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Prudent peasantries:
Multilevel adaptation to drought in early modern Spain (1600-1715)

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Abstract:
Climate change being a product of industrialization 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 weather 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 that many strategies used by households and communities overlapped, potentially generating a redundancy effect and fostering 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 anthropogenic climate change.

1. INTRODUCTION

Adaptation to climate change has been defined as the adjustments made in practices, processes, and structures to cope with changing climatic conditions.[1] 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), or households (e.g., pooling).[2] Despite the potential of past accumulated experience to help identify, assess, and reflect on how current and future societies can adapt to climate change, the contribution of historical studies to research on adaptation to anthropogenic climate change is still limited.[3] In this article, we offer new empirical and methodological insights to strengthen such interdisciplinary dialog about human adaptation to a changing climate.

Adaptation strategies to climate variability take place at a range of scales.[4] Indeed, researchers have noted that successful climate adaptation does not take place at a single level of social organization, but across households, communities, nations, and international platforms in multilevel adaptation processes.[5] Thus, investigating how we collectively adapt to climate changes, variability, and extremes requires an understanding of multi-scalar interactions. The question remains open on whether there are specific levels of social organization that enhance more efficient adaptation processes, and, if so, why.

Past historical events can provide insights to understand how adaptation processes have taken place at different levels of social organization. Indeed, the historical perspective might provide a background to improve contemporary efforts for multilevel agreements and coordination. However, few studies have explicitly examined how past societies adapted to climate variability and extremes across different levels of social organization.[6] Economic historians concerned with the management of risk in preindustrial societies have described two critical levels: communities and households. For example, McCloskey described how, despite the short-term cost of diversification, English peasants opted for scattering plots across micro-climates to reduce the risk of harvest failures, arguing that such 'prudent peasants' were the primary actors dealing with risks.[7] This individualistic approach has been contested by other authors, who

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[1] 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.

[2] For recent studies in arid and semi-arid areas, see "Authors 2013a"; "Authors 2016a".

[3] 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.

[4] 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.

[5] "Authors 2016b".

[6] 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.

[7] 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.

argued that English medieval societies had developed a variety of cooperative institutions (i.e., farmers' fraternities and customary pro-poor laws) to pool risks and thus collectively ensure their livelihoods.[8] In other words, the conception of the 'prudent peasant' was enriched with the idea of the 'prudent village'. In this paper, we argue that the two views are not exclusive and that both levels of organization in preindustrial societies – communities and households – contributed to cope with climate variability in varying and complex ways.

To examine this question, we study the strategies to cope with recurrent droughts developed at the community and household levels during the seventeenth and early eighteenth centuries. Our case study focuses on two neighbouring municipalities of north-eastern Spain (Terrassa and Sant Pere), where droughts were the most salient climate impact.[9] Although the municipalities shared similar cultural, organizational, and environmental attributes, they differed in terms of settlement patterns, economic activities, and social structure. We use archival data from the study period to reconstruct social responses to drought developed by Councils and households. We then compare the strategies documented at the two levels to discuss how they differed and overlapped.

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 that explain the relatively few historical treatments of vulnerability are 1) the lack of consensus on definitions and approaches to vulnerability, 2) the difficulty of identifying such an intangible concept in the historical record, and 3) our imperfect knowledge about past climate (e.g., insufficient data resolution over spatial and temporal scales).[10] The same reasons might apply to the study of past adaptation, although adaptation has a more tangible expression than vulnerability and may be easier to track in the historical record. In this article, we explore two methodological options to overcome the problems that so far have limited the historical treatment of adaptation. First, we use a specific taxonomy to classify adaptation. The taxonomy used is receiving growing consensus in the literature on adaptation to climate change, but has so far been scarcely applied to the study of past societies.[11] Although we are aware that this taxonomy imposes a present-centred approach that risks simplifying the 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 our methodology to collect and analyse archival data in detail. In many historical studies, methods are either implicit or developed in footnotes, something that hampers communication with interdisciplinary audiences, which are not used to reading historical studies.[12] We make our empirical choices explicit to facilitate

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[8] 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.

[9] "Authors 2016c".

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

[11] For an exception, see "Authors 2016a". See literature used to classify adaptation in footnote 37.

[12] Some historians 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).

interdisciplinary discussion about the methodological constraints of reconstructing adaptations to climate with archival sources.[13]

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, which during the study time was integrated in the Crown of Aragon). In Spain, the studied centuries correspond to the early modern period, an age of rising urbanization and early market integration. However, while sixteenth century Spain experienced economic and cultural growth (the so-called Golden Century), the seventeenth century was mostly a period of economic and cultural decline.[14] The population remained strongly Catholic at a time of destructive religious wars in much of the rest of Europe. The studied period is characterized by climatic changes due to the Little Ice Age, although the implications of these climatological events for the Mediterranean basin, and specifically for the Iberian Peninsula, remain debated.[15]

Early modern societies in Spain were organized at multiple scales. In Catalonia, the administrative scale had several levels. Provinces were 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 overlapped with the administrative one. The diocese of Barcelona was divided into parishes, which not always overlapped with municipalities. Our case study focuses on two municipalities (Terrassa and Sant Pere) comprising seven different parishes (Figure 1, Table 1).

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[13] 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.

[14] Pablo Fernández-Albaladejo, *La Crisis de la Monarquía* (Barcelona: Crítica/Marcial Pons, 2009).

[15] 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.

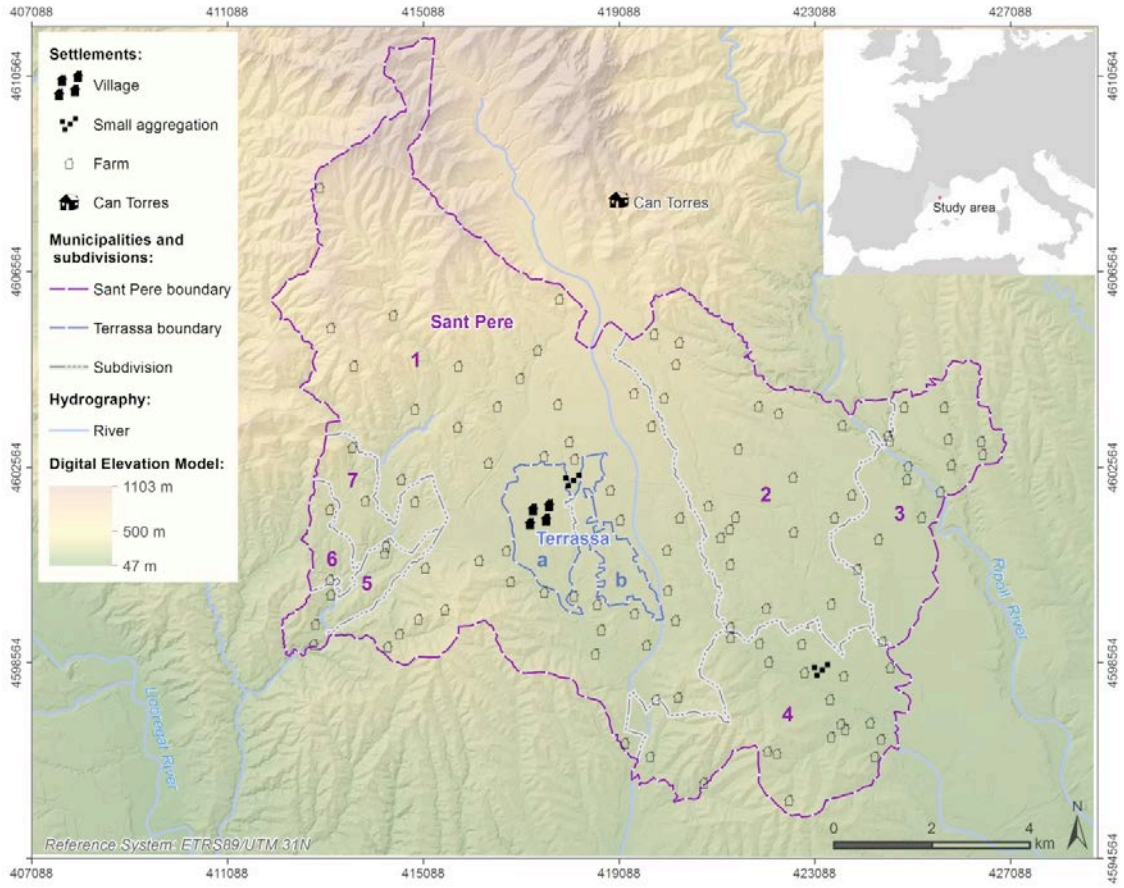


Figure 1. Map of the study area. The municipality of Sant Pere comprised the parishes of Sant Pere (1), Sant Julià d'Altura (2), Sant Vicenç de Jonqueres (3), Sant Quirze (4), Sant Miquel de Toudell (5), Sant Martí de Sorbet (6) and Santa Maria de Toudell (7). The municipality of Terrassa included the village of Terrassa (a) and another jurisdictional territory called Quadra de Vallparadís (b).[16]

Table 1. Population, area, and population density in the municipalities of Terrassa and Sant Pere.[17]

	Terrassa	**Sant Pere**
Households in 1553 [estimated population]	210 [840]	125 [500]
Households in 1700-1701 [estimated population]	299 [1196]	185 [740]
Area (sq km)	5	109
Household density in 1553		

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

[17] 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. Municipal area estimated from fig. 1. See methods section and tab. 2 for an explanation of how documentary sources are cited throughout this paper.

(households per sq km) [estimated density in people per sq km]	42.1 [168.3]	1.1 [4.6]
Household density in 1700-1701 (households per sq km) [estimated density in people per sq km]	59.9 [239.7]	1.7 [6.8]

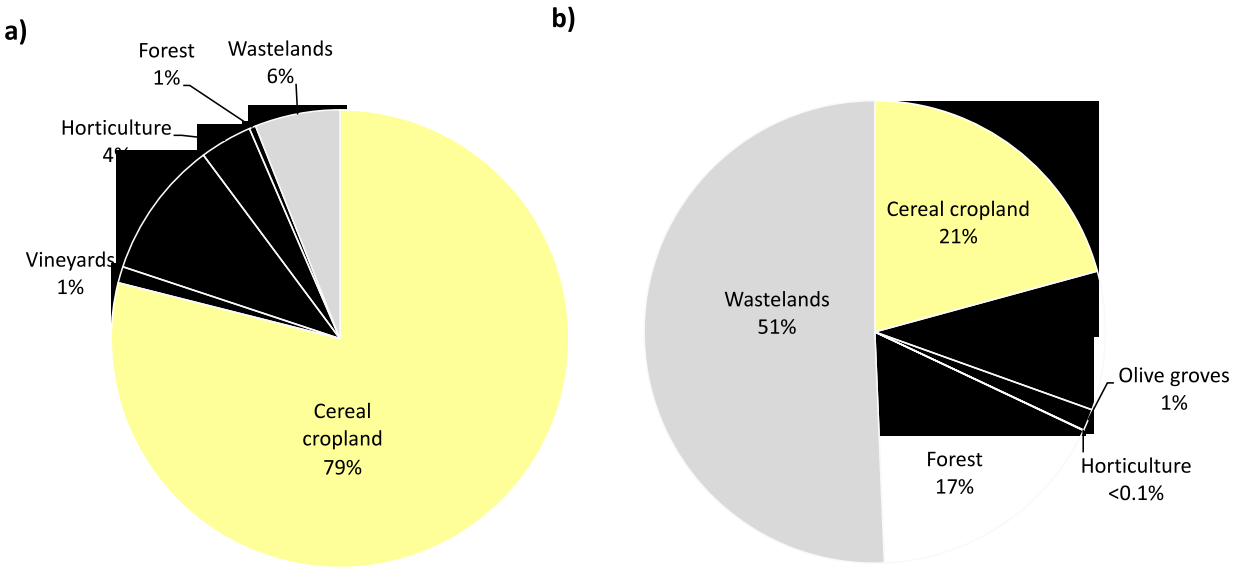
From the late twelfth to the fifteenth century, the study area was governed by a single political institution: the Council of the village and the territories of Terrassa, which had jurisdiction over the walled village and the farmhouses scattered across the seven different parishes (Figure 1).[18] The village and the parishes were represented in the Council, although they often had disputes for their relative weights in decision making. The sixteenth century was marked by a demographic and territorial expansion of the village, which propelled villagers' demands for more political power relative to the inhabitants of the farmhouses. By mid sixteenth century, the tension was further exacerbated by the decision to invest on a new church inside the village, which threatened the status of the outside parish church.[19] The differences on matters such as the fiscal policy and the system to elect Council members fostered division between the village and the surrounding farmhouses. In 1562 a privilege granted by the King formalized the administrative and political segregation of our study area into two sovereign entities, i.e., the Council of Terrassa and the Council of Sant Pere.

Water resources in the studied municipalities were scarce. They 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. Approximately 3 km of its middle course crossed the north-eastern part of Sant Pere (Figure 1). Groundwater was also used, particularly the superficial aquifers in the alluvial plain, exploited with shallow wells and underground water tunnels. Therefore, the water bodies upon which the studied communities relied on were highly dependent on rainfall. Nowadays, mean annual precipitation in Terrassa is 584.1 mm, although during the late seventeenth century rainfall was probably higher.[20] According to documentary proxies based on rain rogation ceremonies, between 1605 and 1710 droughts occurred every 4.6 years, representing a recurrent hazard which regularly affected agricultural production, food security, water supply, and social and economic well-being.[21]

Terrassa

[18] M. Solé, 'El Marc Institucional i Polític de la Terrassa Moderna', *Terme* 4 (1989): 26–42.
[19] J. Verdaguer, 'Les Xacres del Pont de Sant Pere de Terrassa', *Terme* 22 (2007): 197–214.
[20] 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.
[21] "Authors 2016c".

In the study period, population density in the municipality of Terrassa surpassed 200 people per square km (Table 1). The population fluctuations between 1553 and 1700 cannot be traced due to the absence of continuous demographic data. However, local studies show trends of population decline by mid-seventeenth century followed by an increase starting in the 1680s, reaching around 300 households at the beginning of the eighteenth century.[22] By the early eighteenth century, cereal cropland was, by far, the most extensive land use in the area, followed by olive groves and horticulture (Figure 2.a). As other Catalan medium villages, most residents earned their living from agriculture, livestock, and artisanal activities, principally wool and, to a lesser extent,



flax manufacturing.[23]

Figure 2. Land uses in the village of Terrassa (a) and Sant Pere (b) by early eighteenth century.[24]

Sant Pere

The second studied municipality integrated seven parishes (Figure 1). We refer to it as Sant Pere because this was the most important parish of the municipality in terms of population, area, and political power. The farmhouses of the municipality of Sant Pere were scattered across a territory of 109 square km. Although the population increased during the study period, human density remained relatively low (Table 1). Only two parishes had small aggregations of houses (Figure 1). Wastelands covered at least half of the territory in the early eighteenth century (Figure 2.b). Wasteland and forest patches were managed for multiple uses such as grazing and shifting cultivation. Cereals and vineyards were predominant in cultivated areas. Rain-fed agriculture, livestock, and forestry were thus the main livelihood sources.[25]

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[22] Berenguer and Coma, 'L'Evolució del Poblament'.
[23] I. Almazán, 'Terrassa en els Segles XVI i XVII: Entre la Solidaritat i la Por', *Terme* 4 (1989): 43–54.
[24] 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 the area of forest and wastelands was probably larger than reported in the sources.
[25] 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.

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.

Community strategies to cope with drought

We reconstructed community strategies to cope with drought by examining documentary records from the municipalities of Terrassa and Sant Pere (Figure 1). The main documentary sources used are the Council minutes of the two municipalities which have a similar format, content, and compilation system.

We conducted a systematic review of the Council minutes of the municipality of Terrassa between 1600 and 1715 (Table 2). These documents (3630 pages distributed in seven volumes) 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.[26] We conducted an exhaustive compilation of information regarding the Council´s decisions oriented to cope with direct and indirect effects of droughts.[27] Some of these decisions mentioned the participation of Sant Pere.

Strategies to cope with drought in Sant Pere within the period 1600-1715 were also reconstructed from the Council minutes, but using a sample of minutes (Table 2). This documentary source is also located in the ACVOC-AHT. Because the Terrassa Council minutes had longer temporal continuity, we used the data gathered from them as a reference to structure data collection from the Sant Pere Council, assuming that the two neighbouring communities were subject to the same drought patterns. Consequently, sampling for Sant Pere Council minutes followed three steps. First, as rogation ceremonies have been widely used by historical climatologists to identify agricultural droughts,[28] we listed the dates of the 24 rogation ceremonies (rain pilgrimages) identified in the Terrassa Council during the studied period.[29] Second, we excluded from the list the rogation dates falling within the temporal gap in the Sant Pere Council minutes (1649-1685). Finally, to identify impacts and ex-ante and ex-post responses to droughts, we reviewed the Sant Pere minutes written six months before and six months after the listed rogations. If drought-related information was detected during this 12-months period, we continued reading minutes until the drought had gone unnoticed in four consecutive Council meetings. This sample comprised 331 pages and represented 20.3 per cent of the total volume of available Council minutes in Sant Pere during the study period.

Table 2. Documentary sources consulted. Location includes the archive or the author, the archival collection, the complete name of the documentary series, and its English translation; citation code includes the acronyms of the archive and the documentary series, or the name of the author, followed by the date or the folio.

Location of documentary	Description	Citation code in the text

[26] Available at: http://arxiumunicipal.terrassa.cat/adigital.php [accessed 8 Nov. 2016].

[27] For a detailed reconstruction of drought-related strategies using this source, see "Authors 2016c".

[28] 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.

[29] See footnote 27.

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

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 neighbouring the two studied municipalities which illustrates the applied practices, everyday experience, and reflections of practitioners facing drought (Table 2).

In medieval and early modern times, agronomic texts 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 everyday decisions.[30] In this work, we reviewed 'The book of agricultural, cottage and pastoral secrets', a popular agronomic source (Table 2). Friar Miquel Agustí wrote this handbook by reviewing related work by classic authors (e.g., Columella) and coetaneous treatises (e.g., Charles Estienne's) but also based on observations and his own practical experience.[31] The treatise was published in Catalan in 1617 and translated into Spanish in 1626. It soon became a

[30] 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.

[31] 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.

popular handbook with about twenty editions by 1805.[32] 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 would be accessible to practitioners. The treatise consists of three volumes, including 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 strategies to cope with drought.[33]

The second source used to identify household's coping practices is private documents written by farmers, a promising historical source that has received scarce attention in climate research.[34] Peasant writings are a hybrid genre in-between autobiographies, account books, historical chronicles, popular agricultural treatises, and family memoirs. Torres calls them family books, since they were written within and for the family, often generation after generation.[35] 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 as the source that more closely matched the criteria of location, period, and content.[36] The family book was written discontinuously from 1699 to 1824 by at least three generations of heirs. We assessed the entire book in search for a sub-period with high quality records, i.e., homogeneous, continuous, dense, and reporting at least one drought event. According to these criteria, the selected sub-period was 1699-1704, which includes the drought of 1700-1701. The period represents about half of the total book length.

3.2 Data analysis

Data from the four primary sources used were entered in spreadsheets to summarize and identify strategies to cope with drought. Spreadsheets were complemented with relevant text fragments that were transcribed from the sources following standard palaeographic criteria.

Data gathered from the minutes of Terrassa and Sant Pere Councils 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 related impacts (186 in Terrassa and 31 in Sant Pere).

Data collected from the agronomic treatise and the family book included: 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, annotations were thematically coded to facilitate the analysis of adaptation practices. Themes included: i) resource accounts (e.g., charcoal, herds, wine), ii) accounts of flour (i.e., amount of wheat sent to the mill), iii) accounts of harvested grains, iv) monetary inputs, v) monetary outputs, vi) debts, vii) qualitative reflexions, viii) family notes, ix) historical chronicles, and x) other contextual data. For instance,

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[32] 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).

[33] Agustí 1617, f. 195 *et seq.*

[34] G.C.D. Adamson, 'Private Diaries as Information Sources in Climate Research', *Wiley Interdisciplinary Reviews: Climate Change* 6 (2015): 599–611.

[35] Xavier Torres, *Els Llibres de Família de Pagès, Segles XVI-XVIII : Memòries de Pagès, Memòries de Mas* (Girona: Universitat de Girona, 2000).

[36] 'Arxiu de la Memòria Personal', available at: http://www.memoriapersonal.eu [accessed 8 Nov. 2016].

we used the accounts of flour and harvested grains to assess when stored grains were critical to compensate drought-driven bad harvests.

Strategies to cope with drought collected from the four primary sources were coded drawing on previous classifications from the literature on adaptation to climate change.[37] We considered eight categories of strategies: forecasting, sharing and cooperation, diversification, exchange, storage, rationing, selection, and mobility (Table 3). We also considered an additional set of "supporting practices", including those that are not strictly coping strategies but are necessary to make them possible. Not all the categories were represented in the documentary sources.

Secondary sources were used to critically frame the primary sources, to interpret and contrast the collected information, 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 to the remains of the farm and its lands.

4. RESULTS

We present our results separately for the two levels of social organization: community and household. Table 3 shows the categories of coping strategies found in the documentary sources at both levels.

Table 3. Categories to classify coping strategies considered in the literature and documented in the sources, by level of analysis.[38]

Category	**Description**	**Category documented at**	
		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.	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 resources for later consumption.	X	X
Rationing (c, d)	Control of the exchange and consumption of limited	X	X

[37] 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 "Authors 2012".

[38] 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) "Authors 2012".

	resources		
Selection (d)	Selection of particular attributes of species, workers, areas, and water supplies as the most suitable to reproduce or rely on.		X
Mobility (a-d)	Seasonal or permanent migration		

4.1. Coping with drought at the community level

Droughts triggered a series of community coping mechanisms. The 1677 drought and food shortage affecting the two municipalities illustrates the causal links between drought, its impacts, and the social responses to them. According to the documentary sources, in March 1677, concerns on food scarcity due to an ongoing agricultural drought motivated the decision to import 7 cubic metres of wheat to Terrassa.[39] In April, the Councils of Terrassa and Sant Pere organized a rogation ceremony to pray for rain.[40] In May, as the supplies from the local market were unable to meet local demand for food, the Terrassa Council imported more wheat.[41] Thereafter imported and stored grains were rationed among the villagers. In addition, the Council purchased 3.5 cubic metres of grain at a high price.[42] When the wheat harvesting season was ending, 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 the rental of the bakery attractive for candidates.[43] Finally, in autumn, new creditors offered their services to fund subsequent grain purchases.[44] This example shows how responding to drought entailed the activation of a series of mechanisms at the community level, including the organization of collective rituals, Council intervention on grain supply, rationing of food, and management of food stores. Strategies like sharing and cooperation, diversification, exchange, storage, and rationing were likewise found in our data (Table 4).

Table 4. Strategies to cope with droughts led by the Terrassa and Sant Pere Councils (1600-1715). Some strategies were performed in collaboration between both Councils (AA); some were fulfilled independently in both Councils (AB); and some were only performed by the Council of Terrassa (A-).

Categories	**Terrassa**	**Sant Pere**	**Strategies to cope with drought**
Sharing and cooperation	A	A	• To organize collective pilgrimages to plead for rainfall.
	A	-	• To adjust and strengthen governance of community water supplies: defence of community water rights, implementation of mechanisms to tackle water conflicts.

[39] ACVOC-AHT, CMT, 5 Mar. 1677.
[40] ACVOC-AHT, CMT, 25 Apr. 1677.
[41] ACVOC-AHT, CMT, 9 May 1677.
[42] ACVOC-AHT, CMT, 19 May 1677.
[43] ACVOC-AHT, CMT, 28 Jul. 1677.
[44] ACVOC-AHT, CMT, 28 Oct. 1677.

	A	-	• To fix and repair collective water infrastructures.
Diversification	A	-	• To build new infrastructures to diversify water supply sources.
Exchange	A	B	• To regulate, negotiate, and follow up collective purchases of basic grains.
Storage	A	B	• To store grain in municipal granaries.
Rationing	A A	B -	• To regulate the distribution of collective grain and food supplies. • To reallocate water rights to limit water consumption, and establish and apply sanctions to control the use of water provided by collective infrastructures.
Supporting practices	A	A	• To organize an annual vow to renew the faith in the Montserrat Virgin, the deity towards which the rainfall rituals are directed.

Sharing and cooperation

In case of severe drought, the Councils organized an extraordinary pilgrimage to pray the Virgin of a close monastery to intercede with God to forgive the community for its immoral behaviour and bring rain.[45] During pilgrimages expectations of relief were shared within and across community members. From 1600 to 1715, the Terrassa Council minutes recorded 24 extraordinary pilgrimages to the Monastery of Montserrat motivated by droughts. At least 58 per cent (14) of these rain pilgrimages were celebrated in cooperation with the Council of Sant Pere (Figure 3), which contributed equally in terms of number of pilgrims and expenses like priests' subsistence allowances and candle wax.[46]

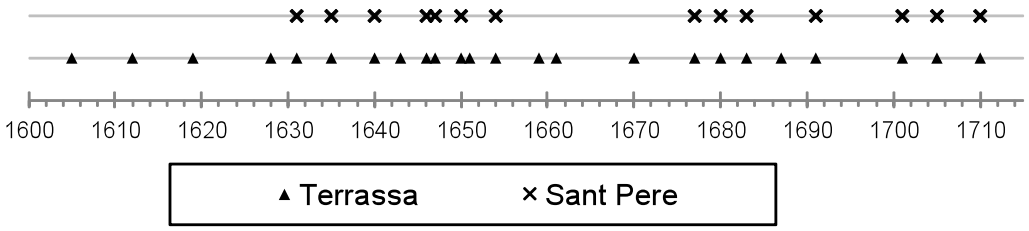

Figure 3. Rain pilgrimages organized by the Councils of Terrassa and Sant Pere, as reported in Councils' minutes.

In the case of Terrassa, cooperation between villagers was also crucial to secure the village's water supplies during drought periods. The Council defended collective entitlements and claimed water rights against higher level institutions such as the King and interceded in the resolution of water conflicts, for instance by responding to those

[45] Extraordinary pilgrimages were organized in addition to pilgrimages regularly held on an annual basis. Collective pilgrimages arguably contribute to community resilience by strengthening social cohesion during crises, reducing the emotional and psychological impacts of drought (e.g., generating a common feeling of hope), and 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; "Authors 2012".
[46] ACVOC-AHT, CMT, 3 May 1635; ACVOC-AHT, CMSP, 23 May 1635.

villagers affected by the negative effects of new water exploitations.[47] The Council also repaired infrastructures supplying water to the village such as the underground water tunnels.[48]

Diversification

Diversification strategies to cope with drought were recorded only in the minutes of the Terrassa Council and mostly consisted in the diversification of water supplies. For example, when the main water supply was drying out, the villagers excavated new underground water tunnels in the hills surrounding the village to secure the supply of water for the drinking fountains and the washhouses.[49] Thus, the village diversified its water sources to include both temporary streams and multiple tunnels collecting groundwater.[50]

Exchange

During periods of drought both municipalities increased their reliance on market exchange to obtain basic grains. In both communities, Council intervention to mediate grain exchanges was part of the local policies to secure access to basic food (e.g., bread grains, meat, and salted fish) and complemented household access to grains (i.e., subsistence and market). Market exchanges arranged under the auspices of Councils served as a temporary emergency strategy because the Council could only prolong bread supplies up to a maximum of three months.[51]

Storage

Municipal silos were an important infrastructure to secure food supply for the community. 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 an additional source of food and could buffer rises in food prices typically occurring after poor harvests.[52] Interestingly, in the reviewed Council minutes, we did not find any mention to the construction or repair of collective water storage devices (i.e., water tanks).

Rationing

The Councils of Terrassa and Sant Pere controlled the allocation of the food that had been imported and/or stored. Depending on the severity of the drought, different regulations were enforced for the allocation of grain across households: fixed amount of grain (same for all), free allocation up to an established maximum amount, or totally free allocation. In some occasions, drought events motivated more restrictive rationing. In 1611, for example, the public officers in charge established a cap of approximately

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[47] 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.

[48] 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.

[49] ACVOC-AHT, CMT, 30 Aug. 1624, 19 Jul. 1689.

[50] 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).

[51] See Appendix (tab. 1.A) for an estimation of how Council-led supply of grains in years of scarcity contributed to cover bread security.

[52] Documented examples in ACVOC-AHT, CMT, 1 Jul. 1631, 12 Jan. 1651; ACVOC-AHT, CMSP, 21 Mar. 1631, 28 Mar. 1631, 21 Apr. 1631.

50 kg of grain per household, while in 1609 grains were freely distributed.[53] In 1651, when the effects of drought on food supply added to the effects of the ongoing Reapers' War, the officers defined the minimum amount of grains to feed each household and confiscated the rest of the households' grains to take them to the municipal granary.[54]
Only the Council of Terrassa implemented water rationing strategies. During some droughts affecting village water supplies, the Council established strategies to control and limit the consumption of water by adjusting precedent rules. 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.[55]

4.2. Coping with drought at the household level

Our data revealed a range of household strategies to cope with droughts including forecasting, diversification, exchange, storage, rationing, and selection (Table 5). We present these strategies in two sub-sections, the first one describing strategies documented in the agronomic literature and the second one describing strategies documented in the Can Torres family book.

Table 5. Household level strategies to cope with drought 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	Strategies to cope with drought	Examples
Forecasting	T	• To monitor meteorological, biological, human, and physical indicators of drought.	• Prediction of next year dryness by interpreting bird migration.
	T	• To assess water resources to guarantee water availability.	• Dig experimental holes in the soil during summer to evaluate groundwater flows.
	TB	• To observe soil properties to adjust the schedule of agricultural practices.	• Plough after observing that the soil is adequate to retain soil moisture.
	B	• To monitor 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	• To develop a poly-cultural system.	• Farms dedicated to agriculture, husbandry and forestry to spread risks across these sub-systems. • Temporary cropping in forest plots to spread risks (slash-and-burn).
	TB	• To diversify within farm´s sub-systems (e.g., agriculture, forestry, husbandry).	• Diversify crops sowed to increase the range of potential bread grains in case of crop failures.
	B	• To scatter cultivated fields.	• Scatter fields across space to foster differentiation (e.g., in micro-climate, soil, pests) and reduce the risk of total crop failure.

[53] ACVOC-AHT, CMT, 5 Jun. 1609, 26 Mar. 1611.
[54] ACVOC-AHT, CMT, 12 Jan. 1651.
[55] ACVOC-AHT, CMT, 6 Jun. 1611, 27 Apr. 1612, 16 Sept. 1651.

	TB	• To diversify food sources.	• Use alternative staple food to alleviate hunger.
	T	• To diversify water sources.	• Intensify the consumption of medium to low quality waters in case of need.
Exchange	B	• To trade.	• Trade farm surpluses in exchange for money or products.
	B	• To buy grains in the market.	• Buy grains in local markets when harvests fail.
	B	• To practice long-term reciprocity.	• In-kind loans of grains, seeds, and food to neighbouring farmhouses, relatives, and workers.
Storage	TB	• To build and maintain physical infrastructures for grain or flour storage.	• Grain stored in farm granaries designed for long-term conservation. • Store surplus crops to compensate future bad harvests.
	TB	• To preserve stored grain or flour.	• Add herbs to stored grain to prevent pests. • Convert damaged grain in the store into ready to consume products. • Grind dry and old grain to prevent damages.
	T	• To build and maintain physical infrastructures for water storage.	• Water tanks to secure water availability.
	B	• To store farm experience in written records.	• Family books to store the experience of drought events, successful farm management practices, etc.
Rationing	T	• To control and limit food consumption in times of scarcity.	• Women rationed staple food and wine among family members during scarcities.
Selection	T	• To select skilled workers.	• Select servants from the farm´s vicinity so that they would have experience in monitoring local indicators.
	T	• To select seeds.	• Reproduce seeds in different micro-climates and soils to make them resistant to a wide range of conditions.
	TB	• To select areas to settle the farm according to water availability.	• Build the farmhouse and design associated irrigated systems in areas ensuring long-term water availability. • Locate dry pastureland in low steepness areas avoiding runoff and that can be irrigated in case of need.
	T	• To select durable water supplies.	• Select 'water veins' not prone to dry when digging wells or constructing fountains.
Supporting practices	TB	• To encourage a long-term perspective on farm management.	• Use and transmission of proverbs on farmer decisions encapsulating the need for long-term planning.
	T	• To maintain family cohesion.	• Women keep social order and cohesion

			among the family farm members, especially in critical periods.
	TB	• To manage the soils to keep soil moisture.	• Range of practices such as fertilization, sowing techniques, or conservation of the herbaceous cover to maintain soil moisture.

4.2.1 Farm strategies reported by Agustí's agronomy treatise

'The book of agricultural, cottage and pastoral secrets' identifies drought coping strategies that fit into five of the eight categories considered: forecasting, diversification, storage, rationing, and selection (Table 5). We did not found mentions to any strategy that fit into the exchange category. References to these strategies are abundant, except for rationing, which is seldom addressed.

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.[56] Weather forecasts were used to inform decisions, plan activities, and anticipate changes in the farm system, so as to reduce production risks derived from hazards, including droughts. Indicators cited in the treatise include a rich body of ethnoclimatological knowledge and beliefs, consisting of various meteorological, animal, vegetal, human, and physical signals.[57] For instance, the presence of spiders inside the Holm oak acorn, a solar eclipse during wheat flowering, or the migration of specific bird species from forests to fields and villages were considered predictors of dryness and sterility for the year to come.[58]

The treatise's author 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 'strength' (ability of not drying out).[59] Groundwater assessments were carried out when soil was affected by summer dryness (in August or September). Tests included experimental holes dug in different soils 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 such as the vapours exhaled by the ground during sunrise on dry days, or the plant species growing in the herbaceous cover. Finally, assessments of the physical suitability of the soil (the 'tilth') determined the advance or delay of the sowing, ploughing, and harvesting so as to minimize drought impacts.[60]

Diversification

Diversification was an essential strategy to cope with the potential impacts of drought. The treatise defended the suitability of having non-specialized poly-cultural farms dedicated to crops (e.g., cereals, vineyards, olive groves, horticulture), husbandry (e.g.,

[56] Agustí 1617, f. 2r, 3v.
[57] 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; "Authors 2016d".
[58] Agustí 1617, f. 4r.
[59] Agustí 1617, f. 144v–144r.
[60] Agustí 1617, f. 77v–81v.

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.[61]

Diversification was also promoted in each farm sub-system (Table 5). For example, diversification of food sources in times of severe drought was crucial, as 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, barley, millet, corn, lupines, buckwheat, oat, rice, and acorns.[62] Preference for different substitutes depending on the severity of the food shortage was indicated. For example, due to its bad taste, oat was prescribed only in cases of extreme famine. Similarly, due to its long digestion, rye was recommended only for poor rural 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 the bread twice, drinking own urine, or preparing other culinary recipes to satisfy the appetite with nuts, cow fat, flower oils, and plant gum.[63]

Farm water infrastructures were designed and built to secure water supply for multiple uses throughout different seasons.[64] 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.[65] During periods of water shortages, it was recommended that water consumption should be 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 optimally preserve grain (e.g., aeration, light, walls treated against pests).[66] 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. It also recommended 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.[67] Damaged grains had to be sent immediately to the mill and quickly consumed.[68] Treatments to store flour include adding tablets made up of cumin and salt, fragments of pine bark, or bay leaves.[69] The author also compiled instructions to appropriately mill grains with the aim to prolong flour storage, for example by selecting only dry and old grains to mill or by producing coarser flour.[70]

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[61] 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.

[62] Agustí 1617, f. 75r, 82r–85r, 88v-91r.

[63] Agustí 1617, f. 91r.

[64] Agustí 1617, f. 144v–145v.

[65] Agustí 1617, f. 146r.

[66] Agustí 1617, f. 81v, 150r.

[67] Agustí 1617, f. 81v–82r.

[68] Agustí 1617, f. 82r.

[69] Ibid.

[70] Agustí 1617, f. 88v.

Storage was not only relevant to prolong the durability of food stocks over time, but also to secure water availability. Water tanks accompanied other infrastructures such as wells, fountains, and water transport systems, securing household water supply.[71] The author includes detailed instructions to build tanks and to 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, flour, or wine, was controlled during periods of scarcity, such as those caused by severe droughts. Rationing of food was women's responsibility, since they were in charge of ensuring household food security through different practices including growing subsistence crops in gardens, raising animals, or preparing tinned food.[72] Interestingly, the control and limitation of food consumption was also among the duties of some male servants.[73]

Selection

Selection strategies to cope with droughts included the selection of skilled workers, resistant seeds, appropriate farm locations, and durable water supplies (Table 5).[74] Here we concentrate on the last one, because the selection of water supplies chiefly determined farm's vulnerability to droughts. The treatise highlights the need to rely on and select durable 'water veins' and distinguished between vertically- and horizontally-supplied water veins, considering the latter more prone to dry and therefore less advisable. Moreover, fountain's assessments were conducted to find the 'mother vein' and select water sources that guaranteed water availability regardless of hydro-climatic variability.

4.2.2. The experience of the farm Can Torres

Strategies to cope with drought identified by the family book of Can Torres fit into five categories: forecasting, diversification, exchange, storage, and selection (Table 5). Diversification, exchange and storage seem to have been particularly relevant to deal with drought in the farm. Remarkably, this family book does not report 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.

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 when describing the drought event of 1700-1701.[75] Monitoring these local indicators to follow-up drought evolution (e.g., onset, changes in intensity, and ending) informed and conditioned important farm decisions such as planting times. For example, during the 1700-1701 drought event, the heir expressed the need to adjust planting times to the monitored drought evolution and soil properties.[76]

Diversification

[71] Agustí 1617, f. 144v–145v.
[72] Agustí 1617, f. 8r–8v.
[73] Agustí 1617, f. 1v–2r.
[74] Respectively in Agustí 1617, f. 1v–2r; f. 79r; f. 86v, 87v, 143v–144v; f. 145v.
[75] ACVOC-AHT, Can Torres 1699-1824, f. 20r.
[76] Ibid.

The Can Torres farm illustrates the polyculture diversification strategies explained in Agustí's treatise. The economy of the farm depended on extensive and intensive agriculture (croplands, vineyards, olive groves, kitchen garden, fruit trees), husbandry (pigs, cows, sheep, goats, poultry, bees), and forestry (wood, charcoal from pine and Holm-oak, 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 that were temporally cultivated (*boïgues*) provided adequate cereal yields without the need of external fertilizers.[77] As in many early modern European forested areas, such plots acted as a buffer that could be used in case of need.[78]
Diversification also occurred in 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 *rojal*. Legumes included faba beans, peas, lupines, and beans. Table 6 synthesizes the diversified structure of crop production which contributed to broaden the range of bread grains when drought or other hazards led to wheat failures. The landscape mosaic of Can Torres consisted of dispersed croplands surrounded by grazing lands and forests (Figure 4). These croplands were managed with different degrees of intensification and their distribution across different soils, ecosystems, and micro-climates was a key element to reduce the risk of total crop failure. As the heir Miquel Batlles wrote in early spring of 1701, during the drought: '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'.[79]

Table 6. Structure of crop production in Can Torres: annual harvest of cereals and legumes (1700-1703).[80]

	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

[77] ACVOC-AHT, Can Torres 1699-1824, f. 18v, 34v.
[78] 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.
[79] ACVOC-AHT, Can Torres 1699-1824, f. 20r.
[80] ACVOC-AHT, Can Torres 1699-1824, f. 27r, 28r, 47r, 63r-63v. Recorded volume of cereals was transformed from traditional (*quarteres*) to contemporary (m^3) units 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.

Lupines	0.4				0.4
Beans				0.3	0.3
Total legumes	1.1	0.3	0.4	0.3	0.6

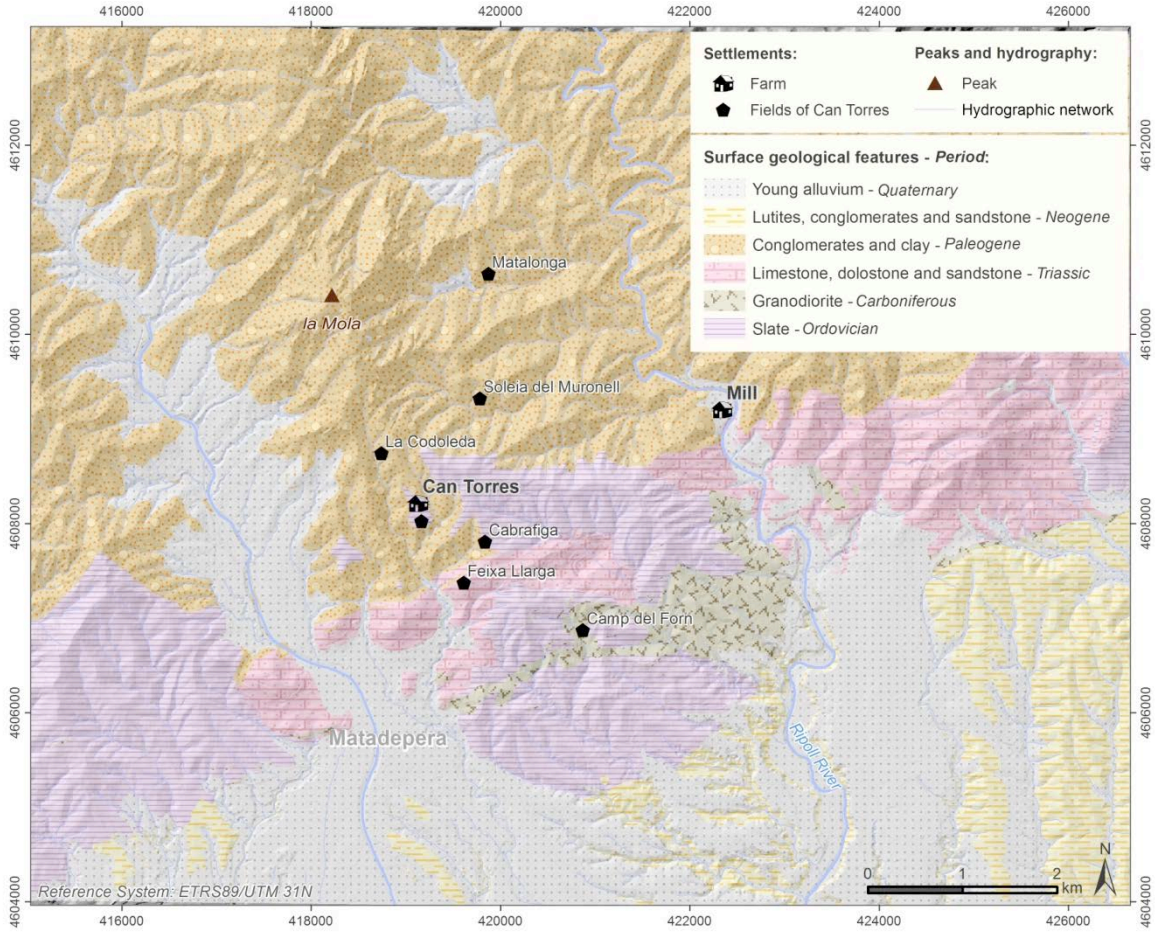

Figure 4. Map of Can Torres: surface geology, hydrographic network, and location of frequently cultivated fields.[81]

From our data, we can infer that diversification of food sources was 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*, which were all varieties produced in the farm (Table 6).

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 herd size of about 100-150 heads, the animals were fed during approximately one year and sold as meat in closer villages

[81] Own elaboration with data from ICGC and ACA.

and cities.[82] Money from the sales of meat and other products allowed farmers to buy grains when their own production was scarce thereby securing food provision to family and workers. For example, in 1702 Miquel Batlles established an agreement with French woodcutters working in Can Torres forests (that he was supposed to feed), so that in case of poor harvests, he would buy wheat in a close city (Manresa) and sell it to them at the prize of Terrassa's market.[83] Even if 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 above agreement shows that when a harvest failed, the heir would resort to the market to secure wheat supply.

The farmer also noted down non-monetary exchanges (gifting and bartering). Cereal and legume seeds, grains for consumption, and even bread were regularly loaned to workers, close neighbours, and relatives, with the agreement to return them in-kind after harvest.[84] Such practices evidence the long-standing social networks of mutual help and reciprocity, and how these networks became particularly relevant in times of scarcity and drought.

Storage

The farmers sent about 6 cubic metres of grains to the mill every year, which according to our estimations correspond to 5400 kg of bread which could feed 17 people over one year.[85] This should suffice to feed household family members and workers. The balance between the amount of bread grains harvested in the farm and those sent to the mill shows that farm production could provide most of the flour needed for farm consumption. Yet, not all the production was consumed, as some harvested grains were kept as seeds and some others were used to pay local charities and in-kind fees.[86] Grain surpluses stored in the farm granary were therefore crucial to compensate for the years of poor harvests without having to rely on external grain supply.

The family book itself is a storage of the local experience in the management of the farm. The written transmission facilitated the accumulation and communication of complex knowledge to the next generations.[87] Miquel Batlles was aware of the importance of knowledge storage when communicating the drought experience of 1700-1701 to his successors. As he stated in the preface of the annotation of the 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'.[88]

Selection

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[82] 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.

[83] ACVOC-AHT, Can Torres 1699-1824, f. 40v.

[84] Exchanges with workers in ACVOC-AHT, Can Torres 1699-1824, f. 5r, 32r, 44r–44v, 61v; and with neighbours and relatives in ACVOC-AHT, Can Torres 1699-1824, f. 10r, 13v, 28v, 39r, 45, 51, 61r, 72r.

[85] See calculations in Appendix, tab. A.2.

[86] ACVOC-AHT, Can Torres 1699-1824, f. 6r, 12v, 15v, 27r, 31r, 37r, 39r, 48r–48v, 58r.

[87] 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.

[88] ACVOC-AHT, Can Torres 1699-1824, f. 20r.

Following a widespread convention in preindustrial times, the location of the farmhouse and irrigated lands was most probably decided taking into consideration access to water, among other criteria. The farmhouse of Can Torres was, for example, surrounded by temporary water streams (Figure 4). Moreover, the farm was less than six km away from the upper course of the Ripoll River. This permanent water flow secured the uninterrupted activity of the watermill used by the farmers of Can Torres even during summer water deficits or hydrological droughts.[89]

5. DISCUSSION

We organize the discussion around three main topics. First, we discuss how documentary gaps and biases pose methodological limits when reconstructing past adaptation to climate impacts. Second, we interpret the reported differences in adaptation strategies 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 constraints can lead to overlook some adaptation strategies, 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 performed. 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 in this study.[90] While the importance of mobility among farmers might not be comparable to nomad societies, migrations or other types of mobility might have been part of the kit of farmers coping strategies, but just not been registered by our primary sources.

Documentary biases also limit archive-based reconstructions of past adaptation strategies. Market exchanges documented at the household level provide a good example of this. Thus, 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 could be an option to secure food supply after poor harvests. The treatise's approach 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.[91] 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 the area and was more integrated into the market than most of the neighbouring farms.[92] Our sources were also probably biased when documenting rationing strategies. The treatise mentioned that food rationing was performed by women and male servants, but no other measure was attributed to women.

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[89] ACVOC-AHT, Can Torres 1699-1824, f. 5r–5v, 17r, 39v, 54r, 66r.

[90] For recent studies reporting mobility as adaptation strategy, see "Authors 2013b"; "Authors 2016a".

[91] 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"'.

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

Because the documents were written by males and addressed to the male heads of the family, the sources used in this paper may downplay or simplify the practices performed by women.

5.2. Adaptation within levels

Community

The analysis of Council minutes suggests that Terrassa and Sant Pere shared similar response strategies for agricultural impacts of drought and often joined forces to collectively organize them (e.g., organizing collective rituals or rationing collective grain supplies). But we also found some divergences specially 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, whereas Terrassa had a collective water supply since the fifteenth century.[93] The fact that most people in Sant Pere municipality lived in scattered farms and therefore the area had a low density of settlements, might have conditioned adaptation strategies 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.[94] And second, low demographic pressure translates in low 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 need to adjust community water institutions or infrastructures during droughts.

Previous research on climate change adaptation has likewise shown differences in the strategies to cope with climatic variability and hazards across communities or villages. Boissière and co-authors found significant differences among six Indonesian villages from the same watershed in their responses to droughts. The authors explain such variation according to the 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.[95] Similarly, farmers and pastoralists in Burkina Faso choose different adaptation strategies to cope with climate variability depending on the agro-ecological zone their village was located in.[96] Our case study

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[93] 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).

[94] Moreover, Councils had lower ability to fund major or new water projects during economic crises, as noted by 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.

[95] 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.

[96] 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.

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

We also found key household adaptation strategies documented both in published sources based on state of the art knowledge (i.e., the agronomic treatise) and in private sources based on the farmer's direct experience (i.e., the Can Torres family book). The treatise compiled a wider range of practices, presumably because this source recorded different response options available for a large variety of farmers.[97] Our findings should be carefully interpreted considering that peasant behaviours are highly variable and that strategies to avoid or reduce risks among households have been shown to be heterogeneous.[98] Barbieri and Mahoney 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.[99] Studies have shown how a range of factors differentiating peasants and farms shape their decisions and therefore the strategies they use to cope with droughts.[100] Because strategies seem to vary from household to household, we note that results based on a few documentary sources are informative, but probably not enough to draw a general picture of how adaptation to drought occurred at the household level.

5.3. Adaptation across levels

We derive two interesting insights from comparing adaptation strategies at the community and the household levels. First, our findings suggest a wider repertoire of practices to cope with droughts used by households as compared to those developed by Councils (Table 4 and 5). This is especially remarkable in the municipality of Sant Pere, where the few strategies developed by the sparsely settled community largely differed from the range of practices performed within farms such as Can Torres.

Second, our data show that some strategies took place at the two levels of social organization whereas some strategies took place at one level only (Table 3). Practices documented at the two analytical levels could be considered cross-level strategies, which in our case study would imply interactions and feedbacks of low complexity, or simply overlap, between the community and the household. 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 households.

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

[98] 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

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

[100] 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 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.

Among other options, we documented how farmers could prevent crop failures from drought (e.g., scattering crop fields), maintain access to grains despite crop failures (e.g., replacing bread grains by minor cereals), and manage their own grain stores (e.g., family rationing).

In contrast, some adaptation strategies were only documented at one of the two levels of social organization. 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, as local authorities were the only ones legitimized to change water institutions. Thus, our findings confirm that both levels of social organization are critical to capture and assess the diversity of coping strategies to recurrent hazards in early modern societies. Moreover, our case study shows that the strategies performed at both levels partially overlapped.

6. CONCLUDING REMARKS

This study provides several methodological and theoretical insights. At the methodological level, using common taxonomies to classify past adaptation strategies helped to discuss the results in relation to 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. Increasing comparability across studies and identifying methodological challenges are essential steps to improve historical approaches to adaptation and to facilitate the indispensable communication within the research community on adaptation to climate change.

At a theoretical level, the wide diversity of strategies to cope with drought documented in our sources adds more evidence to the fact that adaptation and resilience-building strategies were a prominent process occurring in Western preindustrial societies, at least for recurrent hazards.[101] However, what is novel from our study is the application of the multilevel approach to these societies.[102] We assessed the different contributions 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. Preferred household practices were instead diversification (livelihoods, food consumption and water sources), food and water storage, and forecasting.

Although we cannot generalize such findings, we 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.[103] Moreover, the partial overlap of strategies from both levels may have generated a redundancy effect that acted as safety-net - 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

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[101] 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.

[102] For previous studies, see footnote 6.

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

levels.[104] Further research should better explain the distinct roles of the different levels of social organization (even beyond households and villages) and their historically changing linkages in the preindustrial context. In light of our findings, multi-scalar approaches for the analysis of social-ecological systems have the potential to better understand past and present adaptation processes.[105]

[104] 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.

[105] 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).