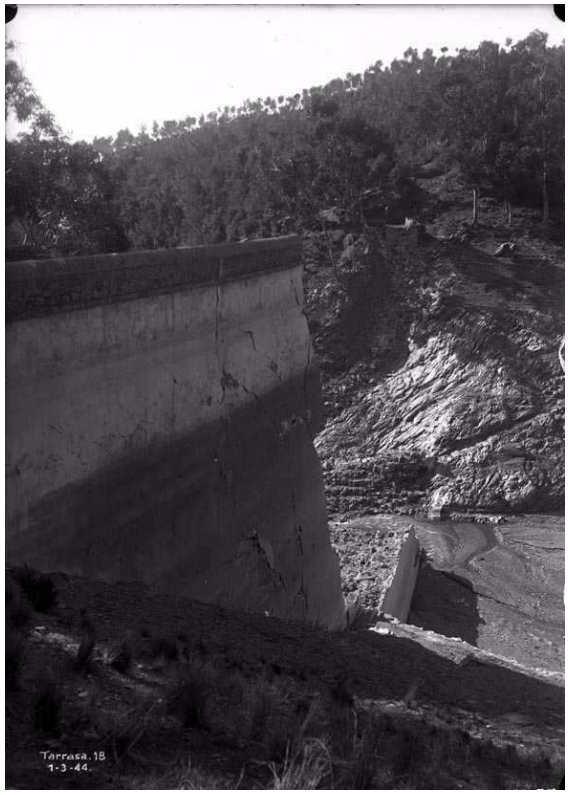

Figure 1.10. The reservoir *Pantà de la Xuriguera* collapsed in February 1944, after heavy floods. Source: ANC, Collection ANC1-211 Fuerzas Eléctricas de Cataluña S.A (FECSA), exp. ANC1-211-N-30159.

[5] In order to assess the role of underground mines in water supply, I estimated the amount of water supplied by mines using the average flows captured by local mines in the last six years (see data sources in Fig. 1.11). Assuming an average consumption of 100 litres per day per person, this flow could supply a population up to 30.000 people. This rough estimation does not take into account the efficiency of the mines system (not all water captured was consumed) and the different uses of water (water consumption was not only driven by the number of citizens, but by the industrial uses of water).

Thus, during the first half of the twentieth century new projects of water supply were studied, debated and negotiated (Pastallé and Solé 2002). In 1934, the Republican government approved the concession to divert water from the Llobregat River to Terrassa. After a brief period of collectivization of the urban water supply during the Spanish Civil War (see similar experiences in other municipalities in Gorostiza et al. 2013 and Gorostiza et al. 2015), the water transfer from Llobregat was inaugurated in 1943. Since then, water supply in Terrassa relies fundamentally on external water sources. At present, the aquifers from the River Llobregat (situated in the municipality of Abrera) provide 56.8% of the water supplied to the city, while the surface water of this river contributes to 26.9% (mean of period 2010-2015, see Fig. 1.11).[6] Moreover, Terrassa is connected to the system Ter-Llobregat (ATLL), a regional system of catching and treatment facilities established in the 1960s to supply water to the municipalities of the Barcelona Metropolitan Region, which contributes a small share of Terrassa yearly supply. Hence, only 1.4 out of 16.2 hm^3 of water that the city consumes annually come from local water resources, such as the nineteenth-century mines and other modern deep wells.

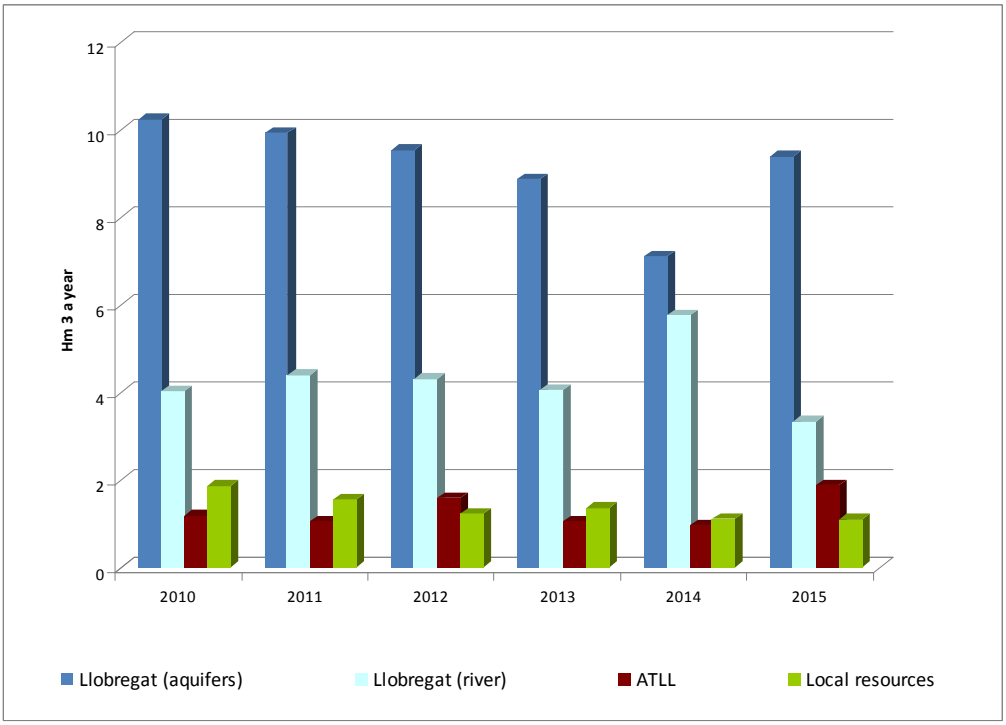

Figure 1.11. Water bodies supplying water to Terrassa (2010-2015): a) aquifers from the Llobregat River, b) surface water from the Llobregat River, c) regional system of Ter-Llobregat (ATLL), d) local water resources, including wells and mines. Source: elaboration based on data provided by the technical staff of the Environmental Office of the Terrassa Town Council.

[6] Due to the local company restrictions to access to recent and historical data, I calculated the proportions of water collected only with data from the last six years (2010-2015).

Water demand and consumption considerably increased during the twentieth century following population growth and urbanization (Pastallé and Solé 2002). During the last decade (2004-2015) water consumption diminished in absolute terms (Fig. 1.12). As Figure 1.12 shows, the decline comes from all four different uses of water. However, the reduction is particularly important regarding the industrial use of water. In 2015, the local industries consumed only 0.83 hm^3, a volume similar to the one provided by local mines (0.89 hm^3). Domestic water consumption per capita has also diminished markedly since 2004 (Figure 1.13). This is a trend also registered in other urban areas from developed countries likely driven by population decline, improved technological efficiency in water supply, and economic disincentives to overconsumption (Poquet and Maresca 2006, Moss 2008, Ostos and Tello 2014). In Barcelona, for example, the recent increase in prize and taxes associated to domestic water was one of the most important drivers of consumption decline (March and Saurí 2014 and 2017).

In sum, as other municipalities of the Metropolitan Region of Barcelona, Terrassa nowadays mostly relies on the abstraction of surface and subsurface water resources from the Llobregat River, which are largely used for domestic needs.

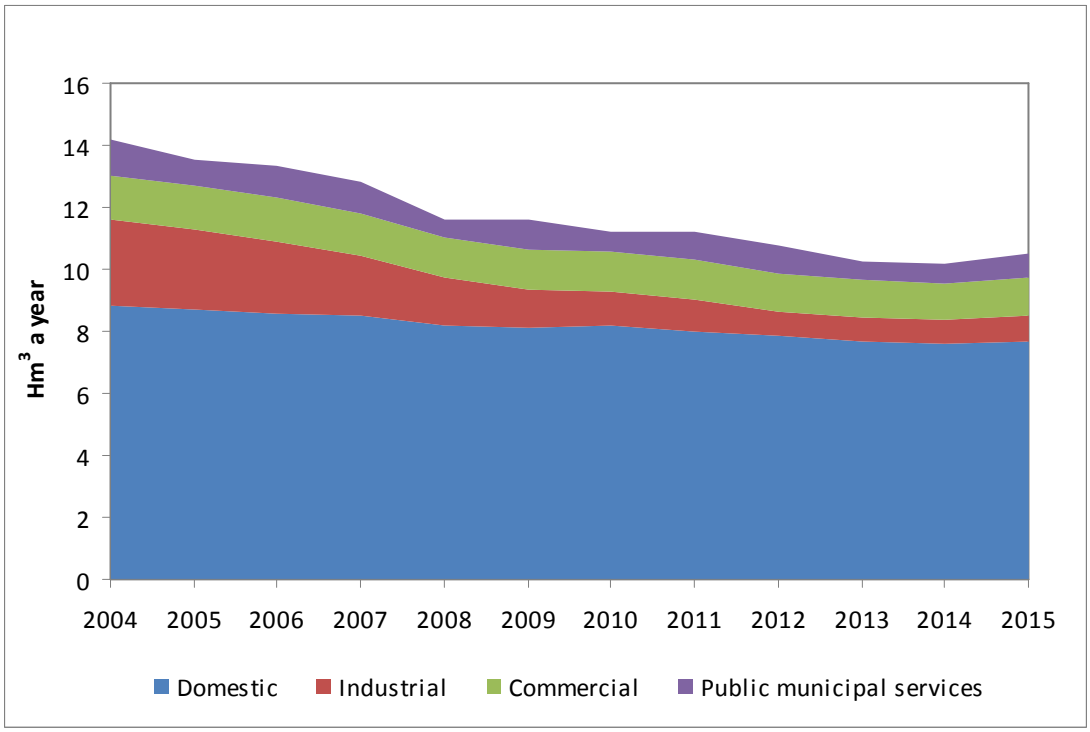

Figure 1.12. Evolution of water consumption in the municipality of Terrassa from 2004 to 2015 (cubic hectometres per year). Source: own elaboration based on data provided by the technical staff of the Environmental Office of the Terrassa Town Council.

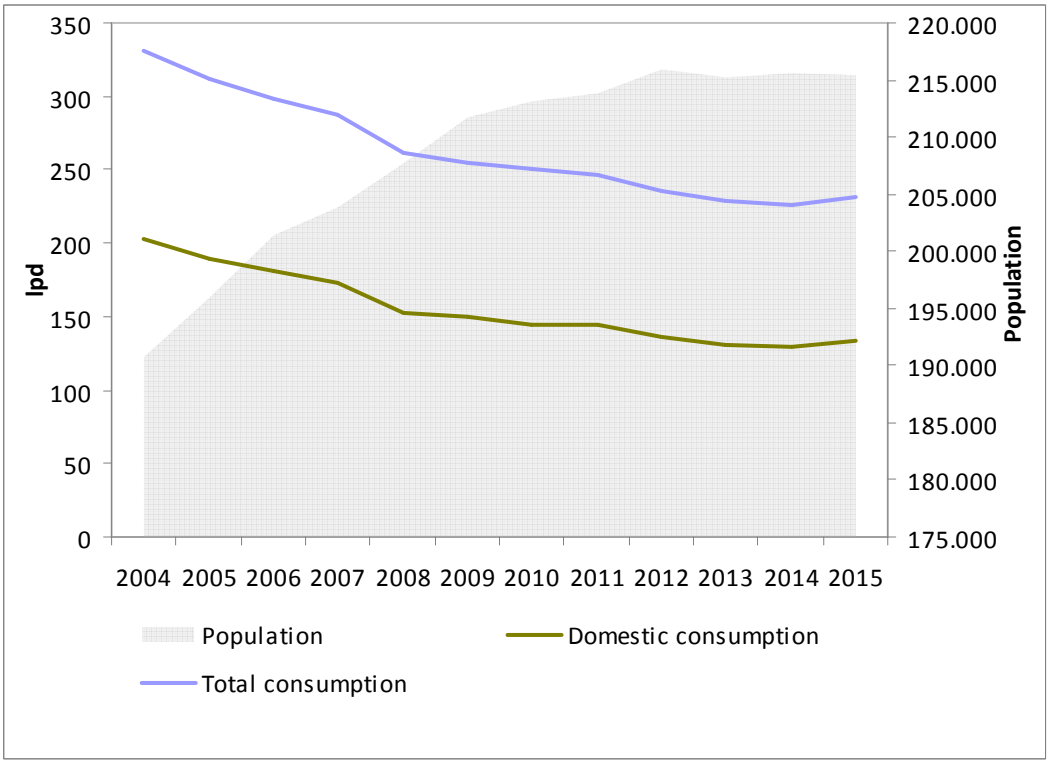

Figure 1.13. Evolution of water consumption per capita in litres per person a day (lpd) in the municipality of Terrassa (2004-2015). Source: own elaboration based on data provided by the technical staff of the Environmental Office of the Terrassa Town Council.

Settlement patterns

Terrassa was originally created as a settlement around a medieval castle built in the ninth century but its consolidation did not occur until the thirteenth century, when the village expanded and was fortified (Moro 1998, Soler 2002, Ruiz 2011). Population concentrated around the central market square with numerous farms scattered in its surroundings (Borfo and Roca 1988). The village grew slowly between the fourteenth and the eighteenth centuries, with small developments along the pathways leading outside the village (Benaul et al. 1987, Roca 1991, Soler 2006, Martínez 2007, Fig. 1.14.a). Importantly, the village (Terrassa) and the scattered farms (Sant Pere) were, since 1562, administratively divided (see Chapter III and Fig. 1.5). This division fostered the creation of another nucleus of concentrated settlement in Sant Pere and limited the area of influence and expansion of the village of Terrassa (Fig. 1.12.a and Fig. 1.5). During the nineteenth century, three successive expansions or *eixamples* configured a grid of streets around the old centre of Terrassa (Benaul et al. 1987, Sanllehí 2005, Nasarre and Badia 2006, Martínez 2007). The first area was developed between the historical centre and the eastern water stream in order to connect Terrassa with the neighbouring centre of Sant Pere (1822-1844, see Fig. 1.14.b). The second expansion (1845-1852) urbanized the south of the old town until the new road to Barcelona, which was finished in 1852. The third *eixample* (1855-1860) expanded the urban area to the north reaching the Barcelona-Zaragoza railway inaugurated in 1856 (see Fig. 1.14.b).

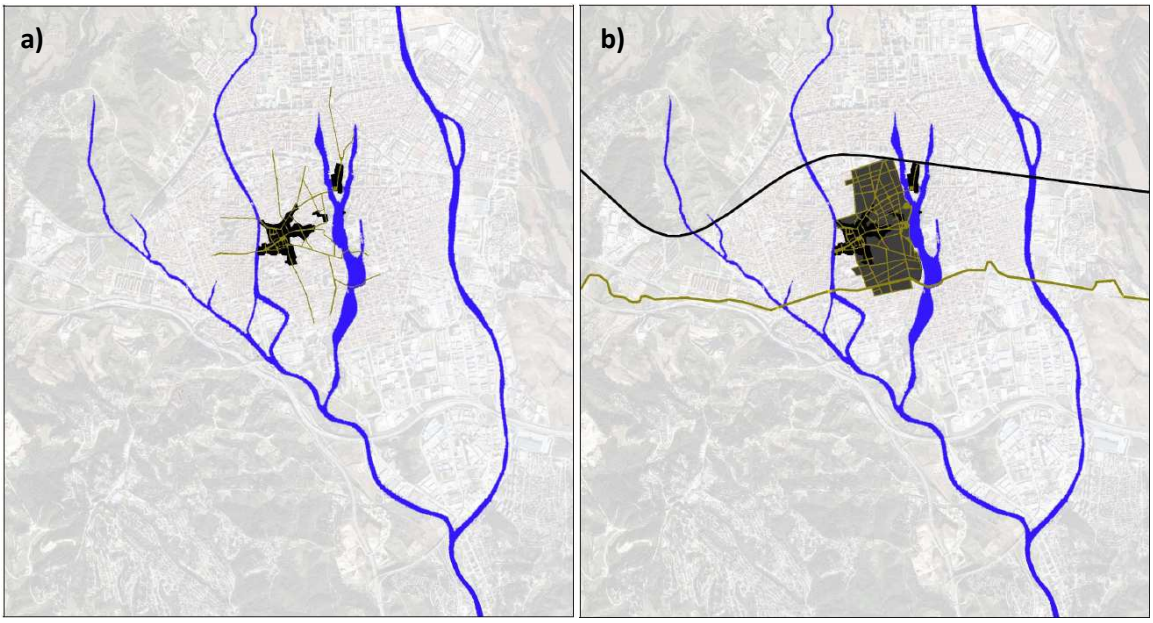

Figure 1.14. Settlement in Terrassa in the seventeenth and eighteenth centuries (a) and in mid-nineteenth century (b). Note: urban area (black area), main temporary water streams and cultivated streambeds (blue line), roads and pathways (yellow line), and railway (black line). The nucleus of Sant Pere is located between two tributary streams on the right side of the Terrassa nucleus. Source: adapted from Martínez (2007: 3, 5).

4.2. A focus on droughts

The empirical work of this dissertation focuses on droughts, a relevant climate extreme in the past that remains a key challenge for present and future societies. Droughts are iconic extreme events within the climate change research community, and increasingly in policy arenas and people's perceptions. Climate change projections for the late twenty-first century warn that droughts will be more frequent and severe in a regional to global scale (Stocker et al. 2013). Although the consequences of global warming for the water cycle are complex to model, studies show that droughts are likely to appear quicker and to be longer and more intense (Dai 2011, Trenberth et al. 2014).[7] Especially vulnerable regions to long-term droughts will be the Mediterranean, southern African regions, and south-western USA (Stocker et al. 2013). Although in the last decade drought management has developed as part of the disaster risk reduction efforts (e.g. Meza-Morales 2010), climate change poses new challenges to drought policies. These challenges include the need to strengthen collaborations with other policy fields different than risk management, the integration of climate change projections in water availability (e.g. snow melting, changing summer deficits) in nascent strategies of drought preparedness, or the consideration of increased agricultural water demands resulting from global warming in pro-active long-term drought management plans (see Head 2014, Stucker and Lopez-Gunn 2014, AghaKouchak et al. 2015). Integration of climate change projections, especially impacts on drought patterns, into urban water supply design and planning is still in its infancy (e.g., Grant et al. 2013).

Droughts in many areas are not new, but rather a recurrent threat that persists from months to years (Fang et al. 2009, Domínguez-Castro et al. 2012, Kaniewski et al. 2015, Cook et al. 2015). This means that many generations of people have interacted with droughts very frequently, with the associated social experience and memory that these constant interactions entail. Thus, the study of droughts is a reasonable way to provide historically informed insights into climate change debates and to reflect on our history of adapting to climate extremes.

As I explained in Section 4.1, droughts recurrently affected the study area due to the combination of irregular precipitation patterns and low availability of exploitable water resources (for regional historical drought patterns see Martín-Vide and Barriendos 1995, Domínguez-Castro et al. 2012, Coll et al. 2016). Reports downscaling climate change

[7] Projected effects of global warming on droughts are far more complex because they depend on many factors and differ among climatic regions (see Sheffield and Wood 2008, Seneviratne et al. 2012, Kirtman et al. 2013, Prudhomme et al. 2014).

projections at the regional level highlight that Catalonia will suffer more frequent and long droughts during the second half of the twenty-first century (Llasat et al. 2016b). Indeed, water availability in littoral river basins that supply the Metropolitan Region of Barcelona will likely be lower and more irregular in the near future than they are nowadays, largely because of the cumulative effects of climate change, upstream reforestation, and increased water demand (Mas-Pla et al. 2016, see also Otero et al. 2011). Thus, the study of past droughts in the study area matters as it can help understand adaptation to drought in a drought-prone area which will likely be more susceptible to increasing and longer droughts in the near future.

But, what do we mean by droughts? Because drought depends on place-based factors such as available water resources and rainfall patterns, there is not a universal definition of drought (Wilhite and Glantz 1985). Initially, the literature focused on differentiating temporary events from long-term processes such as water scarcity and aridity. Nowadays, the debate is focused on what causes droughts. Previous definitions approached drought as a climate-induced temporary lack of water (see Table 1.1). Kallis (2008) suggested a definition acknowledging that this temporary lack of water is, at least partly, caused by abnormal climate conditions thus pointing out that other non-climatic drivers might also trigger and induce droughts. Recently, some researchers have argued that drought definitions need to be revisited in the face of the Anthropocene in order to explicitly include the human processes that drive and modify drought development (Van Loon et al. 2016a). Specifically, they question the usefulness of separating natural drivers (e.g., precipitation deficit) from human drivers (e.g., unsustainable groundwater abstraction) which, for example, can increase the intensity of droughts or influence the physical threshold considered to establish "normal" water levels (Van Loon et al. 2016b).

Table 1.1. Drought terminology. Source: selected terms and definitions adapted from Van Loon et al. (2016a) and Van Loon et al. (2016b).

Term	Definition
Drought	*Temporary lack of water compared to normal conditions*
Climate-induced drought	*Drought caused by climate*
Human-induced drought	*Drought caused by human influence on water cycle*
Human-modified drought	*Drought caused by the combination of climate and human influence on water cycle, or climate-induced drought enhanced or alleviated by human activities*
Meteorological drought	*Drought manifested as rainfall reduction*
Agricultural drought	*Drought manifested as below-normal soil moisture levels*
Hydrological drought	*Drought manifested as below-normal surface water or groundwater levels*

Socio-economic drought	*Drought causing socio-economic impacts*
Aridity	*Long-term dryness as feature of climate, with long-term average precipitation being much lower than potential evaporation*
Water scarcity	*Long-term imbalance between water demand and water supply, caused by high demand, low water availability and/or problems with water supply*
Water shortage or stress	*Acute lack of water for social, economic or environmental needs, caused by temporary imbalance between water demand and water supply*
Overexploitation or depletion	*Long-term unsustainable use of water resources resulting in gradual decrease in water availability*

Importantly, drought signal propagates across the water cycle and therefore anomalies such as the reduction of water tables manifest in delay from the initial precipitation deficit (Van Loon 2015). As a consequence, scholars distinguish among deficits of rainfall (i.e., meteorological droughts), soil moisture (i.e., agricultural droughts), and surface or subsurface flows (i.e., hydrological droughts) (see Table 1.1). Moreover, socio-economic drought is defined as drought noticed by and affecting societies and economies (see broader definitions in Mehran et al. 2015), although this definition might lead to confusion because it does not refer to a specific manifestation of the drought propagation cascade, but to the heterogeneous socio-economic impacts resulting from the abovementioned manifestations of drought in different parts of the water cycle (Van Loon et al. 2016b).

As many other hazards, each drought event and its manifestations can be characterized depending on its specific intensity (i.e., degree of rainfall or water reduction), duration (i.e., time lasting between the onset and the end), spatial coverage (i.e., geographical area affected by drought impacts), and severity (i.e., the combination of intensity, duration, spatial coverage, and water demands) (Wilhite 2000).

Some researchers have operationalized the definition of drought depending on the study area, methodology, or research goals. For instance, to reconstruct past drought events and society's vulnerability, resilience and adaptation to them, Gil-Guirado and co-authors (2016: 187) considered that a "*drought begins when historical sources explicitly attribute a lack of water to a lack of rain and ends when at least three months —the length of a season— elapse without news about it*". This dissertation focuses on climate-induced droughts and human-modified droughts (see definitions on Table 1.1) and considers all the typologies of drought manifestations and impacts, that is meteorological, agricultural, hydrological, and socio-economic droughts. Hence, I consider that there is drought when historical sources mention a

temporary lack of water, including rainfall, soil water, surface water, groundwater, and water supply, caused, at least partly, by climate. I only consider the events and their effects when they are recorded in human-made documentary sources. Accordingly, drought manifestations that were unnoticed or simply not recorded in the reviewed archival documents are excluded from this research.

4.3. Chronology

This dissertation comprises the period between the early seventeenth century and the late nineteenth century. Yet, specific chronologies are used in each empirical chapter. Overall, I use a long term approach to capture trends and changes in adaptation patterns over long periods of time. However, temporal resolution is increased during specific periods when required by the research questions. This is the case, for example, of the analysis developed in Chapter IV which focuses in detail on particular drought events.

The first two empirical chapters (Chapters II and III) focus on the early modern period. The early modern period has been often defined as the period spanning from the 1453 Ottoman conquest of Constantinople or the 1517 Lutheran reform to the 1789 French Revolution (Molas 2007, Simón 2012). This period represents, therefore, a time of transition between the medieval and the modern periods. Yet, across the globe there were different "early modernities" and regions had different historical developments during this period (Eisenstadt and Schluchter 1998, Starn 2002). Indeed, postcolonial studies critique the epochal concept of "early modernity" as being Eurocentric and ambiguous about what is and what is not modern (Chakrabarty 2011, Davis 2015).

In the Spanish historiography, the early modern period[8] is considered to begin in the late fifteenth (1492 Columbus expedition to America) and end in the early nineteenth century (1808 Spanish uprising against Napoleonic troops) (Molas 2007, Simón 2012). Four trends characterize this period in Spain: i) the Columbus exchange between the New World (Americas) and the Old Word (Eurasia), which brought new crops, fostered Spanish colonialism (including the annihilation of indigenous civilizations), and expanded participation in global trade; ii) the slow definition of the territorial nation state and the reconfiguration of the Spanish Monarchy, during a period of successive wars among European nations ; iii) the emergence of new social groups and divisions based on wealth; and iv) the gradual transformation of worldviews and cultural practices due to processes such as the Protestant Reform and the Enlightenment (Casey 1999, Espino and Martí-Escayol 2012). While the sixteenth century was associated with a period of economic and cultural growth (the so-called

[8] In the traditional Spanish historiography, this period is called the *Edad Moderna* (modern age), following the French-derived system of periodization that divides historical time into four ages or epochs: ancient, medieval, modern, and contemporary (Simón 2012). Some historians also consider that the seventeenth century in Catalonia has significant continuities with the period *baixmedieval* (late medieval period, which ranged from the thirteenth to the fifteenth centuries). Along this dissertation I use the "early modern" English term to label this historical period.

Siglo de Oro in Spanish), most of the seventeenth century was a period of economic and cultural decline (see Bernal 2007, Fernández-Albaladejo 2009, Parker and Smith 2005).

In Chapter II and III, I focus on the years between 1600 and 1715 to study long-term changes in adaptation patterns before the Industrial Revolution. During these years, the institutions and context shaping the production of the documentary records analysed kept a significant level of continuity. For instance, the institutions of local decision-making in Catalonia (i.e., Councils) consolidated since the late fourteenth century and suffered little change until the 1715, when the Bourbon Monarchy transformed them, with consequent effects in the ways of making and recording decisions (Casas 2015).

The last empirical chapter (Chapter IV) examines and develops a longer term chronology. Specifically, it examines the period between the early seventeenth and the late nineteenth century (1600-1870s). Thus, it covers a period of massive social, cultural, political, demographic, economic, and environmental transformations. The term traditionally used to refer to these processes of transformation towards industrial societies is "modernization", although numerous scholars critique the notion and theory behind this term due to its ethnocentrism, uni-linearity, and implications for development programs (Chakrabarty 2011, see the section of Introduction in Chapter IV). Environmental historians have described how, during the seventeenth and eighteenth centuries, societies began to exhaust existing resources (Marks 2012). Thus, according to Radkau (2008), by the end of the eighteenth century there were signs of fuel and resource scarcities. It is also a period of expansion of global markets via sea trade. European societies increasingly imported raw resources from the colonised New World and specialized in certain manufactures. For example, by late eighteenth century, the port of Barcelona exported alcoholic beverages (wine and distilled spirits), cork, cotton and linen clothes, nuts, and paper; and imported cotton, linen textiles, iron, sugar, cereals, salted fish, and wood (Nadal et al. 2012). Hence, market specialization was a key driver of land-use changes. In Catalonia, market specialization occurred since the second half of the eighteenth century through the expansion of cash crops such as vineyards (Badia-Miró and Tello 2014). Clothes exports also show how the manufactures of clothiers were prominent in late eighteenth-century Catalonia, although the process of textile industrialization started the following century (see Benaul and Deu 2004, Nadal et al. 2012, Marfany 2012).

Many histories and theories have tried to explain European industrialization. Some of these theories argue that industrialization was driven by internal factors such as existing transport infrastructures or knowledge accumulation, while others also take into account the role of the

Colonial world emphasizing how the Americas allowed (some) Europeans to import cheap agricultural commodities (consequently freeing labour and subsistence lands in Europe) and expanded profitable markets for exporting manufactured goods (Pomeranz 2000). Importantly, as Barca and Bridge (2015) have recently noted, the process of industrialization entailed enormous environmental transformations and social differentiation, such as the accelerating generation of urban waste, the expansion of extractive frontiers, or the unequal socio-spatial exposure to pollutants. Indeed, for many scholars, industrialization marks the emergence of the Anthropocene as a new geological era (for recent debates about the onset and periodization of the Anthropocene see Lewis and Maslin 2015). In sum, the last empirical chapter focuses on the "modernization" period to explain how local adaptation to climate extremes was inter-twinned with the socioeconomic, political and environmental transformations that unfolded with it.

4.4. Archival methods

The use of archives as a source of empirical data to study climate and society relations has advanced due to the contributions of specific sub-fields such as environmental history, historical climatology, or historical geography. This literature has argued that archival research can help place the multiple human experiences and interpretations of climate (and weather) in specific geographical and historical contexts and therefore to consider how they vary over space and time (Pillatt 2012b, Carey et al. 2014). Hence, over the last decade, historians, historical geographers, and historical climatologists have attempted to expand the range of archival techniques and sources to study changing interactions between societies and climates. Traditionally examined documentary sources had much in common with so-called "cultural proxies" used for climate reconstructions (e.g., Martín-Vide and Barriendos 1995, Pfister et al. 2009, Domínguez-Castro and García-Herrero 2016). Therefore, ecclesiastical records, public documents, and other heterogeneous sources such as logbooks, chronicles, and paintings, configure the methodological toolkit. Recent methodological efforts seem to concentrate on identifying and reviewing the potential contribution of scarcely analysed sources such as private diaries (Adamson 2015) and re-assessing the value of well-known and popular sources such as parish registers (Veale et al. 2017). Researchers have also pointed out some caveats and limitations emerging when using specific documentary sources to better understand how climate and its variations affected people in the past. Such limitations include inaccuracy, subjectivity, or dispersion of relevant information (see also Endfield and Fernández-Tejedo 2006).

Archival-based research on climate-society relations spanning several centuries faces two more challenges: i) limitations related to lack of homogeneity and continuity of data over time, and ii) the high volume of information potentially available. The first challenge is especially relevant when comparing different data and sources over long periods of time (Gil-Guirado et al. 2016). To preserve homogeneity and continuity, historical climatologists typically opt for the analysis of long-term documentary series produced by institutions characterized by slow change (Rodrigo and Barriendos 2008, Domínguez-Castro et al. 2008). I followed this recommendation when selecting sources for long-term analyses of adaptation to droughts (Chapter II and IV), although I acknowledge that such sources require a critical interpretation that takes into account changes in institutions (i.e., the change in sources' producers, functions, and audience).

Dealing with the second challenge requires formal procedures to select some documentary sources and exclude others. It also requires establishing data collection protocols that provide enough evidence to achieve the research objectives. Methodological decisions condition the research outcomes and therefore should be carefully explained as potential sources of caveats and biases. Hence, the documentary data that nourishes the present work were collected and analysed following systematic procedures. As the research process unfolded along the three central articles (Chapters II to IV), I adapted the archival research protocol to their specific research questions (see Section 3). Figure 1.15 summarizes the main steps of the methodology used:

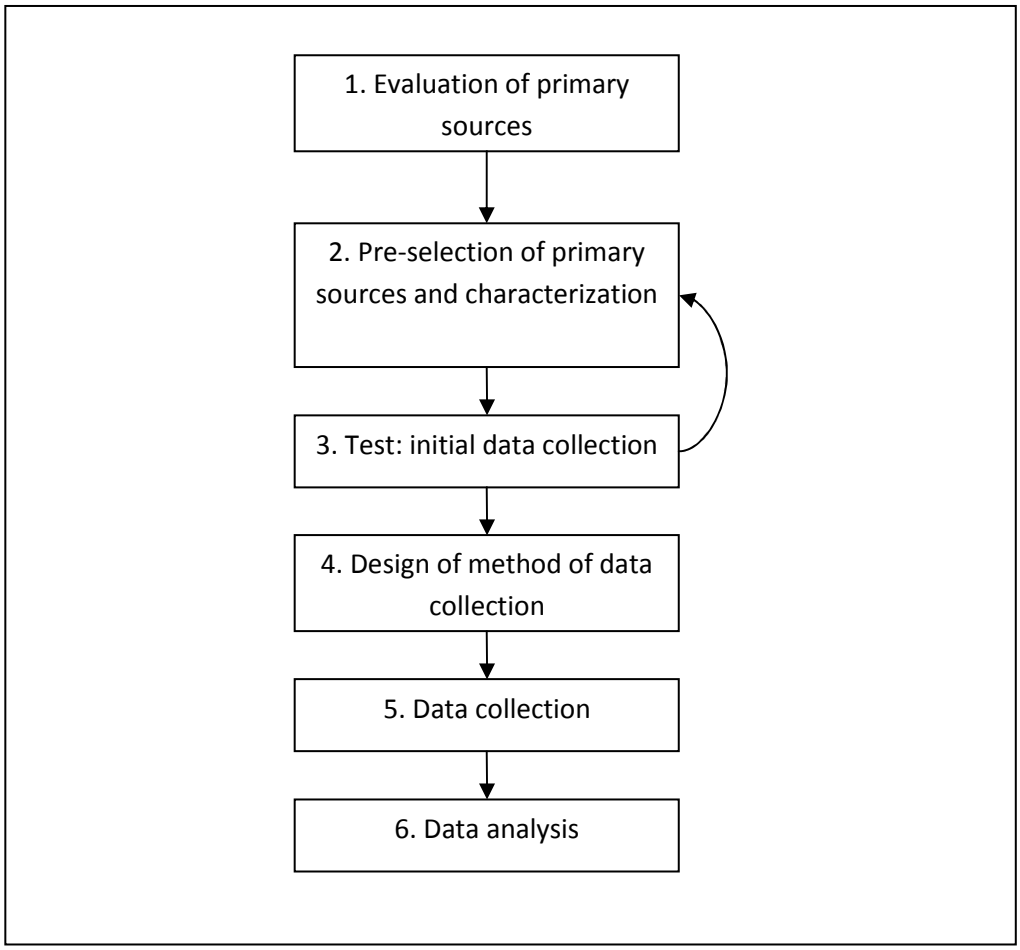

Figure 1.15. Six methodological steps followed in this archival-based research.

Step 1 corresponds to the process of evaluation of available primary sources. Criteria used for this initial evaluation include accessibility (e.g., language and format), interpretation (e.g., degree of source cataloguing), reliability, time range covered (specifically noting homogeneity and continuity over time), spatial scope, and potential density of relevant information. To do so, I created tables with a list of sources. I then evaluated each source by consulting archives,

archival databases and secondary sources, and drawing on the expert knowledge of historians and archives' staff (see Appendix I, Table AI.1). Step 2 consisted in the pre-selection of the best evaluated primary sources and a more detailed characterization of those. Specifically, I developed an indexing card to describe items such as the archival location of the source, the production and history of the source, the audience it was intended to address, the type of writing, the length, and the available secondary sources describing or using these sources (see Appendix I). In Step 3, I carried out a preliminary data collection on the pre-selected and characterized sources. This test aimed at evaluating real accessibility (e.g., clarity of the text and languages used, quality of the manuscript), density of information (relevant data per unit of source), and time required for data gathering (average time per unit of source). For instance, in the archival research for Chapter III, I randomly selected three folios of the agrarian treatise and conducted a preliminary data collection in those folios. The test showed that the source was accessible and the estimated time of data collection per folio was acceptable, although the density of information relevant for the research goals was low in certain passages. Step 4 consisted in the design of the specific method of data collection for each primary source. I designed the method of data collection according to the insights gained in the previous test and chose between an exhaustive (i.e., reading the entire source or the entire series) or a selective method (i.e., reading only selected fragments or periods of the source) (see Table 1.2). In the example of the agrarian treatise, after consulting the index of subjects and the table of contents, I only selected for review certain sections and chapters of the three volumes of the treaty. The definitive collection of data configured Step 5. During this process, I created spreadsheets to collect data of interest from the sources and I transcribed selected fragments. I checked the meaning of unknown words in specialized dictionaries. Moreover, to better interpret the meaning of the selected primary sources and to situate them within their historical context, I reviewed secondary literature and drew on the archives´ staff expert knowledge. Finally, collected data was analysed in Step 6. I decided the methods of data analysis depending on the specific goals of each empirical chapter and the information gathered from the primary sources (see Table 1.2, last column). Specifically, I examined and processed the records through three different analytical lenses. First, to classify the adaptation practices documented, I codified them using categories emerged from research on climate change (Chapter II, Chapter III). Second, I operationalized the long-term perspective through a quantitative (Chapter II) and a qualitative analysis (Chapter IV). And third, I introduced the multilevel analysis from complex systems (Chapter III) and a governance perspective (Chapter IV).

Table 1.2. Summary of sources and methods of data collection and analysis used in Chapters II, III, and IV.

	Period	Main primary sources	Data Collection	Data Analysis
Chapter II	1600-1715	Council minutes of Terrassa	Exhaustive review (100%)	• Codification of adaptation practices using a classification from research on the human dimensions of climate change • Quantitative long-term analysis: Council decisions per unit of time
Chapter III	1600-1715	Council minutes of Terrassa	Exhaustive review (100%)	• Codification of adaptation practices using a classification from research on the human dimensions of climate change • Multi-level analysis (household and community)
		Council minutes of Sant Pere	Review of a sample (25.5%) selected according to the results from the Terrassa Council minutes	
		Agricultural treatise	Review of a sample (31.3%) selected from the index of subjects and the table of contents	
		Farm family book	Review of a period with high quality records (50.0%)	
Chapter IV	1600-1870s	Council minutes of Terrassa	Exhaustive review (100%)	• Information structured using core questions from climate change research • Qualitative long-term analysis: historical narrative, adaptive cycle, and periodization • Multi-level analysis (local and supra-local governance actors)
		Series of historic documents	Selective review, derived from advanced search in the digital archival catalogue	
		Water company collection	Selective review, derived from advanced search in the digital archival catalogue	

5. Thesis outline

This doctoral dissertation consists of a compilation of three scientific papers preceded by this general introduction and followed by a final conclusion. As each chapter has been conceived as a self-encompassing unit, some overlap or redundancy between the chapters could not be avoided. Overlap mostly affects the case study sections, source descriptions, explanations on terminology, and methods. The fact that each of the three articles is intended for a particular journal and oriented to particular audiences and research communities also conditioned the concepts used, which had to be adapted to different audiences. For instance, the first article (Chapter II) is oriented to an interdisciplinary readership not used to archival research, while the second one (Chapter III) is oriented to the environmental history community, trained in archival methods but less experienced in the debates and analytical categories of climate change literature. Hence, in Chapter III, I could further discuss and share the methodological caveats and limits of the archival analysis carried out, a debate that would probably not be of such interest to the interdisciplinary audience to which the article presented here as Chapter II was intended.

This **introductory chapter** presents the motivation of this dissertation, the state of the art, the research aims and questions, as well as the research design and the methodologies used.

The **second chapter** corresponds to the first article, which examines pre-industrial adaptation to climate with a long-term perspective. The specific aims of this paper are a) to understand and document how pre-industrial communities experienced and collectively responded to climate extremes (droughts) over long periods of time, and b) to uncover other, non-climatic contemporary threats and processes that shaped these responses. The chapter deals with these questions by systematically investigating the typology, timing, and context of drought responses in the village of Terrassa between 1600 and 1715. The results show that the early modern community of Terrassa adopted a mixture of symbolic, institutional and infrastructural responses to cope with recurrent droughts. Results also show that responses changed over time, significantly decreasing since the first third of the sixteenth century. In order to explain this pattern, the chapter discusses how mounting public debt and successive wars could have limited the range of available response options. This chapter was presented at the ICREA International Conference on "*Small-scale societies and environmental transformations: co-evolutionary dynamics*", and was published in 2016 in the journal *Ecology and Society*, as part of the ICREA Conference Special Feature. The article was nominated by the journal editors as a candidate for the prize of best paper of the year.

The **third chapter** corresponds to the second article. The chapter aims to understand multi-level adaptation to climate extremes in pre-industrial societies. To do so, I reconstruct adaptation strategies used at the community and at the household levels between 1600 and 1715 and identify potentially overlapping and cross-level strategies. Empirically, the research is based on four main sources of information: the council minutes of Terrassa, the council minutes of Sant Pere, a popular agrarian treatise directed to farmers, and the private writings of a family farm. I apply a detailed analytical framework derived from studies addressing recent climate and global environmental change to classify adaptation strategies. The article discusses the methodological caveats that remain when researching past human adaptation to recurrent climate extremes with archival sources. This article was submitted in December 2016 to the journal *Environment and History* and is still under review.

The **fourth chapter** corresponds to the third article. This chapter addresses the socio-environmental transformations associated with the transition from the early modern period to the consolidation of industrialization in Catalonia. The chapter documents and discusses how and why adaptation to droughts changed over the course of "modernization". To illustrate this question, I review multiple sources from the period between 1600 and 1870s, a period during which the agrarian village of Terrassa turned into an industrial city . This chapter tracks the long-term changes in water governance regimes in Catalonia to understand how they conditioned local adaptation to drought. In addition, it considers the role of changing governance actors beyond the local council, such as state agencies and delegates fostering political centralization and private companies in charge of urban water supply. A summary of this article has been accepted in the symposium on "*Adaptation and Resilience to Droughts: Historical Perspectives in Europe and beyond*" to be held at the University of Strasbourg (France) in June 2017. The communications from this symposium will be published in a Special Issue.

The **fifth** and last chapter provides the general conclusions of the dissertation based on the three empirical chapters summarized above. The conclusion addresses both the conceptual and methodological contributions of this thesis. Moreover, I discuss the challenges and opportunities of seeking policy implications from historical studies and suggest future research areas.

Finally, in the Appendix section, I present methodological information (Appendix I), and the list of historical sources consulted (Appendix II).

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CHAPTER II

Long-term Community Responses to Droughts in the Early Modern Period:

The Case Study of Terrassa, Spain*

* **Grau-Satorras, M.**, I. Otero, E. Gómez-Baggethun, and V. Reyes-García. 2016. Long-term community responses to droughts in the early modern period: The case study of Terrassa, Spain. *Ecology and Society* 21(2): 33. http://dx.doi.org/10.5751/ES-08232-210233

Research part of a Special Feature on *Small-Scale Societies and Environmental Transformations: Co-evolutionary Dynamics.*

Abstract

New challenges posed by global environmental change have motivated scholars to pay growing attention to historical long-term strategies to deal with climate extremes. This paper aims at understanding long-term trends in community responses to cope with droughts in order to explain how many preindustrial societies co-evolved with local hydro-climatic dynamics and coped with climate extremes over time. The specific goals of this work are 1) to analyze how local communities experienced droughts over long periods of time and 2) to document the spectrum of recorded community responses to drought. Our research covers over one century (1605-1710) of responses to drought at the community of Terrassa, Barcelona, Spain. Data were collected through archival research. We reviewed and coded 2076 village Council minutes. Our results show that the local community adopted a mixture of symbolic, institutional, and infrastructural responses to drought and that drought-related decisions varied through time. We discuss adaptation strategies on the basis of the distinct physical signals of drought propagation and the role of non-climatic historical factors, such as warfare and public debt, in shaping responses. We conclude that long-term perspectives on pre-modern history and comparable empirical studies are fundamental to advance our understanding of past social responses to hydro-climatic extremes.

Keywords: adaptation; agricultural drought; coping strategies; Early Modern period; environmental history; hydrological drought.

1. INTRODUCTION

Global environmental change cannot be understood or tackled effectively by only looking at its current and future impacts. Understanding past societal experiences to cope with change can offer a more comprehensive perspective by situating current and future hazards within long-term historical processes (Brázdil et al. 2005, Pfister 2010). As McIntosh et al. (2000:3) noted "by ignoring the great laboratory of millennia of responses to environmental change, we condemn ourselves to reinventing a very complex wheel in the face of one of humanity's greatest challenges".

Histories of climate disasters, hazards and risks at national and regional scales have a long tradition (e.g., Kempe and Rohr 2003, Alberola and Olcina 2009). However, few studies have used empirical evidence to systematically analyze how past societies coped with change and to examine their resilience or vulnerability to hazards and risk (Fraser 2007, Helbling 2007, Juneja and Mauelshagen 2007, Pfister 2007, Endfield 2008, Gerrard and Petley 2013). This literature has challenged static, passive or apocalyptic assumptions over past societies, revealing the historically changing ability of societies to effectively deal with environmental change. For example, focusing on Medieval societies, Gerrard and Petley (2013) argue that experience in dealing with known threats resulted in resilient communities which developed sophisticated coping skills and organizational accomplishments. Drawing on examples from Colonial Mexico, Endfield (2012) notes that experiencing climate variability and climatic extremes challenged society's resilience, but also resulted in an increase of societies' repertoire of adaptive responses. Using data from peasant communities in SW Spain between the seventeenth and twentieth centuries, Gómez-Baggethun et al. (2012) document a wide range of coping strategies to build resilience and cope with climate extremes.

Following this line of research, in this study we systematically reconstruct past community adaptation practices to recurrent hydro-climatic extremes, specifically droughts, during the Early Modern period. Our research covers over one century of responses to drought at the community of Terrassa, Barcelona, Spain. We interpret documented coping strategies by accounting for both the hydro-climatic anomalies that societies aimed to tackle and the historical factors shaping their responses.

Hydro-climatic extremes do not affect equally all societies, not even the same society at different points in time. Indeed, the literature on disasters and risks notes that human communities only perceive and experience certain physical climate anomalies as disasters,

thus recognizing the social construction of hazards (Quarantelli 1998). Consequently, as Glantz and Katz (1977) argued, one should ask "when is a drought a drought?". As many hazards, droughts are context-dependent and therefore properties from both the specific drought (e.g., intensity, duration, spatial coverage) and the system (e.g., local climatology and seasonality, land uses, water demand) need to be considered to determine when the community experiences -and therefore documents- drought (Wilhite 2000). Moreover, three distinct physical phenomena occur when drought signal propagates through the water cycle: i) meteorological droughts, i.e., dryness resulting from deficiencies of precipitation; ii) agricultural droughts, i.e., depletion of soil moisture supplies; and iii) hydrological droughts, i.e., shortfalls on surface and sub-surface water supply (Wilhite and Glantz 1985, Wilhite 2000). Yet, while regional and local contexts have started to be considered to understand past impacts from and responses to droughts (Endfield 2008), the different signals of drought propagation have not been scrutinized when reconstructing adaptation strategies.

In this research, we reconstruct short-term responses to droughts as well as long-term water management adjustments ultimately affecting drought response. We use the term adaptation in its broad sense as adjustments in ecological, social, and economic systems in response to actual or expected environmental stimuli, their effects or impacts (Smit et al. 2000). However, our focus is on adaptations by communities. To increase the dialog and cross-fertilization between the study of past and contemporary adaptation processes (Carey 2012), we analyze historical data using frameworks and terminologies developed to understand and assess adaptation to current climate change (e.g., Adger et al. 2007).

2. METHODS

We carried out archival research to reconstruct adaptive practices to droughts over the studied period. The chosen methodology suited our purpose because it allowed us to gather a wide range of information on adaptive practices. This information would be otherwise impossible to collect in a period for which a coherent register and database on droughts does not exist.

Case study selection: community and period

We used the following criteria to choose the case study: i) location, prioritizing areas prone to hydro-climatic variability and droughts; ii) data availability, i.e., accessibility to long-term documentary evidence on adaptive practices; and iii) feasibility in terms of size and bureaucratic complexity. Based on these criteria, the current city of Terrassa in the Barcelona Metropolitan Region, Spain, was selected.

We aimed at analyzing long-term data during the pre-modern period, i.e., before the economic, social and ecological changes brought about by the secularization of social life and knowledge, industrialization and urbanization. Since we needed continuous documentary data along a sufficiently long temporal period, we selected the seventeenth century. In the studied community, this century represents a relatively homogenous historical period preceding the beginning of two processes that completely transformed society: the transition from subsistence to market agriculture and the formation of the modern state. Moreover, we took into consideration the institutional change linked to the establishment of the Bourbon Monarchy which entailed data discontinuity since 1715.

Data collection

Documentary sources reviewed for this research are located in the City Archives of Terrassa, the Parish Archives of Terrassa, and the Diocesan Archives of Barcelona. These sources include minutes from local (e.g., Council, brotherhoods, parish) and regional (e.g., Barcelona's diocese) institutions, court proceedings, and family heritage collections. We assessed the archival records with criteria adapted from the literature on historical climatology, including acceptable density of records, optimum reliability, precise dating of events and adaptive responses, homogeneity over time, and accessibility of documentary sources (Barriendos et al. 2003, Rodrigo and Barriendos 2008). Based on these criteria, we focused our analysis on only one of the sources: Terrassa Council minutes, located in the City Archives of Terrassa (hereafter ACVOC-AHT for its Catalan acronym).

Council minutes consist of norms adopted and decisions made by the local government concerning, but not limited to, maintenance and regulation of infrastructure (e.g., fountains, pipelines, streets), regulation of resource use (e.g., pastures, quarries), public budget and taxes, leasing of public services (e.g., bakery, butcher's), and regulation of activities in public spaces. The minutes are handwritten in Catalan and structured in five sections: 1) date, 2)

constitution (place, type of meeting, members), 3) deliberations and agreements, 4) mayor's approval, and 5) notaries' signatures. The reliability of this primary source derives from the systematic procedure to record decisions, which remained unchanged over the study period, and the finality of the source. As the minutes were archived in a way that they could be easily consulted by successive local authorities, they were written in detail, compiled in books, and properly filed. Furthermore, they document the diversity of views within the Council and also report internal disagreements. However, Council members were only male and often connected with the local elite (Hernández 1996); consequently its documentary records may reproduce biased views in terms of gender and social groups.

The Council minutes were accessed on-line and downloaded through the ACVOC-AHT website (http://arxiumunicipal.terrassa.cat/adigital.php). We conducted a systematic compilation of information from seven volumes of the documentary series from 1600 to 1715, including 2076 Council minutes. Later, we established the actual analytical period from the first to the last agricultural drought event registered in that period (1605-1710, comprising 1908 Council minutes).

Data analysis

To process the minutes we created a spreadsheet that included 1) the date of the minute, 2) a summary of the content of each minute registered by the source (which included between 0 and 13 decisions), and 3) comments on manuscript quality. The meaning of unknown words was consulted in specialized dictionaries on folk lexicon (Alcover-Moll 2002), medieval Catalan (IEC 2015) and eighteenth century Spanish (RAE 2015). Data were analyzed using two techniques: 1) inductive coding based on grounded-theory approach and 2) deductive coding based on content analysis (Bernard 2006).

First, we reviewed in the spreadsheet the main types of decisions recorded in the minutes and coded them under the following thematic categories: (1) natural resource management, (2) religion and culture, (3) governance and institutions, (4) public services and infrastructures, (5) economic affairs, and (6) health and education. When appropriate, major themes were split into subthemes, e.g., natural resource management was divided into (1.1) water, (1.2) agriculture and food, and (1.3) other resources. This codification was used to facilitate the selection of drought-related decisions and to systematize contextual data.

Second, we selected those decisions which, a priori, seemed relevant for understanding adaptation to drought. We identified 122 Council meetings deliberating on water management and droughts, from which relevant decisions were transcribed following standard paleographic criteria from the International Commission of Diplomatics (Bautier 1984). Data from selected Council meetings were complemented with another primary source (court proceedings) and secondary sources (e.g., regional historiographies). On the basis of this information, we selected only decisions related to adaptation to drought (comprising 110 decisions in 93 Council meetings). We coded those decisions using categories from the literature on adaptation to climate change (Smit et al. 1999, Noble et al. 2014) and sub-categories derived from institutional studies (Anderies et al. 2004). We thus divided the selected decisions into three types of responses a) symbolic and ritual, b) institutional, and c) infrastructural.

To further characterize drought responses, we chose representative examples of the identified decisions and used descriptive statistics to explore variables allowing for quantitative analyses. Documentary sources are cited throughout the text as "ACVOC-AHT, Llibre de Consells de la Universitat de la vila" plus the corresponding file, the temporal period covered by the file, and the date of the minute. Additionally, we cite complementary primary sources (i.e., court proceedings) as "ACVOC-AHT, Fons de l'Administració Reial i Senyorial".

3. CASE STUDY

Historical background

In the seventeenth century, the Iberian Peninsula was governed by different kingdoms. The Principality of Catalonia belonged to the Crown of Aragon (Fig. 2.1a), governed since the sixteenth century by the same monarch as the Crown of Castile. Catalonia was divided in several administrative territorial jurisdictions (*vegueries*, see Fig. 2.1b). During the study period, Terrassa was the second most populous village in the *vegueria* of Barcelona*,* ranging from 300 to 400 households (Fig. 2.1c), mostly composed of peasants and wool workers. As a consequence of an administrative split in the village's territory occurred in 1562, the village remained small in size –approximately 4 km^2 (Cardellach et al. 2006). During the seventeenth century the village was mostly surrounded by traditional Mediterranean subsistence crops including cereal croplands, olive groves, horticulture and vineyards, as well as wastelands and forest (Roca 2013). Cash crops expanded during the eighteenth and nineteenth centuries (Badia-Miró and Tello 2014).

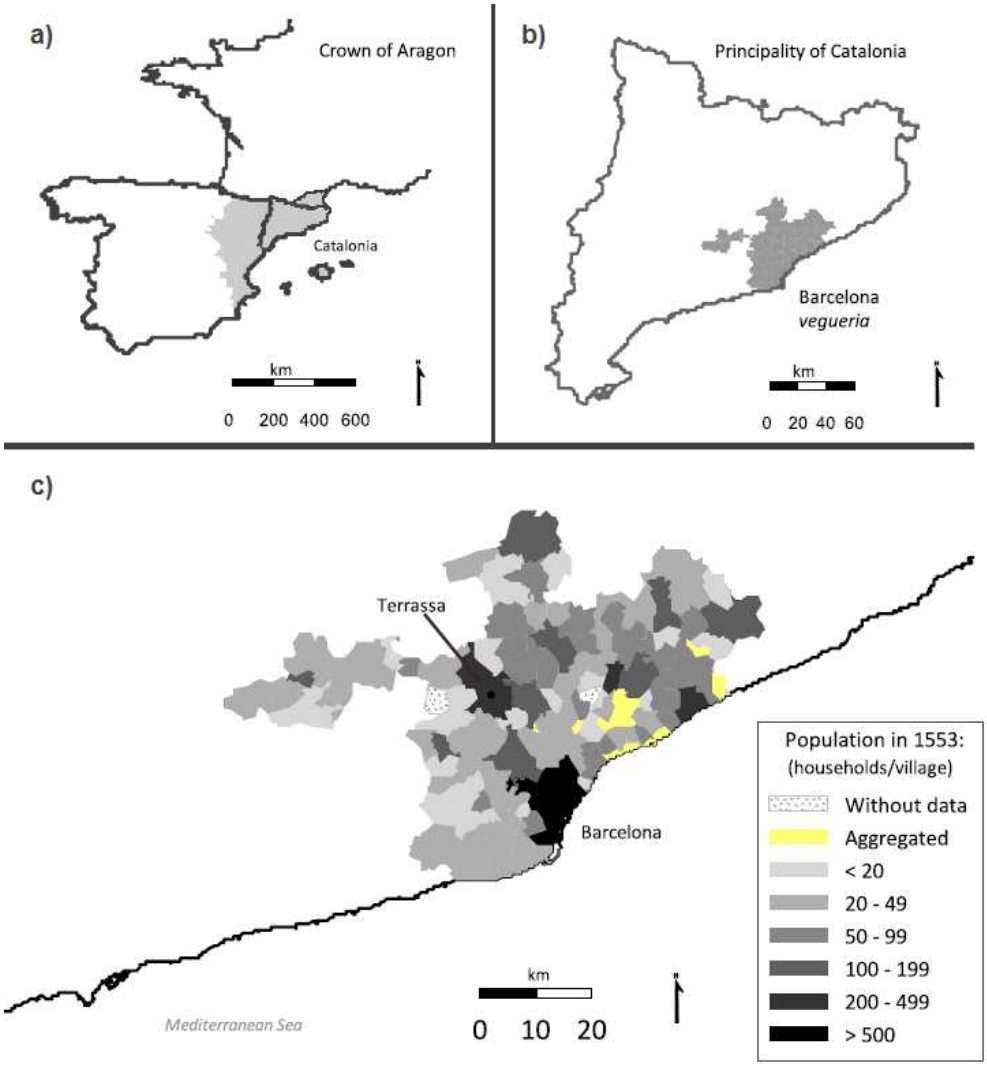

Figure 2.16. Location of the studied community: a) Crown of Aragon highlighted in grey, with the Principality of Catalonia; b) Principality of Catalonia, with the Barcelona *vegueria* highlighted in grey; c) population from the villages belonging to the Barcelona *vegueria*. Sources: population data are derived from the Household Survey of 1553 (Iglésies 1981, CED 2015). Note. Village boundaries reproduce current municipal limits. Contemporary autonomous villages belonging to other municipalities in 1553 are labelled as "aggregated".

Recurrent threats to community livelihoods included droughts, warfare and institutional instability, debt, epidemics, and food crises. Probably among the most evident threats were the successive wars. During the confrontation between the Castilian and French monarchies in the early seventeenth century, Catalan villages such as Terrassa were forced to quarter Castilian troops (Sanabre 1996). In 1640, Catalan peasants revolted against the war-related burdens and aligned with the French. This gave rise to an armed conflict that lasted until 1652 (Elliott 1984), when French troops laid siege to the village of Terrassa (Sanabre 1996). During

post-war period, in the 1650s, insecurities and bandits spanned (Messeguer 2009). The village was also affected by the War of the Spanish Succession (1701-1714) confronting the Bourbon and Habsburg monarchies.

A second important threat in this period was the public debt that accumulated as a consequence of different events including the public purchase of the lord's patrimony (1621), the endorsement of wool workers' private debt after the worsening of Mediterranean trade, the costs of the war, and the levy of taxes by the King with retrospective effect (Hernandez 1996). To pay back debts, the Council of Terrassa subscribed agreements with the creditors (in 1659, 1670 and 1702), according to which debt repayment had priority over other public expenditures, and sold the lord's patrimony again (1661).

Climatology and drought patterns

The precipitation regime of the Iberian Peninsula is characterized by a marked spatial and temporal variability resulting from a complex relief and diverse atmospheric patterns (Lana and Burgueño 2000). At the study area, climate is mainly conditioned by three factors: low altitude (<300m), proximity to the Mediterranean Sea (<25km), and complex regional topography including littoral and pre-littoral ranges, the Llobregat valley and the Catalan Central basin. Mean annual temperature is 14-15ºC, with fluctuations along the year slightly buffered by marine thermoregulation (Martín-Vide et al. 2008:19-32). According to instrumental records from the twentieth century (compiled and homogenized by Prohom and Salvà 2011), mean annual precipitation in Terrassa is 584.1 mm with high variation from year to year (SD=146.8 mm). The minimum annual precipitation recorded since 1925 was 338.8 mm (coinciding with a period of prolonged drought) whilst the maximum was 1041.5 mm in 1962 (resulting in catastrophic floods). Terrassa is situated in the transition area between two different precipitation regimes: continental, with drier winters and summers, and littoral, with summer deficits (see classifications in Clavero et al. 1997:18 and Martín-Vide et al. 2008:18). Precipitation series show that summers are the driest season, with the lowest monthly rainfall in July (average=30 mm).

As with precipitation, drought patterns are also conditioned by topography and large-scale atmospheric circulation (Lana and Burgueño 1998) resulting in great spatial variability. Moreover, differences in spatial patterns increase with longer drought time scales (Vicente-Serrano 2006) presumably increasing spatial fragmentation and complexity in hydrological droughts.

Local values of water and the water cycle

During the Medieval and until the Early Modern period, hazards such as earthquakes, floods or droughts were perceived as part of God's will (Christian 1982). Such belief, mediated by the Catholic doctrine, considered that the ultimate driver of the hazard was people's immoral behavior. To obtain forgiveness for such behavior, devotees practiced vows, penitential processions to holy places or new devotions (Bossy 1985). These rituals provided expectation of relief and maintained social cohesion during crises (Gómez-Baggethun et al. 2012).

God's will as ultimate explanation not only included hazards (Gerrard and Petley 2013) but also encompassed the whole hydrological cycle (Linton 2010). This sacred vision, integrated in the Genesis narrative, implied the belief of an initial Creation in which chaotic "waters" were ordered. Waters were divided between the heaven (rain) and the earth (surface and groundwater).

Water institutions

Under the Catalan feudal regime, many local resources, e.g., woodland or surface waters, and services, e.g., the bread oven or the smithy, belonged to the local lord although villagers had access and withdrawal rights through specific licenses (Giralt et al. 2008). The crisis of the Late Middle Ages, linked to the Black Pest of the fourteenth century, led to changes in the access and management of such common resources. During the sixteenth and seventeenth centuries, a conflictive renegotiation of rights over the commons between lords and village communities took place (Olivares 2000). Consequently, during our study period water rights were not always clearly defined and were thus a source of conflict (ACVOC-AHT, "Fons de l'Administració Reial i Senyorial", exp. 109/31, 11/5/1616; Ibid, exp. 116/7, 18/2/1620; Ibid, exp. 124/4, 11/12/1624; Ibid, exp. 160/33, 11/8/1646). According to the Catalan Constitutions, all flowing waters and springs belonged to the king, but the villages had the right to use them (Generalitat 1995:248). In practice, however, waters were managed through local laws which often combined elements of such Constitutions with customary rules. In Terrassa, water rights were split across different actors, including the king, the lord, the community, brotherhoods, monasteries, and individuals. Rights that were clearly established included those affecting water owned by the community (e.g., fountains with their tunnels and sinks), the lord (e.g., fountain), the king (e.g., water streams and mill ponds), and some individuals (e.g., pools). For instance, in 1441 an agreement was reached between the lord and the community on the main water supply of the village by which one third of water was for the lord and two thirds for

the villagers (Galí-Barba 1992). Undefined or overlapping rights often resulted in conflicts around access and distribution of water. For instance, in 1614 a conflict took place over springs and their water between the royal and the village jurisdiction (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 3/3, 1592-1616, 29/7/1614). The king claimed he was the only owner of springs and the only one who could lease use rights over springs' water. Based on local customary uses dating back to immemorial times, however, the village Council defended their autonomy to lease springs' water to individuals. While both parts recognized access, withdrawal, management and exclusion rights for the village, they disagreed on the right of alienation, i.e., the right to sell or lease either one or more of the above rights (as defined by Ostrom and Schlager 1996). Hence, while the village was not legally entitled to alienate water, in practice and according to its customary laws, it was acting as full owner of these water resources.

In sum, our studied community consisted of i) multiple actors with different rights, from access to management and to alienation (Ostrom and Schlager 1996), ii) a hybrid system with overlapping institutions and jurisdictions, from customary rules to pre-modern state laws (Roth et al. 2005), and iii) a changing institutional framework due to the constant negotiation of rights between actors across the studied period.

Water infrastructures

In the Early Modern period, water infrastructures in Catalonia did not differ much from previous medieval technologies. Both were mainly based on locks (*assuts*), which diverted water from rivers into canals; animal-driven water wheels (*sínies*); and underground tunnels (*mines* or *foradades*), which collected and transported groundwater by gravity (Giralt et al, 2008:153). The latter, slightly modified from the original Persian *qanat* system and probably introduced in Spain by the Arabs, were used in the Mediterranean and other arid regions both for irrigation and for urban water supply (Weingartner 2012).

In the seventeenth century, the water used by the studied community belonged to the Llobregat and the Besòs river basins. The community Council managed the water provided by a medieval set of local collecting facilities, including an underground tunnel built during the fifteenth century, ancient springs, sinks, and several temporary streams which probably were diverted using locks and canals (Galí-Barba 1992; ACVOC-AHT, "Fons de l'Administració Reial i Senyorial", exp. 98/8, 24/7/1604; Ibid, exp. 109/29, 10/5/1616; Ibid, exp. 126/21, 24/3/1626).

Beyond the community Council, other stakeholders used and managed a diversity of water infrastructures, including temporary streams (which brought the water from the pre-littoral range to the village), irrigation canals for gardens and mills, springs, shallow wells, domestic cisterns or ponds to store rainwater, and farmer and industrial ponds (e.g., ACVOC-AHT, "Fons de l'Administració Reial i Senyorial", exp. 101/11, 18/7/1608; Ibid, exp. 112/12, 10/1/1618; Ibid, exp. 153/28, 8/8/1641).

4. RESULTS

From the total of 1908 Council meetings celebrated between 1605 and 1710, only 5% (n=93) included decisions regarding responses to drought. From these, we identified 110 drought-related decisions adopted by the Council, which we classified as symbolic and ritual (26 decisions), institutional (39 decisions), and infrastructural responses (45 decisions) (Table 2.1).

Decisions adopted in Council meetings varied notably through time. We identified two periods characterized by different intensity of activity regarding drought-related decisions. The first interval, 1605-1631, covers barely ¼ of the studied period but concentrates 58% of all water-related decisions adopted by the Council, most of them concerning institutional and infrastructural responses. During this period the Council took an average of almost three decisions on drought and water issues per year. In 1611 only, as much as eight decisions were adopted, including repairing the drinking fountain, channeling of surplus waters, establishing new sanctions to avert over-consumption, and solving water rights conflicts (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 3/3, 1592-1616, 9/2/1611, 11/4/1611, 21/4/1611, 21/5/1611, 6/6/1611, and 9/8/1611). Drought intensified over the next year, when the community and other Catalan villages conducted rituals praying for rain during April and May (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 3/3, 1592-1616, 27/4/1612; Sans 1997, Giralt et al. 2008:44).

The second interval, 1632-1710, was characterized by fewer regulations concerning droughts and water. This interval covers ¾ of the studied period but accounts for only 42% of drought-related decisions, with an annual average of 1.5 decisions. Between 1632 and 1710, we found few infrastructural and institutional responses although we also found a higher proportion of symbolic and ritual responses, especially over the 1640s, 1650s and 1700s. Figure 2.2 shows the different types of responses to drought displayed over decades.

Table 2.3. Responses to droughts among the village community of Terrassa (Barcelona), as reported by documentary sources (1605-1710). N refers to the total number of decisions.

Categories	Responses	N	Examples from our study period
Symbolic and ritual			
	Adjusting local symbols	2	Change of the local patron to St. Eudald (protector against drought)
	Community rituals	24†	Pilgrimages to the Virgin to plead for rain
Institutional			
	Definition of boundaries (resource and users)	2	Allocation of water rights according to profession (e.g., construction workers)
	Collective-choice arrangements	2	Agreements between the council and particulars to design public infrastructures
	Monitoring	1	Establishing sanctions after monitoring users' behaviour
	Definition and enforcement of gradual sanctions	12	Gradual sanctions for diverting water courses, using watering troughs, over-consumption, or degrading the sewage system
	Conflict-resolution mechanisms	15	Tackling and solving conflicts between particulars and the council, between particulars, or with external agents
	Recognition of rights	7	Recognition and defence of community rights for irrigation and public infrastructure
Infrastructure			
	Improvement or maintenance of old water infrastructure	28	Regular maintenance of drinking fountains, channels, galleries, watering troughs, etc.
	Building new collective water infrastructure	9	Searching new water sources and building up water infrastructures
	Sewage works	3	Monitoring and managing latrines
	Water quality management	3	Control of pollution sources (e.g., hemp fermentation pools)
	Leakage control	2	Identification of leakage causes and arrangement (e.g., waterwheels)

† Documented decisions regarding ordinary pilgrimages (n=46) are not included.

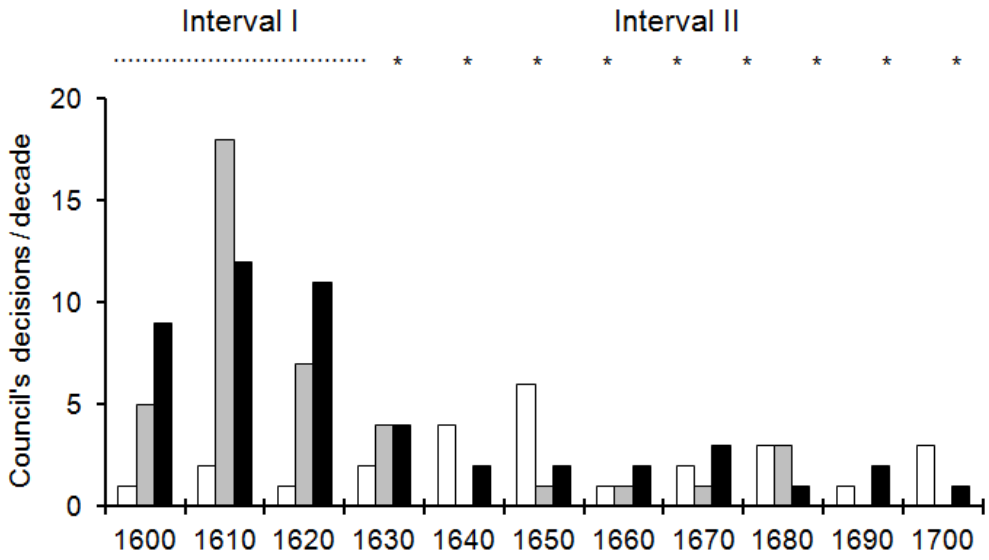

Figure 2.17. Responses to droughts displayed over decades, as reported by documentary sources. Open bars: decisions regarding symbolic responses; shaded bars: decisions regarding institutional responses; solid bars: decisions regarding infrastructural responses. See results section for a description of each category.

Symbolic and ritual responses

The first category of responses to drought concerns those mediated by local religious beliefs (Table 2.1). As hazards were perceived as divine punishments for the immoral behavior of people, since the eleventh century, pilgrimages were a common community response to earthquakes, epidemics, and droughts (Cardús 1947). In response to any of those hazards, local people walked to the Monastery of Montserrat, following a pathway of 24 km (Fig. 2.3). The Virgin was asked in rogation ceremonies to intercede with God so that He would forgive the community for the sins committed and cease God's anger (hazard). Previous research has documented that people from Terrassa went on a pilgrimage in May 1428 to ask God to end up with the suffering caused by the aftershocks of an earthquake occurred several months before. Another pilgrimage is reported in September 1578 to stop a hazardous epidemic (Sanjuan 1995).

In 1516, the Council of Terrassa started to organize periodic pilgrimages to Montserrat, which took place every year in September (Sanjuan 1995). Through those pilgrimages, the village community ratified its commitment and devotion to the Virgin of Montserrat, worshiped by many villages and cities since Medieval times within the Barcelona *vegueria* and other Catalan territories (Fig. 2.3). In addition to those annual pilgrimages, during 1605-1710 we recorded 24 extraordinary pilgrimages to Montserrat, all of them motivated by droughts. That is, when a severe drought occurred, people organized an *ad hoc* pilgrimage. Pilgrims' rogations to the Virgin asked for water or rain, good crops, and solution to problems such as soil dryness, sterile and dry weather, water shortage and crop dryness. We documented rain pilgrimages occurring during war years, but in such instances devotees did not go to Montserrat, but to nearby hermitages (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 6/1, 1645-1657, 25/4/1651 and 2/5/1654).

The periodicity and seasonality of extraordinary pilgrimages is shown in Figure 2.4. We approached periodicity by calculating the time interval between two consecutive pilgrimages. Extraordinary pilgrimages were organized every 1-10 years with an average periodicity of 4.6 years. The period between pilgrimages was of 3 years in 30% of the cases and of 4 years in 17% of the cases (Fig. 2.4a), although we also identified differences between the first interval (1605-1631), when the average periodicity was of 6 years, and the second interval, when the average periodicity was of 4 years (see Fig. 2.2). Out of the 24 pilgrimages analyzed, 20 occurred in spring (especially in April and May), 3 in winter, and 1 in autumn (Fig. 2.4b). Our findings are, therefore, coherent with the seasonality of rogation series in other Mediterranean areas of the Iberian Peninsula (Domínguez-Castro et al. 2010).

The 24 drought-related pilgrimages identified differed in terms of the number of participants and invested resources. According to the sources, the number of participants typically ranged between 20 and 60 pilgrims and some priests. Representatives of brotherhoods and musicians were seldom reported in the sources. As for material symbols, the crucifix was a central element of the ritual. Candles, torches and flags were bought when the Council's budget allowed it. Besides the public money, in some pilgrimages the brotherhoods or the villagers themselves contributed to the expenses.

Other symbolic and ritual responses related to droughts also included the adjustment of local symbols, such as the patron saint. In the Roman Catholic tradition, a patron saint is a holy person who protects a certain group of faithful (in our case, the community), interceding, advising and tutoring them (Cunningham 2005). After the drought of 1659 and during a post-war period, the local Council decided to adopt St. Eudald, the protector against bad waters (*males aigües*), as the local patron (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 7/1, 1658-1678, 4/5/1659 and 9/5/1659). St. Eudald was probably imported from the village of Ripoll, located about 70km NE, where he was worshiped since a drought occurred in the eleventh century (Bonet-Llach 1984).

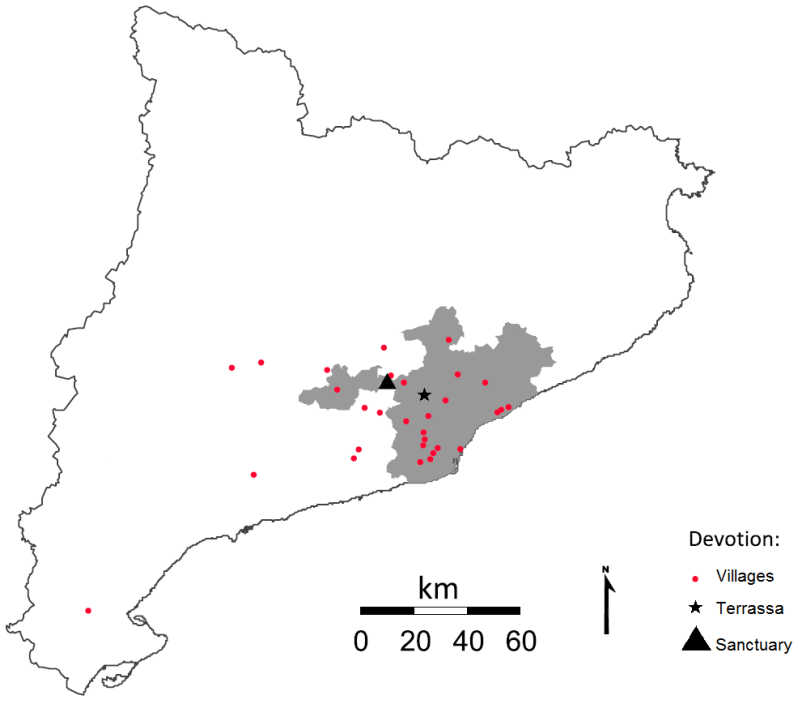

Figure 2.18. . Devotion to the Virgin of Montserrat and location of the Sanctuary. Villages of devotees were located within the Barcelona *vegueria* (in grey) and in other territories of Catalonia. Sources: Sources: devotion is represented by villages performing collective pilgrimages during or before the seventeenth century, as cited by Albareda (2010) and Verdés (2007).

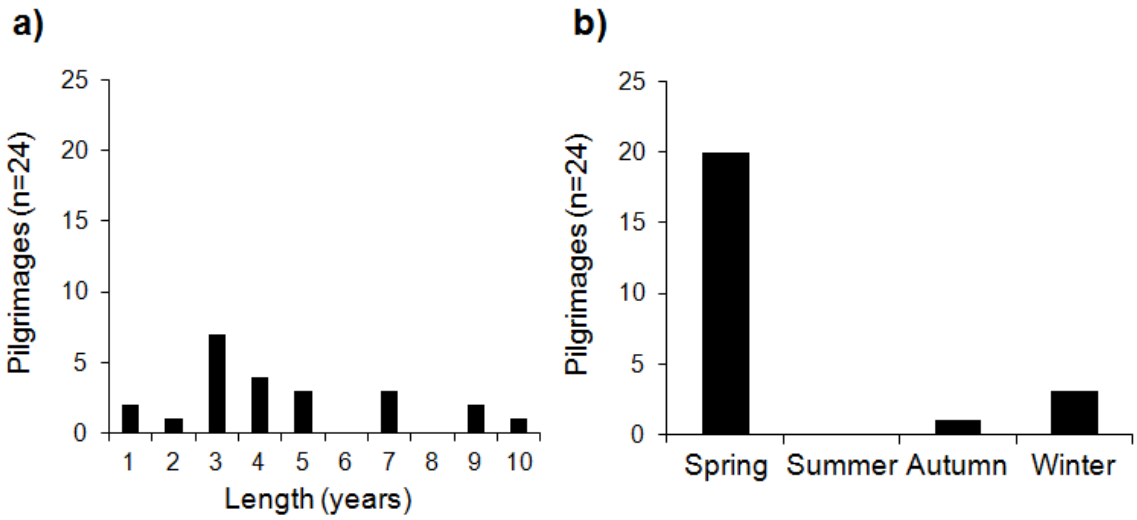

Figure 2.19. Periodicity (a) and seasonality (b) of extraordinary pilgrimages. Note: Periodicity was calculated as the time interval between two consecutive pilgrimages. Seasonality was based on astronomical seasons in Spain: spring (20th March - 20th June), summer (21st June – 22nd September), autumn (23rd September – 20th December), and winter (21st December – 19th March).

Institutional responses

The second category of responses to drought includes institutional changes (Table 2.1), mainly 1) mechanisms for conflict resolution, 2) enforcement of flexible sanctions, and 3) defense of community water rights against larger institutions. These changes stemmed from Council decisions or legal actions in courts. Institutional regulations during our study period varied greatly. We found a high regulatory activity in the first decades, but since then few institutional adjustments were enacted and they were concentrated in the 1630s and the 1680s (see Fig. 2.2). From the 39 decisions involving institutional responses to drought, 77.5% were established before 1631.

We documented struggles over water rights which seemed to have occurred independently of droughts. When a drought occurred, however, conflicts exacerbated, fostering new ways of dealing with water rights (Table 2.1, row 7). For instance, conflicts for surplus water in drinking fountains – the water flowing out after usage – occurred from 1610 to 1626. Since 1613, a village's dyer reclaimed his right to divert surplus water towards his business but the Council denied it. Then, during the drought of 1618, the dyer was denied access to any public position, probably in order to avoid that he would grant himself access to this water (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 4/1, 1616-1625, 16/6/1618 and 3/11/1618).

The Council also enacted sanctions intended to adjust behavior of villagers in relation to local rules regulating the use of water resources in sinks, fountains, troughs, and irrigation channels (Table 2.1, row 6). In some cases, sanctions were non-economic and oriented to solve particular situations such as preventing excessive aquifer consumption by individual water-lifting devices. In these cases the sanctions consisted in the prescriptive closure of such devices by the Council (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 3/3, 1592-1616, 9/5/1607; Ibid, exp. 4/1, 1616-1625, 2/9/1617). In most cases, however, sanctions were economic, with the resulting revenue being typically divided in three parts: one for the accuser or the affected person (e.g., villagers, guilds, Council members, or public officers), one for the King's representative, and the third one for the construction of a new church. This system resulted in a distribution of the responsibility for monitoring rule compliance. During some drought crisis, the severity of sanctions increased, and more restrictions were enforced. For example, the typology of vessels to collect water in the public fountain was regulated in 1609, but -during the drought of 1612- new sanctions were enforced to punish the use of big vessels (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 3/3, 1592-1616, 28/10/1609 and 27/4/1612). Other institutional adjustments included the defense of community water rights, the redefinition of users' boundaries, or agreements between the villagers and the Council to design water infrastructures (Table 2.1).

The institutional reconfigurations described above were not isolated events but rather constitute a cumulative set of local laws over a time period spanning several centuries (e.g., Cardús 2000). Since the local water resources were governed by a complex institutional system, there were multiple actors and overlapping institutions and jurisdictions. Laws or norms were pulled from this set of local laws when new conflicts or needs emerged.

Infrastructural responses

Decisions regarding water infrastructures included the maintenance of existing water infrastructures and the construction of new ones, complemented with practices related to water quality management, sewage works and leakage control (Table 2.1). Most investments on maintenance were aimed at securing water supply from the public fountain. The Councilors assessed the state of the fountains' tunnels and, if convenient, hired professionals to clean them out. In times of high public debt, the villagers themselves were in charge of this task (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 4/2, 1626-1635, 10/5/1628; Ibid, exp. 6/1, 1645-1657, 16/9/1651). Maintenance was often instituted by assigning tunnel

cleaning to certain public officers. For instance, the maintenance of the public sink was attributed to the herald through specific instructions starting in 1637 (ACVOC-AHT, “Llibre de Consells de la Universitat de la vila”, exp. 5/1, 1635-1645, 18/7/1637). The construction of new water infrastructures often followed water shortages. For example, during the drought of 1612, the Council gave permission to search for water supplies around already exploited water bodies (ACVOC-AHT, “Llibre de Consells de la Universitat de la vila”, exp. 3/3, 1592-1616, 12/7/1612).

As with institutional responses, infrastructural responses followed an irregular pattern (Fig. 2.2). Two thirds of the actions (67%) were performed during the first interval (1605-1631), with several peaks, especially in 1611 and 1625. The second interval (1631-1710) includes several periods of over a decade without any change in infrastructure. The prioritization of infrastructure maintenance (28 decisions) over the construction of new infrastructure (n=9) is a characteristic feature of ancient regime water systems in Catalonia (Giralt 2008). Yet, during our study period, the proportion of construction over maintenance varied with time. Specifically, search for new water supplies and construction of water infrastructures concentrated mostly between 1607 and 1628, to be only reactivated after 1689 (e.g., ACVOC-AHT, “Llibre de Consells de la Universitat de la vila”, exp. 3/3, 1592-1616, 9/5/1607; Ibid, exp. 4/1, 1616-1625, 18/1/1619 and 30/8/1624; Ibid, exp. 8/1, 1678-1715, 19/7/1689).

5. DISCUSSION

Hydro-climatic factors influencing responses to droughts

In December 1604, bread riots led by poor people, particularly women, took place in the open market of Barcelona, at the time called the "Plaça del blat" (Wheat square) (Elliott 1984:57). A long-lasting drought was affecting many areas of Catalonia. A few weeks later, in January 1605, the Council of Terrassa organized a costly rain pilgrimage to Montserrat. During the following months, the Council also agreed to purchase wheat, a decision not taken since 1599, and established new measures to secure water supply during summer (ACVOC-AHT, “Llibre de Consells de la Universitat de la vila”, exp. 3/3, 1592-1616, 24/1/1605, 10/2/1605, and 4/8/1605). These responses appear constantly interlinked, but, were winter pilgrimages and summer water supply maintenance driven by similar events? We argue that to understand when communities experienced and perceived a hydro-climatic anomaly as a drought (i.e., hazard), we need to scrutinize the physical properties of drought signals and to situate them in

the context in which they occurred. Unfortunately, documentary records provide few evidences to characterize with precision the specific impacts or the intensity, spatial, and temporal scope of each documented drought. In more complex bureaucracies, these properties are more plausible to be recorded (e.g., Barriendos and Martín-Vide 1997) allowing to identify the physical processes by which accumulated precipitation deficit turned into drought. Interpretation of historical documents enables us, however, to distinguish between two signals of drought development: agricultural and hydrological droughts.

Agricultural droughts are defined as deficits in soil moisture supplies. Other than from rainfall deficits, such droughts are driven by factors such as land uses, plant water requirements, or soil properties (Wilhite 2000). As many preindustrial societies, the studied community was highly vulnerable to agricultural droughts, because basic food crops such as cereals were grown without irrigation. Furthermore, soils in the study area have low water holding capacity (Roca 2013), exacerbating water stress on rain-fed crops. The major documented response to soil moisture droughts was rain pilgrimages which explicitly asked God for good harvests or to stop soil sterility. With a mean interval of 4.6 years between pilgrimages (Fig. 2.4a), this strategy was recurrently pursued by the community during the study period. Interestingly, no pilgrimage was held in summer, when scarce precipitation leads to maximum deficits in soil moisture (see Fig. 2.4b). A possible explanation is that, since crops were adapted to recurrent summer deficits, the impact of low rain was probably lower during summer. In fact, recent studies in Spain contrasting proxies for agricultural droughts (rogation series) with instrumental data (precipitation series) confirm that the threshold of precipitation deficit that typically led to celebrate a rogation was much lower in spring than in any other season (Domínguez-Castro et al. 2012). In other words, drought related to soil water supplies was experienced and collectively tackled when water deficit affected rain-fed crops, and specially the harvest of basic food crops.

Impacts in streamflow and groundwater manifest with delay from precipitation deficiencies and are reported later than agricultural droughts (Wilhite 2000). Hydrological droughts depend on the characteristics of the water basin, such as geology, topography, soil properties and vegetation, the precedent meteorological conditions, and the strategies of water management (Vicente-Serrano and López-Moreno 2005). These drought-controlling mechanisms can delay, attenuate, lengthen, and pool the propagation of rainfall anomalies into the hydrological system (Van Lanen et al. 2013). Due to the lack of perennial streams, the studied community relied on semi-confined superficial aquifers and temporary streams. Aggravated by water scarcity, hydrological droughts were documented locally as the drying up of fountains or the

lowering of groundwater levels. They were especially tackled by the community when impacting the village groundwater supplies. Human management was perceived as an important determinant, probably because anomalies in these water bodies appeared decoupled from climate variability. For instance, some responses to the drying up of fountains were designed after assessing the potential anthropogenic causes of the water shortage (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 3/3, 1592-1616, 4/8/1605 and 1/3/1607). As explained above, local waters were managed by institutional practices and through collective infrastructures gradually constructed since the Medieval period. Community responses to hydrological droughts had to be integrated with these strategies of long-term water management.

Considering the cumulative nature of droughts and its propagation through the water cycle (McKee et al. 1993), together with key contextual factors such as local land uses and water bodies, helps to understand the complexity of the events that generated community actions in relation to droughts. As noted by Zaidman et al. (2002), this complexity has fostered an interpretation of droughts as a whole phenomenon, rather than considering the distinct interrelated elements that constitute them. The recent interest on reconstructing not only climate patterns, but also the social responses to climatic stressors, has powerfully re-introduced the constructivist approach on disasters (Quarantelli 1998, Hoffman and Oliver-Smith 2002). However, we contend that while taking into account the ideological, cultural, and social context in which hazards are constructed and perceived is important, attention should not be diverged from the physical environment in which they occur.

Historical factors influencing responses to droughts

As today, in pre-modern times, droughts were not always the sole reason driving adaptive responses. Recognizing and interpreting the particular historical context in which adaptive responses occur brings to light the way in which other factors play an equal or secondary role. In our case study, warfare and public debt might have influenced community responses to drought (see historical background section). Although we consider both factors at the local scale, they were not particular to our case study, but threatened many communities during the Early Modern period (Olivares 2000).

Successive wars and subsequent institutional instability affected community responses in different ways. First, insecurity associated to wars could lead to prioritize responses that strengthen social cohesion, possibly explaining the higher proportion of symbolic and ritual measures adopted in the 1640s and 1650s, as compared to other decades (Fig. 2.2). Second,

the co-existence of two authorities during war conflicts, namely the French and the Spanish viceroyalties in the 1640s and the 1690s, and the Habsburg and Bourbon monarchies since 1700, probably discouraged the enacting of new water-related institutions by the local Council. And third, the mandatory supply to the armies by the village implied high costs in terms of resources and manpower, which probably reduced investments in water infrastructures (Fig. 2.2).

Some authors have pointed out the interconnection between wars and disasters, but mostly interpreting the first as preconditions of the second, or alternatively the second as a consequence of the first (Schnek 2007). Adamson (2014) highlighted that western colonial India was highly resilient to droughts, but the system was threatened when climatic stress was coupled with warfare. However, this work documented a punctual war, whereas our study period was plagued by successive wars. Given the frequency of both wars and droughts, the community might have accumulated experience in dealing with droughts coupled with warfare. For instance, during the ending of the Reapers' War, and few months before the 1652 village's siege, the Council organized a rain pilgrimage, ordered to fix water infrastructures, and established new sanctions after checking out the state of drying fountains (ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 6/1, 1645-1657, 16/4/1651, 25/4/1651, 16/9/1651, and 31/10/1651). Hence, although responses to drought by Council were altered by such military conflicts, they continued over periods of warfare.

The mounting public debt was another factor conditioning responses to drought. Public debt limited the range of response options to those involving low costs, possibly also discouraging infrastructural responses since the 1630s (Fig. 2.2). Debt-induced changes in the ownership of lord's patrimony, including the drinking fountains, conditioned both infrastructure and institutional responses in the 1680s, because the new lord claimed water rights over them and designed water infrastructures unilaterally (e.g., ACVOC-AHT, "Llibre de Consells de la Universitat de la vila", exp. 8/1, 1678-1715, 29/8/1683). Recent studies illuminate the way in which public debt influences the water cycle. For instance, March and Saurí (2013) explain how institutional changes in water management - and specifically, recent water privatization in Metropolitan Barcelona - are justified by a large debt resulting from the combination of costly environmental European directives and austerity policies enforced during the economic crisis started in 2008. Debt has also been reported to affect vulnerability to drought at the household level. Liverman (1990), for instance, states that low-income Mexican farmers indebted from technological investments are more vulnerable than farmers using traditional

techniques. However, we still lack a general understanding on how debt directly or indirectly affects collective drought responses both in the contemporary and pre-modern contexts.

6. CONCLUSION

We presented a systematic analysis of long-term responses to drought by a pre-modern community. Our case study illustrated the wide range of strategies implemented and developed to cope with droughts at the community level. Symbolic and ritual responses, institutional reconfigurations, and changes in water infrastructures were put in place by the village Council. We suggested that this repertoire of practices recorded during the Early Modern period had much in common with the accumulated and slowly-changing institutional settings, water technologies, and religious practices of the Medieval period.

The long-term approach enabled us to explore the ways in which responses changed across the study period (1605-1710). We discussed how the changes in temporality and in the type of responses were influenced by hydro-climatic and non-climatic factors. Through this approach, we provided an attempt to interpret past coping strategies from a socio-environmental standpoint. First, we took into account how signals of drought propagation manifested in the local environment and were tackled separately by the community. Although limited by partial records of droughts, documentary sources enabled us to distinguish between responses dealing with agricultural droughts from those dealing with hydrological droughts. Second, we examined the combined role of drought and major historical processes threatening many communities in the Early Modern period. We noted that while the community might have accumulated experience on dealing with droughts coupled with warfare, public debt was probably a key factor limiting the range of response options.

More empirical cases are needed to compare social responses to hazards, historical turning points, and potential shared drivers (Helbling 2007, Carey 2012). For this endeavor, recovering and reviewing local documentary records seems a suitable option. Yet, our paper suggests some of the challenges of undertaking such task. Only 5% of the Council meetings held during the study period recorded decisions regarding responses to drought and in some cases no decisions were made during an entire decade. In other words, even if droughts are a recurrent threat, both dispersed records and short-term analyses can favor faulty interpretations of social passivity or isolated responses. The research effort of long-term archival studies thus offers the possibility to provide coherency and linkages among past coping strategies and to explain them within their changing historical context.

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CHAPTER III

Prudent Peasantries:

Multilevel Adaptation to Drought in Early Modern Spain (1600-1715)*

* **Grau-Satorras, M.**, I. Otero, E. Gómez-Baggethun, and V. Reyes-García. Prudent Peasantries: Multilevel Adaptation to Drought in Early Modern Spain (1600-1715). Submitted to: *Environmental History*.

Abstract

Climate change being a product of modernity can easily fuel the idea that adaptation to climate impacts is something new. Scholars of the past, however, show that societies have dynamically and heterogeneously coped with climate variability and with recurrent and abrupt extremes. This research aims to explore adaptation in preindustrial societies taking into account different levels of social organization. We argue that this multilevel perspective can enrich our understanding of the critical levels contributing to cope with climate impacts in past societies. Archival research was carried out in the early modern villages of Terrassa and Sant Pere (Barcelona, Spain) to reconstruct the set of strategies to cope with recurrent droughts both at the community and the household levels. We found that peasant families developed a wider range of strategies than communities, but importantly many strategies from both levels overlapped. Partial overlapping could generate a redundancy effect and foster more complex strategies operating through cross-level interactions. By studying past adaptation strategies with common taxonomies and detailed methodologies, our paper aims to improve interdisciplinary communication with research about the human dimensions of climate change.

Keywords: adaptation; climate change; drought; multilevel analysis; preindustrial.

1. INTRODUCTION

Adaptation to climate change has been defined as the adjustments made in practices, processes, and structures to cope with changing climatic conditions.[9] Throughout history, societies have adopted manifold strategies to cope with and build resilience to changing climatic conditions by, for example, spreading risk across assets (e.g. diversification), time (e.g. storage), and households (e.g. pooling).[10] Despite the potential of past accumulated experience -retrievable from historical and archaeological records- to help identify, assess, and reflect on how current and future societies can adapt to climate change, the contribution of studies with historical perspective to research on adaptation to climate change is still limited.[11] In this article, we offer empirical and methodological insights to strengthen such promising interdisciplinary dialog on past and present research about human adaptation to changing climate.

Adaptation strategies to climate variability take place at a range of scales.[12] Investigating how we collectively cope with and adapt to climate changes, variability, and extremes requires a deeper understanding of multi-scalar interactions, as researchers have noted that successful climate adaptation does not seem to take place at single levels of social organization, but across households, communities, nations, and even international platforms in multilevel adaptation processes.[13] However, the question remains open on whether there are specific levels of social organization that allow for most informative adaptation assessments, and why.

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[9] James J. McCarthy, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken, and Kasey S. White, *Climate Change 2001: Impacts, Adaptation and Vulnerability – Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2001), pp. 89-90.

[10] For recent studies in arid and semi-arid areas, see see V. Reyes-García, M. Salpeteur, L. Calvet-Mir, T. Serrano-Tovar, and E. Gómez-Baggethun, 'Coupling Technology with Traditional Knowledge and Local Institutions to Deal with Change in Rural Households: A Focus on the Semi-Arid Tropics', *Science et Changements Planetaires - Secheresse* 24 (2013): 340–9; A.L. Balbo, E. Gómez-Baggethun, M. Salpeteur, A. Puy, S. Biagetti, and J. Scheffran, 'Resilience of Small-Scale Societies: A View from Drylands', *Ecology and Society* 21 (2016):53.

[11] M. Carey, P. Garone, A. Howkins, G. Endfield, L. Culver, S. Johnson, and others, 'Forum: Climate Change and Environmental History', *Environmental History* 19 (2014): 281–364.

[12] W.N. Adger, N.W. Arnell, and E.L. Tompkins, 'Successful Adaptation to Climate Change across Scales', *Global Environmental Change* 15 (2005): 77–86. Here we refer to 'scale' as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon and to 'levels' as the units of analysis that are located at different positions on a scale, as defined by D.W. Cash, W.N. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, and others, 'Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World', *Ecology and Society* 11 (2006): 8.

[13] V. Reyes-García, A.L. Balbo, E. Gómez-Baggethun, M. Gueze, A. Mesoudi, P.J. Richerson, and others, 'Multilevel Processes and Cultural Adaptation: Examples from Past and Present Small-Scale Societies', *Ecology and Society* 21 (2016): 2.

Looking back in time can provide insights to understand how adaptation processes have historically taken place at different levels of social organization. Indeed, the historical perspective might provide a background to contemporary efforts for multilevel agreements and coordination. To our knowledge, few studies have explicitly examined how past societies adapted to climate variability and extremes across different levels of social organization.[14] Economic historians concerned with the management of risk in preindustrial societies have independently described two critical levels: communities and households. For example, back in the 1970's, McCloskey described how, despite the short-term cost of diversification, English peasants opted for scattering plots in open fields and across micro-climates to reduce the risk of harvest failures, arguing that such 'prudent peasants' were the primary actors dealing with risks.[15] This individualistic approach was soon contested by other authors, who argued that English medieval societies had indeed developed a variety of cooperative institutions (i.e., farmers' fraternities and customary pro-poor laws) to pool risks and thus collectively ensure their livelihoods.[16] In other words, the conception of the 'prudent peasants' was enriched with the idea of the 'prudent village'. We argue that the two views are not exclusive and that these two critical levels of organization - peasant families and communities – differently contributed to cope with climate variability and extremes in preindustrial societies.

To examine this question, we study the strategies developed at the community and household levels to cope with recurrent droughts during the seventeenth and early eighteenth centuries. Specifically, our case study focuses on two neighbouring municipalities of north-eastern Spain (Terrassa and Sant Pere), where droughts were the more salient climate impact.[17] Although the municipalities shared similar cultural, organizational, and environmental attributes, they differed in terms of settlement, economic activities, and social structure. We use archival data from the study period to reconstruct in detail community responses developed by Councils and

[14] For some exceptions, see Greg Bankoff, 'Cultures of Disaster, Cultures of Coping: Hazard as a Frequent Life Experience in the Philippines', in C. Mauch and C. Pfister (eds.), *Natural Disasters, Cultural Responses: Case Studies toward a Global Environmental History*, pp. 265–84 (Lanham: Lexington Books, 2009) and G.H. Endfield, 'The Resilience and Adaptive Capacity of Social-Environmental Systems in Colonial Mexico', *Proceedings of the National Academy of Sciences* 109 (2012): 3676–3681.

[15] D. McCloskey, 'English Open Fields as Behavior Towards Risk', *Research in Economic History* 1 (1976): 124–70; see also D. McCloskey, 'The Prudent Peasant: New Findings on Open Fields', *Journal of Economic History* 51 (1991): 343–55.

[16] G. Richardson, 'The Prudent Village: Risk Pooling Institutions in Medieval English Agriculture', *Journal of Economic History* 65 (2005): 386–413. See also M. Kimball, '"Farmers" Cooperatives as Behavior Toward Risk', *American Economic Review* 78 (1988): 224–32.

[17] M. Grau-Satorras, I. Otero, E. Gómez-Baggethun, and V. Reyes-García, 'Long-term Community Responses to Droughts in the Early Modern Period: The Case Study of Terrassa, Spain', *Ecology and Society* 21(2016): 33.

household practices used in family farms. We then compare the strategies documented at the two levels to discuss their differences and overlaps.

This research also aims to provide methodological insights. In her study about the vulnerability to climate variability and extremes in colonial Mexico, Endfield argued that the three main reasons why there have been relatively few historical treatments of vulnerability are 1) the lack of consensus on definitions and approaches to vulnerability, 2) the difficulty to identify such intangible concept (i.e., vulnerability) in the historical record, and 3) the imperfect knowledge we have about past climate (e.g. insufficient resolution over spatial and temporal scales).[18] The same reasons might well apply to the study of past adaptation, although adaptation has more tangible expressions than vulnerability. In this article, we explore two methodological options to overcome problems that so far have limited the historical treatment of adaptation. First, we use a specific taxonomy to classify adaptation which is receiving growing consensus in the adaptation to climate change literature, but has so far been scarcely applied to the study of past societies.[19] Although we are aware that this taxonomy imposes a present-centred approach that risks simplifying our historical analysis, its use might improve mutual understanding between researchers on present and past adaptation. Moreover, this classification merges categories traditionally explored in historical studies, such as diversification and storage, with less commonly enquired categories such as forecasting or rationing. Second, we describe in great detail our methodology to collect and analyse archival data. In many historical studies, methods are accurately developed across the footnotes, however, this procedure can difficult communication with wide audiences not used to read historical narratives.[20] For this reason, in this paper we make our empirical choices explicit to facilitate interdisciplinary discussion about the methodological constraints of reconstructing human adaptations with archival sources.[21]

[18] Georgina H. Endfield, *Climate and Society in Colonial Mexico: A Study in Vulnerability* (Oxford: Wiley–Blackwell, 2008), pp. 3-4.

[19] For an exception, see Balbo, Gómez-Baggethun, Salpeteur, Puy, Biagetti, and Scheffran, 'Resilience of Small-Scale Societies'. See literature used to classify adaptation in footnote 37.

[20] Some historians also point out that footnotes can favour that certain methodological aspects remain implicit, see Kenneth Lipartito, 'Historical Sources and Data' in M. Bucheli and D.R. Wadhwani (eds.), *Organizations in Time: History, Theory, Methods*, pp. 302-303 (Oxford: Oxford University Press, 2014).

[21] For a recent discussion on how qualitative climate change research communicates methodological aspects and the implications for interdisciplinary cooperation, see J.Ø. Nielsen and S.A.L. D'haen, 'Asking about Climate Change: Reflections on Methodology in Qualitative Climate Change Research Published in Global Environmental Change since 2000', *Global Environmental Change* 24 (2014): 402–9.

2. CASE STUDY

Background

Our case study examines social responses to drought over the seventeenth and early eighteenth centuries in two neighbouring communities located in Catalonia (a territory in north-eastern Spain at that time integrated in the Crown of Aragon). In the Spanish context, these centuries correspond to the early modern period, an age of transition between late feudalism and the emergence of modern Western states characterized by the expansion of global trade and the gradual erosion of traditional social divisions and beliefs.[22] Climatologically, this period is characterized by changes in climate dynamics due to the Little Ice Age, although their implications for the Mediterranean basin, and specifically for the Iberian Peninsula, remain debated.[23]

Early modern societies in Spain were organized at multiple scales. In Catalonia, there were several levels in the administrative scale, with provinces being administrated by an institution called *vegueria*. The vegueria of Barcelona had approximately a hundred municipalities governed by local Councils with different powers depending on their past privileges. The society was also organized around the religious scale, which paralleled the administrative one. The diocese of Barcelona was divided into parishes, which not always fully overlapped with municipalities. Our case study focuses on two municipalities (Terrassa and Sant Pere) comprising seven different parishes (Figure 3.1, Table 3.1).

[22] James Casey, *Early Modern Spain: A Social History* (London: Routledge, 1999).

[23] J. Luterbacher, E. Xoplaki, C. Casty, H. Wanner, A. Pauling, M. Küttel, and others, 'Mediterranean Climate Variability over the Last Centuries: A Review', *Developments in Earth and Environmental Sciences* 4 (2006): 27–148. For a global overview of the Little Ice Age, see Jean M. Grove, 'The onset of the Little Ice Age', in P.D. Jones, A.E.J. Ogilvie, T.D. Davies, and K.R. Briffa (eds.), *History and Climate: Memories of the Future?*, pp. 153–85 (Kluwer Academic/Plenum Publishers: New York, 2001). For its consequences in the western Mediterranean, see F.S. Rodrigo, M.J. Esteban-Parra, D. Pozo-Vázquez, and Y. Castro-Díez, 'Rainfall Variability in Southern Spain on Decadal to Centennial Time Scales', *International Journal of Climatology* 20 (2000): 721–32; J. Luterbacher, E. Xoplaki, C. Casty, H. Wanner, A. Pauling, M. Küttel, and others, 'Mediterranean Climate Variability over the Last Centuries: A Review', *Developments in Earth and Environmental Sciences* 4 (2006): 27–148; and Armando Alberola, *Los cambios climáticos: La pequeña edad del hielo en España* (Madrid: Cátedra, 2014).

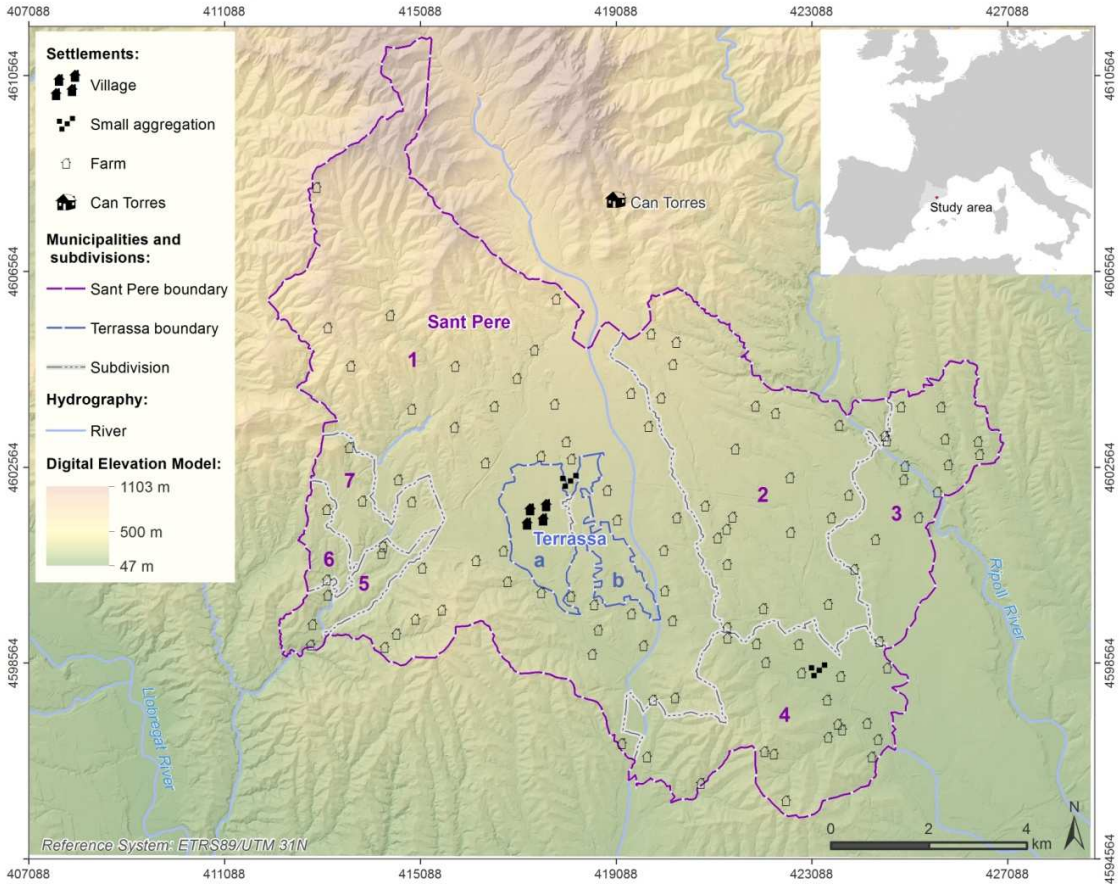

Figure 3.20. Map of the study area: Sant Pere comprised the parishes of Sant Pere (1), Sant Julià d'Altura (2), Sant Vicenç de Jonqueres (3), Sant Quirze (4), Sant Miquel de Toudell (5), Sant Martí de Sorbet (6) and Santa Maria de Toudell (7); while the village of while the village of Terrassa (a), also included another jurisdictional territory called Quadra de Vallparadís (b). [24]

[24] Map elaborated with data from the Terrassa town Council (2004), the *Institut Cartogràfic i Geològic de Catalunya* (ICGC, 2016), and the *Agència Catalana de l'Aigua* (ACA, 2005).

Table 3.4. Case study description. [25]

	Terrassa	Sant Pere
Population in 1553 (households) [estimated population]	210 [840]	125 [500]
Population in 1700-1701 (households) [estimated population]	299 [1196]	185 [740]
Surface (sq km)	5	109
Population density in 1553 (households per sq km) [estimated people per sq km]	42.1 [168.3]	1.1 [4.6]
Population density in 1700-1701 (households per sq km) [estimated people per sq km]	59.9 [239.7]	1.7 [6.8]

From the late twelfth to the fifteenth century, the study area was governed by a single political institution, i.e. the Council of the village and the territories of Terrassa, with jurisdiction over the walled village and the farmhouses scattered across the seven different parishes (Figure 3.1).[26] The village and the parishes were represented in the Council, although they often had disputes for their relative weights on decision making. The sixteenth century was marked by a demographic and territorial expansion of the village, which propelled villagers' demands for more political power than people living in the sparsely settled farms. By mid sixteenth century, the tension was further exacerbated with the decision to invest on a new church inside the village, which threatened the status of the outside parish church.[27] Solé points out that the differences on matters such as the fiscal policy and the system to elect Council members fostered division between the village and the surrounding farms. Finally, the administrative and political segregation into two sovereign entities (i.e., the Council of Terrassa and the Council of Sant Pere) was formally enacted in 1562 through a privilege granted by the King.

Water was scarce in the studied municipalities which primarily relied on a network of temporary streams born in the pre-littoral range and belonging to the Llobregat and the Besòs river basins. The only permanent stream was the Ripoll River, a tributary of the Besòs River.

[25] Population data from Josep Iglésies, *El Fogatge de 1553: Estudi i Transcripció* (Barcelona: Fundació Salvador Vives Casajuana, 1979), pp. 177, 322-326; Ferran Berenguer and Joan Coma, 'L'evolució del poblament', in J.M. Benaul (ed.) *Història de Terrassa* (Terrassa: Ajuntament de Terrassa, 1987), pp. 40-42; ACVOC-AHT, CMT, 18 Apr. 1700; ACVOC-AHT, CMSP, 8 May 1701. Number of people is estimated using a conservative coefficient of 4 persons per household. Surface data estimated from fig. 3.1. See methods section and tab. 3.2 for an explanation of how documentary sources are cited throughout this paper.

[26] M. Solé, 'El Marc Institucional i Polític de la Terrassa Moderna', *Terme* 4 (1989): 26–42.

[27] J. Verdaguer, 'Les Xacres del Pont de Sant Pere de Terrassa', *Terme* 22 (2007): 197–214.

Approximately 3 km of its middle course crossed the north-eastern part of Sant Pere (Figure 3.1). The communities also used groundwater, particularly the superficial aquifers formed in the alluvial plain, exploited with shallow wells and underground water tunnels. The water bodies upon which they relied on were therefore highly dependent on rainfall. Nowadays, mean annual precipitation in Terrassa is 584.1 mm, although during the late seventeenth century rainfall in areas closer to Barcelona was probably higher than this.[28] According to documentary proxies based on rogation ceremonies asking God for rain, between 1605 and 1710 droughts occurred every 4.6 years, thus representing a recurrent hazard which regularly affected agricultural production, food security, water supply, and, more generally, social and economic well-being.[29]

Terrassa

In the study period, population density in the village of Terrassa surpassed 200 people per square km (Table 3.1). The population fluctuation from 1553 to 1700 cannot be monitored due to the absence of continuous demographic data. However, local studies show trends of population decline by mid-seventeenth century and thereafter a population increase starting in the 1680s reaching around 300 households at the beginning of the eighteenth century.[30] By the early eighteenth century, cereal cropland was by far the most extensive land cover, followed by olive groves and horticulture (Figure 3.2.a). As other Catalan medium towns, most residents earned their living from agriculture, livestock, and artisanal activities, principally wool and, to a lesser extent, flax manufacturing.[31]

[28] Precipitation data from Marc Prohom and Gabriel Salvà, *Els Pluviòmetres de Mina. L'Observació Meteorològica Impulsada per Mina Pública d'Aigües de Terrassa SA* (Terrassa: Fundació MPATSA, 2011). For early modern precipitation patterns, see M. Barriendos, 'Climatic Variations in the Iberian Peninsula during the Late Maunder Minimum (AD 1675-1715): An Analysis of Data from Rogation Ceremonies', *Holocene* 7 (1997): 105–111. For regional drought patterns during this period, see F. Domínguez-Castro, R. García-Herrera, P. Ribera, and M. Barriendos, 'A Shift in the Spatial Pattern of Iberian Droughts during the 17th Century', *Climate of the Past* 6 (2010): 553–63.

[29] Grau-Satorras, Otero, Gómez-Baggethun, and Reyes-García, 'Long-term Community Responses to Droughts'.

[30] Berenguer and Coma, 'L'evolució del poblament'.

[31] I. Almazán, 'Terrassa en els Segles XVI i XVII: Entre la Solidaritat i la Por', *Terme* 4 (1989): 43–54.

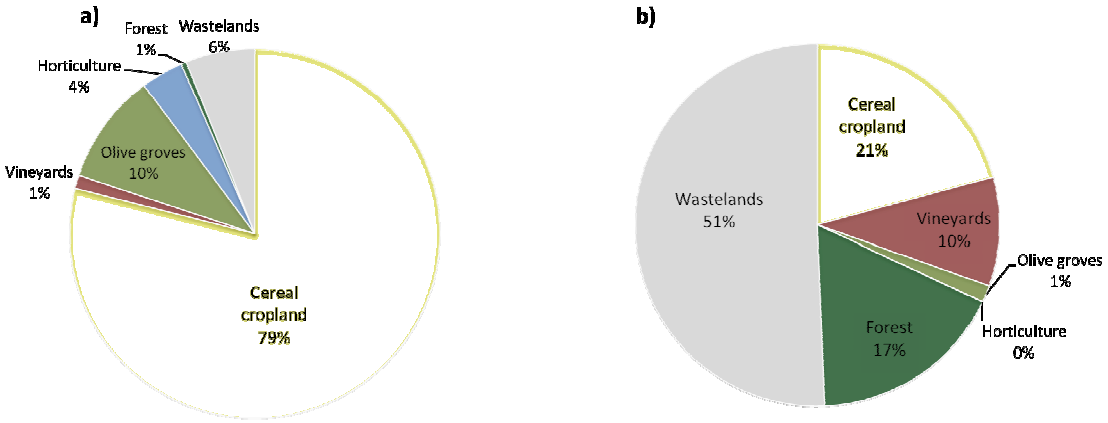

Figure 3.21. Land uses in the village of Terrassa (a) and Sant Pere (b) by early eighteenth century. [32]

Sant Pere

The second municipality covered in our study was composed by seven parishes (Figure 3.1). In what follows we refer to it as Sant Pere, because this was the most important parish of the municipality in terms of population, surface, and political power. The farmhouses of Sant Pere were scattered across a vast territory surpassing the 100 square km. Although the population increased during the study period, human density remained relatively low (Table 3.1). Only two parishes had small aggregations of houses (Figure 3.1). Wastelands covered at least half of the territory in the early eighteenth century (Figure 3.2.b). Indeed, wastelands and forests patches were managed for multiple uses such as grazing and temporary cultivation. In cultivated areas, cereals and vineyards were predominant. Rain-fed agriculture, livestock, and forestry were the main livelihood sources.[33]

3. METHODOLOGY

3.1. Data Collection

Our analysis of strategies to cope with droughts focuses on two main levels of social organization: the community and the household.

[32] Data from P. Roca, 'Allò que la Vinya s'Endugué. L'Expansió Vitícola del Segle XIX com una Etapa en l'Evolució del Paisatge i la Societat Rural del Vallès Occidental', *Jornades d'estudi, Vinyes, Vins i Cooperativisme Vitivinícola a Catalunya* (L'Espluga de Francolí: 2013), p. 3. According to this author forest and wastelands surfaces were probably larger than reported.

[33] Almazán, 'Terrassa en els Segles XVI i XVII'; P. Roca, 'Agricultura i Creixement Urbà a la Zona de Terrassa. 1750-1850', *Terme* 6 (1991): 36–51.

Community-based strategies to cope with drought

We reconstructed community strategies by examining documentary records from both the village of Terrassa and the neighbouring Sant Pere municipality (Figure 3.1). The main documentary sources we used are the Council minutes of the two municipalities as they share a similar format (e.g., structure, vocabulary), content (i.e., the themes covered), and compilation system (i.e., minutes' books).

We conducted a systematic review of the Council minutes of the village of Terrassa from 1600 to 1715 (Table 3.2). These documents are located in the City Archives of Terrassa (hereafter ACVOC-AHT for its official acronym). The Council minutes were accessed on-line and downloaded from the ACVOC-AHT website.[34] We conducted an exhaustive compilation of information from the seven volumes of the documentary source (i.e., 3630 pages). Our search was directed to identify strategies to cope with direct and indirect effects of droughts.[35] Decisions mentioning the participation of Sant Pere were also noted.

Strategies to cope with drought in Sant Pere were reconstructed from a sample of Council minutes covering the period from 1600 to 1715 (Table 3.2). The documentary series of this primary source are also located in the ACVOC-AHT and the digital copies were facilitated to us by the archive staff. Because the Terrassa Council minutes had more continuity, we used them as a reference for the climatic chronology to structure the analysis of Sant Pere, assuming that the two neighbouring communities were subject to the same drought patterns. Data sampling for Sant Pere Council minutes followed three steps. First, we listed the dates of the 24 rogation ceremonies (rain pilgrimages) identified in the Terrassa Council minutes from 1600 to 1715.[36] Rogation ceremonies have been widely used by historical climatologists to identify the occurrence of agricultural droughts, an intermediate signal of drought propagation.[37] Second, we excluded from the list the rogation dates with no documentary records available in the Sant Pere Council minutes (1649-1685). If drought-related information was detected at the beginning or end of those 12 months, we continued reading minutes until the drought went unnoticed in four consecutive Council meetings. This sample comprised 331 pages and represented 20.3 per cent of the total volume of available records in Sant Pere during the

[34] Available at: http://arxiumunicipal.terrassa.cat/adigital.php [accessed 8 Nov. 2016].
[35] For a detailed reconstruction of drought-related strategies using this source, see Grau-Satorras, Otero, Gómez-Baggethun, and Reyes-García, 'Long-term Community Responses to Droughts'.
[36] Ibid.
[37] For an application in Spain, see F. Domínguez-Castro, P. Ribera, R. García-Herrera, J. M. Vaquero, M. Barriendos, J. M. Cuadrat, and others, 'Assessing Extreme Droughts in Spain during 1750–1850 from Rogation Ceremonies', *Climate of the Past* 8 (2012): 705–22. Drought propagation means that the impact of rainfall deficit appears delayed across the water cycle, from soil moisture to groundwater.

study period. To ensure sampling accuracy, we expanded this initial sample. Based again on data from the Terrassa minutes, we selected three years outside the period 1649-1685 and without rain pilgrimages, but when more than four drought-related decisions were documented. The selected years were 1607, 1611, and 1625, for which we reviewed all the Sant Pere Council minutes (85 pages).

Table 3.5. Details and codes of documentary sources consulted and cited. Location includes the archive or the author, the archival collection, the complete denomination of the documentary series, and its English translation; the code used to cite sources throughout the text includes the acronyms of the archive and the documentary series, followed by the date or the folio.

Location	**Citation code**	**Description of the documentary sources**
City Archives of Terrassa, 01/01 Ajuntament de Terrassa, *Llibre de Consells de la Universitat de la vila* (Council minutes of Terrassa).	ACVOC-AHT, CMT, followed by date.	Books of minutes of the village Council of Terrassa. Homogeneous and continuous (1562-1715). Seven volumes. Handwritten.
City Archives of Terrassa, 01/02 Ajuntament de Sant Pere de Terrassa, *Llibre de Consells de la Universitat forana* (Council minutes of Sant Pere).	ACVOC-AHT, CMSP, followed by date.	Books of minutes of the Sant Pere Council. Continuous (1562-1649; 1685-1729) with a temporal gap (1649-1685). Four volumes. Handwritten.
Miquel Agustí, *Llibre dels secrets d'agricultura, casa rústica i pastoril* (The book of agricultural, cottage, and pastoral secrets).	Agustí 1617, followed by number of folio.	Agricultural treatise written by Miquel Agustí. Three volumes. Printed (Barcelona: Esteve Lliberós, 1617).
City Archives of Terrassa, 12/06 Fons Can Falguera, *Llibre de notes dels hereus de Can Torres* (The family book of Can Torres).	ACVOC-AHT, Can Torres 1699-1824, followed by number of folio.	Family book of the farm of Can Torres. Discontinuous (1699-1824). Handwritten. 150 folios.

Household's strategies to cope with drought

To identify household's practices to cope with droughts we systematically reviewed 1) a popular agricultural treatise compiling practices conducted at early modern farms and 2) a family book from a farm in the study area which illustrates the applied practices, everyday experience, and reflections of practitioners (Table 3.2).

Agronomic texts in medieval and early modern times typically combined both theoretical and applied agroecological knowledge. Empirical research comparing agronomic literature and praxis has shown how early modern European agricultural handbooks compiled management practices of both literate and illiterate farmers, presenting them as a basis to inform

decisions.[38] In this work, we reviewed a popular agronomic source: 'The book of agricultural, cottage and pastoral secrets' (Table 3.2). Friar Miquel Agustí wrote this handbook by reviewing related work by classic authors (e.g., Columella) and coetaneous treatises (e.g., Charles Estienne) but also based on observations and its own practical experience.[39] The treatise was published in Catalan in 1617 and translated into Spanish in 1626. It soon became a popular handbook with about twenty editions by 1805.[40] The author's motivation, stated in the foreword of the first edition, was to facilitate farmers' access to agricultural knowledge by writing it in a vernacular language that was accessible to practitioners.

The treatise consists of three volumes, 65 chapters, and 194 folios. We reviewed the index of subjects and the table of contents of the treatise to select the chapters and pages potentially containing information on farming practices, water management prescriptions, and coping with drought strategies.[41] Our data were primarily derived from the first volume of the treatise, which contains general information on task planning, forecasting skills, or the role of different family members in the farm, followed by specific chapters compiling knowledge on gardening, medicinal plants, fruit trees, forestry, crops, and pastures. The selection comprised 10 out of 24 chapters, which accounted for about half of the first volume in folios. We also selected specific sections from the second volume dedicated to vineyards, olive groves, artisanal distillation, and food conservation, and of the third volume, which focused on animal husbandry and farmhouse design.

The second source used to identify household's coping practices were private documents written by farmers, a promising historical source that has received scarce attention in climate research.[42] Peasant writings represent a hybrid genre in-between autobiographies, account books, historical chronicles, popular agricultural and culinary treatises, and family memoirs. Torres calls them family books, since they were written within and for the family, often

[38] R.C. Hoffmann and V. Winiwarter, 'Making Land and Water Meet: The Cycling of Nutrients between Fields and Ponds in Pre-Modern Europe', *Agricultural History* 84 (2010): 352–80.
[39] M.A. Martí-Escayol, 'Les Fonts del "Llibre dels Secrets d'Agricultura" de Miquel Agustí. El MS754 de la Biblioteca de Catalunya i el MS291 de la Bibliothèque Nationale de France', *Afers* 23 (2008): 289–311; X. Luna-Batlle, 'El Llibre dels Secrets d'Agricultura, Casa Rústica i Pastoril (1617) de Miquel Agustí: Un Llibre No del Tot Obert', *Manuscrits* 31 (2013): 65–87; X. Luna-Batlle, 'Els "Secrets d'Agricultura" (1617) de Miquel Agustí en el Context dels Llibres Agronòmics Europeus', *Manuscrits* 33 (2015): 17–32.
[40] Amadeu J. Soberanas, 'Les Edicions del "Prior"', in M. Agustí, *Llibre dels Secrets de Agricultura, Casa Rústica i Pastoril*, pp. 39–45 (Barcelona: Alta Fulla, 1988).
[41] Agustí 1617, f. 195 *et seq.*
[42] G.C.D. Adamson, 'Private Diaries as Information Sources in Climate Research', *Wiley Interdisciplinary Reviews: Climate Change* 6 (2015): 599–611.

generation after generation.[43] We consulted an on-line database of private documents written in Catalonia from medieval times to the early nineteenth century and selected the family book of the farm of Can Torres (Table 3.2) as the source that more closely matched the criteria of location (i.e., farm located at the case study area), period (i.e. written during the study period), and content (i.e., containing detailed household practices and the experience of at least one particular drought event).[44] The family book was written discontinuously from 1699 to 1824 by at least three generations of heirs.

We collected data only for a period with high quality records, defined here as those being homogeneous, continuous, and dense, and reporting a drought event. After assessing the overall book according to these criteria, we selected the period ranging from 1699 to 1704, which includes the drought of 1700-1701 and represents about half of the total book length.

3.2 Data analysis

Data from the four primary sources used in our research (Table 3.2) were summarized and systematized in spreadsheets to facilitate the identification and assessment of coping strategies. In all cases, data sets were complemented with relevant source fragments that were transcribed following standard palaeographic criteria.

The minutes of Terrassa and Sant Pere Councils were processed using a comparable spreadsheet that included: 1) the date of the minute, 2) a summary of the content of potentially relevant decisions (in terms of drought management and adaptation), and 3) comments on manuscript quality and context. We then compiled those decisions explicitly reporting strategies to cope with droughts and drought impacts (186 in Terrassa and 31 in Sant Pere).

The information collected from the agronomic treatise and the family book was entered in two spreadsheets compiling 1) the folio number and leaf side, 2) the chapter or date, 3) a summary of the content of each paragraph, and 4) comments on information related to adaptation practices. For the family book, a thematic coding was applied to the information gathered in the spreadsheet to facilitate the analysis of adaptation. Specifically, book annotations were grouped along the following themes: i) resource accounts (e.g., charcoal, herds, wine), ii) accounts of flour (amount of wheat sent to the mill), iii) accounts of harvested grains, iv)

[43] Xavier Torres, *Els Llibres de Família de Pagès, Segles XVI-XVIII: Memòries de Pagès, Memòries de Mas* (Girona: Universitat de Girona, 2000).
[44] 'Arxiu de la Memòria Personal', available at: http://www.memoriapersonal.eu [accessed 8 Nov. 2016].

monetary inputs, v) monetary outputs, vi) debts, vii) qualitative reflexions, viii) family notes, ix) historical chronicles, and x) other contextual data. For instance, we used the accounts of flour and harvested grains to assess when stored grains were critical to compensate drought-driven bad harvests while satisfying food consumption needs.

Coping strategies documented in the four primary sources were then coded drawing on previous classifications from the literature on adaptation to climate change.[45] Strategies were divided into eight categories: forecasting, sharing and cooperation, diversification, exchange, storage, rationing, selection, and mobility. We also considered a set of supporting practices enabling one or more of the reported coping strategies. Although we considered the eight categories, we only found some of them in the documentary sources (see Table 3.3).

Secondary sources were used to select and critique the primary sources, to interpret and contrast the information collected, and to inform the discussion of the results. For the specific case of Can Torres, the data set derived from the family book was complemented with available published sources about this farm, geological and topographical cartography, and field visits.

4. RESULTS

We present our results separately for the two levels of social organization. Table 3.3 summarizes the categories found in the documentary sources at the community and household levels.

[45] Our classification builds on categories used by Paul Halstead and John O'Shea, *Bad Year Economics. Cultural Responses to Risk and Uncertainty* (Cambridge: Cambridge University Press, 1989); Arun Agrawal, *The Role of Local Institutions in Adaptation to Climate Change* (Washington: Social Development Department, World Bank, 2008); T. Thornton and N. Manasfi, 'Adaptation Genuine and Spurious – Demystifying Adaptation Processes in Relation to Climate Change', *Environment and Society: Advances in Research* 1 (2010): 132–155; and E. Gómez-Baggethun, V. Reyes-García, P. Olsson, and C. Montes, 'Traditional Ecological Knowledge and Community Resilience to Environmental Extremes: A Case Study in Doñana, SW Spain', *Global Environmental Change* 22(2012):640–650.

Table 3.6. Categories considered in the literature and categories documented to classify coping strategies, by level of analysis. [46]

Category	Description	Category documented	
		Community level	**Household level**
Forecasting (a)	Observation and monitoring of indicators predicting future conditions		X
Sharing and cooperation (b-d)	Joint use and governance of material and symbolic goods and services across households or communities	X	
Diversification (a-d)	Increase in the variety of consumption and livelihood strategies	X	X
Exchange (a-c)	Transactions of material and symbolic goods and services	X	X
Storage (a, b, d)	Accumulation and preservation of available resources to be consumed later in time	X	X
Rationing (c, d)	Control of the circulation and consumption of limited resources among group members	X	X
Selection (d)	Choose particular attributes as the most suitable to reproduce or rely on		X
Mobility (a-d)	Seasonal movement or permanent migration of people		

4.1. Council initiatives to cope with drought

Our data shows that drought anticipation or occurrence triggered a series of community institutional mechanisms to cope with it. To assess causal links between drought, its impacts, and the social responses to cope with them, we start with an illustrative example: the 1677 drought and food shortage affecting the municipalities of Terrassa and Sant Pere. The documentary sources explain that, in March 1677, concerns on food scarcity due to an ongoing agricultural drought motivated the decision to import 7 m^3 of wheat to Terrassa.[47] In April, the Councils of Terrassa and Sant Pere organized a rogation ceremony to pray for rain.[48] In May, the Terrassa Council allowed to gradually sell imported and stored wheat when the supplies from the local market were unable to meet food demand.[49] In addition, the Council purchased 3.5 m^3 of grain at a high price.[50] When the wheat harvesting season was finishing, the

[46] Categories adapted from a) Halstead and O'Shea, *Bad Year Economics*; b) Agrawal, 'The Role of Local Institutions'; c) Thornton and Manasfi, 'Adaptation Genuine and Spurious', and d) Gómez-Baggethun, Reyes-García, Olsson, and Montes, 'Traditional Ecological Knowledge and Community Resilience'.
[47] ACVOC-AHT, CMT, 5 Mar. 1677.
[48] ACVOC-AHT, CMT, 25 Apr. 1677.
[49] ACVOC-AHT, CMT, 9 May 1677.
[50] ACVOC-AHT, CMT, 19 May 1677.

conditions for leasing the public bakery were re-adjusted by conditioning obligatory bread supply to wheat availability.[51] Finally, in autumn, new creditors offered their services in order to fund subsequent grain purchases.[52] This example illustrates how the response to drought activated a series of mechanisms at the community level, including the organization of collective rituals, Council intervention on the supply of grain, rationing of bread, and management of food stores. Several other strategies, classified as sharing and cooperation, diversification, exchange, storage, and rationing were also documented for other drought events. In the next sections, we present the range of strategies developed by the Terrassa and Sant Pere Councils to cope with droughts from 1600 to 1715 according to our analytical categories (Table 3.4).

Table 3.7. Strategies to cope with droughts effects lead by the Terrassa and Sant Pere Councils (1600-1715). Strategies can imply pooling between both Councils (AA); similar strategies can be performed independently in both Councils (AB); or be only performed by the Council of Terrassa (A-).

Categories	**Terrassa**	**Sant Pere**	**Strategies documented**
Sharing and cooperation	A	A	• Collective pilgrimages to plead for rainfall
	A	-	• Adjust and strengthen governance of community water supplies: defence of community water rights, implementation of conflict-resolution mechanisms to tackle water conflicts
	A	-	• Fix and repair collective water infrastructures
Diversification	A	-	• Build new infrastructures to develop diversified water supply systems
Exchange	A	B	• Regulate, negotiate, and follow up collective purchases of basic grains
Storage	A	B	• Build and maintain physical infrastructures to store grain: municipal granaries
Rationing	A	B	• Regulate the distribution of collective grain and food supplies
	A	-	• Rationing of water: reallocate water rights to limit water consumption, establish and apply sanctions to control the use of water provided by collective infrastructures
Supporting practices	A	A	• Annual vow to renew the faith in the deity to which the rainfall rituals are directed

[51] Bakeries were considered a public monopoly and had the obligation to provide adequate rations of bread to villagers; ACVOC-AHT, CMT, 28 Jul. 1677.
[52] ACVOC-AHT, CMT, 28 Oct. 1677.

Sharing and cooperation

In case of severe drought, the Councils used to organize an extraordinary pilgrimage to pray the Virgin of a close monastery to intercede with God to forgive the community for their immoral behaviour and bring rain again.[53] From 1600 to 1715, the Terrassa Council recorded 24 extraordinary pilgrimages to the Monastery of Montserrat motivated by droughts. At least 58 per cent (n=14) of these rain pilgrimages were jointly celebrated between Terrassa and Sant Pere (Figure 3.3), who contributed equally to the expenses of the ritual in terms of resources (e.g., priests' subsistence allowance and wax for the candles) and number of pilgrims.[54]

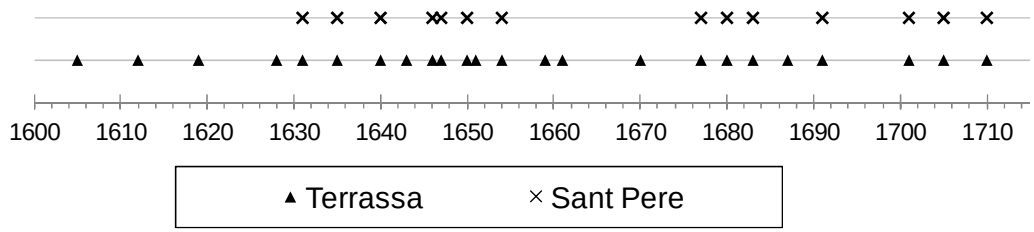

Figure 3.22. Rain pilgrimages organized by the Councils of Terrassa and Sant Pere, as reported in Council minutes.

Cooperation was also crucial in the case of Terrassa to secure village water supplies during drought periods. On the one hand, governance of water supplies was strengthened by defending collective entitlements against higher level institutions, such as the King, claiming water rights or by interceding to help in the resolution of water conflicts.[55] On the other hand,

[53] Extraordinary pilgrimages were organized in addition to pilgrimages regularly held on an annual basis. Collective pilgrimages have been reported to contribute to community resilience by strengthening social cohesion during crises, by reducing the emotional and psychological impacts of drought (e.g., generating a common feeling of hopelessness), and by triggering social expenditure that worked as stimulus for the local economy. For some illustrations, see Endfield, *Climate and Society in Colonial Mexico*, pp. 83-87; Gómez-Baggethun, Reyes-García, Olsson, and Montes, 'Traditional Ecological Knowledge and Community Resilience'.

[54] ACVOC-AHT, CMT, 3 May 1635; ACVOC-AHT, CMSP, 23 May 1635.

[55] ACVOC-AHT, CMT, 29 Jul. 1614, 8 Aug. 1883, 27 Aug. 1883, 29 Aug. 1683; ACVOC-AHT, CMT, 2 Sept. 1617, 11 Nov. 1628, 30 Nov. 1628.

infrastructures supplying water to the village were repaired and fixed under the control of the Council of Terrassa.[56]

Diversification

Strategies to cope with drought consisting on the diversification of water supplies were recorded only in the minutes of the Terrassa Council. For example, the villagers excavated new underground water tunnels in the surrounding hills when the main water supply was drying.[57] The village thus diversified its water sources to include both temporary streams and multiple tunnels collecting groundwater.[58]

Exchange

During periods of drought the municipalities studied relied more heavily on market exchange to obtain basic grains. In both communities, Council intervention to mediate exchange was part of the local policies to secure access to basic food (e.g., bread grains, meat, and salted fish) and complemented household ways to access grains (i.e. subsistence and market). Market exchanges arranged under the auspices of Councils served as a temporary and emergency strategy because it could only prolong bread supplies up to a maximum of three months.[59]

Storage

Municipal silos were an important infrastructure in the local system for securing food supply. Collected data show that the two Councils built silos and safeguarded the stores across the study period. Indeed, management of collective grain stores was particularly relevant during drought periods, because storages provided another source of food and could also buffer rises

[56] ACVOC-AHT, CMT, 10 Feb. 1605, 4 Aug. 1605; 9 Feb. 1611, 11 Apr. 1611, 21 Apr. 1611; 16 Apr. 1651, 16 Sept. 1651; 22 Jun. 1691.
[57] ACVOC-AHT, CMT, 30 Aug. 1624, 19 Jul. 1689.
[58] Reliance on multiple water resources is a strategy employed since ancient times, see Robert Maliva and Thomas Missimer, 'Ancient Water Management', in *Arid Lands Water Evaluation and Management*, pp. 501-528 (Heidelberg: Springer, 2012).
[59] See Supplementary materials (tab. S.1) for an estimation of how Council-led supply of grains in years of scarcity contributed to cover bread security.

in food prices typically coupled with poor harvests.[60] Interestingly in more than the 2000 Council minutes reviewed, we did not find any mention about the construction or reparation of collective water storage devices.

Rationing

The Councils of Terrassa and Sant Pere also controlled the distribution and rationing of stored and imported food. The sources document how different regulations were enforced for the allocation of grain across households: same weight for all, free weight up to an established maximum, or totally free weight. In some occasions, drought events motivated more restrictive rationing. In 1611, for example, the public officers in charge set a cap of approximately 50 kg of grain per household.[61] In 1651, when the effects of drought on food supply added to the effects of an ongoing war (the Reapers' War), the officers defined again the minimum requirements to feed each family.[62]

Only the Council of Terrassa implemented strategies concerning water rationing. Specifically, during certain droughts affecting village water supplies, the Council established strategies to control and limit the consumption of water by adjusting precedent water institutions. For example, the Terrassa Council defined and enforced new sanctions to control the use of water from common drinking fountains and adapted the allocation of water rights in order to limit and reduce water consumption.[63]

4.2. Coping practices at the household level

In this section we shift the focus of analysis from the community to the household. We present the results on household practices to cope with droughts in two separated sub-sections, each one examining strategies of forecasting, diversification, exchange, storage, rationing, and selection reported in the revised sources (Table 3.5). The first sub-section is devoted to the practices compiled in the agronomic literature and the second one reviews the documented practices in the Can Torres family book.

[60] Documented examples in ACVOC-AHT, CMT, 1 Jul. 1631, 12 Jan. 1651; ACVOC-AHT, CMSP, 21 Mar. 1631, 28 Mar. 1631, 21 Apr. 1631.
[61] ACVOC-AHT, CMT, 26 Mar. 1611.
[62] ACVOC-AHT, CMT, 12 Jan. 1651, 4 Mar. 1651.
[63] ACVOC-AHT, CMT, 6 Jun. 1611, 27 Apr. 1612, 16 Sept. 1651.

Table 3.8. Strategies practiced in farms to cope with droughts effects during the early modern period, as documented in the agronomic treatise (T), the Can Torres family book (B), or in both sources (TB).

Categories	Source	Coping practices	Examples
Forecasting	T	• Monitoring of meteorological, biological, human, and physical indicators to forecast dryness	• *Prediction of next year dryness by interpreting the migration of birds*
	T	• Assess water resources to guarantee water availability	• *Dug experimental holes during summer to evaluate groundwater flows*
	TB	• Observation of soil properties to adjust the schedule of agricultural practices	• *Plough after observing that the soil is adequate to retain soil moisture*
	B	• Monitoring of physical indicators to follow-up drought evolution	• *Interpret the changes in the water level of fountains and ponds to follow the different stages of drought*
Diversification	TB	• Poly-cultural system	• *Farms dedicated to agriculture, husbandry and forest to spread risks* • *Temporary cropping of forest plots to spread risks*
	TB	• Diversification in each sub-system	• *Diversify crops sowed to increase the range of potential bread grains in case of crop failures*
	B	• Scatter cultivated fields	• *Distribute fields across the space to increase differences (e.g., micro-climates, soil, pests) and reduce risk of total crop failure*
	TB	• Diversification of food sources	• *Designate alternative staple food to alleviate hunger*
	T	• Diversification of water sources	• *Intensify the consumption of medium to low quality waters in case of need*
Exchange	B	• Exchanges and commercialization	• *Trade with farm surpluses to obtain exchangeable and monetary assets*
	B	• Market-based access to grains	• *Buy grains in local markets when harvests fail*
	B	• Long-term reciprocity	• *In-kind loans of grains, seeds, and bread*
Storage	TB	• Build and maintain physical infrastructures for grain or flour storage	• *Grain stored in farm granaries well-designed for long-term conservation* • *Store overproduction to compensate future bad harvests*
	TB	• Practices and treatments to well-preserve stored grain or flour	• *Add herbs to prevent pests in stored grain* • *Convert damaged stored grain into ready to consume products* • *Grind dry and old grain to prevent damages*
	T	• Build and maintain physical infrastructures for water storage	• *Water tanks to secure water availability*
	B	• Store farm experience in written records	• *Family books to store the experience of drought events, successful farm management practices, etc.*
Rationing	T	• Control and limit food consumption in times of scarcity	• *Women should ration staple food and wine among family members during scarcities*
Selection	T	• Select workers skilled	• *Select servants from the same area to be experienced on monitoring local indicators*
	T	• Seed selection procedures	• *Reproduce seeds in different micro-climates and soils to make them more resistant*
	TB	• Select appropriate locations to secure water	• *Settle the farmhouse and associated irrigated systems depending on water availability*

			• *Choose dry grazing lands which avoid sloping terrains and, in case of need, can be irrigated*
	T	• Select durable water supplies	• *When constructing wells or fountains select water veins not prone to be dried out*
Supporting practices	TB	• Long-term perspectives on farm management	• *Proverbs on farmer's decisions encapsulating the need for long-term planning*
	T	• Maintenance of family cohesion	• *Women should keep social order and cohesion among the family farm members, especially in critical periods*
	TB	• Manage the soils to keep soil moisture	• *Range of practices such fertilization, sowing techniques, or maintenance of the herbaceous cover to conserve soil moisture*

4.2.1 Farm strategies reported by the agronomy treatise

Strategies to cope with droughts and their impacts identified in 'The book of agricultural, cottage and pastoral secrets' fit into five of the eight categories considered: forecasting, diversification, storage, rationing, and selection. We did not found mentions to any strategy that fit into the exchange category. References to the various strategies are abundant, except for rationing, addressed only in some scattered passages of the treatise. We detail below the most illustrative examples documented (see Table 3.5).

Forecasting

The treatise's author recommends the male household head and his workers to familiarize themselves with weather omens (*presagis*) and to adjust farm management accordingly.[64] Weather forecasts were used to inform decisions, plan activities, and anticipate changes, so as to reduce production risks derived from droughts (and other hazards). Indicators cited in the treatise include a rich body of ethnoclimatological knowledge and beliefs, consisting of various meteorological, animal, vegetal, human, and physical signals.[65] For instance, the presence of spiders inside the Holm oak acorn, a solar eclipse during wheat flowering, or the migration of

[64] Agustí 1617, f. 2r, 3v.

[65] The forecasting signals documented here are consistent with those reported in contemporary small-scale societies by H.C. Eakin, 'Seasonal Climate Forecasting and the Relevance of Local Knowledge', *Physical Geography* 20 (1999): 447–60; V. Reyes-García, Á. Fernández-Llamazares, M. Guèze, A. Garcés, M. Mallo, M. Vila-Gómez, and others, 'Local Indicators of Climate Change: The Potential Contribution of Local Knowledge to Climate Research', *Wiley Interdisciplinary Reviews: Climate Change* 7 (2016): 109–24.

specific species of birds from forests to fields and villages, predicted dryness and sterility for next year.[66]

The agronomic writer also compiled techniques to evaluate expected water availability (*judici d'aigües*) to find underground water flows ('water veins'), and to predict their quality (taste and healthiness) and ability of not drying out ('strength').[67] Groundwater assessments were carried out when soil was affected by summer dryness (in August or September). Tests included experimental holes dug in different places and the evaluation of their sound. The same holes could be filled up with sponges or wool and then their humidity was used as indicator of water abundance. Water strength assessments were complemented with other types of observations, for example, of the vapours exhaled by the ground during sunrise on dry days, or the species growing in the herbaceous cover. Finally, assessments of the physical suitability of the soil (the 'tilth') determined the advance or delay of the times of sowing, ploughing, and harvesting crops so as to minimize drought impacts.[68]

Diversification

Diversification was an essential strategy to cope with the potential impacts of drought and it is emphasized in different chapters. The treatise reinforced the idea of non-specialized poly-cultural farms dedicated to Mediterranean crops (e.g., cereals, vineyards, olive groves, horticulture), husbandry (e.g., grazing in grasslands or feeding animals in the farm), and forest uses (e.g., tree plantations). This poly-cultural system illustrates how early modern households in dispersed settlements diversified livelihood sources to structurally reduce risks.[69]

Diversification was also promoted in each sub-system of the farm (Table 3.5). For example, diversification of food sources in times of severe drought was crucial when food storages or markets alone were unable to fulfil household food demands. Acknowledging the recurrence of food shortages, the author listed alternative crops that could replace wheat, such as rye,

[66] Agustí 1617, f. 4r.
[67] Agustí 1617, f. 144v–144r.
[68] Agustí 1617, f. 77v–81v.
[69] On-farm diversification has been documented as a traditional risk-buffering strategy in many regions and still serves as an adaptive strategy in contemporary farms, see P. Halstead, 'Waste Not, Want Not: Traditional Responses to Crop Failure in Greece', *Rural History* 1 (1990): 147–64; H. Meert, G Van Huylenbroeck, T. Vernimmen, M. Bourgeois, and E. van Hecke, 'Farm Household Survival Strategies and Diversification on Marginal Farms', *Journal of Rural Studies* 21 (2005): 81–97; and C. Barbieri and E. Mahoney, 'Why Is Diversification an Attractive Farm Adjustment Strategy? Insights from Texas Farmers and Ranchers', *Journal of Rural Studies* 25 (2009): 58–66.

barley, millet, corn, lupines, buckwheat, oat, rice, and even acorns.[70] Preference for different substitutes depending on the severity of the food shortage was acknowledged. For example, due to its bad taste, oat was prescribed only in cases of extreme famine. Similarly, due to their long digestion, barley and buckwheat were recommended only for less refined (in practice poor) people. In cases of extreme food crises, the friar compiled 'secrets to alleviate hunger', for example, toasting animal livers, adding almonds and sugar to bread, cooking twice the bread, drinking own urine, or preparing other culinary recipes to satisfy the appetite with nuts, cow fat, flower oils, and plant gum.[71]

Farm water infrastructures were designed and built to secure water supply for multiple uses and in different seasons.[72] The author listed preferences and uses depending on the water origin. For instance, rainwater (especially from thunderstorms) was preferred as drinking water, while water from lakes was less recommended for humans because of its poor quality.[73] During periods of water shortages, consumption should be further spread across water sources with different qualities.

Storage

Storage was encouraged in the treatise as a strategy to cope with multiple threats. The friar reviewed the ideal characteristics and location of the granary to preserve grain optimally (e.g., aeration, light, walls treated against pests).[74] It prescribed that stored grains should be treated with herbs (e.g., oregano, sage or marjoram) or cold cereals (e.g., millet) to prevent pests, that grains should be frequently mixed to be oxygenated, and that grains should be spread under the sun during daily hours and stored again hot and clean.[75] Damaged grains had to be sent immediately to the mill and be quickly consumed.[76] Treatments to store flour include adding tablets made up of cumin and salt, fragments of pine bark, or bay leaves.[77] The author also compiled instructions to appropriately mill grains with the aim to prolong the storage of flour, for example by selecting only dry and old grains to mill or by producing coarser flour.[78]

[70] Agustí 1617, f. 75r, 82r–85r.
[71] Agustí 1617, f. 91r.
[72] Agustí 1617, f. 144v–145v.
[73] Agustí 1617, f. 146r.
[74] Agustí 1617, f. 81v, 150r.
[75] Agustí 1617, f. 81v–82r.
[76] Agustí 1617, f. 82r.
[77] Ibid.
[78] Agustí 1617, f. 88v.

Storage was not only relevant to prolong the durability of food stocks over time, but also for water. Farm water tanks accompanied other water infrastructures such as wells, fountains, and water transport systems, securing household water supply.[79] The author includes detailed instructions to build the tank and collect the water, as well as treatments to conserve water qualities such as the introduction of freshwater fishes.

Rationing

The consumption of staple food like stored grain and flour or wine, was under control during periods of scarcity, such as those caused by severe droughts. Rationing of food was one of the female household head responsibilities, since she was in charge of household food security and tasks related to ensure it, such as growing subsistence crops in gardens, raising animals, or preparing tinned food.[80] Interestingly, the control and limitation of food consumption was also among the duties of servants.[81]

Selection

Table 3.5 synthesizes four strategies of selection reported by the treatise to cope with droughts, including the selection of skilled workers, resistant seeds, appropriate farm locations, and durable water supplies.[82] Here we concentrate on the last one, because the selection of water supplies chiefly determined farm's vulnerability to hydrological droughts. The treatise highlighted the need to rely on and select durable water veins and distinguished between vertically-supplied water veins and horizontally-supplied veins, considering the later less advisable as they are more prone to be dried out. Moreover, fountain's assessments aimed to find the 'mother vein' so as to select water sources that guaranteed water availability regardless of hydro-climate variability.

[79] Agustí 1617, f. 144v–145v.
[80] Agustí 1617, f. 8r–8v.
[81] Agustí 1617, f. 1v–2r.
[82] Respectively in Agustí 1617, f. 1v–2r; f. 79r; f. 86v, 87v, 143v–144v; f. 145v.

4.2.2. The experience of Can Torres farm

Strategies to cope with drought and its impacts identified in the family book of Can Torres are classified into five categories: forecasting, diversification, exchange, storage, and selection. Diversification, exchange and storage seem to have been particularly relevant to deal with drought in Can Torres farm. Remarkably, we have not documented any strategy of rationing such as limiting food consumption among farm members. We detail below the most illustrative examples registered by the farm's heir Miquel Batlles (see Table 3.5).

Forecasting

The records do not mention specific weather predictions. However, observations of the water level of fountains or ponds, the volume of drainage from roofs, the water flow of pathways, or the dust fog were used to describe the changes experienced during the drought event of 1700-1701.[83] Monitoring of such local indicators to follow-up drought evolution (e.g., onset, changes in intensity, end) informed and conditioned sensitive farm decisions such as planting times. During this particular event, the heir also expressed the need to adjust planting times depending both on the monitored drought evolution and the soil properties.[84]

Diversification

The Can Torres farm provides a good illustration of the polyculture diversification strategies explained in the treatise. The economy of the farm depended on extensive and intensive agriculture (e.g., croplands, vineyards, olive groves, the kitchen garden, fruit trees), husbandry (e.g., pigs, cows, sheep, goats, poultry, bees), and forest exploitation (e.g., wood, pine and Holm-oak charcoal, firewood, and other products such as acorns or juniper oil). The coexistence of permanent and shifting agriculture in Can Torres also contributed to spread risks. The small forest plots (called *boïgues*), temporally cultivated, provided adequate yields of cereals without the need of external fertilizers.[85] As in many early modern European forested

[83] ACVOC-AHT, Can Torres 1699-1824, f. 20r.
[84] Ibid.
[85] ACVOC-AHT, Can Torres 1699-1824, f. 18v, 34v.

areas, such plots functioned as a common buffer system that could be exploited in case of need.[86]

We corroborated that diversification was de facto constituting each sub-system of the poly-cultural farm. The reconstruction of crops harvested between 1700-1703 shows that cultivated cereals included wheat, oat, *mestall*, spelt, and other ancient varieties of wheat such as wheat *rojal*. Legumes included faba beans, peas, lupines, and beans. Table 3.6 synthesizes the diversified structure of crop production which contributed to broaden the range of bread grains alternatives in case that drought or other hazards led to wheat failures. Moreover, the landscape mosaic of Can Torres was configured by dispersed croplands surrounded by grazing lands and forests managed with different degrees of intensification (Figure 3.4). The sowing of such dispersed fields distributed in different soils, ecosystems, and micro-climates was a key element to reduce the risk of total crop failures. As Miquel Batlles wrote during the drought in early spring of 1701: 'In my permanent fields below the farmhouse the wheat has well grown from dust, except in the clay margins of the field and in the *Camp del Forn* [the oven field] which has also a different soil. But in all the soils with white and red slate the wheat and *mestall* have grown all I could desire'.[87]

[86] For an example, see Henning Hamilton, *Slash-and-Burn in the History of the Swedish Forests* (London: Overseas Development Institute, 1997), pp. 19–24. For its practice in Catalonia, see Emili Giralt, Josep M. Salrach, and Eva Serra (eds.), *Història Agrària Dels Països Catalans: Vol. 3, Edat Moderna* (Barcelona: Fundació Catalana per a la Recerca, 2008), pp. 60-61, 113-115.
[87] ACVOC-AHT, Can Torres 1699-1824, f. 20r.

Table 3.9. Structure of crop production in Can Torres: annual harvest of cereals and legumes (1700-1703). [88]

	1700	**1701**	**1702**	**1703**	**Annual average**
	m^3	m^3	m^3	m^3	m^3
Wheat	5.8	7.9	3.4	6.5	5.9
Mestall	1.4	1.2	0.9	4.4	2.0
Spelt	1.4	0.4			0.9
Wheat *Rojal*			1.5	0.7	1.1
Oat	2.8	3.6	3.1	5.5	3.8
Total cereals	11.4	13.1	8.8	17.1	12.6
Faba beans	0.6	0.3	0.2		0.4
Peas	0.1		0.2		0.1
Lupines	0.4				0.4
Beans				0.3	0.3
Total legumes	1.1	0.3	0.4	0.3	0.6

[88] ACVOC-AHT, Can Torres 1699-1824, f. 27r, 28r, 47r, 63r-63v. Recorded volume of cereals was transformed from traditional (*quarteres*) to contemporary units (m^3) by using the conversion for the case of Terrassa from Francesc Teixidó, *Pesos, Mides i Mesures al Principat de Catalunya i Comtats de Rosselló i Cerdanya a Finals del Segle XVI (1587-1594)* (Barcelona: Fundació Noguera, 2008), p. 101.

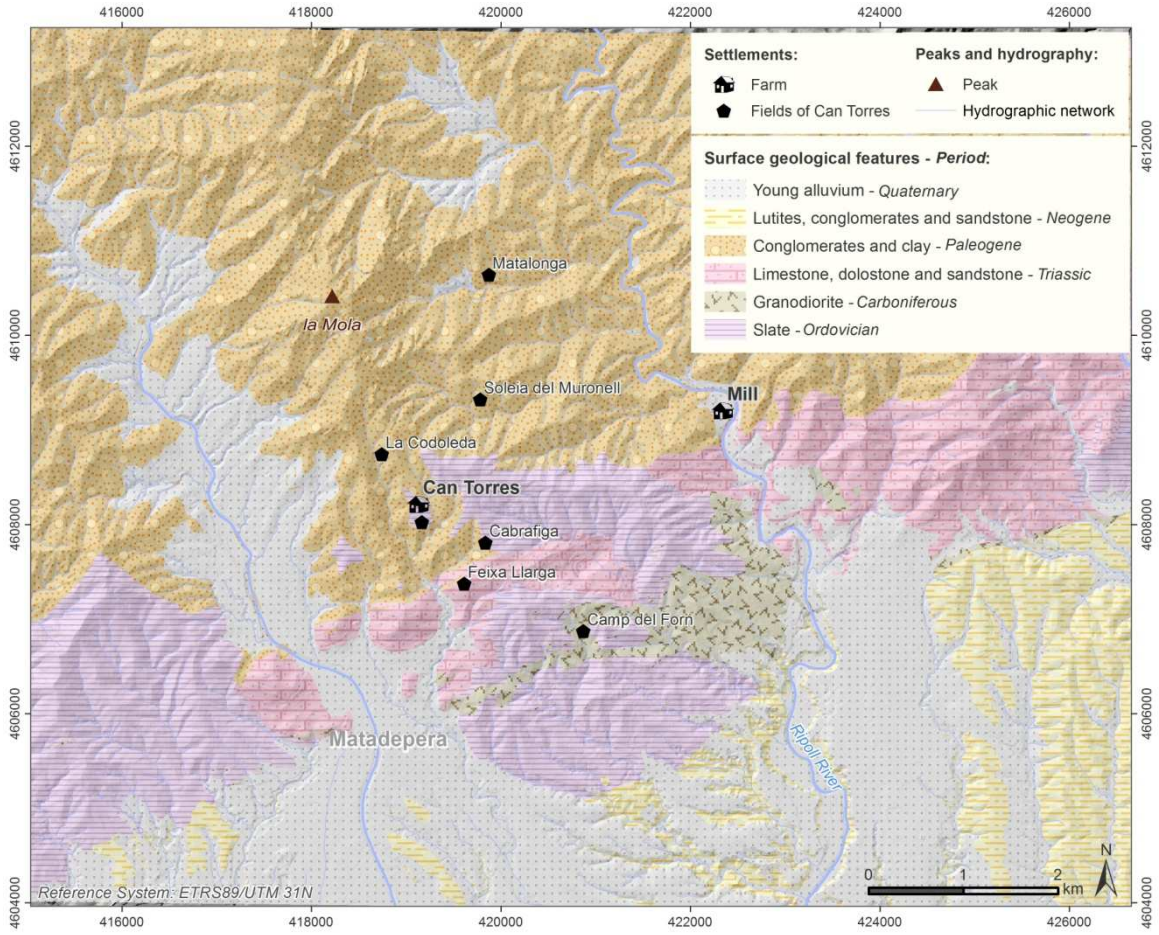

Figure 3.23. Map of Can Torres: surface geology, hydrographic network, and localization of fields frequently cultivated.[89]

Diversification of food sources was probably used in Can Torres to tackle food shortages in general and drought-driven shortages in particular. Flour could be obtained from grains other than wheat, including *mestall*, spelt, or wheat *rojal* all varieties own-produced in the farm (Table 3.6). This strategy is consistent with the prescriptions of the agrarian treatise, where specific types of cereals and even animal fodder were reclassified as bread grains to be relied upon in critical times.

Exchange

Can Torres traded some farm products in local and regional markets. Herds of goats and sheep were the main source of cash. With an average stock size of about 100-150 heads, the animals

[89] Own elaboration with data from ICGC (2016) and ACA (2005).

were feed during approximately one year and sold to supply meat in closer villages and cities.[90] Money from these sales allowed farmers to buy grains when their own production was scarce thereby securing food provision to its family and workers. For example, in 1702 Miquel Batlles established an agreement with French woodcutters working in Can Torres forests, so that in case of poor harvests, he would buy wheat in a close city (Manresa) and sell it to them at the prize established in the market of Terrassa.[91] Despite the promise, we have not documented any single purchase of external grain in the accounts of expenses from 1699 to 1704, not even during the drought of 1700-1701.

The farmer also noted down non-monetary exchanges (gifting and bartering). Cereal and legume seeds, grains for consumption, and even breads were regularly loaned to workers, close neighbours, and relatives, with the agreement to return them in-kind after harvest.[92] Such practices evidence the long-standing social networks of mutual help and reciprocity, particularly relevant in times of scarcity and drought.

Storage

Annually, the farmers sent approximately 6 m^3 of grains to the mill, which according to our estimations could be transformed into 5400 kg of bread and feed 17 people over one year.[93] The balance between the amount of bread grains harvested and those sent to the mill shows that farm production could provide most flour needed for own consumption. Yet, part of the harvested grains was kept as seeds and another part was used to pay local charities and in-kind fees, resulting in a lower amount of grains available for consumption.[94] Grain surpluses stored in the farm granary were therefore crucial to compensate for the years of poor harvests without need to rely on external grain supply.

The family book itself was also a repository storing the local experience managing the farm. Written transmission facilitated the accumulation and communication of complex knowledge

[90] ACVOC-AHT, Can Torres 1699-1824, f. 20r–20v, 65r–65v; P. Roca, 'Una Masia de la Muntanya Vallesana a l'inici del Segle XVIII: El Llibre de Notes dels Hereus de Can Torres de Matadepera (1699-1704)', *Arraona* 18 (1996): 26–31.
[91] ACVOC-AHT, Can Torres 1699-1824, f. 40v.
[92] Exchanges with workers in ACVOC-AHT, Can Torres 1699-1824, f. 5r, 32r, 44r–44v; and with neighbours and relatives in ACVOC-AHT, Can Torres 1699-1824, f. 10r, 13r, 28v, 39r, 45, 51, 61r, 72r.
[93] See calculations in Supplementary materials, tab. S.2.
[94] ACVOC-AHT, Can Torres 1699-1824, f. 6r, 12v, 15v, 27r, 31r, 37r, 39r, 48r–48v, 58r.

to next generations.[95] Miquel Batlles explicitly used this strategy to store and communicate the drought experience of 1700-1701 to his successors, as he stated in the preface of the annotation about such event: 'Exhortation and warning for the experience of possessors that will come to my house. You will understand that in October 1700 the Pope died in Rome, and died the same month the King of Spain without son or daughter [...] In April 1700 it rained in abundance [...] but from the 5th of September of 1700 until the 6th of February of next year it didn't rain at all'.[96]

Selection

Following a widespread convention in preindustrial times, the farmhouse and irrigated lands location was most probably decided, among other criteria, on the basis of water access. The farmhouse of Can Torres was, for example, surrounded by temporary water streams (Figure 3.4). Moreover, the farm was less than six km far by foot from the upper course of the Ripoll River. This permanent water flow secured the activity of the watermill used by Can Torres, without interruptions during summer water deficits or hydrological droughts.[97]

5. DISCUSSION

We organize the discussion around three main topics. First, we discuss how documentary gaps and biases pose methodological limits when reconstructing past adaptations. Second, we interpret the reported differences in adaptation practices by separately discussing them at the two levels of analysis studied here, i.e., the community and the household. And finally, we discuss how the two levels of social organization could complement, overlap, and interact in order to successfully cope with droughts.

5.1. Methodological considerations

Documentary gaps and biases are well-acknowledged in historical research methods. When investigating past human adaptation, these methodological constrains can lead to overlook

[95] M. Leonti, 'The Future Is Written: Impact of Scripts on the Cognition, Selection, Knowledge and Transmission of Medicinal Plant Use and Its Implications for Ethnobotany and Ethnopharmacology', *Journal of Ethnopharmacology* 134 (2011): 542 –555.
[96] ACVOC-AHT, Can Torres 1699-1824, f. 20r.
[97] ACVOC-AHT, Can Torres 1699-1824, f. 5r–5v, 17r, 39v, 54r, 66r.

some adaptation practices, downplay strategies performed by social groups not directly involved in the production of the primary sources, and reduce the range and diversity of actual strategies.

On the one hand, documentary gaps can induce faulty interpretations and narrow the range of adaptation strategies documented. For instance, although previous research has stressed the role of mobility as a millenary human strategy to cope with dry periods, practices that could be classified in the mobility category were not recorded in any of the four sources reviewed.[98] While its importance may not have been comparable to the one it had for nomad societies, migrations or other types of mobility might have been part of the kit of coping strategies, but just not being registered by the primary sources considered.

Documentary biases also limit archive-based reconstructions of past adaptation strategies. The market exchange documented at the household level provides a good example of this bias. While the treatise (1617) did not include any section on commercialization as a strategy to buffer drought impacts, the family book of Can Torres (1699-1704) reported how market access was an option to secure food supply after poor harvests. The approach from the treatise could be biased for two reasons: 1) the poly-cultural farm was viewed by the author as a self-sufficient economic unit, and 2) the agronomic handbook did not specifically cover economic information at the farm level, which however is well covered by other manuals on household economic management.[99] Moreover, the records of Can Torres regarding market exchanges could be just outliers not representing the reality of most farms, as this particular farm was one of the four largest taxpayers of its area and was further integrated into the market than most of its neighbouring farms.[100] Sources were also probably biased when documenting rationing strategies. The treatise's author mentioned that food rationing was performed by women and servants. Because in accordance to the contemporary patriarchal convention, the documents were male-biased and written or addressed to the heads of the family, the sources may downplay the practices of rationing performed by women.

[98] For recent studies reporting mobility as adaptation strategy, see see E. Oteros-Rozas, R. Ontillera-Sánchez, P. Sanosa, E. Gómez-Baggethun, V. Reyes-García, and J. A González, 'Traditional Ecological Knowledge among Transhumant Pastoralists in Mediterranean Spain', *Ecology and Society* 18 (2013): 33; and Balbo, Gómez-Baggethun, Salpeteur, Puy, Biagetti, and Scheffran, 'Resilience of Small-Scale Societies'.

[99] The author's views and the scope of the book are analysed in Luna-Batlle, 'El Llibre dels Secrets d'Agricultura'; and Luna-Batlle, 'Els "Secrets d'Agricultura"'.

[100] Roca, 'Una Masia de la Muntanya Vallesana': 12.

5.2. Adaptation within levels

Community

The analysis of Council minutes suggests that, for agricultural impacts of drought, Terrassa and Sant Pere shared similar response strategies and often joined forces to organize their strategies collectively (e.g., organizing collective rituals or rationing collective grain supplies). We also found, however, some divergences mainly when tackling the hydrological impacts of drought. For instance, the Council of Terrassa implemented decisions to ration water consumption or to diversify the village water supply system. In contrast, the Council minutes of Sant Pere do not document any decision regarding water rationing or diversification during drought events. According to secondary sources, there was no municipal water supply system in Sant Pere until the late nineteenth century, which contrasts with Terrassa, a village with collective water supplies since the fifteenth century.[101] The fact that most people in Sant Pere municipality lived in scattered farms and therefore configured low-density settlements, might have conditioned our findings in two aspects. First, sparse settlement could have hindered the construction of costly water systems even when the autonomous Council of Sant Pere was created in 1562.[102] And second, lower demographic pressure means less water demand, which presumably would have delayed the introduction of a collective regulatory system. In other words, the difference between the two Councils regarding the strategies documented might be due to the fact that, without a developed water supply system in Sant Pere and with small pressure on water resources, there was no room to adjust community water institutions or infrastructures during droughts.

Previous research on climate change adaptation across villages or communities has shown differences in the strategies to cope with climatic variability and hazards. Boissière and co-authors found significant differences among six Indonesian villages from the same watershed in their responses to cope with droughts. The authors explain such variation according to the

[101] For Sant Pere: J. Verdaguer, 'Arrencant Fites i Esborrant Rètols. Dels Orígens, Existència i Desaparició del Poble de Sant Pere de Terrassa (1562-1904)', *Terme* 19 (2004): 43–62; David Laudo, *La Creu Alta. Jonqueres, Sant Pere de Terrassa (1700-1904): Un Terme Desaparegut* (Sabadell: Fundació Ars, 2005), p. 360; Joan M. Oller, Francesc J. Suárez, and Joaquim Verdaguer, *Serveis d'Aigua a Terrassa* (Terrassa: CEDEA and Fundació Privada Mina d'Aigües de Terrassa, 2007), pp. 77-79. For water supply in Terrassa: Joan B. Galí, *Notícies Sobre l'Abastament d'Aigua a Terrassa: Dels Orígens al 1842* (Terrassa: Mina Pública d'Aigües de Terrassa, 1992).

[102] Moreover, Councils had lower ability to fund major or new water projects during economic crises, as noted J.A. Mateos, 'The Making of a New Landscape: Town Councils and Water in the Kingdom of Aragon During the Sixteenth Century', *Rural History* 9(1998): 123-39.

particular agro-ecological conditions of each village: while coastal villages developed responses to the intrusion of salty water into wells, the inland communities moved to the forest during drought.[103] Similarly, farmers and pastoralists in Burkina Faso from villages located in three agro-ecological zones opted for different adaptation strategies to cope with climate variability depending on the zone.[104] Our case study illustrates how in the same agro-ecological zone a densely populated market village developed a more sophisticated toolkit of strategies to cope with recurrent droughts than a newly created administrative community with sparse settlement.

Household

At the household level, our results show that key household adaptation strategies were documented both in published sources based on state of the art knowledge (agronomic treatise) and in private sources based on the farmer's direct experience (Can Torres family book). The treatise compiled a wider range of practices, presumably because this source recorded different response options available for a variety of farmers.[105] These findings should be carefully interpreted considering that peasant behaviours are highly variable and, more specifically, that strategies to avoid or reduce risks among households are heterogeneous.[106] Barbieri and Mahoney, for example, found that Texas' farmers with lower incomes or those attached to the farm for multiple generations place more importance to reducing farming risks through diversification strategies than higher income or less place-attached farmers.[107] Specifically, several studies have showed how a range of factors differentiating peasants and farms shape their decisions and therefore the strategies they use to cope with droughts.[108]

[103] M. Boissière, B. Locatelli, D. Sheil, M. Padmanaba, and E. Sadjudin, 'Local Perceptions of Climate Variability and Change in Tropical Forests of Papua, Indonesia', *Ecology and Society 18* (2013): 13.

[104] N. Zampaligré, L.H. Dossa, and E. Schlecht, 'Climate Change and Variability: Perception and Adaptation Strategies of Pastoralists and Agro-Pastoralists across Different Zones of Burkina Faso', *Regional Environmental Change* 14 (2014): 769–83.

[105] Luna-Batlle, 'Els "Secrets d'Agricultura"'.

[106] H.C. Eakin, 'Institutional Change, Climate Risk, and Rural Vulnerability: Cases from Central Mexico', *World Development* 33 (2005): 1923–38; G. Feola, A.M. Lerner, M. Jain, M.J.F. Montefrio, and K.A. Nicholas, 'Researching Farmer Behaviour in Climate Change Adaptation and Sustainable Agriculture: Lessons Learned from Five Case Studies', *Journal of Rural Studies* 39 (2015): 74–84; J. Mrgić, 'Wine or Raki - The Interplay of Climate and Society in Early Modern Ottoman Bosnia', *Environment and History* 17 (2011): 613–37

[107] Barbieri and Mahoney, 'Why Is Diversification an Attractive Farm Adjustment Strategy?'.

[108] S.H. Eriksen, K. Brown, and P.M. Kelly, 'The Dynamics of Vulnerability: Locating Coping Strategies in Kenya and Tanzania', *Geographical Journal* 171 (2005): 287–305; F. Toni and E. Holanda, 'The Effects of Land Tenure on Vulnerability to Droughts in Northeastern Brazil', *Global Environmental Change* 18 (2008): 575–82; L. Head, J. Atchison, A. Gates, and P. Muir, 'A Fine-Grained Study of the Experience of

Because strategies seem to vary from house to house, we note that results based on a few documentary sources are informative, but probably not enough to draw a general picture of this level.

5.3. Adaptation across levels

The down-scaling exercise shifting the focus from the community to the household level revealed two interesting patterns. First, our findings suggest a wider repertoire of practices to cope with droughts deployed by farm families than those developed by Councils (Table 3.4 and 5). This is especially remarkable in the municipality of Sant Pere, were the few strategies developed by the sparsely settled community largely differed from the range of practices performed at farms such as Can Torres. Second, from our analysis we can derive that strategies ranged from those taking place at the two levels to strategies taking place only at one single level (Table 3.3). Practices documented at the two analytical levels could develop into cross-level strategies, which in our case study would imply interactions and feedbacks of low complexity, or simply overlap. For instance, Council efforts to prolong access to bread grains by importing, storing, and rationing them across households, overlapped and interacted with practices developed by families. Among other options, we documented how farmers could prevent crop failures from drought (e.g., scattering crop fields), could maintain access to grains despite crop failures (e.g., replacing bread grains by minor cereals), and could manage their own grain stores (e.g., family rationing). In contrast, some coping strategies were only documented in one of the two levels. Forecasting strategies, for example, were only recorded in households, whereas specific rationing strategies such as changes in water allocation were only documented at the community level because local authorities were the ones legitimized to change water institutions. Thus, our findings confirm that both levels of social organization were critical to assess and capture the diversity of coping strategies to recurrent hazards developed in preindustrial societies and, in our case study, they partially overlapped.

Drought, Risk and Climate Change among Australian Wheat Farming Households', *Annals of the Association of American Geographers* 101 (2011): 1089–1108; M. Keshavarz, E. Karami, and F. Vanclay, 'The Social Experience of Drought in Rural Iran', *Land Use Policy* 30 (2013): 120–29.

6. CONCLUDING REMARKS

The wide diversity of coping practices documented in the sources adds more evidence to the fact that adaptation and resilience-building strategies were prominent in preindustrial Western societies, at least for recurrent hazards.[109] However, what is novel from this study is the application of the multilevel approach to preindustrial societies.[110] In this light, we assessed the different contribution of two critical levels of social organization on drought adaptation in early modern Spain. In general terms, our case study shows that critical strategies at the community level included sharing and cooperation (for either symbolic or material goals), food market exchanges, and the rationing of food and water across its members; whereas preferred household practices were diversification (livelihoods, food consumption and water sources), food and water storage, and forecasting. Although we cannot generalize such findings, we nevertheless argue that they enrich the debate about whether risks in medieval and early modern societies were tackled by 'prudent peasants' or 'prudent villages', bringing the new insight that the two levels contributed in different ways to adaptation in Western peasant societies.[111] Moreover, partial overlapping of strategies from both levels may have generated a redundancy effect - that is, when strategies failed at one level, they could still succeed at the other one - and facilitated cross-level linkages - complex strategies operating through interactions between the two levels.[112] Our analysis should be expanded with further research to better explain the distinct roles of the different levels of social organization and their (changing) linkages in the preindustrial context. In short, multi-scalar approaches adopted to analyse social-ecological systems should also be central to better understand past and present adaptation processes.[113]

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[109] Previous reviews illustrating the broad array of adaptation strategies in preindustrial European societies include M. Juneja and F. Mauelshagen, 'Disasters and Pre-Industrial Societies: Historiographic Trends and Comparative Perspectives', *The Medieval History Journal* 10 (2007): 1–31; C.M. Gerrard and D.N. Petley, 'A Risk Society? Environmental Hazards, Risk and Resilience in the Later Middle Ages in Europe', *Natural Hazards* 69 (2013): 1051–79.

[110] For previous studies, see footnote 6.

[111] McCloskey, 'The Prudent Peasant'; Richardson, 'The Prudent Village'.

[112] The term of redundancy is also used in ecology to describe the different species performing similar ecosystem functions, see B. Walker, 'Biodiversity and ecological redundancy', *Conservation Biology* 6 (1992): 18-23. For the implications of redundancy for ecosystem resilience, see A.S. Mori, T. Furukawa, and T. Sasaki, 'Response diversity determines the resilience of ecosystems to environmental change', *Biological Reviews* 88 (2013): 349–364.

[113] For the foundations of approaches considering the distinctive scales of socio-ecological systems, see Crawford S. Holling, Lance H. Gunderson, and Garry D. Peterson, 'Sustainability and Panarchies', in L.H. Gunderson and C.S. Holling (eds.), *Panarchy: Understanding Transformations in Human and Natural Systems*, pp. 63–102 (Washington: Island Press, 2002).

This study has also some methodological insights. Using common taxonomies to analyse past adaptation helped to discuss and contrast the results with other studies in the literature. We also noted methodological caveats which can reduce the diversity of strategies documented and downplay those strategies performed by social groups not directly involved in the production of the documentary sources. Both increasing comparability and identifying methodological challenges are essential steps to improve historical approaches to adaptation and to facilitate the indispensable communication within the adaptation to climate change research community.

Supplementary material

Council initiatives: exchange

According to our estimations, the annual volume of purchased grain contributed to secure bread supply for a maximum of 36 days in Terrassa and 52 in Sant Pere, under the assumption of 880 grams daily individual consumption. If daily bread consumption was reduced to an individual ration of 500 g, the bread supply could be extended to a maximum period up to 92 days (column 5, Table S.1).

Table S.1. Estimation of how Council-led supply of grains in years of scarcity contributed to cover bread security, as reported in the Council minutes.[114]

	Annual grain volume purchased	**Estimated annual bread per person**	**Contribution to food security**		
	m^3 grain/y	*kg bread/ person*y*	*% bread daily ration*	*days with complete bread ration*	*days with reduced bread ration*
Terrassa (minimum)	7.0	5.2	1.9	7	13
Terrassa (maximum)	34.8	26.1	9.7	36	63
Sant Pere (minimum)	20.9	20.9	7.8	28	50
Sant Pere (maximum)	38.2	38.2	14.3	52	92

[114] Recorded volume of cereals was transformed from traditional units (*quarteres*) to contemporary units (m^3) by using the conversion for the case of Terrassa from Francesc Teixidó, *Pesos, Mides i Mesures al Principat de Catalunya i Comtats de Rosselló i Cerdanya a Finals del Segle XVI (1587-1594)* (Barcelona: Fundació Noguera, 2008), p. 101. Second, volume was converted into weight using a reference hectoliter weight of 75 kg/hl, following G. Feliu, 'Les Mesures Tradicionals Catalanes: Un Garbuix Racional', *Butlletí de La Societat Catalana d'Estudis Històrics* 15 (2004): 9–27. Third, to estimate the mass of bread made out of wheat grains we used the weight relation of 1 kg wheat = 0.8 kg flour = 1.2 kg of bread, adapted from Feliu, 'Les Mesures Tradicionals Catalanes': 10-11. Fourth, we considered the individual bread ration of 880 g per person and day, as estimated by X. Cussó and R. Garrabou, *Alimentació i nutrició al Vallès Occidental. Un segle i mig de canvis i permanències: 1787-1936* (UHE Working Paper, 2012), using historical records on food consumption in the region before the first nutritional transition of late eighteenth century. And fifth, we established as reduced bread ration 500 g per person and day. Although demographic changes occurred during the study period, we considered a standard population of 1000 persons in Terrassa and 750 in Sant Pere (see tab. 3.1).

Household practices: storage

Annually, the farmers of Can Torres sent approximately 6 m^3 of grains to the mill, which according to our estimations could be transformed into 5400 kg of bread and feed 17 people over one year (same bread rations and assumptions as Table A.1). The comparison between the amount of bread grains harvested and those sent to the mill shows that farm production could provide most flour needed for own consumption (columns of "Balance" 4 and 5, Table S.2). Yet, part of the harvested grains was kept as seeds and another part was used to pay local charities and in-kind fees, resulting in a lower amount of grains available for consumption. Grain surpluses stored in the farm granary were therefore crucial to compensate for the years of poor harvests without need to rely on external grain supply. For instance, the surplus of 1701 could have compensated the deficit of production in 1702 (Table S.2).

Table S.2. Balance between bread grains produced and consumed in Can Torres (1699-1704).[115]

	Produced		**Consumed**	**Balance**	
	Wheat harvest	**Bread grains harvest**	**Sent to mill**	**Using only wheat**	**Using all bread grains**
	m^3	*m^3*	*m^3*	*m^3*	*m^3*
1699		9.4	6.3		+3.1
1700	5.8	8.6	5.7	+0.2	+2.9
1701	7.9	9.5	5.7	+2.2	+3.8
1702	3.4	5.8	6.6	-3.2	-0.9
1703	6.5	11.6	3.9	+2.6	+7.7
Correction			*6.7*	*-0.2*	*+4.9*
Average	5.9	9.0	6.2	-0.3	+2.7

[115] Data from ACVOC-AHT, Can Torres 1699-1824, f. 27r, 28r, 47r, 63r-63v; Ibid. 5r-5v, 17r, 39v, 54r, 66r. Bread grains produced calculated by adding the annual harvest of wheat, *mestall*, spelt, and *rojal*; annual bread grains consumed were calculated as the grains sent to the mill after summer harvest until next harvest (i.e., from August to July of next year). In 1699, the heir only noted down the total cereals consumed and harvested without specifications of typology of crops. In 1703, grains sent to the mill are documented only until February 1704, we have corrected these data by estimating the grains consumed from March-July using the monthly average of previous months.

CHAPTER IV

Long-term Patterns of Continuity and Change in Climate Adaptation:

A Case Study in the Barcelona Province, Spain (1600-1870s)*

* **Grau-Satorras, M**., I. Otero, E. Gómez-Baggethun, and V. Reyes-García. A summary of this article has been accepted in the symposium on "*Adaptation and Resilience to Droughts: Historical Perspectives in Europe and beyond*" to be held at the University of Strasbourg (France) in June 2017. The communications from this symposium will be published in a Special Issue.

Abstract

Adapting to climate change implies addressing its local manifestations, for which, in a rapidly urbanizing world, cities, towns, and other densely populated areas are urged to be the first responders. To design local adaptation plans and policies for cities, the urban and climate agendas are strongly betting on social and technological innovation, but less attention is being devoted to learn from past adaptation experiences. In this article, we argue that historical explanations can help situate adaptation initiatives within changing regimes of environmental governance, illuminating the relation between adaptation to locally-manifested climatic extremes and the different ways to access and manage the environment. To do so, we focus on droughts and water governance during the "modernization" period to address the following specific questions: 1) how local communities responded to droughts over the course of modernization?; 2) how water governance regimes conditioned local adaptation patterns?; and 3) to what extent such local adaptations were increasingly embedded in a context of multilevel governance? We address these questions through a literature review and a multiple-source archival research exploring the case study from the village of Terrassa (NE Spain), which turned into an industrial city during the nineteenth century. The time frame of our analysis ranges from the early seventeenth to the late nineteenth century (1600-1870s), thereby covering the transition from early modernity to the establishment of the liberal political and economic system in Spain. Our results are organized in three different phases: i) pre-industrial (1600-1720s), ii) transition (1720s-1808), and iii) modern (1808-1870s). For each phase, we explain the water regime and the multilevel governance context and document the adaptation practices put in place in response to two representative drought events. Long term patterns of continuity and change in drought adaptation are identified and discussed in the context of the changes operating over the studied period. We conclude by pointing out two possible implications of our findings for current debates on adaptation to climate change.

Key words: adaptation, climate history, drought, water conflicts, water governance.

1. INTRODUCTION

Adapting to climate change implies addressing its local manifestations, for which, in a rapidly urbanizing world, cities, towns, and other densely populated areas are urged to be the first responders in adapting to climate change (Rosenzweig et al. 2010). Local governments are considered to be key agents in implementing adaptation policies both because of their proximity to local stakeholders and because of their accumulated place-based knowledge to deal with climate risks (Roberts 2008, Corfee-Morlot et al. 2011, Hunt and Watkiss 2011). Moreover, most local governments control public functions considered critical for climate change adaptation, such as land use and water supply regulation or emergency planning (Naess et al. 2005, Measham et al. 2011). With the goal to design local adaptation plans and policies, the urban and climate agendas are strongly betting on social and technological innovation, but less attention is being devoted to learn from past adaptation experiences. Current adaptation policies can benefit from incorporating a historical perspective, as past adaptation experiences can illuminate long-term patterns overlooked on short-term adaptation assessments and can help to identify past inertia inserted in current decision contexts (Carey et al. 2014, Wise et al. 2014). Moreover, as we argue along this article, historical explanations can help situate adaptation initiatives within changing regimes of environmental governance, therefore illuminating the relation between adaptation to locally-manifested climatic extremes and ways to access and manage the environment.

A historical period relevant for understanding societal adaptations to climatic extremes and environmental governance regimes is the time covering the transition to the so-called), the "modern" world. This transition deeply transformed both climate-society relations and (environmental) governance systems. For instance, during this period climate and weather started to be instrumentally measured with an expanding network of meteorological stations (Camuffo and Jones 2002, Brázdil et al. 2010) at the same time that the developments to "modern" political regimes re-defined the access to and exploitation of (renewable and non-renewable) natural resources (González de Molina and Martínez-Alier 2001, Warde 2006, Armiero 2011).

According to Marks (2012), the "modern" world is marked by four notable characteristics: i) energy is produced from fossil fuels, ii) industry is concentrated in urban clusters, iii) sovereign territorial nation-states order political action, and iv) the gap between wealthiest and poorest peoples and regions grows. In turn, "modernization" has been defined as the transition period from medieval, or "pre-modern", to "modern" societies and environments (see the classical

and new theoretical approaches in Reyes 2001). Yet, "modernization" does not imply one single path or linear process by which, for example, rural communities and landscapes converted into urban clusters. Rather, the term denotes the multiple place-based and historically contingent transformations in which the abovementioned "modern" characteristics emerged and became dominant (Gaonkar 2001). Indeed, "modernization" theories have been fairly criticized since the 1960s for being too Eurocentric, imprecise about the non-modern/modern divide, and for their applications as development models in non-Western countries (e.g. Wallerstein 1974, 1980 and 1989, Ferguson 2005, Chakrabathy 2011, Davis 2015). Taking into account these controversies, in this article we use the notion "modernization" to refer to the set of encompassing historical processes transforming settlement and spatial patterns (e.g., urbanization, globalization), economic activities (e.g., liberalization, capitalism, industrialization), political systems (e.g., state-building), and cultures (e.g., secularization). In Europe, these transitions spanned from the so-called early modern period (i.e., the historical period between the late fifteenth and the late eighteenth centuries) to the nineteenth-century industrial period.

Adaptation to climatic extremes seems to have changed over the course of "modernization", although the direction and magnitude of change remain controversial. Thus, authors debate the extent to which "modernization" contributed to improve human adaptation to climatic extremes. According to Messerli and colleagues (2000), both Industrialization and Enlightenment contributed to decrease vulnerability to climatic extremes in Central Europe, mostly due to the use of new agrarian techniques increasing agricultural yields. The same is argued for adaptation to droughts and floods in the Hispanic cities of Murcia (Spain) and Mendoza (Argentina), where during the period between 1750s and 1950s vulnerability was reduced and adaptability increased as a result of the building of more effective infrastructures, which reduced flood damages and diminished drought impacts on yields (Gil-Guirado et al. 2016, see similar views in Richards 2003:84).

Other authors, however, have argued that apparently "modern" robust short-term adaptations could lead to – unintended – catastrophic long-term consequences. For instance, during the nineteenth century, colonial India market-driven drought policies mitigated short-term food scarcity, but at the expense of increasing households' food dependency on markets. The strategy ultimately fuelled extensive famines when severe drought was coupled with warfare and decrease of food markets (Adamson 2014). Similarly, Enfield (2008) questions the extent to which eighteenth-century economic growth and free trade in colonial Mexico boosted differential vulnerabilities to climate and weather extremes. Finally, in the field of historical

disasters, it has been emphasized the ambivalence of the process, as "*while modernization has generally led to a reduction of risk in terms of human life, it has also contributed to capitalist speculation and deliberate risk-taking*" (Mauch and Pfister 2009: 8).[116]

The debate over how "modernization" affected adaptation to climate extremes calls for more empirical studies documenting and explaining changes in adaptation to climatic extremes over this period of deep transformations. In this study, we provide empirical evidence to this debate by exploring specific, but complex, histories of local adaptation to climatic extremes. Particularly, we focus on the ways local communities responded to droughts over time and how changing water governance regimes shaped local adaptations. We focus on droughts because these climate extremes were ordinarily suffered in past, but will also matter for future climate change scenarios (Dai 2011, Van Loon et al. 2016, Gudmundsson and Seneviratne 2016). Water governance consists on the range of political, social, economic, and administrative systems put in place to regulate the management of water resources and the provision of water services at different levels of society (Rogers and Hall 2003, see a discussion of the notion in Pahl-Wostl et al. 2010). Some researchers have noted that existing water governance regimes significantly shape drought policies (March 2010, Van Lanen et al. 2016). Recent drought management plans in European river basins, for example, are the result of implementing more comprehensive water policies such as the Water Framework Directive of 2000 (Estrela and Vargas 2011). In this line, a long term perspective can help explain the continuities and discontinuities in drought adaptation and how these patterns are coupled (or decoupled) with changes in the water governance regimes.

The main aim of this work is to understand how and why local adaptation to droughts changed during "modernization". We start by examining long-term continuity and change in adaptation practices to cope with drought undertaken by local governments. We then discuss how water governance regimes conditioned local adaptation patterns and to what extent such local adaptations were increasingly embedded in a context of multilevel governance. Our study is based in a case study from the village of Terrassa, which turned into an industrial city during the nineteenth century and is nowadays integrated in the Metropolitan Region of Barcelona (NE Spain). The time frame of our analysis ranges from the early seventeenth to the late

[116] Studies on this literature, have interpreted "modernization" both as a cause and as a result of disasters. Christian Pfister (2009), for example, argues that disasters were the "salt of the modernization process", because they improved emergency preparedness and encouraged technological development. In other contexts, and particularly in the Colonial world, "modernization" exacerbated the effects of disasters (e.g. Taithe 2009, Damodaran 2009).

nineteenth century (1600-1870s), thereby covering the transition from early modernity to the establishment of the liberal political and economic system in Spain.

The article is organized as follows. First, we present the case study. The second section explains the methodology used. The results are organized in three different phases in which we divided the studied period. For each of these phases, i) we explain the water regime and the multilevel governance context, and ii) we illustrate and document adaptation practices in response to two representative drought events occurring in each phase. From our results, long terms patterns of continuity and change in drought adaptation are identified and discussed in the context of political, social, and economic changes operating over the studied period.

2. CASE STUDY

2.1. Chronology and periodization

We reviewed changes in water governance regimes and the multilevel governance context in which they operated in Catalonia (Spain) between 1600 and 1900 (see Fig. 4.1 and Table 4.1). Specifically, we tracked: i) changes in local political and economic autonomy and in the intervention of supra-municipal administrative levels in local governance; ii) changes in water institutions (e.g., rights, policies, agencies); and iii) changes in water consumption, usage, and supply. Results from this literature review were used to identify turning points and divide *"the seamless continuum of past time into a sequence of discrete periods that perform roughly the same storytelling function as the chapters of a book*" (Cronon 2004:3). To visualize the changing trends of long-term water governance regimes, we approached the identified periods as phases in an adaptive cycle (see similar analyses in Gunderson et al. 2002, Méndez et al. 2012; Fig. 4.1). Hence, we considered three phases, hereafter referred to as i) pre-industrial (*growth*), ii) transition (conservation and initial release), and iii) modern phase (release and early renewal).

The pre-industrial phase (1600 to 1720s) was characterized by the presence of local governments (Councils) with large levels of autonomy and of water governance regimes that continued to operate primarily through late medieval institutions (feudal water rights) and technologies (traditional water facilities). During this phase, Catalonia belonged to the Crown of Aragon, an independent kingdom autonomously integrated into the Spanish Monarchy (see Table 4.1, Fig. 4.2). Governance scales resulted from merging medieval regional divisions (e.g., *vegueries* configuring the Crown of Aragon) and incipiently centralized structures of the

Spanish Monarchy. For instance, royal agencies such as the Royal Heritage administered water rights in Catalonia. Such water rights were slowly accumulating, for which we considered the water regime as in a phase of "growth" (see Fig. 4.1).

The transition phase (1720s-1808) was characterized by initial intervention of Spanish supra-municipal levels on local governance. In this phase, regional and Catalan government bodies were transformed and new delegates of the Spanish Crown, such as *intendentes* and *corregidores,* were put in place (Table 4.1). During the second half of the eighteenth century increasing water demand from industrial development, agricultural intensification, and population growth evidenced the limits of the traditional water rights system (see "conservation" and initial "release" in Fig. 4.1).

Finally, the modern phase (1808-1870s) was characterized by the new economic and political configuration adopted by the Spanish state in the aftermath of the Napoleon wars (1808-1812) and the Spanish liberal revolution (1812-1874). In this phase, centralization continued, governance scales changed, and more State agencies were created. For instance, multiple State agencies were in charge of controlling the operations of local governments regarding water supply and public works. The water rights system was re-defined and partly liberalized and urban water supply systems were expanded and improved (see "release" and early "renewal" in Fig. 4.1). The 1866 and 1879 Water Acts officially set the scene for a new regime of water.

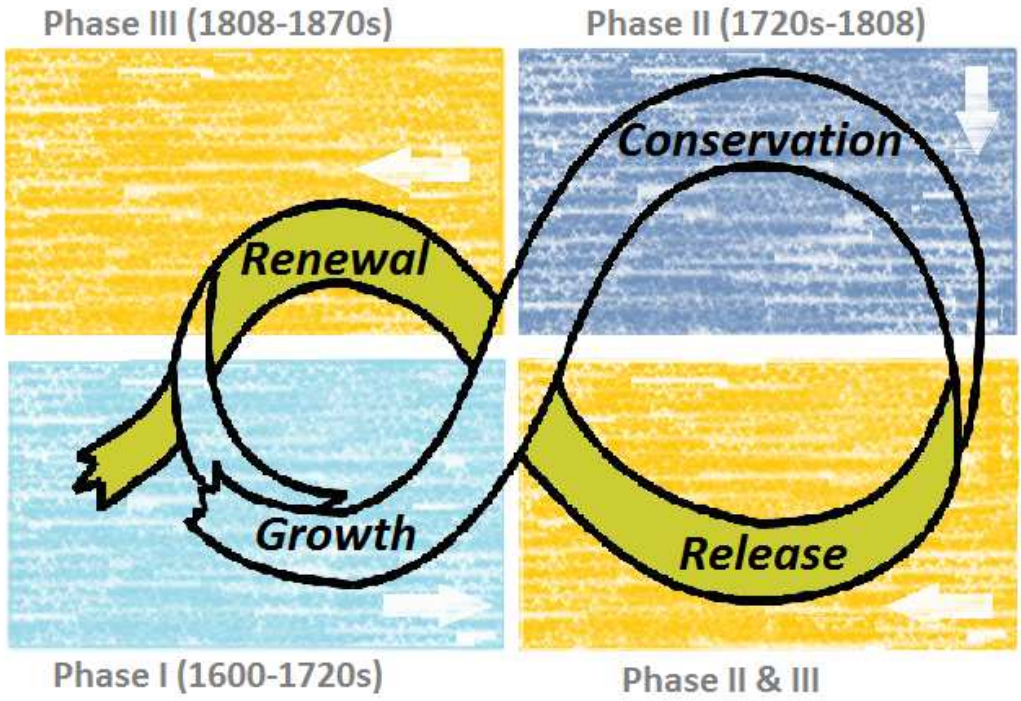


Figure 4.24. Water management regimes in Catalonia from 1600-1870s, approached as an adaptive cycle (Gunderson et al. 2002, Chapin et al. 2009): *growth* corresponds to the continuation of the medieval water rights regime (1600-1720s), *conservation* to the "water fever" phase (1720s-1808), and *renewal* to the initial definition of the modern water rights system (1808-1870s). The phase of release started by late eighteenth century and ended up during the nineteenth century.

Table 4.10. Administrative organization of governance scales at which agencies managing water and droughts operated during the study period in Catalonia, as reported in the literature review.

Governance scale	Phase 1 (1600-1720s)	Phase 2 (1720s-1808)	Phase 3 (1808-1870s)
Spain	Monarchy	Monarchy	State
Catalonia	*Diputat General*	*Intendencia*	*Governador civil*
Regional	*Vegueria*	*Corregimiento*	
Municipal	Council	*Ayuntamiento borbónico*	*Partido judicial* *Ayuntamiento constitucional*

2.2. Study area

Our study centres on the municipality of Terrassa (NE Spain, see Fig. 4.2). With 215.121 citizens, Terrassa is nowadays an important sub-centre of the Metropolitan Region of Barcelona (Catalán et al. 2008, Idescat 2017). During the study period, its population grew from one to twelve thousand people. Below, we summarize the physical context and socio-economic transformations occurred in the study site during the period of reference.

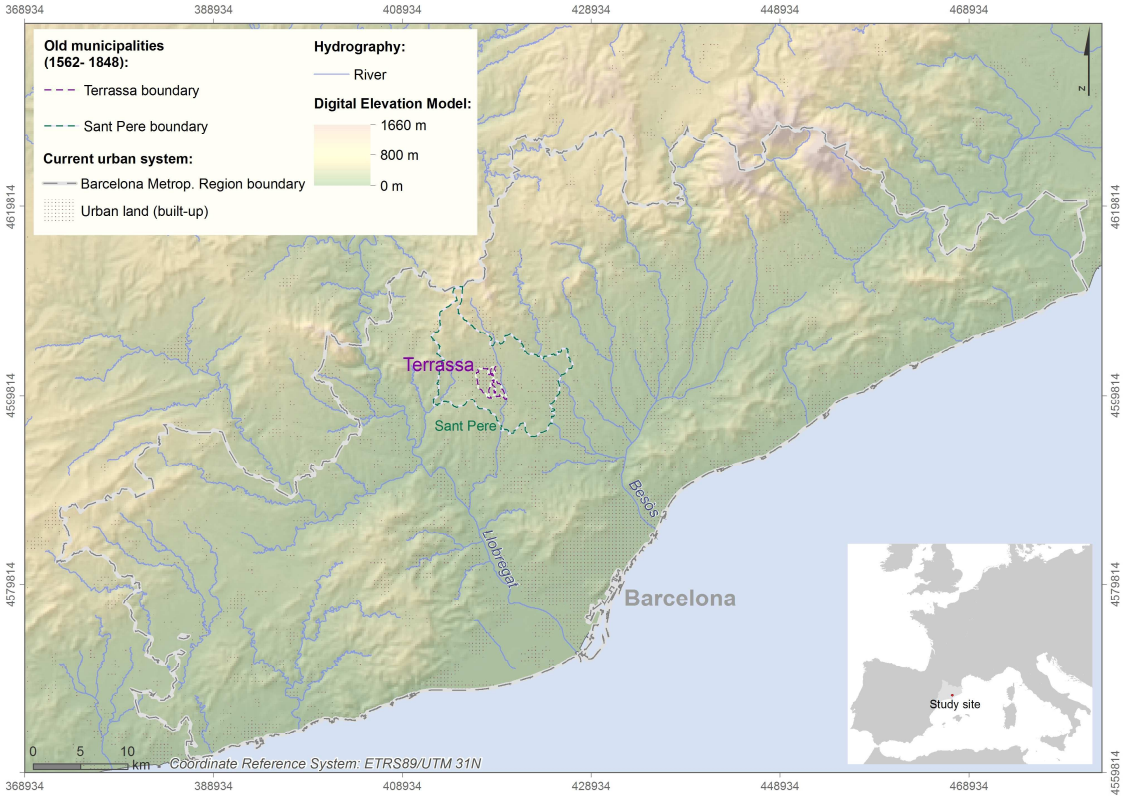


Figure 4.25. Map of the study area. Source: own elaboration based on data from *Instituto Geográfico Nacional* (2009), *Institut Cartogràfic de Catalunya* (2016) and *Agència Catalana de l'Aigua* (2010). In the study period the current municipality of Terrassa was divided in two municipalities: Sant Pere and Terrassa.

Waterscape and climate

Despite the gradual increase in water use experienced during eighteenth and nineteenth centuries, up until 1943 Terrassa relied on local water resources. In the absence of permanent water flows, local water resources in the area consist of aquifers and a network of temporary streams. Although groundwater accumulates across the different layers of the regional sedimentary basin, past groundwater extractions mainly exploited shallow aquifers (Prohom and Salvà 2011). The temporary streams drain from the pre-littoral mountain range to the Llobregat (SW) and the Besós (SE) river basins, both flowing into the Mediterranean Sea (Verdaguer 2000). Thus, local water resources significantly depend on rainwater. Mean annual precipitation in Terrassa is 581.7 mm (period 1961-1990, data from Prohom and Salvà 2011), but large monthly and annual variability makes water management challenging (Arisó 1982, Fig. 4.3). Although the study site is situated in a transition area between two slightly different precipitation regimes: continental, with drier winters and summers, and littoral, with important summer deficits (Clavero et al. 1997:18 and Martín-Vide et al. 2008:18), local

climate presents more similarities with Mediterranean climates (*Csa* in Köppen classification). The lowest monthly rainfall is typically during summer (July average is 24.3 mm), but dryness is not uncommon in winter months (e.g., February and March rainfall averages are 31.2 mm and 35.8 mm, respectively) (period 1961-1990, Prohom and Salvà 2011).

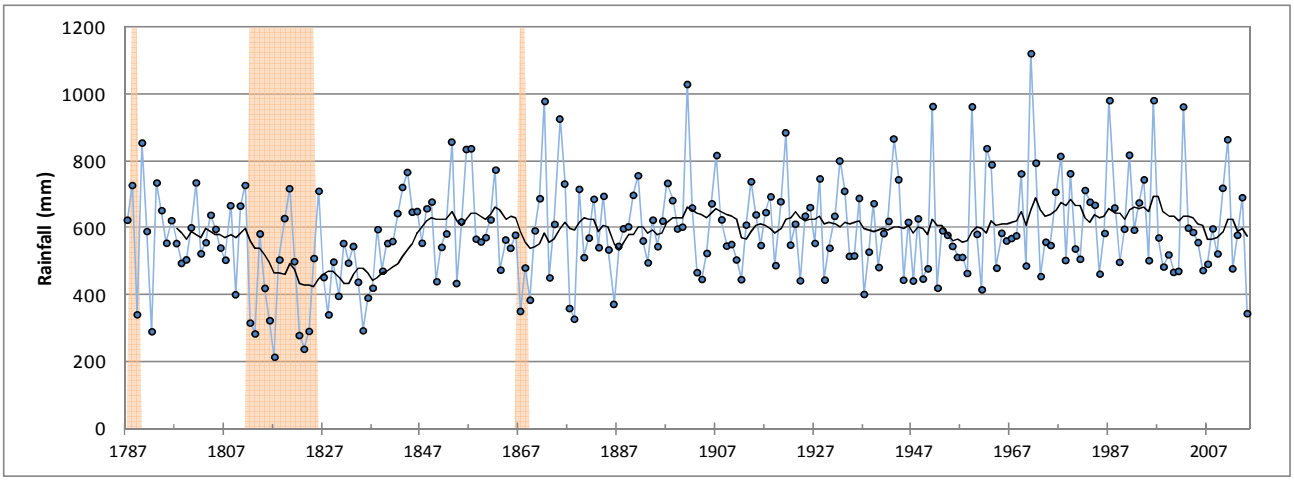


Figure 4.26. Annual rainfall series in Barcelona from 1787 to 2015, with an 11-year-low-pass filter (solid line). Shaded periods correspond to droughts mentioned in the text. Source: own elaboration based on data from Prohom et al. (2016).

Socio-economic transformations

During the seventeenth century, most villagers in Terrassa worked in the primary sector, the textile manufacture (mainly wool and to a lesser extent flax), and artisanal activities (Almazán 1989). The predominance of an agrarian economy (cereals, olive groves, vineyards, and cattle) was stimulated by the proximity of Barcelona (Roca 1991). Between 1566 and 1717, the village barely exceed one thousand people, although it was already one of the most populated areas in the Barcelona region (*vegueria*) (Fig. 4.4, Berenguer and Coma 1987). The 1717 and 1722 censuses reveal that the dominant economic sectors were still agriculture (38-41%), artisanal activities (20-21%), and textile manufacturing (8-9%) (Muñoz 1984:76, Benaul 1991:253). The remaining sectors, including liberal professionals, domestic servants, or clergyman, only employed 10% of the working population. Importantly, between 20-24% of the population was considered poor.[117] The estimated water consumption in the village of Terrassa remained low between 1600 and 1720s, approximately between 20 and 60 m^3 per day (Fig. 4.4).

[117] Some problems of these earlier censuses are that they were motivated by fiscal goals (which together with the post-war context could explain the high poverty rate) and only counted adult male

The proportion of artisans and manufacturing workers increased in the eighteenth century boosted by the growth of the textile sector, which towards the end of the century represented between one and two thirds of the total population (Iglésies 1969:83, Benaul 1991:257). As in other regional centres in Catalonia and mostly because of immigration of the rural population, population increased threefold between 1717 and 1801, surpassing the three thousand inhabitants at the turn of the nineteenth century, (Fig. 4.4, Ferrer-Alòs 2007). Given this growth, Terrassa water consumption probably surpassed the 150 m^3 per day by the end of the eighteenth century (Fig. 4.4). Agriculture in the *Vallès* county had started to specialize in winegrowing, although in medium-sized centres such as Terrassa cereals and vegetable plots oriented to fulfil the local demand remained important land-uses (Garrabou et al. 2007, Roca 2002, Roca 2013). Despite the expansion of agricultural lands, agricultural water demand was probably low in the area, because vineyards were rain-fed and the gardeners cultivated the humid beds of the temporary streams reusing leftover water.

In 1828, 60% of the working population in Terrassa was employed in the industrial, commercial and artisanal sectors (Benaul 1991), reflecting the leading position of Terrassa, and the nearby town of Sabadell, in the Spanish industrialization of wool manufacturing (Benaul 1992, Nadal et al. 2012). This process also explains the acceleration of urbanization and demographic growth in Terrassa over the nineteenth century, when the municipality's population surpassed the ten thousand people (Fig. 4.4). Terrassa obtained the city title in 1877 (Gabriel 2002). By then, water consumption estimates suggest that the city could have surpassed the 1000 m^3 per day (Fig. 4.4).

workforce. As a consequence of not counting women, children and elders, the individuals with occupations reported in the 1717 census only represented the 17% of the local population. Moreover, the census used ambiguous categories such as labourers (*jornaleros*) that overestimated the rate of the agricultural sector (Muñoz 1984, Moreno et al. 1988, Benaul 1991). Finally, categories were not mutually exclusive, for example, clothiers coordinating woollen-cloth production usually owned and cultivated land (see Marfany 2012).

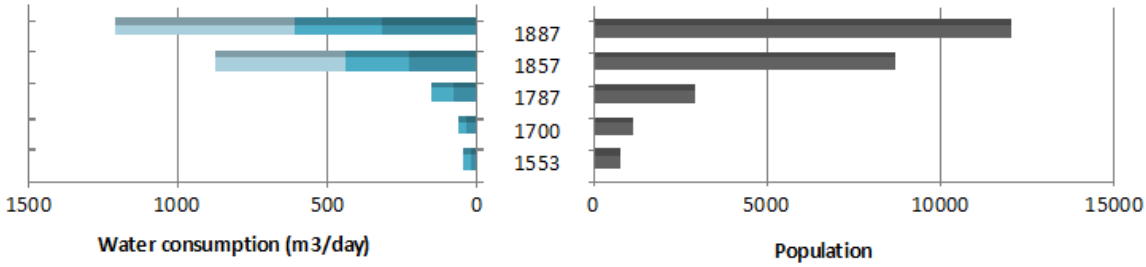


Figure 4.27. Population growth and estimated water consumption from 1553 to 1887. Note: water consumption was estimated using three levels of individual consumption in litres per person per day (lpd). For the seventeenth and eighteenth centuries, we considered an individual consumption of 26 lpd (dark blue) and 50 lpd (medium blue), respectively based on the averages from Barcelona reported by Tello and Ostos (2012) and the endowment goal of the 1866/1879 Spanish Water Acts. For the nineteenth century, we also included the 100 lpd (light blue), based on the averages from Tello and Ostos (2012). Source: population data from Idescat (2017) and Berenguer and Coma (1987).

3. METHODS

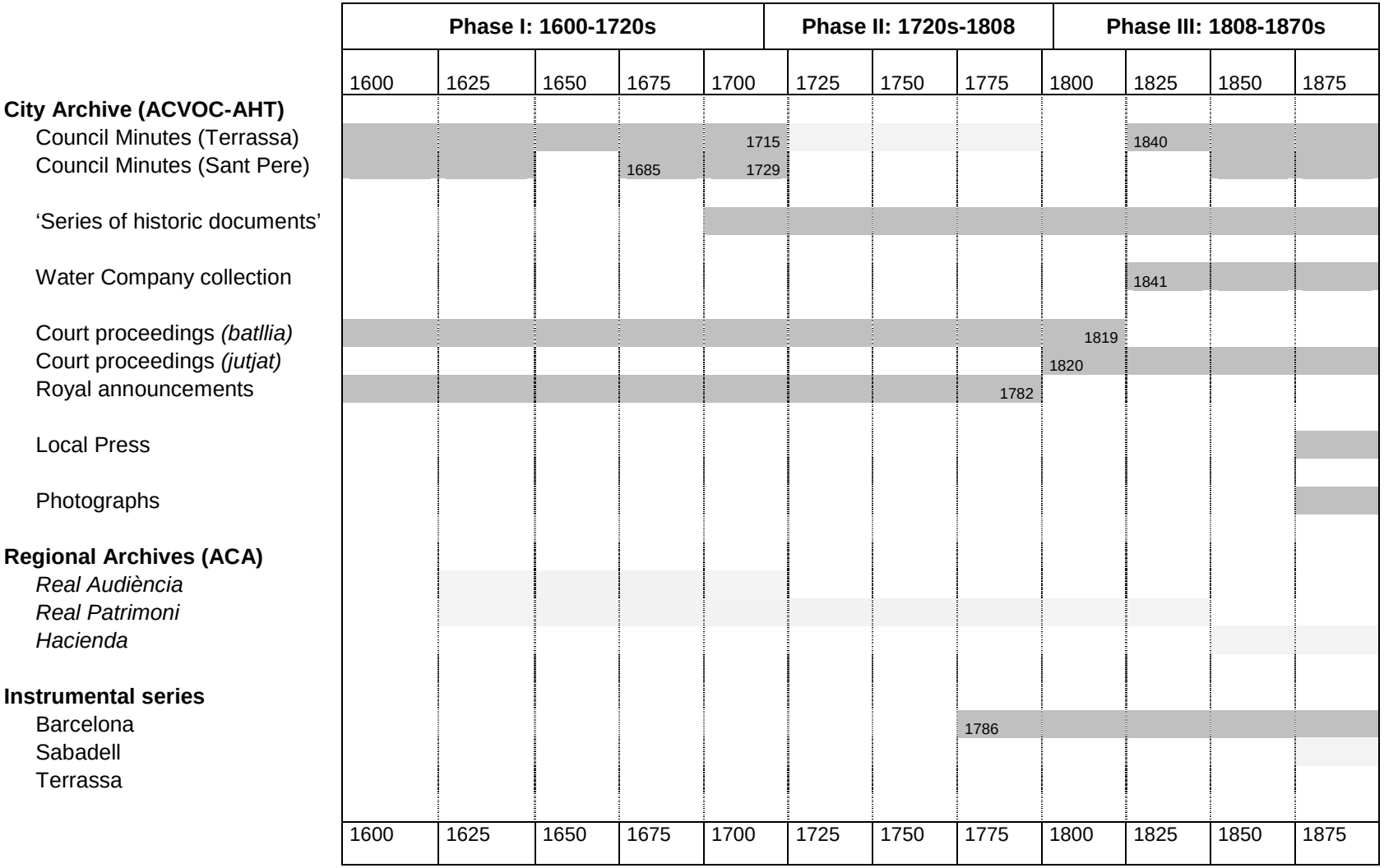
3.1. Archival research: selection of sources

For the archival research, we looked at documentary sources providing evidence of local responses to drought over the studied period. The two main sources used are i) the minutes from the Terrassa Council and ii) a set of archival documents from the local government of Terrassa locally known as 'Series of historic documents', all of them located in the City Archives of Terrassa (hereafter ACVOC-AHT for its official acronym, Table 4.2). The minutes are compilations of the meetings held by the local government, which during the study period was gradually transformed from Old Regime institutions (*Consell*) to early municipalities (*Ayuntamiento borbónico*) first, and then to constitutionally recognized municipalities (*Ayuntamiento Constitucional*). The second source consists of a varied set of documents produced by or directed to the local government of Terrassa such as correspondence, petitions, inventories, and economic accounts (Puig et al. 2010). We also reviewed the archival documents of the local water company, which were made accessible in 2015 via the City Archives (Pastallé 2014, 2015).

Additional sources of information include instrumental series of precipitation from Terrassa (Prohom and Salvà 2011) and the nearby cities of Barcelona (Prohom et al. 2016) and Sabadell (Benet-Crusafont 1986); court proceedings; royal announcements (partially compiled by Cardús 2000); local press; council minutes from the neighbouring municipality of Sant Pere; and supra-municipal official documents stored in the Crown of Aragon Archive (Table 4.2).

Minutes of the Catalan government from 1600 to 1713, transcribed by Sans (1996, 1997, 1999, 2000, 2002, 2003, 2005, 2007), were also reviewed. Finally, graphic materials such as historic maps (Burgueño and Gras 2014: 138-139; Nadal et al. 2006: 213-217) and photographs from the collections stored in the Municipal Archive of Terrassa (hereafter AMAT for its official acronym), the *Tobella* Archive, and regional archives were also reviewed.

Table 4.11. Documentary sources and their temporal coverage. Sources were continuously (i.e., without documentary gaps, shaded cells) and discontinuously (i.e. containing data gaps, light shaded cells) recorded over time. Numbers in boxes indicate exact year of start or end of documentary series.



3.2. Data collection and analysis

For each phase we collected two main types of information. First, we collected background information on major contemporary political and economic developments from secondary sources and described the administrative organization, water governance regimes, and water conflicts between uses and social groups. Second, we collected primary data on drought events and related coping practices adopted by the local government. To contrast the consistency of data across sources and to cover the temporal gaps in sources, we reviewed data from the different documentary sources available for each of the three phases (Table 4.2).

For each phase, we selected the two most representative drought events on the basis of i) the documented coping practices, ii) the actors involved, and iii) the magnitude of its impacts (see Table 4.3). Depending on available information, each drought event was characterized through a set of descriptors, including severity, scope, impacts in other regions, and precipitation dynamics. We situated each drought event in the broader political and socio-economic context, paying special attention to how coping practices were potentially affected by contemporary threats such as wars, epidemics, and political outbreaks. Next, we documented the strategies implemented by the local government in response to each drought event and the roles of other actors involved in shaping local water governance and adaptation to drought. Importantly, although we are aware that "coping" and "adaptation" owe different meanings in the climate change literature (e.g. Berkes and Jolly 2001), we did not have enough information to clearly differentiate between them. So, both terms are used interchangeably along the results section.

Finally, we drew on the core questions proposed by Smit et al. (2000) to structure information and track changes in adaptation in each phase: 1) who or what adapts?, 2) how does adaptation occur?, and 3) adaptation to what? We adapted these questions for our case study and asked: 1) who led or decided local adaptation to droughts?, ii) how drought adaptation was characterized and what strategies were developed?, and iii) what drought impacts address the identified strategies? So, for each of the drought events selected, we systematically document the governance actors involved, the coping practices developed, and the drought impacts tackled.

4. RESULTS AND DISCUSSION

4.1. Pre-industrial phase: 1600-1720s

The 'old rights' water governance regime

In late medieval and early modern times, local Council attributions in Catalonia depended on municipal charters granted by the King, acquired privileges, and customary rights (Casas 2015). By 1632, 28% of the municipalities in Catalonia were under royal jurisdiction, 47% under lords' jurisdiction, and 25% under ecclesiastic jurisdiction (Burgueño and Gras 2014: 46). While local government bodies were formally controlled by such heterogeneous elites, in practice, all enjoyed a high degree of political autonomy (Torras-Ribé 1981). For instance, local governments had the capacity to elaborate local laws (*ordinacions municipals*) without major intervention from royal delegates, lords, or the church (Font-Rius 1999). Local authorities could also regulate and control food supply, education, local markets, public works, and inter-municipal pathways. Local tributary systems were established in the late fourteenth century to address municipal debt (Ortí-Gost et al. 1996), although in the seventeenth century municipal budgets suffered from mounting burdens from royal taxes and war effort (Hernández 1996, Espino 2014).

The water governance regime corresponded to the medieval rights system. Water was owned by lords (in central and southern Spain) and royal authorities (in north-eastern Spain coinciding with the Crown of Aragon), who granted water rights for specific uses. Water in Catalonia was formally owned by the Royal Heritage (*Real Patrimoni*), which could lease water use rights (licenses called *domini útil*) to communities and individuals (Maluquer de Motes 1982). Holders of such use rights could lease water to others, so in practice water use rights were split across multiple stakeholders and regularly adjusted through negotiations among the parts (Grau-Satorras et al. 2016). Available technologies restricted harvesting capacity to the exploitation of surface and shallow water bodies, which were mainly used for human and livestock consumption, irrigation, watermills, and small-scale manufactories (Lemeunier 2000, Calatayud and Martínez-Carrión 1999 and 2005). Water supply systems in villages and medium-sized towns included basic water facilities such as public drinking fountains, watering troughs, and washhouses (Matés 1999).

Drought events and coping strategies

We documented drought mentions in 24 years between 1600 and 1715. Yet, drought events could extend for several years. Below we describe the two events for which we found more documentation of the Council initiatives to cope with drought.

The 1604-1605 drought

During the winter of 1604, a severe drought affected large areas of eastern, central, and southern Spain (Rodrigo and Barriendos 2008, Domínguez-Castro et al. 2010) with prospects of negative crop impacts fuelling speculation on grain prices (Sans 1996: 502-503). In January 1605, the Council of Terrassa organized a costly rain pilgrimage to the monastery of Montserrat, located 24 km away from the village (see also Grau-Satorras et al. 2016). Rogations were a common ritual in Catholic societies whereby locals organized religious processions to ask the mercy of God and pray for rain (Fig. 4.5). During the following months, the Council decided to buy wheat for the first time since 1599 and established measures to secure water supply during summer. Such measures included the reparation of water conduits, the assessment of competing water uses of the villages' public drinking fountain, and restrictions to water polluting activities like the operation of hemp fermentation pools (ACVOC-AHT, Terrassa Council Minutes, 1592-1616, 24/1/1605, 10/2/1605, and 4/8/1605). In other words, Council strategies to cope with droughts mostly focused on dealing with drought impacts on local water and food supply. To guarantee the supply of cereals, higher government levels took more drastic measures, such as the viceroy prohibition, in the spring of 1605, to export grains outside Catalonia (Sans 1996: 502-503, Gilabert-Bruniquer 1912[1614]: 200-202), although in practice large volumes of food were traded in black markets (Giralt et al. 2008: 264-267).

Figure 4.28. Pilgrimage ritual from Terrassa (year unknown). Source: Reproduced with permission. AMAT, Ragon Collection, exp. 148954.

The debt drought of 1677

By the end of the seventeenth century, Council strategies to cope with droughts continued to focus on impacts on food and water supply, though investments on water infrastructures or rituals were constrained by mounting indebtedness of local governments (Grau-Satorras et al. 2016, Chapter III). Concerned by expected food scarcity from an ongoing drought, in March 1677 the Council of Terrassa imported 7 m^3 of wheat (ACVOC-AHT, CMT, 5/3/1677). In April, together with the Council of the neighbouring community of Sant Pere, the Terrassa Council organized a rogation to pray for rain (ACVOC-AHT, CMT, 25/4/1677). In May, as the local market supplies were unable to meet local demand for food, the Council imported wheat (ACVOC-AHT, CMT, 9/5/1677). Thereafter imported and stored food was rationed among the villagers. In addition 3.5 m^3 of grain were purchased by the Council at an unusually high price (ACVOC-AHT, CMT, 19/5/1677). When the wheat harvesting season was coming to an end, the conditions for leasing the public bakery were re-adjusted because nobody wanted to rent it. Bakeries were a public service and had the obligation to provide bread to the villagers.

However, during this drought event, the Council conditioned the obligatory supply of bread to wheat availability to make it more attractive for candidates to rent the bakery (ACVOC-AHT, CMT, 28/7/1677). Finally, in the autumn, new creditors offered their services to the village Council in order to fund subsequent grain purchases (ACVOC-AHT, CMT, 28/10/1677).

Summary and discussion

The revised documentary sources reveal a range of local management practices to cope with droughts during this phase (see Table 4.3). These practices included collective action led by the village Council, such as the organization of rain rogations, the construction and reparation of water infrastructures, adaptations in water institutions, resorting to trade to secure staple food supply, and the rationing of food and water among the villagers. Overall, the bulk of coping practices were oriented towards the impacts of droughts on food supply (i.e., agricultural drought) and water supply (i.e., hydrological drought). The local Council lead most drought-related initiatives alone, but sometimes collaborated with neighbouring councils. Yet, Council decisions were influenced by food merchants, who constrained access to grain markets, and debt creditors, who limited the financial capacity of Councils. We also found initiatives at other levels of governance, particularly the viceroy, but they seemed to have little impact in shaping local adaptation strategies.

4.2. Transition phase: 1720s – 1808

The "water fever" and the exhaustion of the old regime rights

During the transition phase, from 1720s to 1808, and following a broader centralization tendency in Spain, the political and economic autonomy of local governments declined, resulting in growing conflicts around access to and control of natural resources (Gómez-Baggethun et al. 2013). In 1716, following the Succession War (1701-1714), local governments in Catalonia were reorganized and thereafter municipal decision-making became increasingly mediated by Spanish Crown delegates (mainly *corregidores* and *intendentes,* see Table 4.1) (Gay-Escoda 1997, Estrada 2003). From 1716, Council members were elected by royal authorities. Additionally, the number of Council members was reduced from tens to only seven or eight councillors (Casas 2015: 157). Furthermore, the creation of new Council positions holding more power than standard councillors (such as the *Regidor Decano*), and of administrators operating between the Council and the regional authorities, such as the

regional delegates known as *corregidores*, changed existing power relations (Casas 2015; see Burgueño and Gras 2014 for differences depending on the municipality).

Likewise, during the eighteenth century the Spanish state tightened the grip on municipal expenditures and revenues (García 1996, Salort 2015). In Catalonia, since 1715 the royal authority of *Intendencia* was in charge of "controlling municipal budgets [...], listing the revenues and expenditures, as well as the debts and levies, of each village" (Casas 2015: 163), activities that were done through the *corregidores*. During the first decades of the eighteenth century, municipalities had to ask permission to royal authorities for any important financial decision, although royal authorities' responsibilities and procedures were not yet clearly defined. State supervision of local policies increased in 1760 with governance developments, including the establishment of a centralized agency for accounting local taxes (*Contaduría General de Propios y Arbitrios del Reyno*), the definition of a formally established hierarchy of fiscal authorities at the Crown, Catalan, regional and municipal levels, and the establishment of a protocol to supervise municipal finances (Casas 2015, see Table 4.1). These institutional reforms intended to standardize municipal budgets and control municipal revenues, while defining the proportion of local taxes to be collected by the state. Thus, financial decisions, such as investments on public works or expenditures on religious rituals, became increasingly controlled, regulated, and supervised by regional authorities.

By the end of the eighteenth century, feudal land and water rights were under mounting pressure, the French Revolution epitomizing the discredit of the feudal tributary system (Millán et al. 2006). However, in Spain the collapse of these institutions was not immediate. New liberal principles claiming individual freedoms against the inferences of lords and Kings coexisted, overlapped, and struggled with the feudal world (Fontana 2007). While water rights changed at a slow pace, water exploitation patterns changed dramatically in this period. Vilar uses the term "water fever" to describe the massive increase of water concessions for irrigation granted by royal authorities to individuals between 1723 and 1808 in Catalonia (Vilar 1968:259-317). Maluquer de Motes (1990) also documents the growth of water concessions for the production of hydraulic energy between 1735 and 1800, noting the parallel and less visible process of conversion of old water rights into new water uses. For example, rights initially granted to use water for mills or irrigation were later used to produce hydraulic energy. Thus, water consumption in Catalonia increased during the eighteenth century, following growing demands from agricultural exploitation (Congost and Pellicer 2012), industry, and urban water supply (e.g. Tello and Ostos 2012).

Moreover, the weakness and loss of legitimacy of the feudal rights regime in the late eighteenth century fuelled new water appropriations and illegal exploitations, and resistance to pay feudal fees (Calatayud 2016, Matés 2016). In fact, in the last two decades of the eighteenth century water conflicts increased dramatically (Saavedra 2009), a trend that persisted during the first decades of the nineteenth century (Serrano 2012). As Serrano (2012) documents, Court cases on water were not only used to solve water conflicts between users, but more so to strengthen and legitimise private rights and to exclude alternative private or collective water uses. Following a European trend, provision and sanitation of urban water collapsed in many Spanish towns and cities since the late eighteenth century (Ruiz Villaverde et al., 2010). Drinking water pollution and water-driven epidemics, among others, forced Councils to build new wells and develop (modest) water infrastructures (Ruiz Villaverde et al., 2010).

Drought events and coping strategies

We documented five drought events during this phase in Terrassa. Below we describe the two events that more precisely illustrate the relations between droughts and the "water fever".

The 1750-1753 drought and the competition for water

The period between 1750 and 1754 was one of the driest recorded in the Iberian Peninsula during the eighteenth century (Domínguez-Castro et al. 2012). Rain rogations in spring 1750 are the first action reported in Terrassa in response to this drought (Oller et al. 2011). Drought and water scarcity affected public drinking fountains and therefore village and troop water supplies. In fact, our documentary sources refer to problems to supply water to the newly established military camp in Terrassa after the Succession War (1701-1714). Municipal pleads were sent to royal delegates (*corregidor*) to prevent the diversion of village water supplies to troops, by pointing out the potential leakages and negative impacts of such diversion (e.g., ACVOC90-36-T2-446, 1734). In 1753, after noting the "water sterility" resulting of the ongoing drought, the new head of the Council (*Regidor Decano*) proposed to assess and repair the central drinking fountain old water conduits to guarantee water supply to both the village and the troops (ACVOC-AHT, Council Minutes, 1715-1794, 15/2/1753). Since 1753, new municipal regulations and conflicts from wheat scarcity and changes on the public bakery regulation are documented (e.g., ACVOC90-36-T2-758, ACVOC90-36-T2-804). It is however not clear whether these actions were specific responses to the drought or to other compound factors contributing to wheat scarcity.

The drought of 1788-1789

Right before the French revolution (1789), an extensive spring drought affected many regions in the Western Mediterranean basin, including Catalan cities like Girona, Barcelona, Tarragona and Tortosa (Domínguez Castro et al. 2012). Barcelona suffered a winter drought the same year (Rodrigo and Barriendos 2008) and instrumental series of rainfall show that 1789 was also one of the driest years in the decades to come (Prohom et al. 2016, Fig. 4.3).

The convergence of a decreased water supply due to climate-driven drought and an increased demand from the "water fever" exacerbated conflicts for the use and appropriation of water that posed new challenges for the local governments. For example, in Terrassa, the Council worked to establish solutions to the conflicts emerging between villagers and a liquor factory accused of polluting water wells (ACVOC90-36-T2-1270, 1788). Municipal authorities were aware of the need to evaluate the impacts that the construction and exploitation of new private water mines (i.e., excavated underground tunnels collecting and transporting groundwater, seeming horizontal wells, see Fig. 4.6) could have on public water availability (ACVOC90-36-T2-1305, 1789). Also, during this time, some particulars plead the municipal authorities to build a new public drinking fountain. Surprisingly, their argumentation was not that a new fountain was needed to better cover village supply or to respond to water shortage, but rather that they possessed old rights over the water of the old public fountain and hence that villagers lacking these rights should supply themselves from another fountain (ACVOC90-36-T2-1301, 1789). Reflecting unequal power relationships among villagers, the letter purposely mentioned some powerful Council members that supported their demand.

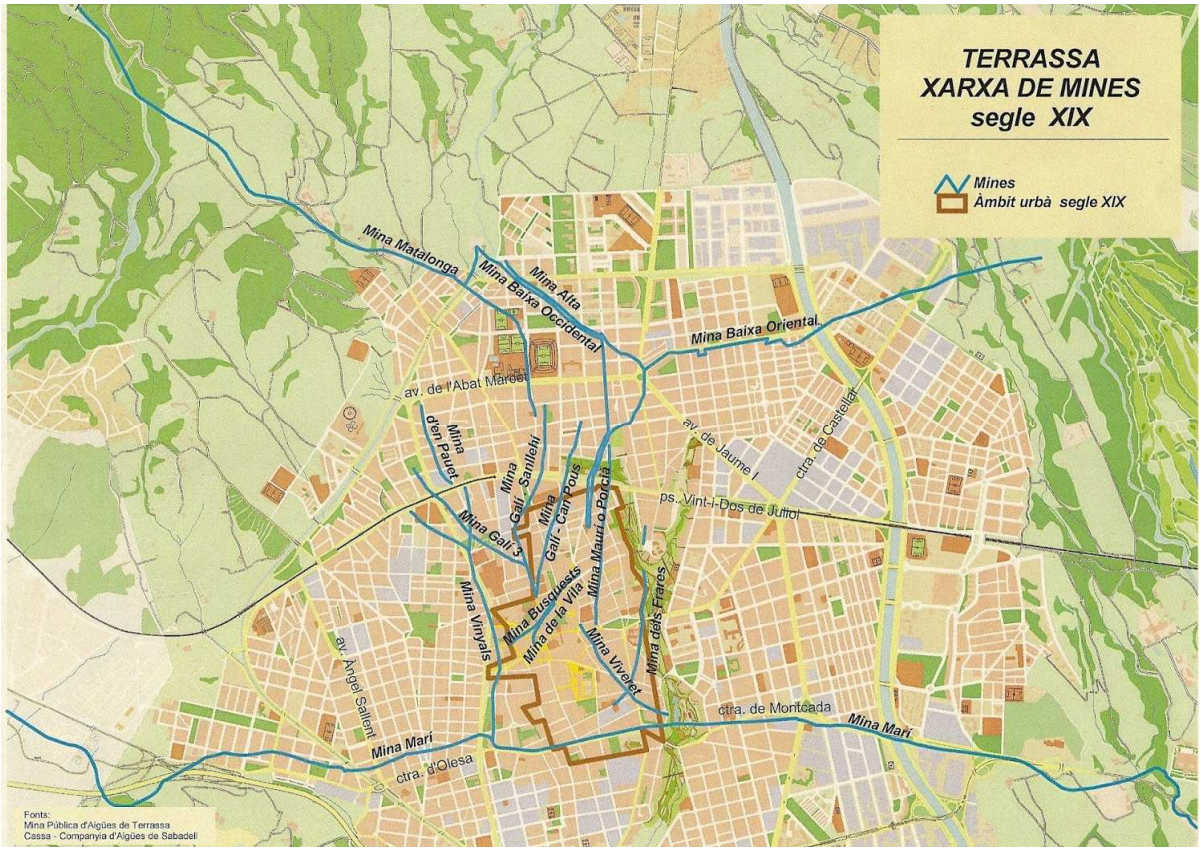


Figure 4.29. Map of the expansion of the mines (blue lines) during the 19th century and the municipal boundaries of Terrassa (brown line). Source: Terrassa town Council, based on data from MPAT and CASSA.

Summary and discussion

Practices to cope with drought implemented by local authorities after the Succession War (1701-1714) and throughout the eighteenth century reflect a degree of continuity with the practices documented for the first phase: rain rogations, reparation of water infrastructures, and devoting resources to the resolution of water conflicts exacerbated by drought. However, increased competition over scarce water resources became a major challenge to local governments. Consequently, the Council started to evaluate the impacts of private appropriations of water resources (i.e., groundwater) and adopted a more prominent role as interpreter of water rights. Hence, Council initiatives in this phase focused on addressing hydrological impacts of droughts in a context of scarcity resulting from growing water use (see Table 4.3). Apart from the potential lobbying of emerging local actors (e.g., military troops and manufactures) who demanded more water, the decision-making on droughts was shaped by the initial subordination of Council decisions to regional delegates of the Bourbon Monarchy (i.e., hierarchical organisation and early centralisation).

4.3. Modern phase (1808-1870s)

Political centralization and incipient water policies

From the late eighteenth century until 1845, central state control over municipal budgets increased with the establishment of new state organisms such as the Revenue Secretary or the General Direction of Local Taxes (Salort 2015). However, the new functioning of municipal revenue did not consolidate until the second half of the nineteenth century, coinciding with a conservative turn in the Spanish state government (Salort 2015). In this process, the 1845 Councils Law was an important landmark (García and Comín 1995; Casas 2015). The law intended to reform taxes to balance municipal revenues, but failed to address the problem of how the municipalities were to cover the growing costs of operating increasingly complex public facilities such as water supply or street lighting (Ruiz-Villaverde et al. 2010). Moreover, the law further reduced Councils' self-governing capabilities. Mayors were elected as state delegates and the central state established increasingly hierarchical procedures for decision-making, downgrading local governments to mere management agencies (Orduña 2005)[118]. This situation also affected water supply facilities. Municipalities were still in charge of planning, organizing, coordinating, implementing, and controlling water supply (Matés 2016). However, provincial and state delegates not only scrutinized these processes, but ultimately held the right to approve or refuse important decisions such as those related to public works or changes in local legislation (Orduña 2005).

The 1866 and 1879 Water Acts officially set the scene for modern Spanish water policy (Costejà et al. 2004). Before 1866, a set of state legislations and parliamentary debates had covered essential water issues such as the distinction between surface and underground waters, the prioritization of water uses, the regulation of surface water concession schemes, the standardization of irrigation institutions, and the definition of the coercive functions of the state in cases of law breaking (Moral et al. 2007, Calatayud 2016). Likewise, water rights were drastically changed during this phase (Maluquer 1982, Calatayud 2016). First, the Cadiz Constitutional Courts privatized and deregulated access to water by abolishing old rights, including lord's (6/8/1811 Decree) and royal fees (19/7/1813 Decree). The decision predominantly affected groundwater resources. Second, during the so-called absolutist period, between 1814 and 1820, King Fernando VII only recovered royal fees (15/9/1814 Decree). That is, only regions such as Catalonia in which the water use rights were granted by royal agencies

[118] See Fontana (2007:185-186, 202) for the political implications of this law and the precedent 1840 law.

had to pay or ask for water rights. And third, the Royal Decree of 19/11/1835 recovered the Constitutional abolition of royal fees and established "*the free right to build watermills* [...] [and] *to open trials and trenches to search groundwater*". Liberalization of rights to access and exploit groundwater resources added more pressure to vulnerable aquifers (Calatayud and Martínez-Carrión 2005).

In general, this phase was characterized by the growth of water demand, but also of water infrastructures. Water consumption increased in parallel with urbanization and industrialization (March 2015) and, in major cities, water resources previously used for irrigation were reallocated to domestic and industrial uses (Ostos and Tello 2014). Especially since the mid-nineteenth century, water supply services were gradually transformed to fulfil domestic and industrial demands (Ruiz-Villaverde et al. 2010, Matés 2016). Modernization of water supply facilities included the construction of large infrastructures to store and transport water, the introduction of new systems for water filtration and disinfection, and the installation of technical devices to ensure adequate pressure at the water network (e.g., water pumps, pressurized pipes, valves). Developing those water supply systems required large investments that surpassed the limited financial capacity of municipalities. For this reason new private water companies were created, especially in the second half of the nineteenth century. These concessions were often characterized by extremely long, sometimes even perpetual, contracts, weak public auction, and biased negotiations benefiting the private interests of powerful actors (Matés 2016). Indeed, water supply services became a major source of social conflict: some discourses defended that water supply should be part of the public domain rather than regulated by the market, while others limited municipal intervention to the area of health control (Masjuan et al. 2008).

Drought events and coping strategies

We documented four drought events in Terrassa during this phase. Below we describe the 1812-1820s mega-drought , which concurred at the same time that tremendous changes in the state and local water governance regimes, and a later drought in 1867-1868 which illustrates the role of the private water company in adapting to droughts.

The 1812-1820s mega-drought

Reconstructed precipitation series in Barcelona evidence an extreme drought event extending from the 1810s to the 1820s (Prohom et al. 2016, Coll et al. 2016; Fig. 4.3), coinciding with a

period of precipitation anomalies in Southern Europe.[119] Instrumentally measured data series and documentary sources describe two significantly severe sub-periods in 1816-1817 and 1822-1824 (Barriendos 2008a, 2008b, Barriendos et al. 2010). Documented drought impacts in Barcelona include poor harvests, increased wheat prices and subsequent scarcity of food, and famine (Barriendos and Dannecker 1999). Historical sources describe 1817 as 'the famine year' ("lo any de la fam") (see also Luterbacher and Pfister 2015). Moreover, the social impacts of drought were exacerbated by the effects of the Spanish uprising against Napoleonic troops (1808-1814) and by a devastating yellow fever epidemic (1821).

During the period, the Council of Terrassa put in place several coping actions. First, from 1815 to 1818, the Council regulated concessions for new private exploitation of underground water resources (ACVOC90-36-T2-1885) and mediated water conflicts between actors competing for the same water resources (e.g. ACVOC90-36-T2-1906). We also documented the intensification of a conflict between the Council and the private owners of a major water source (Mine *Busquets*) (ACVOC90-36-T2-1785, ACVOC90-36-T2-1886, ACVOC90-47-T2-4091), which finished with an agreement by which the owners had to grant three fifths of the water source to the municipal authorities in return for a right to expand their mine (Oller et al. 2008:24-25). Conflicts were probably exacerbated by the uncertainty generated after the abolition of old water rights and their partial restoration (Calatayud 2016). Municipal responses to drought also included the traditional collective rain rogations that were performed during the spring of 1817 coinciding with the famine year (ACVOC90-36-T2-1895). During the second sub-period of the mega-drought (1821 to 1824) efforts by the Council were oriented to mediate private water conflicts by interpreting new and old water rights (e.g., ACVOC90-36-T2-1937). Public action was also directed to cope with drought impacts while preventing the spread of yellow fever. For example, in 1822 the local government asked the state delegates permission to fund the reparation of the dried public washhouse or the construction of another one "*to preserve necessary cleanliness and avoid the introduction of any pestilential disease*" (ACVOC90-36-T2-1998). They also negotiated with entitled villagers the allocation of fountain surplus water, which the authorities aimed to divert to the new public washhouse (ACVOC90-36-T2-1993, see Fig. 4.7).

[119] Recent climate research about the Dalton Minimum - the low solar activity period from 1790 to 1830 - has argued that large volcanic eruptions occurring in 1809 (unkown volcano), 1815 (Tambora), 1831 (Babuyan Claro) and 1835 (Cosiguina) were the main drivers of precipitation anomalies in Southern Europe during those years (Anet et al. 2014, for temperatures see Wagner and Zorita 2005).

Figure 4.30. Public washhouse with women cleaning clothes (right) close to the public fountain in the central square (Terrassa, year unknown). Source: Reproduced with permission. AMAT, Ragon Collection.

Yet, a significant shift in the local water management regime took off in the late 1820s, coinciding with the last years of the creeping mega-drought, the first urban expansion of Terrassa (1822-1844), and the initial mechanization of the wool industry (Benaul et al. 1987, Nasarre and Badia 2006). In 1828, the Council of Terrassa asked the King Fernando VII permission to search underground water in the lands comprised within 1.5 leagues around the village (ACVOC90-36-T2-2296, ACVOC90-36-T2-2321). These lands covered an area of about 220 km^2, well beyond the 5 km^2 of Terrassa and therefore extended to the neighbouring Sant Pere municipality (see Fig. 4.2). The Council of Terrassa also had a controversial petition to the King: the exemption to pay fees for trading water to be used for manufacture (ACVOC90-36-T2-2296). These petitions are important because it laid the foundations for the establishment, in 1842, of the private water company owned by the local industrial elite, called *Mina Pública d'Aigües de Terrassa.* This company obtained the water rights and existing water infrastructures from the Council in order to expand those infrastructures by constructing a network of underground galleries to exploit groundwater for industrial and urban water uses (Pastallé and Solé 2002, ACVOC-M135-1842/01/01-2336-1-3, see Fig. 4.6).

The modest drought of 1867-1868

In autumn 1865 Terrassa suffered severe floods and a disease outbreak (Oller et al. 2011:12). Dry conditions though started in 1866. According to instrumental time series of precipitation from Barcelona, the springs of 1866 and 1867 were significantly dry (66 mm and 48 mm, respectively, while the average during 1787-2015 is 156 mm, Prohom et al. 2016). Several drought rogations were organized in the spring of 1868 (ACVOC-AHT-A103, 13/4/1868:f.28r-29 and 4/5/1868:36r). In June, the town Council also agreed to evaluate the dryness of the old washhouse by examining the leakages and the conduits of the mine supplying water (ACVOC-AHT-A103, 8/6/1868: f.48). However, the technical commission of public works, supervised by regional state delegates, confirmed that the conduits were not leaking (ACVOC-AHT-A103, 18/6/1868:51r; ACVOC-AHT-A103, 6/8/1868, 10/8/1868, 17/8/1868). Probably, this finding hastened the decision to "*prohibit water extractions in all public drinking fountains, washhouses and watering troughs with barrels* [...] *for uses different than drinking and cooking*" (ACVOC-AHT-A103, 22/6/1868: f.52). In this meeting, the Council also asked the 27-year-old water company to increase the flow of water in the drinking fountains deemed "*insufficient at present to supply the town*" (ACVOC-AHT-A103, 22/6/1868:f.52-52r and 25/6/1868). This decision reflects the fact that most significant coping practices documented were led by the water company *Mina Pública d'Aigües de Terrassa.* Under the supervision of the municipal authorities, the water company repaired decentralized water facilities to secure water supply in the new urban areas that, since 1820s, expanded around the historic town centre (ACVOC-AHT-A103, 27/8/1868). In December 1868, for instance, the private company initiated a project to renovate and improve the water deposit of a drinking fountain initially constructed in 1844 in an area of city expansion (ACVOC-AHT-M135, exp. 2332/19, 1868; ACVOC-AHT-A103, 3/12/1868 and 7/12/1868; Oller et al. 2007; see Fig. 4.8). Finally, it should also be noted that the drought coincided with a revolutionary period in Spain that changed Council composition and organization (ACVOC-AHT-A103, 7/10/1868), although we have not documented a direct influence of this political process on the coping practices reported.

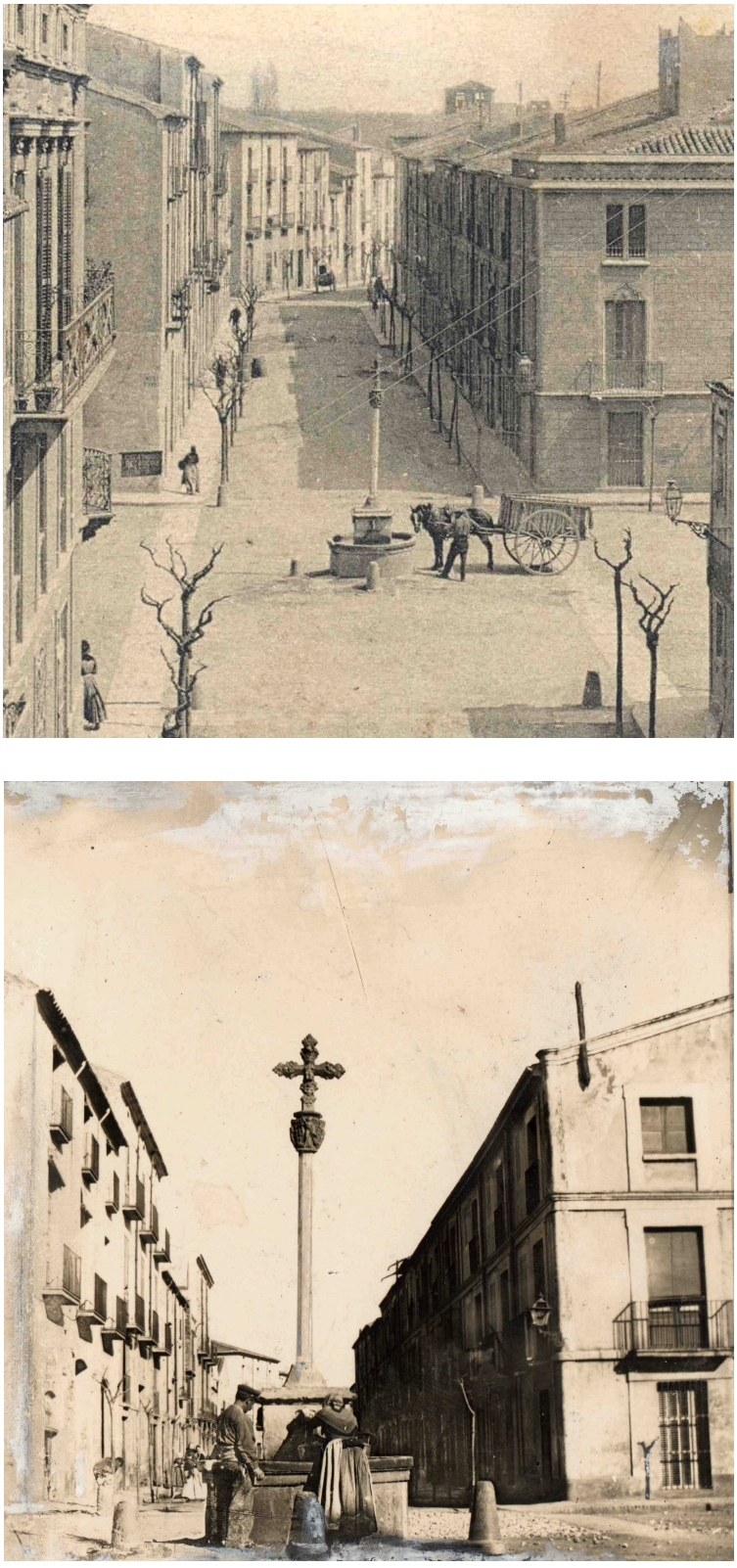


Figure 4.31. "Creu Gran" drinking fountain and watering trough renovated in 1868 (Terrassa, 1890s and 1910, respectively). Source: Reproduced with permission. AMAT, Town Collection, exp. 126381 and AMAT, Ragon Collection, exp. 56574.

Summary and discussion

In sum, strategies to cope with drought changed during the 1808-1870s phase, following the transformations in the water regime and the regional context of industrialization and state centralization. In the first decades of the modern phase, Council responses were similar to those of the previous phases (e.g., rain rogations), but also included other responses that occurred continuously during the eighteenth century, such as limitation to private water exploitations, interpretation of water rights, and resolution of water conflicts. In the last decades of the phase, traditional rain rogations were also documented, but new strategies appeared. These new strategies were co-managed by the public and private water sector and focused on the improvement and expansion of the water supply network following urban growth. Health control through the improvement of the water supply system was an important municipal attribution during the whole phase, even more than in previous ones. The municipality, therefore, basically addressed the impacts of droughts on urban water supply inexorably coupled with (modern) water scarcity. During this phase, local initiatives to cope with droughts started to be embedded in a multilevel governance context which included local actors, such as the Council, the industrialists, the private water company, and the experts, as well as non-local actors, such as regional delegates of the state (e.g. *governador*) and other state agencies.

From this phase, we can also learn about the bi-directional relationship between droughts and water governance. In other words, while water governance can create water scarcity, as we have seen, drought can also favour - together with other factors - transformations in the local water governance system. The process of privatization of the water supply that took place in many Spanish villages and cities in the second half of the nineteenth century was largely driven by the combination of poor municipal finances, increasing population demands, and water-fuelled industrialisation (see Ruiz-Villaverde et al. 2010, March 2010). Yet, the combination of climate-driven water shortfall (the mega-drought), the local context of water scarcity (due to the imbalance between growing water demands and the low availability of water), and the changing governance structures (the 1835 liberal legislation deregulating groundwater rights) propelled an earlier process of urban water privatization in the case of Terrassa. Posterior local adaptations to drought were shaped by such transformation of the local water governance. Particularly, the private water company adopted a key role in water supply during drought events, as illustrated in the above recount of the 1867-1868 drought.

Table 4.12. Summary of changes in local adaptation to droughts during the study period.

	Adaptation core questions		
	WHO?	**HOW?**	**TO WHAT?**
Phase 1: 1600-1720s	Local Council, sometimes with neighbouring councils, influenced by food merchants and debt creditors	Strategies to secure and ration water and staple food. Collective rogation rituals	Agricultural droughts, hydrological droughts
Phase 2: 1720s-1808	*Ayuntamiento borbónico*, increasingly subordinated to royal delegates (e.g., *corregidor, Intendencia*)	Need to deal with conflicting interests over water. Strategies to secure water supply. Collective rogation rituals	Prominence of hydrological droughts. Water scarcity
Phase 3: 1808-1870s	*Ayuntamiento Constitucional*, subordinated to state delegates (e.g. *governador civil*), and co-managed with private water companies	Strategies to secure and expand water supply. Collective rogation rituals	Prominence of groundwater droughts. Water scarcity

5. CONCLUSION

Open debates about the direction and magnitude of change in adaptation to climatic extremes during "modernization" call for more studies documenting and explaining the complexities of such patterns. In this work, we report changes in local responses to drought impacts, the characteristics of the strategies implemented to cope with them, and the actors affecting and deciding on local drought adaptation strategies between 1600 and 1870s. We also document some continuities along the three centuries. We think that our findings, while in line with previous literature, also provide two novelties contributing to current debates on adaptation.

Two of our findings mesh with previous literature. First, we found that rain rogations became long-standing strategies during a period of deep transformations. This finding adds more evidence on how cultural changes, and therefore cultural adaptations, are complex and slow. In other words, it confirms that secularization was not a one-sided unilinear shift from religious to scientific ideas and practices, but a more complex process during which religious and

scientific explanations and responses to climate extremes coexisted (Beattie 2004, Beattie and Stenhouse 2007, Mauelshagen 2009, and Janku et al. 2011). Second, while in the pre-industrial phase food and water impacts seem to be equally relevant, in the transition and modern phases water impacts gained attention, as reflected in the fact that Council initiatives to secure food during drought events are only reported in the pre-industrial phase. At first sight, our findings dovetail with previous studies stating that improved agricultural and food security systems in Europe during the eighteenth and nineteenth centuries reduced the need to adapt to food scarcities during climate extremes (e.g., Gil-Guirado et al. 2016). Nonetheless, it is worth to say that, despite lower public intervention, some social groups probably remained vulnerable to such scarcities and famines associated with or exacerbated by climate extremes (see Endfield and Fernández-Tejedo 2006, van Cruijningen et al. 2012). As Adamson (2014) has pointed out for the case of India, nineteenth-century food security improvements could increase households' food dependency on markets and, in certain droughts, turn into extensive famines. Future research should therefore contextualize the role of local governments on dealing with drought-derived food impacts within the debates about the changing vulnerability of food systems to environmental changes (see Fraser 2006, 2011).

Two novel findings from this work merit attention. First, we found that decisions regarding drought adaptation slowly became more hierarchical and centralized in the transition phase, and embedded in a multilevel governance context during the modern phase. This process is explained by the eighteenth-century political centralization context lead by the reformist Bourbon state in Spain and the Spanish colonies and the consolidation in the nineteenth-century of the state-building project (Lynch 1992, Orduña 2005, Fontana 2007, Rodrigo-Mora 2010). Indeed, the actors involved in or shaping local adaptation changed across the study period. For instance, debt creditors, who exert notable power during the seventeenth century limiting the range of response options to droughts, were somehow replaced by the state agencies supervising municipal budgets in the nineteenth century. Thinking historically about who was involved in local adaptations can help to situate "modern" institutions weaknesses and path-dependencies. For instance, current policies for urban adaptation to climate change, such as the 'Mayors Adapt' initiative, face several challenges. Among them, the development of multilevel approaches to plan, fund, and implement adaptation actions and the integration of adaptation goals and principles into day-to-day decision-making remain key (Nalau et al. 2015, Shi et al. 2016). Two barriers identified to such institutionalization of adaptation are "modern" governmental fragmentation and poor vertical coordination between levels of government (Vogel and Henstra 2015). Our case study shows how decisions on local

adaptations to droughts were progressively inserted in such multilevel systems of governance during "modernization".

The second novel finding of this work is that while local responses to (hydrological) droughts were driven by the changing ways to access, manage, and exploit water, some droughts were also fundamental to shape the development of the local governance of water. This observed historically-changing relationship between water regimes and droughts highlights the need to take seriously policy fields such as the water sector when dealing with the local manifestations of climate change. In fact, our finding agrees with recent calls for considering a hydrological perspective that better explains and helps to manage most droughts impacts (Van Lanen et al. 2016). In Catalonia, conflicting interests over local water resources seem to intensify from the mid-eighteenth to the mid-nineteenth century. In our case study, hydrological droughts during this period were coupled with underlying water scarcity caused by this increased use. Indeed, the liberalization of the old water rights in Spain during the first half of the nineteenth century opened up a window of opportunity for the privatization of groundwater resources. Our case study shows how the combination of the new legislation, the mega-drought, the water scarcity, and several other contextual factors fostered the creation of a powerful private company which still today is in charge of the urban water supply. In fact, the local water company is cited in the urban water supply literature as the oldest documented private water company still operating nowadays in Spain (Ruiz-Villaverde et al. 2010, Matés 2014). The establishment of the company implied that subsequent drought episodes were co-managed by the public and private water sector and this collaboration mostly concentrated on catching and distribution water facilities.

Overall, this work suggests that without a long-term approach we cannot recognize and explain the "moments of transformation" that critically changed environmental governance systems and, ultimately, adaptation patterns. Further historical examples explaining such moments of transformation can contribute to make more grounded the debates about adjustment and transformation that today abound in the adaptation to climate change literature.

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CHAPTER V

Conclusions

1. Theoretical contributions

This thesis aims to bring historical accounts to research on the human dimensions of climate change to help in the understanding and conceptualization of long-term patterns of adaptation to locally-manifested climate extremes. It contributes to the emerging, but still scarce, literature using concepts and analytical frameworks from the climate change literature to study changing relationships between societies and climate, climate variability, and climate extremes (see Orlove 2005, Fraser 2007, Endfield 2008, Adamson 2014, Kelso and Vogel 2015, Hannaford and Nash 2016). The empirical chapters of this dissertation contributed to this cross-fertilization endeavour in three different ways.

First, I used **analytical categories** used in the climate change and global environmental change literatures to systematically classify past adaptation practices. Specifically, in Chapter II, I applied descriptive categories such as institutional and infrastructural decisions (derived from Smit et al. 1999, Noble et al. 2014, and Anderies et al. 2004) to classify the wide range of strategies implemented by early modern communities to cope with droughts. In the same line, in Chapter III I built on the work of Halstead and O'Shea (1989), Agrawal (2008), Thornton and Manasfi (2010), and Gómez-Baggethun et al. (2012) to derive analytical categories emphasizing the goal of adaptation (e.g., diversification, rationing, and exchange) and applied them to the analysis of household and community adaptation strategies. The use of a classification system recognized in the climate change literature to understand past adaptation strategies not only helps to visualize the patterns and trends of adaptation processes, but it also contributed to compare the relevance of some strategies in different (past and present) contexts, thus allowing for some level of generalization on the relevance of given categories. For example, the use of the mentioned adaptation strategies classification system allowed me to detect, in Chapter III, a lack of references to mobility strategies in the reviewed documentary sources, a strategy that has been important in similar societies and environments. Such findings are helpful in defining future research agendas: is mobility an adaptive strategy increasingly used as transport opportunities improve across time? or it is just that I was not able to detect this strategy from the sources?

Second, I incorporated a **multilevel perspective** to uncover how long-term adaptation patterns developed across different levels of social organization. This analytical framework derives from two intellectual traditions slowly infused in the adaptation literature, i.e., complex socio-ecological systems and European policy analysis. The first tradition emphasizes the interactions and feedbacks among distinctive temporal, spatial and management scales of socio-ecological

systems (Gunderson and Holling 2002, Cash et al. 2006). The second tradition refers to the multiple levels or spheres of governance, including European, national, and sub-national policy arenas (Kern and Bulkeley 2009). This dissertation explores the differential contributions of the two traditions when applied to historical processes. In Chapter III, I used the approaches of the first tradition to discuss overlapping and possible cross-level interactions between adaptation strategies applied at two specific organization levels, i.e., the household and the community. In turn, in Chapter IV, drawing from the second tradition, I analysed changes in the governance system occurring over a long period of time characterized by state construction and initial liberalization. During this period, multiple public and non-public actors from organizational levels beyond the local were increasingly co-involved in water governance thus shaping local actions and decisions to cope with and adapt to droughts.

Finally, through this work I argued for the need to develop a **long-term perspective** in order to reinforce the approach that understands adaptation as a set of dynamic and historically-contingent processes. As Simonet (2010) has noted, the notion of "adaptation" refers to both a process (i.e., the actions undertaken to adapt) and its outcome (i.e., the resulting successful situation in which the actors can better live or cope with the stressor). The ambivalence of the term can lead to many interpretations on what is ultimately adaptation. While climate change research often focuses on the short-term effectiveness of adaptation, approaching adaptation as a set of processes can help recognize key questions such as the historical legacies affecting or conditioning contemporary adaptations, the accumulated (and sometimes forgotten) past experience, or the long-term effects of adaptation decisions upon different social structures (Pfister 2010, Adamson 2014, Wise et al. 2014). Particularly, by approaching adaptation to droughts as historical processes, in Chapter IV I identified and explained crucial moments of transformation which had long-term implications in water governance regimes and subsequent adaptations.

This dissertation also informs ongoing debates from **historical literature** of climate, disasters, and risks, while challenging some of their assumptions. The analysis in Chapter II suggests that a wide and dynamic repertoire of practices to cope with droughts was developed during the early modern period, adding evidence to the studies that challenge static, passive, or apocalyptic views of pre-industrial climate adaptation strategies in Western societies (Juneja and Mauelshagen 2007, Gerrard and Petley 2013). Indeed, I noted that drought-related Council decisions decreased between 1600 and 1715, showing that change in adaptation patterns may not be always incremental over time. I explained this reduction - and even lack - of responses by discussing the role of contextual factors that threatened local communities

more immediately in the seventeenth-century Spain: war and public debt. Hence, the discussion revisits the debate about the causality of adaptation and (neo) climate determinism by pointing out the need to take also into account long and slow non-climatic processes to understand changes in adaptation patterns. In Chapter III I enriched the debate about whether risks in medieval and early modern societies were tackled by "prudent peasants" or "prudent villages" (McCloskey 1991, Richardson 2005), bringing the new insight that the two organizational levels - i.e., households and communities - contributed in different ways to adaptation to recurrent droughts in Western (early modern) peasant societies. Finally, in the third article (Chapter IV), I contributed to previous debates on how adaptation to climatic extremes changed over the course of "modernization" (e.g., Messerli et al. 2000, Mauch and Pfister 2009, Gil-Guirado et al. 2016). Particularly, I shed light on the complex processes operating during this long transition period which changed adaptation patterns through centralization and hierarchization of decision-making, decreasing public attention to food impacts of droughts, and transforming the ways to cope with droughts impacting water supply.

2. Methodological contributions

This archival-based dissertation contributes to the slowly growing body of empirical studies that use documentary sources to understand changing relations between climate and society (e.g., Pfister 2007, Adamson 2015, Gil-Guirado et al. 2016, Veale et al. 2017). Particularly, this work provides three methodological contributions to these efforts.

The first methodological contribution relates to the uses of historiographical sources. The work presented here suggests that, while pointing at innovative sources and re-examining traditional ones are critical exercises, further attention is needed on how to process and analyse these valuable sources. This dissertation developed and described in detail the systematic techniques of data collection and data analysis employed. Although these methods were adjusted to a particular case study and directed to specific documentary sources, and are therefore not generalizable, the process itself can be used to inspire future researchers, as the documentation of the methodological process makes it easy to discuss potential biases and caveats, which might result in methodological improvements.

Second, in order to inform and engage with climate change debates, I designed methods of data analysis which aim to foster such cross-fertilization. Hence, as I argued in the first section of this chapter, I used an interdisciplinary lens to choose the analytical perspectives (i.e.,

frameworks to classify adaptation practices and multilevel analysis). It should be noted, however, that while the use of these classifications can help reveal gaps in the analysis of past adaptive strategies, these categories should not be uncritically applied to historical data. After all, these classifications have been often built up thinking about contemporary small-scale societies (for some exceptions see Halstead and O'Shea 1989 and Gómez-Baggethun et al. 2012), and the uncritical use of such categories in past societies can condition the way we document and comprehend their adaptation patterns (see an elaboration on how our subjective preferences to analyse the past emerge from the experiences and debates of our own times in Chakrabarty 2011).

The third methodological contribution of this work is the development and operationalization of two long-term perspectives to study climate-society relationships and particularly changing adaptations to climate extremes over long periods of time. On the one hand, I carried out a quantitative analysis of the timing of responses to drought between 1600 and 1715 (Chapter II). Quantification allowed me to graphically display the number of documented decisions per decade, which in turn helped visualizing possible changing adaptation patterns over the study period. On the other hand, I developed a qualitative analysis of long-term adaptation patterns. Particularly, in Chapter IV, I used periodization, historical narrative, and the framework of the adaptive cycle to explain and situate changing ways of adapting to drought over the course of "modernization", contributing to explain the multiple drivers shaping adaptation processes.

During the development of this work I also noted some methodological caveats and limitations that the researcher faces when drawing on archival sources to do research on past adaptation strategies. In overall, I found difficulties to document inequalities among social groups and differences in their ability to cope with droughts. I was also unable to apply certain well-known analytical distinctions, such as coping vs. adaptation strategies, to the actions and decisions documented by archival research. These caveats are important as they limit the dialogue between research on past and current adaptation strategies.

Chapter II also highlighted two challenges of undertaking quantitative long-term archival reviews. First, the approach requires high research effort for gathering little information. For example, only 5% of the Council meetings held during the study period recorded decisions regarding responses to drought and, in some cases, no decisions were made during an entire decade. However, I had to review all the documentation to reach this conclusion. And second, quantitative systematic analyses of adaptation practices do not necessarily explain the reasons behind adaptation patterns, for which such analysis needs to be carefully complemented with

qualitative data and contextualized with secondary sources. In Chapter III, I discussed how documentary gaps and biases can limit and condition our narratives of past social adaptation to climate extremes. Particularly, these biases can result in a reduction of the diversity of strategies documented and downplay strategies performed by social groups not directly involved in the production of the documentary sources. Finally, the long-term and multiple-source analysis from Chapter IV adds concerns, already raised by previous research, about how to address the comparability of sources from different historical periods.

3. Policy implications

Scholars debate how much can we learn from history for current debates on climate change. The environmental historian J. McNeill (2008: 44), for example, concluded that history can only partially help us with global warming challenges because "*there is no precedent in human history for a global disaster that affects whole societies in multiple ways at many different locations all at once*". Similarly, Adamson (2015: 606) suggested that learning direct lessons from social adaptation to climate extremes in the past is limited "*because society continually changes, as does climate*". While acknowledging that analogies to current climate change challenges might not be identifiable, as Carey (2012: 242) summarizes, "*historians and others doing historical climatology have begun to extract lessons from the past*". For example, Carey (2012) highlights how history proves that adaptation to climate change is not going to occur simply because we scientifically understand the process, as adaptation stems from firm policy decisions. Indeed, past governmental policies were not only driven by climate science, but also by other political agendas such as imperialism. Similarly, researchers have also shown how historical perspectives can inform contemporary climate adaptation challenges (see Hannaford and Nash 2016).

While acknowledging the inappropriateness of deriving direct lessons from the past, I make the effort to elevate my findings to a higher level of abstraction to derive five implications for policy research from the results presented here. First, my results suggest that adaptation is a process that happens over long periods of time. Strategies that seem adaptive in the short-term might have unintended consequences over long-term periods. Therefore, policies aiming to improve adaptation strategies should be constantly revised and re-adapted to the changing context in which they are implemented, and calls for “urgent” adaptation actions need to take into account the long-term nature of adaptation processes. Second, successful adaptation might involve different levels of governance, or actors that have power or influence at

different levels. Contemporary strategies focusing on a single level -such as the Mayors adapt initiative- might end up being unsuccessful unless they recognize and get the support of institutions and actors operating at other governance levels. Yet, processes of centralization can hinder place-based adaptation to the local manifestations of climate change. Third, specific analyses of a small region or locality can contribute to visualize and illustrate the importance of path-dependencies. For example, the private water supply system inherited from the nineteenth century in Terrassa determines the way how hydrological droughts are now managed and how local adaptation policies in this sector are planned. As a result, demand-oriented infrastructure agendas such as improving the connections with the regional system of catching and treatment facilities called ATLL are increasingly presented as the solution to future climate change and water challenges. Recognizing the path-dependency embedded in the adaptation agenda might help look for alternative solutions. Fourth, drought has many meanings, and impacts in different ways societies as they change. In our case study, adaptation strategies that successfully targeted hydrological droughts before the "water fever" might have failed to adequately respond to droughts influenced by increasing industrial and urban water demand (i.e., human-modified droughts). Therefore, adaptation plans should be continuously revised and contextualized, as well as changed along with the changes in the water regime. And finally, we have also seen how adaptation strategies and their relative importance might change as people adapt to more immediate and direct stressors such as wars or debt. This finding adds evidence to previous literature on multiple stressors, and as such has important policy implications, as policies narrowing down adaptation to only climate change might prove irrelevant in people's daily life if they overlook more immediate challenges for people´s lives and livelihoods.

4. Outlook for future research

I identify two lines of possible further inquiry for adaptation research. First, future research could further elaborate analytical approaches and current debates on adaptation that build upon, or presume, a temporal dimension such as the adjustment vs. transformation perspectives, or the coping vs. adaptation categories, by grounding them on historical studies. For instance, distinguishing between adaptation and coping involves decisions on what do we mean by "short-term" and "long-term" periods and whether these decisions can be applied universally to all historical and geographical contexts. Second, we need to expand studies using and operationalising multilevel perspectives. My research brought evidence showing how such

analysis can contribute to better understand how complex adaptation processes develop across spatial, temporal, and governance levels.

The historiography of climate change addressing the socio-cultural dimensions of past human relations with climate is growing, but still remains unevenly distributed over historical periods and places to draw more general conclusions. For instance, my case study is located at the western Mediterranean area, where few similar analyses have been conducted (for some examples in Spain see Alberola and Olcina 2009, Alberola 2014, Gómez-Baggethun et al. 2012, Gil-Guirado et al. 2016). Future empirical studies might help to situate and compare reported social responses to a (presumably) similar climate, historical turning points, and potentially shared drivers. This literature can also benefit from integrating the insights from other bodies of knowledge beyond climate sciences or historical disciplines. For instance, recent developments on hydrology establishing new definitions and terminology of droughts can help re-think and improve the way we approach, detect, and analyse societal relations with droughts. Further and enhanced interdisciplinary collaborations can contribute to this end. Also, establishing long-term collaborations between researchers and those who safeguard, and often know best, the archival sources can definitively benefit research. Explaining the needs of our research and sharing the findings with archivists can in turn improve cataloguing efforts and facilitate the identification of valuable sources.

Finally, we need more studies emphasizing the differential ways in which various sectors of the society experience and adapt to past climatic extremes. For example, despite their key role on water management and provision, I found scarce mention to women in the reviewed documentary sources. Moreover, none of them was directly written by women. Only Court proceedings and photographs - most of them recorded at the end of the study period – make visible the role of women in managing water and therefore provide some information on the differential ways men and women might have suffered and coped with drought (see Fig. 5.1). Similarly, I recurrently reported drought-driven rituals (i.e., rain rogations) in Council minutes, possibly because of their symbolic role, but probably also because of the importance of ecclesiastic institutions in the social life of the early modern period. Yet, other equally important strategies led by less powerful groups might have been less well documented by the sources. Such neglects are important because biased records shape the way we memorialize past climate and society relationships (Endfield 2014) and therefore how we imagine future ways to experience and adapt to the local manifestations of climate change in our complex, diverse, and unequal communities. Critical examination of the past, combined with the insights

from other interdisciplinary research, can therefore pave the ground to inspire more inclusive, sustainable, and just climate change adaptation strategies.

Figure 5.32. Public washhouse (Sant Julià de Vilatorta in Barcelona province, ca. 1915-1925). Source: ANC, Collection Brangulí (ANC1-42), exp. 005238.

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