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Climate variability and grain production in Scania, c. 1702-1911

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Abstract. Scania (sw. *Skåne*), southern Sweden, offers a particularly interesting case for studying the historical relationship between climate variability and grain production, given the favourable natural conditions in terms of climate and soils for grain production, as well as the relative lack of heat-sensitive grain varieties like wheat in its production composition. In this article, I combine a contextual understanding of historical grain production in Scania, including historical, phenological and natural geographic aspects, with quantitative analysis of available empirical sources to estimate the relationship between climate variability and grain production between the years c. 1702-1911. The main result of this study is that grain production in Scania was primarily sensitive to climate variability during the high summer months of June and July, preferring relatively cool and humid conditions, and to some extent precipitation during the winter months, preferring relatively dry conditions. Furthermore, grain production was relatively insensitive to climate variability during the spring, autumn and harvest seasons. At the end of the study period, these relationships were shifting as the so-called early improved cultivars were being imported from other parts of Europe. Finally, I also shed new light on the climate history of the region, especially for the late 18th century, previously argued to be a particularly cold period, through homogenization of the early instrumental series from Lund (1753-1870).

1 Introduction

In recent years, numerous studies have explored the relationship between grain yields, prices and climatic change in medieval and early modern Europe. The fundamental assumption underlying these studies is that grain production to a substantial degree is affected by variability in temperature and precipitation (Edvinsson *et al.*, 2009; Holopainen *et al.* 2012; Esper *et al.*, 2017; Pribyl, 2017; Ljungqvist *et al.*, 2021a; Ljungqvist *et al.*, 2021b). Most of these studies have either focused on particularly temperature-sensitive grain types like wheat, or temperature-sensitive agricultural regions, like Finland or the Scottish Highlands (Parry & Carter, 1985; Brunt, 2015; Huhtamaa & Helama, 2017a). In these historical contexts, cold conditions becomes the ‘grim reaper’ (Holopainen & Helama, 2009). However, in the long-term, grain farming even in the northern border regions of European agriculture has shown considerable adaptability and resilience (Huhtamaa & Helama, 2017b; Solantie, 1992; Huhtamaa & Helama, 2017b; Degroot, 2021). A diversified grain production has been identified as an important aspect of this resilience (Michaelowa, 2001). In this article, I argue that an understanding of the impact of climatic variability and change on agriculture as well as explanations of resilience in terms of grain diversity, need to be grounded in an understanding of the phenology of historical grain varieties.

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Attempts to account for the resilience, or the ability of early modern farmers and farming systems to cope with climate variability, in intensive grain farming areas of Europe north of the Alps like northern France and England, have remained mainly hypothetical (Michaelowa, 2001; Tello *et al.*, 2017). Early modern Scania offers an especially interesting case in this regard. The climate of Scania is and was relatively mild, comparable to that of northern France and most of England. From an agronomic point of view it is often stressed that Scania has the longest vegetative period of present-day borders Sweden (; Osvald, 1959; Persson, 2015). Furthermore, the southwestern half of Scania, roughly the extent of the historical county of Malmöhus, contains large areas of soils of exceptionally high quality (Lantbruksstyrelsen, 1971). For most of the historical period, Scania was an important surplus producer of grains in the Kingdom of Denmark and from 1658 in the Kingdom of Sweden, respectively (Åmark, 1915; Bohman, 2010). At the same time, since at least the 17th century up until the end of the 19th century, Scanian farmers relied on Scandinavian grain varieties adapted to relatively cooler and humid climates with short growing seasons, i.e. conditions often prevalent at the northern limits of agriculture (Lundström *et al.*, 2018; Larsson *et al.*, 2019).

The aim of this article is to study the relationship between climate variability and grain production in Scania during the period c. 1702-1911. Given that the role of climate cannot be conceptualized neither in a simplistic or deterministic manner, it has to be contextualized in the specific agrarian and ecological context (Haldon *et al.*, 2018; van Bavel *et al.*, 2019; Degroot, 2021). Accordingly, this article starts out by contextualizing the study and setting the historical background, followed by a theoretical and conceptual discussion of factors relevant for grain production in Scania during the study period. Subsequently, I present and discuss the climate- and agricultural production data used for this study. I employ largely quantitative methods, combining both inductive data-driven statistical techniques as well as deductive modelling, inspired by previous research in the field. Finally, results are discussed in relation to the historical context as well as to previous research.

1.1 Background

Scania is situated in the southern-most tip of the Scandinavian Penninsula in the borderlands between Sweden and Denmark. The farming districts on the plains of Scania have, and continue to be, some of the most productive arable farming regions in Scandinavia, owing mostly to its mild climate and rich soils. In the Danish and Swedish historiography, Scania is commonly referred to as a *kornbod* (roughly translated as ‘breadbasket’). Adam of Bremen in his Gesta Hammaburgensis ecclesiae pontificum from c. 1075 AD describes Scania as the most prosperous of the provinces in the Danish kingdom (Bremensis, 2002). However, the natural geography of Scania is and was not uniform (Svensson, 2016). Besides the arable plains, Scania was constituted by a relatively diverse landscape of forests, somewhat variable but mostly hospitable coastal areas, lakes and hills with different soils and natural conditions (Lidmar-Bergström *et al.*, 1991).[1] Farming was to some extent adapted to this

[1] The Scanian landscape has also undergone change over time, particularly during periods of land reclamation when forests and wetlands have been converted to arable lands.

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variability in natural conditions, especially in the period prior to the late 19th century (Dahl, 1989; Gadd, 2000; Bohman, 2010). During the period c. 1750-1850, Scania underwent what has been called the agrarian revolution, implicating a general transformation of agriculture as well as dramatic and sustained increased in production (Olsson & Svensson, 2010). Subsequently, Scanian agriculture has continued to sustain its growth trajectory, intermittently interrupted by various agrarian and economic crises (Myrdal & Morell, 2013).

Scanian farmers did also face challenges. Situated between two rivalling Kingdoms, Denmark and Sweden, the fertile plains of Scania have been fought over and acted as a battleground in numerous wars. After 1711, there was relative peace compared to the preceding centuries (Frost, 2000). Like in the rest of Europe, colder climatic conditions prevailed in most of the second half of the 16th century and throughout most of the 17th century. The period c. 1560-1630 was particularly cold and experienced overall increased climatic variability (see Fig. 1). In the 1690s, there was also recurrent span of cold years with late springs in the Baltic area, culminating in the disastrous years of 1695-1697 leading to mass mortality throughout the region and especially in northern Sweden, Estonia and Finland (Dribe *et al*., 2015; Lilja, 2008). Reconstructions of ice-winter severity from the western Baltic indicate that the period experienced greater volumes and persistence of winter ice compared to preceding and subsequent periods, and the Sound between Scania and Zealand was covered with ice for most of the years 1694-1698. Similar findings have been made for other parts of the Baltic (Speerschneider, 1915; Koslowski & Glaser, 1999; Leijonhufvud *et al*., 2010).

During portions of the 18th century, there was a 'return' to milder temperatures, albeit with some notable exceptions with especially cold periods in the early 1740s and 1780s. The most notably challenge in terms of natural conditions pointed out in previous research is the increasing degree of sand drift and soil erosion in Scania during the later parts of the 18th century and early 19th century . As Bohman (2017a & 2017b) has shown, these agro-ecological crises were mostly local and temporary, counteracted by land management policies at the local and regional level. The causes behind the increasing soil erosion and sand drift has similarly been framed as anthropogenic, in the form of deforestation and intensified land use practices. Mattsson (1987) argued that another underlying factor behind these agro-ecological issues was climatic variation in the form of the generally colder conditions during the Little Ice Age and increased heavy winds and storms, particularly easterlies, during the latter half of the 18th century. Mattsson (1987) relied on instrumental observations from Lund for his conclusions, and as I argue below, these measurements show inaccurately low temperatures in the last decades of the 18th century, the very decades Mattsson point out as particularly cold. In the following century, the 1810s and the 1840s stand out for being relatively cold (Tidblom, 1876; Cappelen *et al*., 2019).

[Figure 1 is somewhere around here]

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1.2 Farming in Scania

Descriptions of agriculture in Scania during and subsequent to the study period have relied on the ethnographic and geographical categorizations made by Campbell (1928), who outlined three different types of farming districts: the plain, the intermediate (or "brushwood", sw. *risbygd*), and the forest districts (Dahl, 1989; Svensson, 2013). According to Campbell (1928), the plains were characterized by specialization in grain production in three-field farming and a relative lack of wood. In contrast to the plains, the typical farm of the intermediate district was oriented towards animal production, practiced one-field farming, sometimes complemented by temporary plots on the wastes (sw. *utmarker*) that were sown for a year or a succession of years. One important limiting resource for the animal-oriented intermediate districts was the suly of winter fodder. To some extent farmers relied on markets to mitigate shortfalls.[2] Forest districts were distinguished by the vicinity and access to forest resources. Arable production consisted mainly of one-field farming supplemented or dominated by swidden or other temporary plots in the forests. Animal production was also somewhat limited, although animals were often kept year-round. Of all the types of districts, the forest districts had the most diversified economies, where limited arable farming and livestock production was combined with handicrafts and forest-related industry, e.g. production of timber, tar, potash and charcoal (Bohman, 2010; Svensson, 2016). Although the types of farming districts varied in their relative specializations, practically all farming in Scania was performed in a mixed farming system, where livestock husbandry and grain production were integrated and mutually dependent. Nonetheless, a closer look at the livestock composition and the overall farming systems of Scania is beyond the scope of this article.

Although some farms were isolated, most farms were located in villages where farming operated under an open-field system (sw. *tegskifte*) with a mixture of private and communal management. Limited enclosure reforms, *storskifte*, were introduced starting in 1749/1757, followed by radical enclosure reforms in 1803 (*enskifte*) and 1827 (*laga skifte*). These latter reforms involved the break-out of the individual farms from the communal management, effectively privatizing land ownership and management. Implementation of these reforms was gradual and intermittent (Gadd, 2011; Gadd, 2018). Hence, for large parts of the study period, decision-making regarding grain production was largely mediated through the village order.

1.3 Grain crops

Rye, barley and oats dominated the composition of grain production during the study period and had done so since the Viking Age, albeit with relatively much internal variation over time. For example, oats production saw a relatively large increase in its share of overall grain production during an export boom in the 19th century (Welinder, 1998; Bohman, 2010).[3] In the late

[2] By buying draught animals like oxen from passing ox-caravans heading north in the spring, farmers could access the necessary labor power required on the fields during the spring season, while allowing the oxen to be fed properly during the relatively abundant summer and autumn seasons and finally be sold at winter markets (Bohman, 2010; Palm, 1997).
[3] While the sources seldom allow for further details, there were many varieties of each grain crop. These different varieties could sometimes vary quite starkly from each other in terms of their characteristics (Leino, 2017).

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19th century and early 20th century, the new so-called improved cultivars (mainly in the form of autumn-rye and autumn-wheat) increasingly took the place as the most dominant grain crops (Leino, 2017). In previous research, the type of farming district and soil types has been seen as the primary factors determining differences in crop composition (Dahl, 1942; Dahl, 1989).[4] Given their historical importance, this study will mainly be limited to analyzing the production of barley, rye and oat varieties. Wheat varieties will also be included in the latter part of the study period (1865-1911).

Rye varieties

Leino (2017) has studied some of the historical grain varieties in Sweden. Examples of rye varieties prevalent in Scania were late-rye (sw. *senråg*), autumn-rye (sw. *larsmässoråg*), sand-rye (sw. *sandråg*) and spring-rye (sw. *vårråg*). Swidden-rye (*svedjeråg*) was most likely also grown, especially in the forest districts. Leino (2017) notes that in historical sources, late-rye is often characterized as allowing very late sowing, all through December in Scania (in some extreme cases this nominally autumn crop was apparently sown in early spring). According to Leino (2017), this type of late sowing of late-rye offered the possibility to incorporate autumn-rye into a two- or three-field system without the need for a full year of fallow after the preceding harvest. This somewhat blurred line between spring- and autumn-rye is consistent with genomic studies of Scandinavian rye landraces (Hagenblad *et al.*, 2012). Regarding the type of soils rye was grown on, previous research have found that in Scania rye varieties were often grown on sandy soils or other well-drained soils (Dahl, 1989; Gustafsson, 2006).

In a broader context of European rye landraces in the pre-1900 period, Fennoscandian landraces have been found in genomic studies to belong to a particular and separate meta-population of rye landraces, distinct from landraces in continental Europe. Furthermore, even southern Scandinavian rye landraces have been found to have more in common genetically with landraces from northeastern Europe rather than those from maritime western Europe (Larsson *et al.*, 2019).

Barley varieties

Southern six-row barley (sw. *sydsvenskt sexradskorn*) was common in Scania, especially in the forest districts, even in the late 19th century. It was sown late, often well into June, due to its sensitivity to frost and its rapid growth, allowing ripening despite late sowing. Two-row varieties like *Scanian two-row barley* (sw. *skånskt tvåradskorn*), was also grown, at least during the 19th century but probably earlier as well. Two-row varieties required more intensive agricultural practices, longer growth periods and richer soils, but offered better resistance to frost and often gave larger yields, compared to six-row varieties. Similar to rye, genomic evidence on barley landraces from Scandinavia and southern Scandinavia in particular, indicate spatial and temporal consistency from the 17th century up until the late 19th century. (Lundström *et al.*, 2018). A distinctive feature of

[4] Wheat and barley were more dominant in the arable plain districts. The share of oats quite low in the forest districts and the share of rye was roughly the same in the different types of districts. Regarding soil types, Bohman (2010) found that barley and oats (and wheat) were more dominant on high quality soils and that rye was more common on poorer soils. Furthermore, the relationship between vegetable production and animal production shifted over time, with an increasing share of vegetable production throughout the 18th and the first half of the 19th century, varying from about 64 % to 97 % of the overall production value (Bohman, 2010).

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these Scandinavian barley landraces in terms of genetic markers is the prevalence of the non-responsive d-h1 allele, which prolongs the flowering during periods of increasing daylight, prolonging the vegetative state and potentially increasing yields in cooler and wetter conditions (Jones *et al.*, 2012; Aslan *et al.*, 2015). It has been suggested that selection and maintenance of barley seed with this particular allele was part of a long-term adaptation process by early farmers (Cockram *et al.*, 2007).[5]

Oat varieties

Historical oat varieties can be grouped into two broad categories: white oats and black oats. Generally, white oat varieties were grown on poorer, and especially wet, soils. According to Campbell (1950), they were better suited for making bread compared to the fodder-oriented varieties that became more increasingly more common during the course of the 19th century. Black oat varieties were more resistant to droughts and were preferably grown on richer, manured soils. Campbell (1950) argued that *Nordic White oats* (sw. *nordisk vithavre*) was the most common variant in Scania. It is more uncertain whether black oats were grown. However, black oat varieties were grown in all neighboring provinces (Halland, Blekinge and Småland), which suggests, together with the fact that there was a widespread trade in seed-grains, that black oats were at least grown locally and intermittently (Campbell, 1950; Leino, 2017).

According to Dahl (1942), oat farming in Scania was *not* an adaptation to local climate like in parts of northwestern Europe. Rather it was other natural conditions, primarily the type of moraine soil common in some areas around the Baltic like Denmark, Scania and northern Germany (sw. *baltisk morän*), as well as local hydrological conditions, namely on soils that were poorly drained that was decisive for oat cultivation. It is important to note that Dahl (1942) conceptualized natural conditions and climate as something static, and that the only secular changes that occurred in natural conditions were due to human intervention, for example by not investing in drainage or through over-cropping.[6] However, given that the climate actually varied over time, one would expect climate effects interacting with factors like soil and the type of cultivated crop. For example, periods of a wetter climate should have had more negative impacts on crops grown on poorly drained soils, whereas crops cultivated on well-drained soils should have been relatively more exposed to drought periods (Osvald, 1959; Weil & Brady, 2017).

[5] An allele is one of several possible expressions of a given gene. The d-h1 allele is the non-response expression of the d-H1 (Photoperiod-H1) gene (Turner *et al.*, 2005).

[6] Dahl (1942) explained changes in the prevalence of oats by trends in the economy, where oats as a less prioritized crop suffered in times of war or scarcity and increased in 'good times' when there was more labor power and manure available. Periods of scarcity or plenty seemed to be something external to the agricultural economy in Dahl's perspective, caused by either war or some other unknown external factor. In general, Dahl (1942) had a static perspective of agriculture in the times before enclosure, were there very little change across the centuries and farmers and villagers adhered to more or less set farming and cropping practices.

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1.4 Crop diversity and resilience

This brief overview of the diversity of grain varieties to be found in early modern Scania testifies to a relatively flexible farming system in terms of sowing and harvest dates as well as the ability to produce under differing agrometeorological conditions, not least during colder or wetter periods. It is important to note in this context the inherent capacity of crop varieties to adapt to local environmental conditions (including local farming practices), that over time should have led to much greater variety, and indeed resilience, than this brief overview suggests (Leino, 2017, Aslan *et al.*, 2015). In the context of historical grain production, I define resilience as the ability of a production system to maintain itself over longer time periods through a combination of biological and institutional flexibility and durability in the face of a variable environment. When discussing adaptation I refer to how a given crop or farming practice performs in a given set of environmental circumstances. I subsume the concept of exaptation (passive or accidental adaptation) under adaptation, given the difficulty in disentangling the two. For example, a particular crop may perform better during colder periods, increasing the production of the crop, which could be due to farmers *actively* adapting to changeable circumstances or the crop being more adapted (passively) relative to the other crops being cultivated. Furthermore, even if farmers are actively increasing the relative production of a given crop, it can still be very difficult to establish whether it is due to adaptation to environmental change, a response to shifting market demands, technological innovation or cultural trends.

Previous research has stressed that, at least in relation to climate 'extremes', a diversified crop production including both spring and autumn crops of different varieties was more resilient in areas of Europe north of the Alps (Michaelowa, 2001; Ljungqvist *et al.*, 2021a). Michaelowa (2001) partly blamed the excess specialization towards autumn-wheat for the relatively poor performance of French agriculture compared to English agriculture during the 18th century, where the latter was more diversified, cultivating autumn-wheat, autumn-rye as well as spring-barley and oats.[7] Utterström (1961) and Michaelowa (2001) argued that colder periods in the early modern period, specifically in the late 17th and 18th centuries, led to reductions in livestock production in France, England and Sweden and that conversely, grain production usually increased in order to fill in the nutritive gap.[8] If such adaptations were made they must have been difficult to implement in the short term and probably also insufficient given that grain production was also vulnerable to spats of cold weather. Pfister (2005) showed how cold and wet conditions during the different seasons of the year were detrimental to livestock production in the Swiss Alps as well as the difficulties of the local communities to adapt given that the cultivated grains and vines were also vulnerable to cold and wet conditions. Grain shortages, sometimes resulting in famines, were relatively common in many parts of Europe up until at least the 19th century (Appleby, 1980; Dribe *et al.*, 2015; Esper *et al.*, 2017).

There have been attempts to detail the relationship between grain production and climate variability in northern Europe during the early modern period in more detail. Brunt (2004) found that English wheat yields during the 1770s were mainly sensitive

[7] Allen (1992) notes that wheat and pulses expanded in the 18th century at the expanse of rye, barley and oats.
[8] According to Bohman (2010), the increasing share of grain production in 18th century Scania was driven by price trends.

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to temperature and to a lesser extent precipitation, depending on local soil conditions. Especially important were summer temperatures. Relatively cool summer temperatures through July benefited wheat yields, supposedly by prolonging the grain-filling period (Brunt, 2004). The following August should then be warm and dry to allow the crops to dry for the coming harvest. Ideally, rainfall should be spread out over many days during the early summer months. Concentrated rainfall during a short time-span risked ruining the crop, the harvest month of August being especially vulnerable. In a later study, Brunt (2015) found that wheat yields were significantly affected by weather shocks throughout the ca 1690-1850 period, with the 19th century largely conforming to the 1770s as to the effects from temperature and precipitation during summers.[9]

Pei *et al.* (2016) studied the relationship between yield ratios and temperature at a continental scale and proposed that European farmers during the period c. 1500-1800 used crop management as a mechanism for climate adaptation. Specifically, farming systems drifted towards increased rye production during colder periods, which the authors argue was a more cold-resistant crop. In an earlier study Pei *et al.* (2015) asserted that extensification of land use was the most prominent strategy in mitigate climatic stress during the same period. However, given differences in soil, climate, available grain varieties and other factors, it seems more reasonable to expect more heterogeneous and contextually dependent adaptation practices at the local and regional level (van Bavel *et al.*, 2019; Ljungqvist *et al.*, 2021a). Furthermore, while rye almost certainly was more cold resistant than wheat, in relation to oats the same seems to be true only when we exclude relatively wet climatic areas (e.g. western Sweden or parts of Scotland). In relation to barley there seems to be limited evidence at all that rye was *overall* the more cold-resistant grain. For example, in northernmost Sweden and Finland grain production was limited almost exclusively to barley. An important caveat in making these type of comparisons is the fact that rye was mostly grown as an autumn-crop whereas barley and oats were exclusively grown as spring-crops and that in many agricultural areas of northern Europe they were more often supplementary than rival crops (Huhtamaa & Helama, 2017b).

Considering Sweden, and southern Sweden in particular, one finds a composition of grain production that was relatively diversified, comparable to that of England in the 18th century described by Michaelowa (2001), with the important exception of wheat that in Sweden was only a marginal crop. Utterström (1957) argued that for grain production northern Sweden, temperature was the most important climatic variable, whereas it was precipitation for southern Sweden. Using more up-to date climate and grain harvest data, Edvinsson *et al.* (2009) largely confirmed the stipulations made by Utterström (1957), at least from 1724 up until the late 19th century, finding a negative association between subjective harvest assessments and June and July temperatures and a positive association with precipitation in the same months and November and December temperatures. After c. 1870, Edvinsson *et al.* (2009) found a shift in the relationship. Precipitation in the summer was still positively correlated with harvest assessments, including May. However, summer temperatures were no longer statistically significant, whereas all the four first months of the year (JFMA) showed relatively large positive associations with harvests assessments. A short digression is perhaps in order here. Compared to summer and spring temperatures, relationships with

[9] Brunt (2015) further found that the effects from weather shocks were large enough to obfuscate long-term productivity trends in subsequent yield estimations, especially in the 1690s and late 1850s.

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winter temperatures are more difficult to explain, given that they are indirect, occurring before the growing season for spring crops. Temperature and precipitation during the winter months do affect the overwintering autumn-crops however, by facilitating or inhibiting the survival of the grains themselves, as well as fungi, soil bacteria and other various grain pests (Holopainen & Helama, 2009; Osvald, 1959). In addition, the nutritive balance of the soil is affected (Ađalsteinsson & Jensén, 1990). Again, it is quite difficult to establish, both empirically and theoretically, the mechanisms and links between these relationships and the subsequent grain harvest. It should be noted that these 'indirect' effects are also at play during the other seasons as well. For example, de Vries *et al.* (2018) found that droughts have different effects on soil bacteria and fungus, and that these effects have long-term consequences for vegetation growing on the soil.

Returning to the discussion of the results from Edvinsson *et al.* (2009), they argued that overall the relationship between climate variability and grain harvests was relatively weak, partly explained by the lack of detail in climate data. Furthermore, they found that the magnitude of the relationships increased in the period 1871-1955 compared to the previous roughly 150 years, which they primarily explained in terms of the increasing shift towards higher yielding and more temperature sensitive wheat production. More controversially, they also hypothesized that climate variability itself was less important to harvest in pre-industrial agriculture, due to chronic seed shortages and a more risk-averse behavior on the part of farmers.

With respect to the differences between different grains, Edvinsson *et al.* (2009) used aggregate official statistics at a national level for the period 1803-1955 (with a gap between the years 1821 and 1859). They found that wheat and rye harvests were positively correlated with October through April temperatures, that barley harvests was positively correlated with temperatures in April, May and August-September and finally that oat harvests were negatively correlated with June-July temperatures. Harvests of all the mentioned grains were positively associated with increased precipitation in May through July. Wheat and rye harvests were negatively associated with increased precipitation in March, whereas the same was true for barley and oat harvests in relation to precipitation in September. However, these results are probably skewed towards the late 19th century and especially the first half of the 20th century considering the gap between 1821 and 1859 as well as the dramatic shifts in the types of cultivated grain varieties that Sweden underwent in the late 19th century (Leino, 2017). Beside the study from Edvinsson *et al.* (2009), Palm (1997) tried to estimate the relationship between the yields of various grains at a farm in Halland between c. 1750-1870, with limited results.

The division of Sweden into a southern and northern half in regards to their relationships between grain production and climate variability arguably needs to be complemented. From an agronomic perspective, southern Sweden is a relatively diverse place in terms of natural geography. Northwestern Scania and the provinces further north on the west coast (Bohuslän, Halland, Västra Götaland) are relatively wet and colder than most of Scania, whereas most of the east coast of southern Sweden is relatively dry (especially during spring and autumn) and experiences on average a few hundred extra hours of sun each year (Persson *et al.*, 2012). In addition, as previously mentioned, Scania stands out relatively to the rest of southern Sweden in terms of the duration of the growing season (Osvald, 1959). Considering the current state of research, there is arguably a need to

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study the specific relationships between various grains and climate variability at a regional and local level. This need is also reinforced by the commonly occurring association between a diversified crop mix and a greater degree of resilience in the literature (Michaelowa, 2001; Lin, 2011).

1.4.1 'Natural' variability

So far, the discussion of grain production has mainly related to natural conditions. However, farming was to some extent constrained institutionally through property rights, the type of farming system, the village order and the tax system. In addition to this, there were the biological constraints of crop phenology and soil nutrient balance. Despite these constraints, farming systems during the study period experienced constant variability. Not least in grain production, as can be seen in estimates of harvest outcomes over time (Olsson & Svensson, 2010; Hallberg *et al.*, 2016). It could be argued that marginal change, in addition to cyclical change, was an inherent part of the system itself. [10] One way to view this variability is that it was purely the result of natural constraints overtaking the institutional constraints. Alternatively, it could be hypothesized that the institutional structure of farming was to some extent flexible, allowing adjustments according the changeable constraints set by nature (Tello *et al.*, 2017). In the following sections, I attempt to estimate the relationship between variability in grain production and climate. First, I describe and discuss the data and methods employed. Secondly, I present and discuss the results. Finally, I conclude the article by interpreting and contextualizing the obtained results.

2 Sources and methods

2.1 Sources on agriculture and grain production

Scania stands out in a Swedish context regarding the availability and extent of a specific historical source material, namely the priestly tithes (*sw. prästetionde)*, which in many parts of Scania remained flexible and proportional to output throughout the 18th and 19th centuries (Olsson & Svensson, 2010). Using surviving tithe records from 36 parishes in Scania, Olsson and Svensson have produced a database, the *Historical Database of Scanian Agriculture* (HDSA), with roughly 85,000 unique farm level observations covering the period 1702-1881, where one observation is one farm's production in one year (Olsson & Svensson, 2017b). The structure of the HDSA is that of an unbalanced panel and includes besides production data on crops and animals, data on farm size and household characteristics, land tenure and other institutional factors, land quality and size, geographical factors as well as relative crop and animal prices. After 1865, the HDSA only covers livestock production. There is instead official statistics on grain production on the county and parish levels, based on reports from the local rural societies (sw. *Hushållningssällskapen*) that begins in 1865 and ends in 1911 (BISOS, 1865-1911). I rely on county-level data only. The 19th-century Swedish official statistics has been subject to some important criticisms. The manner in which the data was

[10] Given field- and crop rotations there was a 'natural' cyclical component to most early modern farming systems as fields rotated between fallow and different crops.

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collected varied to some extent locally as it was up to the local representatives in the rural societies to establish data collection procedures (Svensson, 1965). This is less of an issue considering that I do not compare different parishes with the BiSOS data. Furthermore, it is commonly argued that total crop production and the amount of arable area is systematically underreported and underestimated in the official statistics. Again, this is not an issue to the extent that I am principally interested in the variations in output over time that is associated with climate variability. There are no obvious reasons to suspect that this part of the variation in output is related to the general underestimation in official statistics.

Constructing grain production series for the earlier period 1702-1865 from the HDSA involves attempting to solve some issues. Firstly, there is an issue related to how the tithe was collected, i.e. that it was collected before threshing, and the amount of seed that was obtained by threshing the same type of grain differed across parishes and farming districts. Therefore, all crop production series are adjusted to local threshing coefficients in line with Olsson & Svensson (2017a).

Secondly, there are issues of non-stationarity in grain production time-series, particularly in the 18th century and beyond, requiring de-trending methods in order to obtain reliable and linear estimations of relationships (Jörberg, 1972; Huhtamaa, 2015; Shumway & Stoffer, 2017). At the same time, detrending risks removing information related to the long-term effects of climate variability on grain production (see Esper *et al*, 2017 and Ljungqvist *et al*, 2021 for a discussion of this in the context of historical grain prices). I estimate *normalized production anomalies* (NPAa) in line with Beillouin *et al.*(2020), employing a locally weighted scatterplot smoothing (loess) for each grain as well as total grain production in the HDSA.[11] I also estimate NPAs for each grain in the BiSOS data. A common smoothing span of 0.25 is used for all series.

$$\tilde{a}_t = \frac{(Y_t - \mu_t)}{\mu_t}, \tag{1}$$

where ã is the normalized production anomaly for a given grain in a cluster or aggregate region at each *t* year. Y_t is the average of the observed annual production outcome for the specific grain for all the villages in the cluster. μ_t is the expected production outcome according to the loess fit.

Thirdly, there is the issue that the HDSA panel is *unbalanced*. Similar to, for example, tree ring-based temperature reconstructions, where the number of tree rings available for the reconstruction usually decline further back in time (Esper *et al.*, 2016), the number of farms in the HDSA is lower in the early decades of the 18th century (the number of farms also goes down in the final decades of the database coverage). Essentially, this increases the risk of sampling bias. However, this problem is partly counteracted by the loess detrending and partly by clustering the data into most-similar clusters.

[11] Beillouin use the term *normalized yield anomalies* (NYA), but here I am mainly relying on production or harvest data I substitute the term yield with the term production to avoid confusion, given the importance of distinguishing the harvest from yield in general when discussing agricultural production.

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2.2 Hierarchical cluster analysis of rye production

Considering the institutional and geographical diversity of Scania, aggregating the data risks masking location or type specific relationships between agriculture and climate, or conversely that some localized trends distorts the overall picture. In order to homogenize data from the HDSA, obtain clearer signals and to reduce the risk of introducing a geographical or institutional bias by grouping the data by parish, type of farming district or cadastral status, I divide all villages in the samples into three different clusters using an hierarchical cluster analysis (HCA). HCA is an algorithmic-based method that cluster the data into 'most-similar' groups based on chosen parameters in the data. I rely on the Euclidean distances and the Ward's D method and cluster the villages based on the threshing-adjusted rye production-series over time. Rye was one of the two most important grains during the study period, and since it was mainly grown as an autumn-crop it required some specific management practices at the village level, and should arguably therefore serve as a more appropriate distinguisher than barley or oats. I use an agglomerative HCA, where each village initially forms a cluster by itself, pairing up with other village as the hierarchy 'moves up', ending with a set cluster limit of 3, see Fig. 2 (Day & Edelsbrunner, 1984).[12]

Some descriptive and interpretative issues come with this approach. If a cluster consist of several different types of farming districts, and parishes are separated into different clusters, describing, interpreting and contextualizing results become difficult. Hence, it is necessary to return to the historical categorizations found in the literature by describing each cluster by its general composition based on type of farming district, soils and institutional make-up.

[Figure 2 is somewhere around here]

Geographically, most of the total sample is located in the county of Malmöhus. Fig. 3 reveals that all clusters are represented by villages in the northernmost parishes of Hjärnarp and Tostarp, the forest and mixed farming districts centered around Billinge and Kågeröd parishes as well as the parishes located in the forest and mixed farming districts around lake Vomb in southern Scania. Cluster 1 is most heavily represented around the parishes around Billinge and Kågeröd as well as around lake Vomb. Cluster 2 is the most geographically spread, covering all of the areas of the total sample, except the plain district parishes around Malmö and Lund. Finally, Cluster 3 is mostly concentrated on the parishes around Malmö and Lund and with some villages in parishes around Röstånga and Kågeröd as well in the southern area of Vomb.

[Figure 3 is somewhere around here]

[12] Euclidean distance is the straight line between two points in classical metric space (Howard, 1994).

Previous studies have relied on modern soil grading that, it has been argued, better capture the 'natural' fertility of agricultural landscapes compared to those found in historical sources. For instance, Bekar (2004) used national survey data from the 1950s and 1960s in his study of historical grain production in England.[13] Bohman (2010), used data from Göransson (1972) who performed a local study of soils in Scania based on the gradient system established by the Swedish national soil survey published in 1971 (Lantbruksstyrelsen, 1971). The data from Göransson (1972) has subsequently incorporated into the HDSA, to describe the soil characteristics of the villages in the sample. The soil grading system is based on 10 levels, where 1 denotes the lowest and 10 the highest quality soil. According to the national survey, Scania is the only region in Sweden with grade 10 soils (Lantbruksstyrelsen, 1971). Table 1 shows the result from clustering in terms of proportion of arable in each grade. Cluster 1 has the largest share of the low quality soils (grade 1 to 4), roughly 39 %, as well as the least amount of high and moderately high quality soils (grade 7-8 and 9-10). Cluster 2 has the largest variance in terms of shares in different types of soils as well as the largest share of moderately high quality soils, ca 54 %. Finally, cluster 3 has the largest share of the highest quality soils, 16 %, as well as the largest amount of moderate soils, 44 %.

[Table 1 is somewhere around here]

Fig. 4 below shows the amount of villages from each type of farming district in the four clusters as well as the institutional make-up in terms of property rights regimes of each cluster (i.e. freehold land owned and managed by peasant-farmers, crown land owned by the state but managed by tenants, and manorial land owned by the nobility but managed by their tenants). Cluster 1, is relatively mixed, with farms in all three different types of farming districts, albeit with most farms in the intermediate and forest districts, with a moderate share of peasant-owned and managed farms. Cluster 2 has the largest amount of manorial farms and almost all farms are located in the intermediate and forest districts. The largest amount of plain districts farms can be found in Cluster 3, which also has the largest amount of crown and peasant-owned farms. Furthermore, Cluster 3 contains almost no intermediate districts farms, and a moderate amount of farms in the forest districts.

[Figure 4]

[13] While the national soil surveys in Sweden and England had quite similar aims, to evaluate and map the 'natural' fertility of soils, they differ in terms of their criteria. The English national soil survey was predominantly based on geological and climatological indicators, while the Swedish survey was based on a mix of geological, yield and price data as well as local expertise (Lantbruksstyrelsen, 1971; Gilg, 1975). Most European countries carried out similar national surveys in the decades following the 1950s (Jones *et al.*, 2005).

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In terms of grain production, Cluster 3 has the largest average production of all grains over time as well as the largest share of rye and barley in its production, which is not surprising given that it has the largest share of plain district villages as well as the largest share of highest quality soils, as shown in Fig. 5. Cluster 2 has similar average production levels as Cluster 3 in the first decades of the 18th century, followed by a relative stagnation for the rest of the century, followed by large increases in production of all grains and in particular oats during the first half of the 19th century. The cluster with the lowest quality soils, Cluster 1, also has the lowest average production levels, although it shows continual increases throughout the period 1702-1865.

[Figure 5 is somewhere around here]

To summarize, Cluster 1 is institutionally mixed and has the lowest quality soils, Cluster 2 is more manorial, has the largest share of soil grades 6-10 of all the clusters and is the most geographically spread cluster. Finally, Cluster 3 is mostly peasant-owned or managed, has the largest share of the highest quality soils (grade 8-10) and lands in the plain districts, notably in the plains around Lund. Average production levels increase in an ascending order from Cluster 1 (the lowest) and Cluster 3 (the highest), although there is some variation over time.

2.3 Sources on the climate

Instrumental measurement data are available from the city of Lund starting in 1748 for precipitation, and in 1753 for temperature. However, the series contains gaps and the temperature series is not homogenous, due to uncertainties in the quality of the early thermometers used as well as changes to their location (Tidblom, 1876). Palm (1997) attempted to cover the gaps in the Lund-series in his study of Djäknebol, Halland, by bridging the Lund-series with the instrumental temperature series from Copenhagen starting in 1768, using the average difference between the two series (Tidblom, 1876; Willaume-Jantzen, 1896; Palm, 1997). In contrast to the Lund series, the Copenhagen series has been subjected to some testing and homogenization efforts, however it has its own gaps between 1777-1781 and 1789-1797 (Cappellen, 2017).

Nearby regions of Europe do have homogenized temperature series extending further back in time, notably Uppsala (from 1722), De Bilt (from 1706), Berlin-Dahlem (from 1719 with a gap between 1722-1727) and Central England (from 1659) (DWD, 2018; Bergström & Moberg, 2002; van Engelen *et al.*, 2001; Labrijn, 1945). One solution would therefore to employ a composite temperature series consisting of the combined averages of these homogenized series starting from 1722. However, this procedure would mean the loss of coverage for the years before 1722 and risk becoming less historically relevant due to the relative loss of information from the Lund series. Thus, I instead attempt to homogenize the Lund series and fill in the missing values using the homogenization software ACMANT (Domonokos & Coll, 2017). ACMANT applies an algorithm to

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homogenize climate series based on the spatial correlations in a network of related climate series. Tab. 2 below shows Pearsson *r* correlation coefficients between monthly average temperatures at Lund and at the other network series, as well as the spatial correlation coefficients.

[Table 2 is somewhere around here]

[Figure 6 is somewhere around here]

After homogenization, the largest corrections occur during the summer (JJA) and autumn (SON) months, where temperatures are adjusted upwards, especially during the late 18th century (see Fig. 6 and Fig. 7). There is a slight tendency for upwards adjustments for the spring (MAM) and winter (DJF) temperatures as well, however it is comparably small.

The finding that the largest deviances between the raw and homogenized series occur in the last decades of the 18th century is in line with the historical evidence on the quality of the Lund meteorological observations discussed by Tidblom (1872) and Bärring *et al*. (1999). For instance, the spot of observations was moved in 1779 to the upper room of the brick and stone tower of *Lundagårdshuset* (altitude 61 m) where the observatory was located. It was probably unheated, and thus most likely a relatively cool location (Bärring *et al*., 1999). Furthermore, the notes left from the *Astronomie Observator* and Professor of Mathematics Nils Schenmark describes corrections made to faulty instruments in the 1770s, and that there was a change in the observers taking the temperature measurements during 1774/1775 (Tidblom, 1876). Similar to the results obtained here, where the largest inter-annual deviations occur during summer is in line with previous studies. For example, when performing manual testing during homogenization of the Stockholm instrumental temperature series (beginning in 1756) Moberg (2002) noted, in line with Modén (1963), that the largest discrepancies due to station location were to be observed during the summer months. This homogenization of the Lund series is in itself an important result as it has bearing on previous studies based on non-homogenized meteorological data from Lund (e.g. Palm, 1997 and especially Mattsson, 1987, who based his conclusions on instrumental temperatures during the latter decades of the 18th century).

[Figure 7 is somewhere around here]

For precipitation, I use instrumental measurements from Lund, beginning in 1748. Since hydroclimate is much less spatially coherent compared to temperature, a similar homogenization approach in line with the temperature reconstructions in the pre-

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1748 period is not suitable. Nonetheless, instrumental precipitation data can be supplemented by regional hydroclimate reconstructions. I use three hydroclimate (drought/soil moisture) reconstructions. The first, from Cook *et al.* (2015), is a Palmer Drought Severity Index (henceforth, PDSI) reconstruction from the Old World Drought Atlas, covering the entire study period, where I use the grid cell centered at 55.75°N, 13.75°E, roughly corresponding to east-central Scania. The second is a Standardised Precipitation-Evapotranspiration Index (henceforth, SPEI) reconstruction compiled by Seftigen *et al.* (2017), which also covers the whole study period (see Fig. 8). These two first reconstruction are independent in the sense that they are based on mutually exclusive data. The third and final reconstruction is a May through July precipitation reconstruction (henceforth, MJJ*pr*) by Seftigen *et al.*(2020) based on the wood densitometric indicator referred to as blue intensity (BI), covering the period after 1798. The second and third reconstruction are not strictly independent given that they are based on same tree ring data, although they are extracted using different methods and the MJJ*pr* is more oriented towards capturing high-frequency variability.

[Figure 8 is somewhere around here]

For the later period, 1865-1911, I use the daily instrumental data for Lund available at the Swedish Meteorology and Hydrology Institute (SMHI, 2021), as well as the hydroclimate reconstructions mentioned above. Finally, some studies employ climate variables based on annual change, month-to-month changes or anomalies from some long-term or moving trend when estimating the relationship between historical grain production and climate (Brunt, 2004; Edvinsson *et al.;*Bekar, 2019). However, the evidence on any potential information added by increasing the complexity of the climate variable involved has been limited (Vogel *et al.*, 2019a; Vogel *et al.*, 2019b). Thus, I follow the example of Beillouin *et al.* (2020) and use 'simple' climate variables.

2.4 Estimating the relationship between grain production and climate

The initial analysis is based on cluster-wise Pearson correlation analysis of pairs of variables. I estimate correlation coefficients between annual normalized yield anomalies of rye, barley, oats, total grain production and climatic variables on a monthly and seasonal basis, using HDSA for the period 1702-1865 and the BiSOS data for the period 1865-1911. Furthermore, I estimate the same relationships during drier and wetter years, respectively. Wet and dry years for the HDSA are defined according to the 33th (dry) and 67th (wet) percentiles of the SPEI during the period 1651-1951. For the HDSA period, this translates 58 dry years and 55 wet years. Due to the low *n* in the latter period 1865-1911 (*n* = 47), I split the data into two halves, each representing the lower (drier, *n* = 23) and higher (wetter, *n* = 24) halves of the SPEI during those years.

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3.1 Correlation results

During the bulk of the period, 1702-1865, there is a negative association between summer temperatures and grain production in all three clusters, with July and June producing the largest and most consistent coefficients, shown in Fig. 9. May yields slight negative correlation coefficients for rye in Cluster 1 and Cluster 3, and August yields similarly a relatively weak negative coefficient for barley in Cluster 1. Overall, very weak results are obtained from the oats series, mostly divergent from the other grains, except for its positive association with a higher SPEI, i.e. wetter summer conditions, which it has in common with the other grains. The seasonal temperature indicators largely correspond to monthly indicators, with JJA consistently showing relatively large negative associations with total grain production in all clusters. Except a slight positive association between oat production and spring temperatures in Cluster 3, monthly and seasonal temperature indicators for the spring and autumn gives almost no statistically significant results.

The results revealed by Fig. 10 for monthly summer precipitation show, inverse with those of temperature and hydroclimate, positive correlations with grain production. Furthermore, there are more differences between the various clusters and grains. There are no significant correlations between rye production and the instrumental summer precipitation variables, although in Cluster 2 and 3 there is a positive correlation with reconstructed MJJ. On the other hand, there is a negative association between January (and February, in Cluster 1) precipitation and rye production in all clusters. Barley, oats and total grain production all show relatively large positive correlations with June and July precipitation and with reconstructed MJJ. The number of rainy days in June and July seems to have been positive for most grain production, and especially barley, in Cluster 2 and 3, respectively. There is also a positive but less consistent association between the number of rainy days in May and for oat production in Cluster 2 and rye production in Cluster 3. The magnitude of the correlations are relatively similar, although they are somewhat higher for barley in relationship to all climate variables, as well as for most grains in Cluster 3 when considering the relationship with precipitation.

[Figure 9 is somewhere around here]

[Figure 10 is somewhere around here]

The results from the BiSOS data, depicted by Fig. 11, are quite consistent with those of the earlier period using the HDSA data, although only for the spring grains (excluding spring-rye and spring-wheat). Notably, the coefficients are much higher for the latter period compared to the earlier period, roughly double in magnitude. May and to a larger extent June and July temperatures are negatively associated with the series for oats, barley and mixed-grain. Furthermore, maximum and minimum

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June temperatures also yield negative coefficients, suggesting the optimal temperature range was relatively cool but not too cold. Similar to the period of the HDSA, the SPEI index is positively correlated with the spring grains. The related MJJ*pr* also yield positive coefficients which are relatively high (between r = 0.46 for barley and r = 0.57 for oats). June precipitation is positive for the three spring grains, whereas no statistically significant results are obtained for July, which is surprising considering the importance of July precipitation in the period 1702-1865. Practically no statistically significant results were found for autumn-rye (except a negative association with precipitation in November), autumn-wheat (except a positive association with MJJ*pr*, r = 0.46), spring-rye and spring-wheat.

[Figure 11 is somewhere around here]

It should be noted here that the historical spring and autumn-varieties of wheat and autumn-varieties of rye experienced the most change of all the grains during this period, when they were substituted by the new improved cultivars or rye and wheat on an increasingly large scale (Leino, 2017). The earlier historical varieties, especially rye, were relatively similar to the spring crops of oats and barley in terms of its relationship to climate variability and were most likely continued at some scale for the first decades of the 1865-1911 period. The latter early improved cultivars have been described as having quite opposite relationship to climate variability, where on average warmer temperatures during spring and summer were beneficial for yields (Leino, 2017; Edvinsson *et al.*, 2009). This qualitative difference between the older and newer varieties might be an explanation for the lack of climate signal in the 1865-1911 period.

[Figure 12 is somewhere around here]

Repeating the analysis on restricted samples where only the years with the driest and wettest summers, respectively, are included, the direction of the relationships remain relatively consistent. Fig. 12 shows the results of the correlation analysis in the early period, considering only dry years (as defined by the SPEI). The magnitude of the negative association between summer temperatures and all grain production except for oats increases, yielding correlation coefficients between -0.3 and -0.52.

[Figure 13 is somewhere around here]

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There is no statistically significant effect from monthly summer precipitation, except for the MJJ*pr* which shows a positive association with most grain production in all clusters, except oats in Cluster 2 and Cluster 3. Considering only wet years in the early period (Fig. 13), summer temperatures are still negatively associated with grain production in all clusters, especially Cluster 1. Furthermore, there is a positive association between rye production and September temperatures in Cluster 2 and 3 in wet years. Notably, quite high correlations results between precipitation during June and especially July during wet years in the early 1702-1865 period (*r* between 0.31 and 0.78).

3.2 Discussion

For roughly two centuries, between early 18th and early 20th centuries, Scanian grain production seems to have had a reversed relationship to temperature compared to other parts of Scandinavia, as well as other parts of Europe (Esper *et al.*, 2017; Pribyl, 2017; Brunt, 2015; Holopainen *et al.*, 2012; Waldinger, 2012; Holopainen & Helama, 2009). This merits some further discussion.

Both Utterström (1957) and Edvinsson *et al.* (2009) argued that the most important constraining agro-meteorological factors in southern Sweden were precipitation and drought. Edvisson *et al.*(2009) also proposed, for Sweden as a whole during c. 1724-1870, that the optimal temperature conditions occurred when the temperature differences between winter and summer where the smallest, i.e. warmer winters and colder summers. Moreover, as previously mentioned, Edvinsson *et al.*(2009) also found the magnitude of effects to be lower in 1724-1870, compared to a later period, 1871-1955. They partly explained this by an increasing shift towards wheat production, which was more sensitive to temperature. Although the authors do not mention it, this trend was also reinforced by the new varieties of autumn-rye (Leino, 2017). More controversially, Edvinsson *et al.*(2009) suggested that before the agrarian transformations in the 18th and 19th centuries, yields were in general so low as to lead to a chronic shortage of seeds, which they suggested overrode the effects from climate variability. Theoretically, low yields leading to low seed quantities could obfuscate the effect of temperature, necessitating some kind of control for the previous year's weather. For example, Bekar (2019) found that English manorial harvests in the 13th and 14th centuries were persistent, i.e. subpar harvests, partly induced by 'weather shocks', persistent into the subsequent year for both wheat and other grain crops like barley and oats. However, the relevance of 14th century England for 18th century Scandinavia is arguably limited. In instances were one might assume persistent harvests would be more apparent (although it is a relatively understudied phenomenon), like northern Finland, one still finds relatively large current-year temperature effects on grain yields and production during the early-modern period (Huhtamaa & Helama, 2017b; Huhtamaa, 2015; Solantie, 1988). Having limited amounts of seed did not obfuscate or exclude the effects from weather. Rather the evidence seems to suggest it made farmers more vulnerable and the effects more apparent.

Returning to the study at hand, there are few reasons to suspect that seed shortages was a major issue in 18th century Scania, given that it was mostly an exporter of grains and experienced more or less ongoing increases in production during the period (Olsson & Svensson, 2010). The results in this study consistently pointed to the importance of temperature and precipitation

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during the summer, particularly the months of June and July, for all the studied grains in the early period and for all spring-crops in the latter period. If anything, it was more difficult to identify a climate signal for the new high-yielding autumn-crops that were introduced in the latter part of the 19th century, although this most likely stems from the difficulty to control for the 'switch' from the older grain varieties to the newer ones.

The argument that grain production in southern Sweden was mainly constrained by precipitation is to some extent supported by the results obtained here. However, instead of focusing on just temperature I would stress the combination of precipitation *and* temperature. In the case of Scania, and probably other parts of southern Sweden as well, it was not merely that drought was a risk, rather cooler and wetter conditions in the summer probably bolstered grain production, at least for the grains cultivated up until the late 19th century, and to some extent the spring-crops cultivated thereafter. Finally, the argument needs to be broadened to include other factors in addition, and in relation, to climate. Utterström (1957) mentions the drifts towards a more continental climate during the period, increasing the risk for drought. Edvinsson *et al.* (2009) argues that Utterström (1957) appear to be correct. I would elaborate upon this argument by emphasizing that the specific grain varieties being cultivated also played an important role of determining this relationship. For example, with the increasing shift towards the new grain varieties in the late 19th and early 20th centuries the negative association between summer temperatures and positive association with summer precipitation largely disappears, at least for autumn-crops. This probably had more to do with the new grain varieties that were cultivated rather than changes to the climate, given that the relationship remained intact for most of the spring-crops.

Nonetheless, it is possible that climate changes over a longer time-scale was an active driver in the relationship between climate variability and grain production, given that the historical grain varieties were changeable and adapted to changing circumstances, not least climate variability at different time scales (Leino, 2017). It can be argued that farming in Scania during the 17th up until the late 19th century was adapted to a relatively cool and humid climate, having experienced multiple cold years and periods of years during the LIA in the 16th and 17th centuries, and possibly earlier as well. Regarding the grain varieties being cultivated, current evidence suggest they were similar or of the same group of varieties grown in more northerly and cold latitudes. For example in regards to rye, Larsson *et al.*(2019) found through genetic analysis of preserved Fennoscandian rye seeds that they all belonged to the same meta-population of rye landraces that had been stable for at least the last 350 years. Similarly, Aslan *et al.* (2015) found that barley landraces from Fennoscandia form a homogenous group of barley landraces, distinct from other parts of Europe. This particular group of northern European barley varieties carry the nonresponsive d-H1 allele that prolongs flowering when exposed to periods with increasing daylight hours. Presumably, this would be beneficial during cooler and wetter periods by taking full advantage of the extended growing season. Studies of modern Finnish barley cultivars have shown that yields for most varieties are negatively correlated with excess rain or drought around the sowing season and positive in the subsequent stages of crop development, whereas they were negatively correlated with temperature at most stages of crop development, especially before heading (Hakala *et al.*, 2012). The homogeneity of barley landraces over time in southern Sweden were confirmed by Lundström *et al.*(2018) who traced it back to at least the

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late 17th century. While Lundström *et al.*(2018) argued that such homogeneity was maintained *despite* repeated crop failures in southern Sweden between the 1700s and the 1900s, I would argue, at least when considering Scania, that such homogeneity was probably maintained because of the *lack* of repeated crop failures. In relation to this argument, I would highlight another important result of this study, namely the absence of a climate signal in the spring and autumn months, as well as the last summer month of August to some extent. This could be interpreted as spring or autumn frosts not being a systematic threat, at least at a regional and semi-local level. Furthermore, it suggests that the combination of the climate in Scania and the farming systems Scanian farmers adhered to offered relatively good margins for the spring and autumn agricultural work seasons, for example by allowing for delays in sowing and harvesting. Again, it should be emphasized that Scania has the longest growing season of all regions cultivating Fennoscandian landraces of rye and barley. However, it is possible that Scania was not exceptional in this regard compared to other parts of Sweden (Edvinsson *et al*, 2009).

The finding that Scanian grain farming was relatively adapted to humid and cold conditions simultaneously speaks to a potential risk in terms of weather extremes, namely drought. Much of the arable land in Scania, as elsewhere in southern Sweden, was situated on well-drained soils on relatively elevated areas whereas meadows were often on more low-lying and wet soils (Dahl, 1942; Gadd, 2001). These circumstantial factors combined with the consistent findings of negative associations with June and July temperatures, and positive associations with precipitation in June and July indicates that summer drought was probably the greatest agro-meteorological risk to grain production. Relative to the benefits of intensive grain production in the region, this was by all accounts a risk worth taking. The fact that most of the efforts in land improvements involved ditching and transforming wetter lands to well-drained arable lands supports the notion that in the weighing of risks relative to benefits, the benefits outweighed the risks (Bohman, 2010).

Nonetheless, it is worth considering what farmers could do to mitigate this risk. In regards to the specific grain cultivation on these well-drained soils, probably very little. It was after all the very same characteristics in the soil that increased the risk of drought that also made a large production of grains possible. Consider for example that grain production in the cluster with the best soils in this study, Cluster 3, showed a relationship with climate variability that was of similar and often greater magnitude than the other clusters. The extensive land reclamation efforts that took place during the 18th and 19th century probably, temporarily and as an unintentional side-effect, helped mitigate the risk by making new lands of variable qualities, not least in terms of drainage, available (Håkansson, 1997). A relatively diversified composition of grain production probably also helped to some extent to make grain farming more resilient in Scania. The slight but important variation between the grains in terms of their relationship to summer temperatures and precipitation, where oats and rye were more sensitive to variation in May and in particular June, and barley was more sensitive to variation in July, accordingly spread out risks. Diversity within each grain variety would also have been helpful in mitigating the risk to drought or other climate anomalies (Hagenblad *et al.*, 2012; Hagenblad *et al.*, 2016; Leino, 2017; Lundström *et al.*, 2018).

Previous research that identified increasing soil erosion and sand drift in Scania during the 18th century partly blamed the relative coldness of the last three decades of the 18th century as indicated by the instrumental temperature measurements taken in Lund (Mattsson, 1987). After the homogenization performed in this study, I found that the largest corrections were made for summer temperatures in the very same period Mattson argued was particularly cold in the late 18th century and that the corrections due were for upwards adjustments. In other words, the c. 1770-1800 was not as cold as suggested by Mattson (1987) or the un-homogenized Lund temperature series. While these findings speak against a regional climate-driven ecological crisis, they do align with the results of Bohman (2017a, 2017b) who downplayed the spatial scale of the ecological crisis, emphasizing its local and conditional character, as well as the counter-acting efforts by local communities and authorities.

Three different hydroclimate reconstruction were employed for this study. In the early period (1702-1865) very few and mostly inconsistent results were obtained from the scPDSI from the OWDA, and no statistically significant results were found for the late period (1865-1911). The SPEI from Seftigen *et al.*(2017) was found to be positively associated with most grain production except barley, consistent over different samples and periods as well as with results from instrumental precipitation. The results of the MJJpr and SPEI could be interpreted as them being relatively more important for estimating hydroclimatic conditions relevant for grain production in the early summer (May and June, in particular). This is supported by the lack of statistically significant effects found between May and June climate variables and barley production and that the most important month for barley seems to have been July, at least in the early period. Furthermore, this also offers an explanation as to why sorting dry and wet periods with the SPEI indicator led to much larger associations between precipitation and temperature in June and July with grain production. If conditions were relatively wet or dry in the early summer, the effects from subsequent precipitation and temperatures later in June and especially July would theoretically have been amplified. An important caveat to these interpretations is that there remains a relatively large degree of uncertainty as to what specific hydroclimate effects are captured by or represented in these reconstructions. Nonetheless, there do seem to be a relationship between the conditions for tree growth in southern Sweden as represented in these reconstructions and grain production in Scania during the study period. Seftigen *et al.* (2015) asserted that even though most high-resolution climate proxies in northern latitude regions are temperature-based, there is also a need for precipitation-based proxies due to the importance of precipitation patterns for economic sectors such as agriculture. The results obtained here confirms both the importance of precipitation patterns for agriculture as well as the relevance of the proxy reconstructions in studying that relationship.

The discussion of the results on the relationship between specific grains to climate variability should also be put in a broader perspective. In terms of crop composition and the type of field-system (a Swedish variant of the open-field systems called *tegskifte*), the farming systems of Scania remained more or less the same until the 19th century, when new crop rotation systems started to be introduced, starting in the plains districts. However, even after the introduction of new crop rotations, which normally meant increasing shares of fodder crops, in Scania grain production continued to retain its primacy, at least in the plains districts (Bohman, 2010). It is thus motivated to argue that the farming systems of Scania overall were resilient towards

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colder conditions, at least until the late 19th century, given the importance of grain production. However, the relationship between livestock production and total production and climate variability would require a study of its own. Taking an even broader perspective, the larger agrarian economy of Scania was increasingly integrated northwards rather than westwards after Scania was annexed by Sweden in 1658. While it is likely that Scanian farmers cultivated northerly grain varieties before 1658, after this date the geographic, economic and political conditions were set for such grain varieties to consolidate their position.

Conclusions 3.3

This article demonstrates the possibilities in estimating the relationship between climate variability and grain production in Scania during the pre-industrial period using available grain production data, climate reconstructions and the network of early instrumental records. Grain production in Scania did not show any systematic relationship or vulnerability to climate variability in the spring and autumn seasons, whereas a relatively clear relationship could be found between grain production and climate variability during the summer season, especially in the months of June and July. Until the introduction of new varieties of autumn-crops in the late 19th century, all grain production was benefitted by relatively cool and wet conditions throughout the summer, although there was a slight but important differentiation between rye and oats, which were more sensitive to conditions in May and June, and barley, which was mostly sensitive to conditions in July. The most apparent agrometeorological risk was summer drought. However, given the relatively wet climate of Scania and the diversification within and between historical grain varieties cultivated in Scania meant that, by and large, this risk was relatively low compared to the benefits on historical grain production in the region. Scania largely conforms to the previous, albeit sparse, picture in the Swedish historiography of the relationship between historical grain production and climate in southern Sweden. However, it stands out compared to other parts of Scandinavia and continental Europe where temperatures were mostly positively correlated with grain production.

The results obtained here should be further developed on by integrating them into a broader model of the impacts of climate variability on agriculture where other factors, e.g. market prices and access, institutional and other geographical factors like soil conditions, are formally accounted for. This need is not least implied by the fact that even in the relatively confined (from a climatic perspective) geographical area of Scania there was differentiation among sets of villages as regards to the relationship between their grain production and climate.

Data availability. All original data used for this article can be found available online through URLs in the reference list.

Competing interest. The author declare that he has no conflict of interest.

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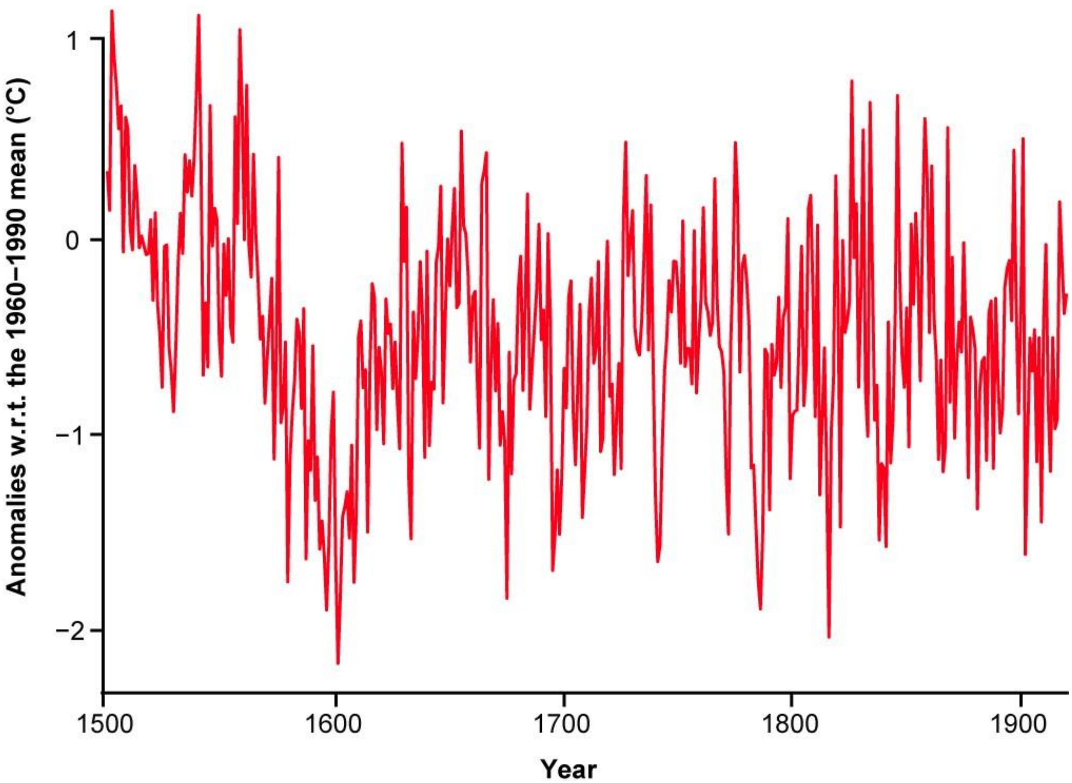

Figure 1: 1500-1920 summer (JJA) temperature reconstruction, from Ljungqvist *et al.*(2019). Based on grid cell at 12.5° E and 57.5° N, corresponding roughly to Mark Municipality in southern Västra Götaland. Source: Ljungqvist *et al.* (2019).

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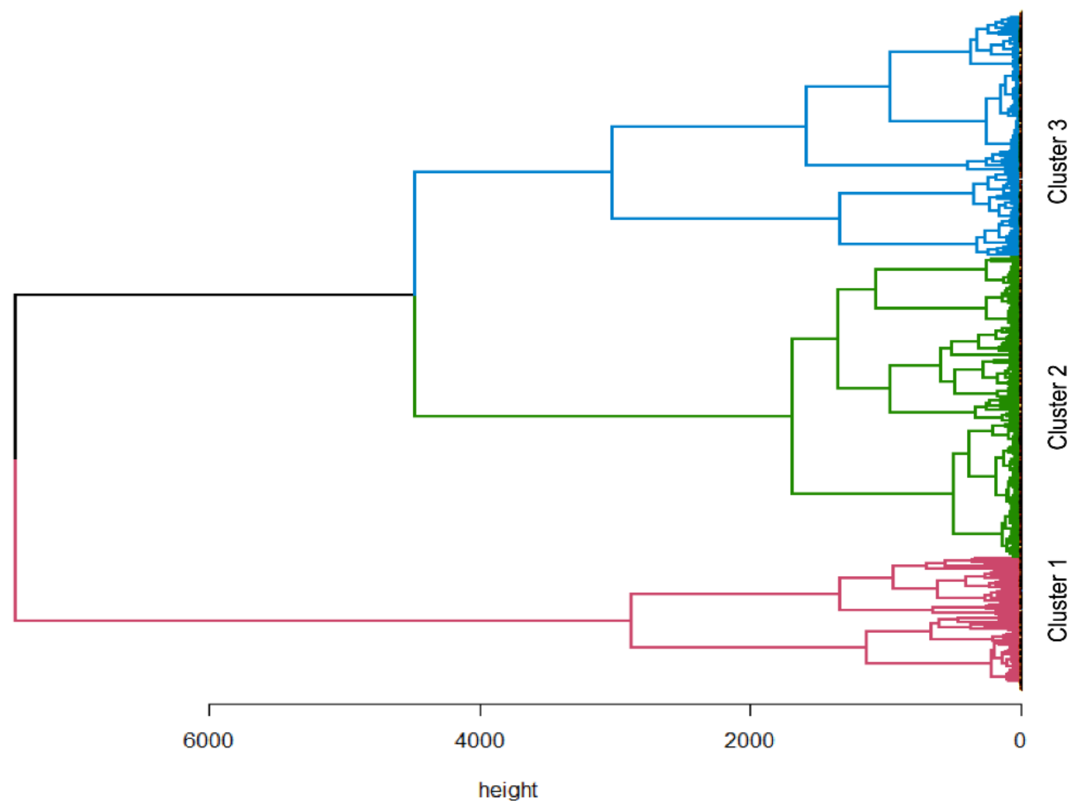

Figure 2: Cluster dendrogram illustrating the sorting process leading to four most-similar clusters. Source: HDSA.

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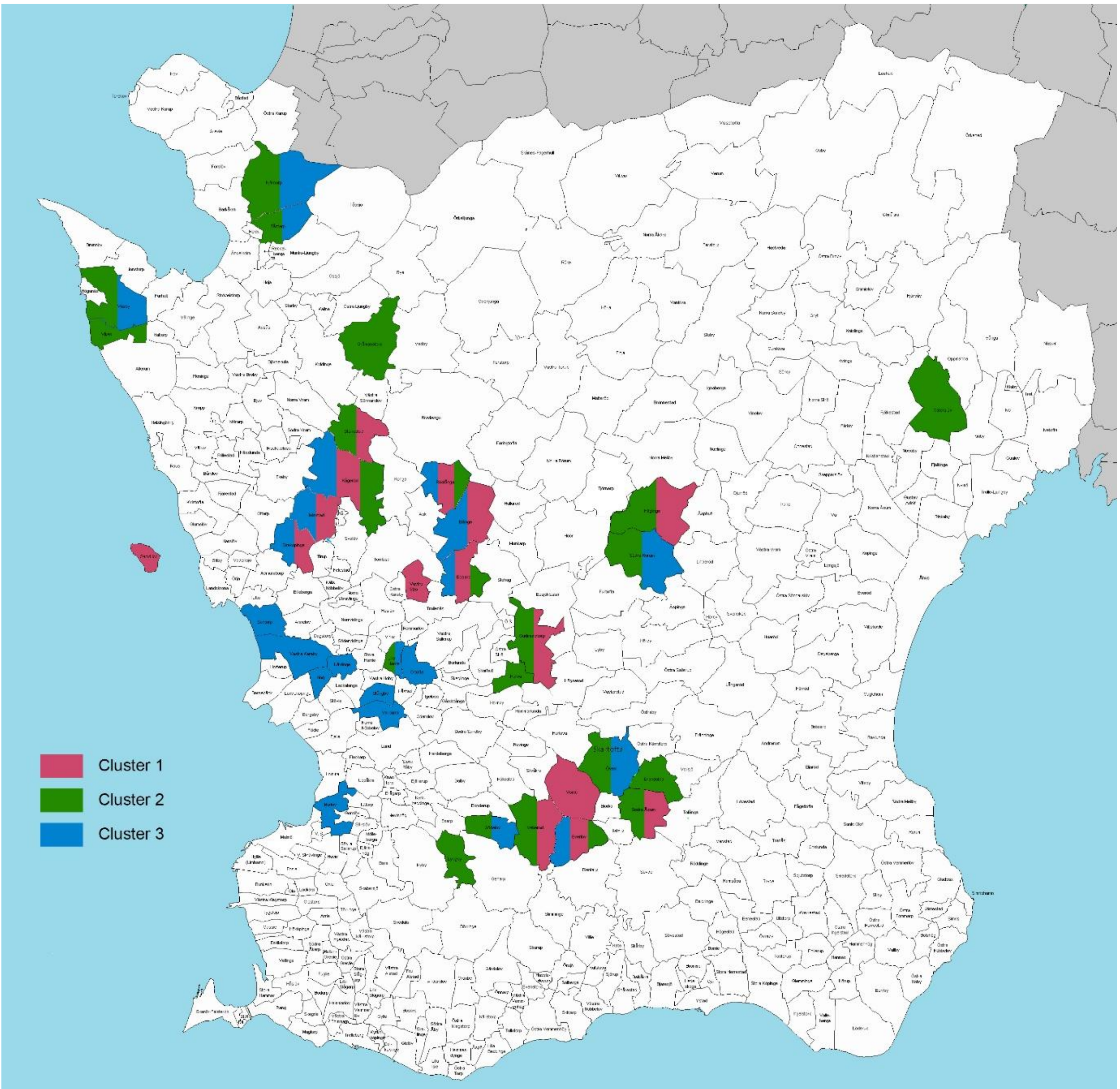

Figure 3: Geographical and administrative (parish) representation of each cluster. Source: author's own edit of the Parish map of Scania from Wikimedia Commons (2010).

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Table 1: Descriptive statistics for each cluster, including proportions of soils of different qualities.

Clusters 1-3	1	2	3
Years covered	1711-1864	1702-1861	1702-1860
Villages	173	137	71
Village-level observations	8511	4311	5551
Farms	481	514	389
Farm-level observations	32420	22054	31432
Soil grades by proportion in each cluster			
1	0	0.001	0
2	0	0.001	0
3	0.16	0.04	0.01
4	0.23	0.11	0.08
5	0.15	0.12	0.25
6	0.16	0.16	0.19
7	0.15	0.38	0.10
8	0.07	0.15	0.21
9	0.02	0.04	0.01
10	0.06	0	0.15

Notes: note that there are no grade 1-2 soils in the sample, whereas the amount of the highest-grade (8-10) soils is quite large.

Source: HDSA.

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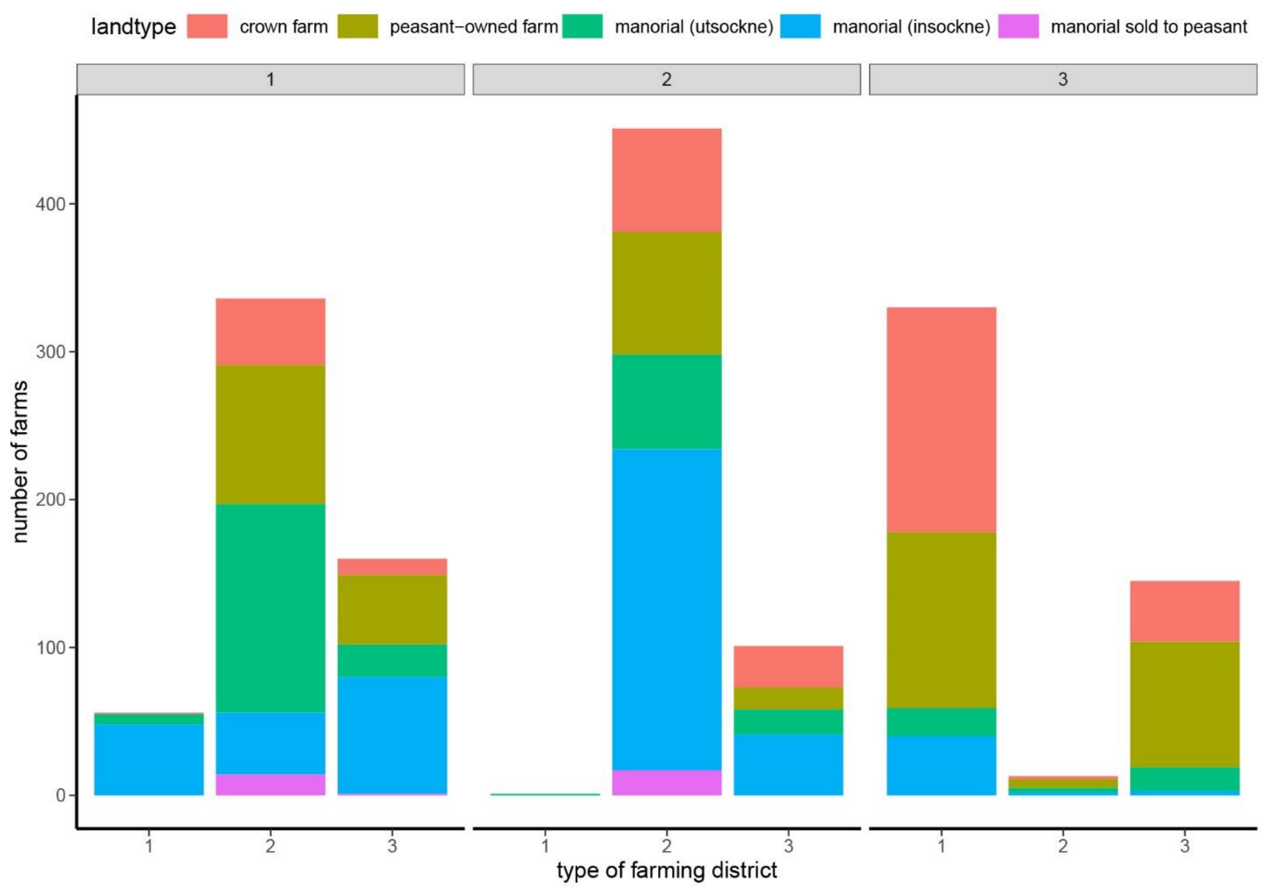

Figure 4: Institutional status of farms, including type of farming district. Each bar-plot represents a cluster with each cluster denoted in the grey-marked area. 1 denotes plain districts, 2 mixed districts and 3 signifies forest districts. Source: HDSA.

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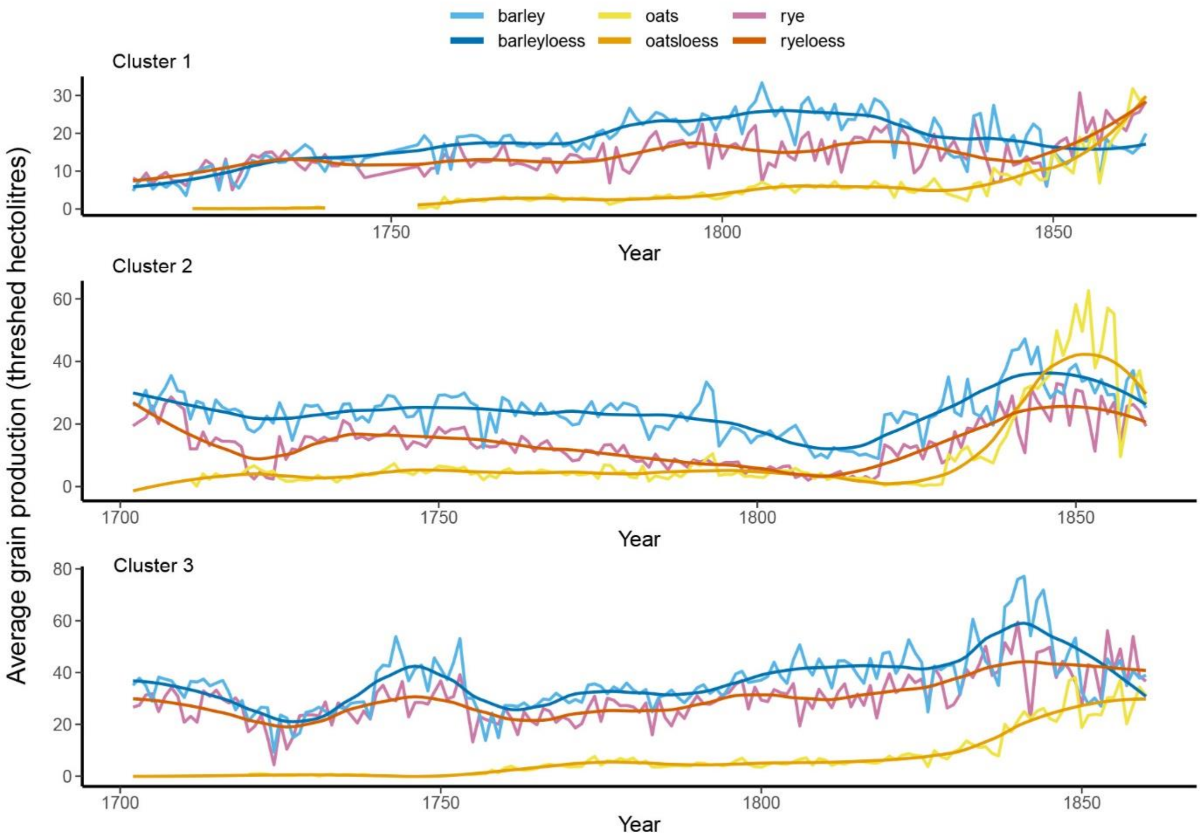

Figure 5: Average grain production (threshed hectoliters) in each cluster over time, including estimated loess. For Cluster 1 the years 1743-1746 are covered by only one farm, heavily skewing the average for those years. Therefore, I have substituted the values for rye and barley for the years 1743-1746 with values obtained from a linear estimation of the relationship between the production of that farm and the average production in the Cluster in the years 1727-1742. Source: HDSA.

Table 2: Correlations between monthly temperatures in Lund and other network series.

	Copenhagen	Central England	Uppsala	Stockholm	Berlin-Dahlem	De Bilt
January	0.93	0.73	0.85	0.88	0.83	0.82
February	0.95	0.78	0.84	0.87	0.89	0.86
March	0.93	0.80	0.83	0.86	0.90	0.88
April	0.77	0.66	0.72	0.71	0.77	0.80
May	0.69	0.43	0.72	0.70	0.76	0.60
June	0.40	0.16	0.55	0.51	0.53	0.45
July	0.56	0.32	0.59	0.57	0.61	0.49
August	0.64	0.41	0.71	0.70	0.66	0.59
September	0.45	0.31	0.60	0.58	0.64	0.47
October	0.70	0.51	0.73	0.75	0.85	0.79
November	0.83	0.41	0.73	0.77	0.83	0.76
December	0.93	0.76	0.86	0.88	0.89	0.80
Annual	0.51	0.67	0.72	0.72	0.77	0.80
Spatial correlation	0.94	0.62	0.83	0.84	0.84	0.75

Sources: Copenhagen (Cappelen *et al.*, 2019), Berlin-Dahlem (DWD, 2018), De Bilt (Durre *et al.*, 2008; Lawrimore *et al.*, 2011), Lund (Tidblom, 1876), Uppsala (Bergström & Moberg, 2002) and Stockholm (Moberg *et al.*, 2002, Moberg, 2021). Notes: Spatial correlation coefficients are obtained by ACMANT, where increment series are correlated after monthly climatic means have been removed (Domonokos & Coll, 2017).

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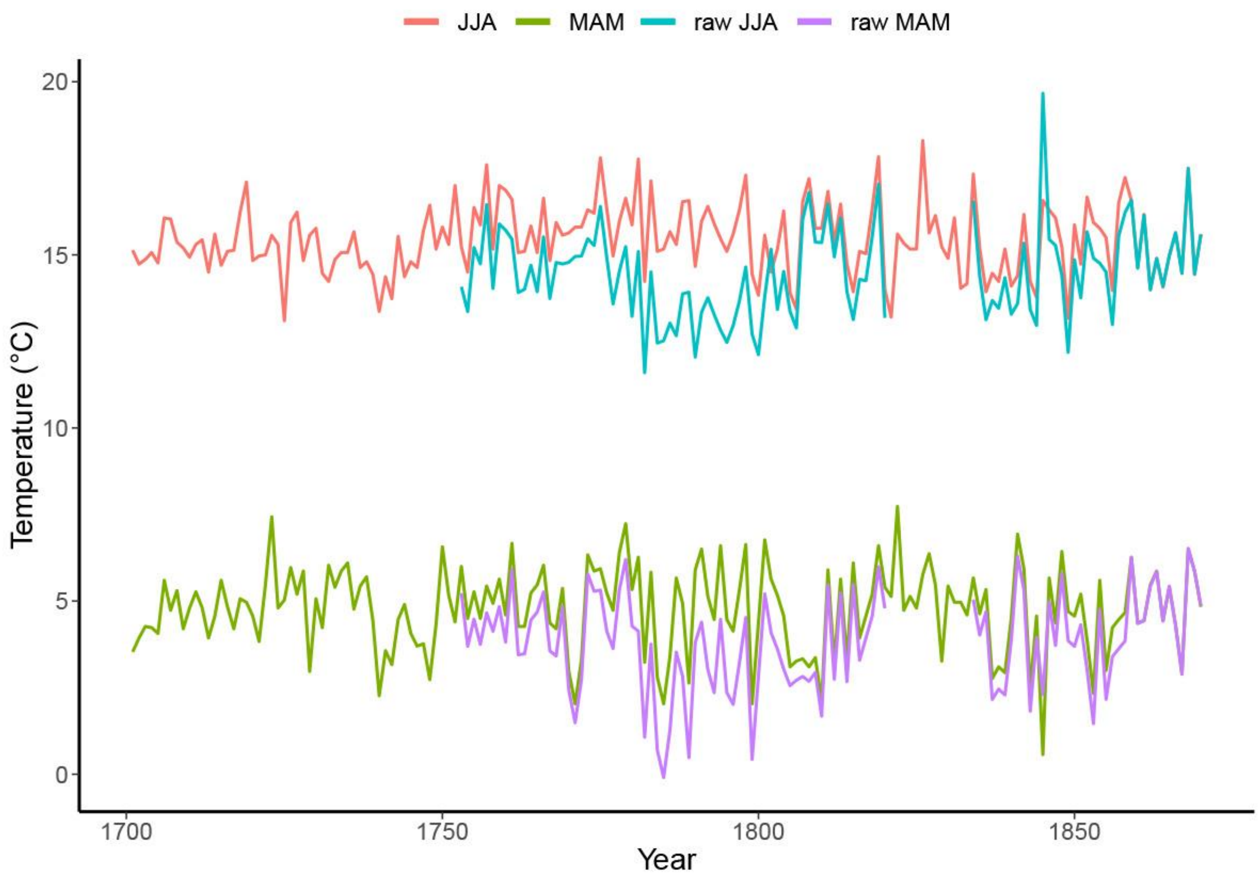

Figure 6: Raw and homogenized seasonal JJA and MAM mean temperatures at Lund, 1701-1870. Sources: see Tab. 2 above.

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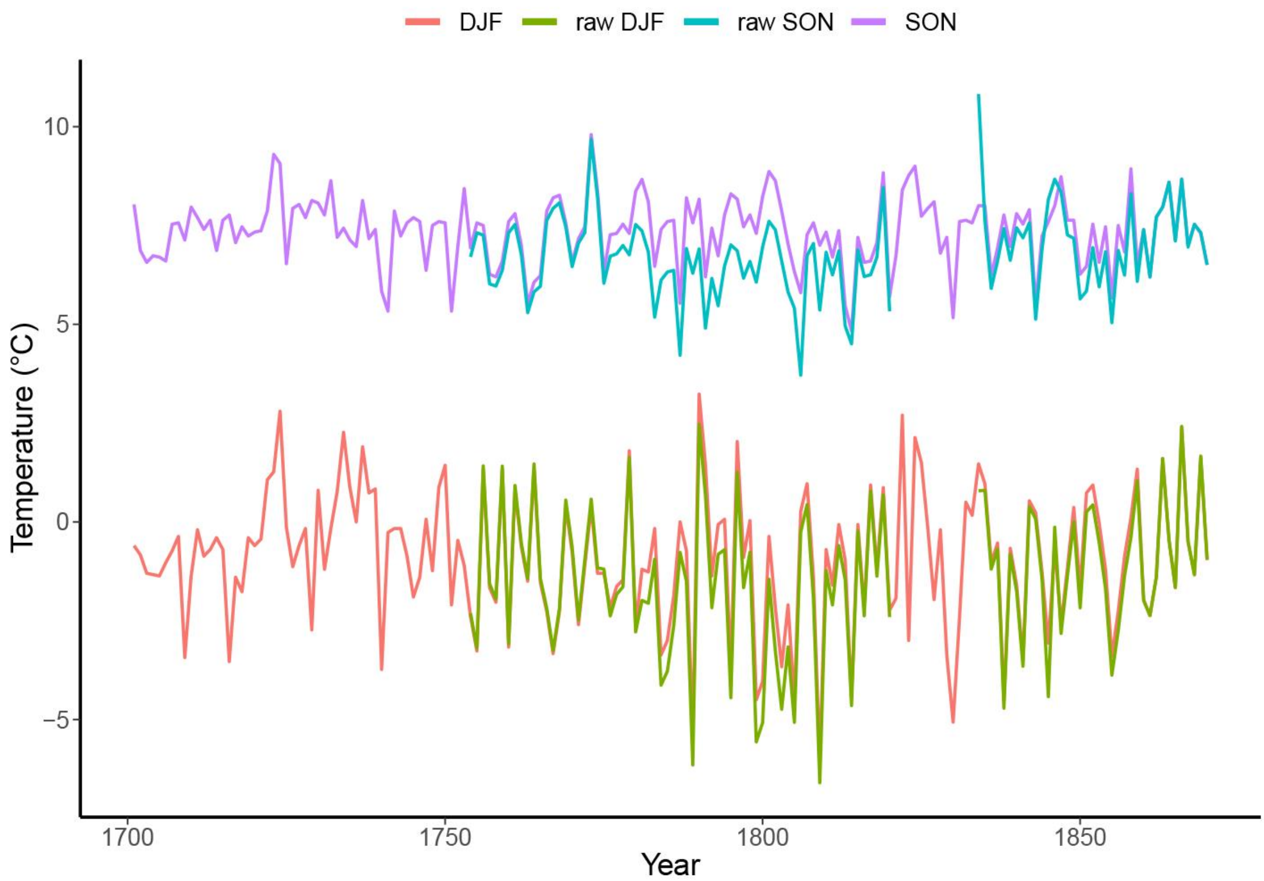

Figure 7: Raw and homogenized seasonal JJA and MAM mean temperatures at Lund, 1701-1870. Sources: see Tab. 2 above.

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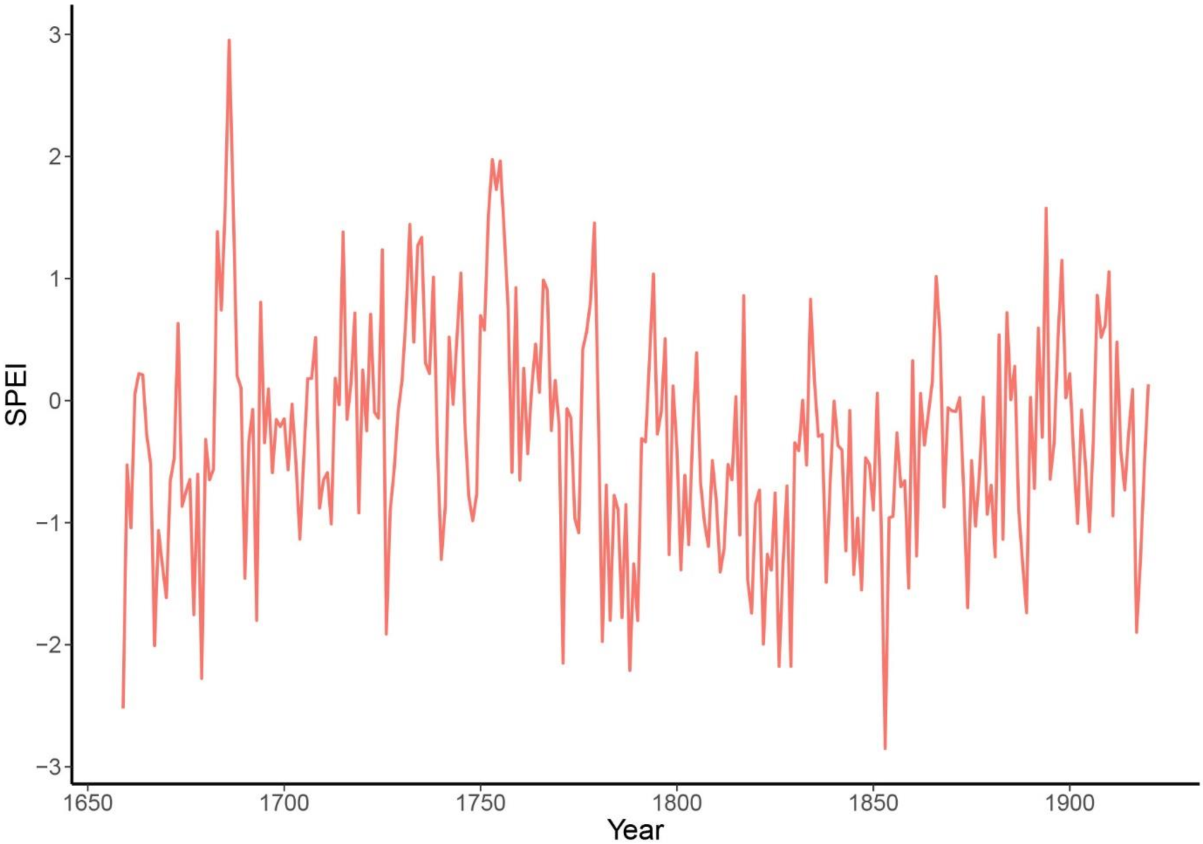

955 **Figure 8**: Reconstruction of southern Scandinavian SPEI, 1659-1920. Source: Seftigen *et al*. (2017).

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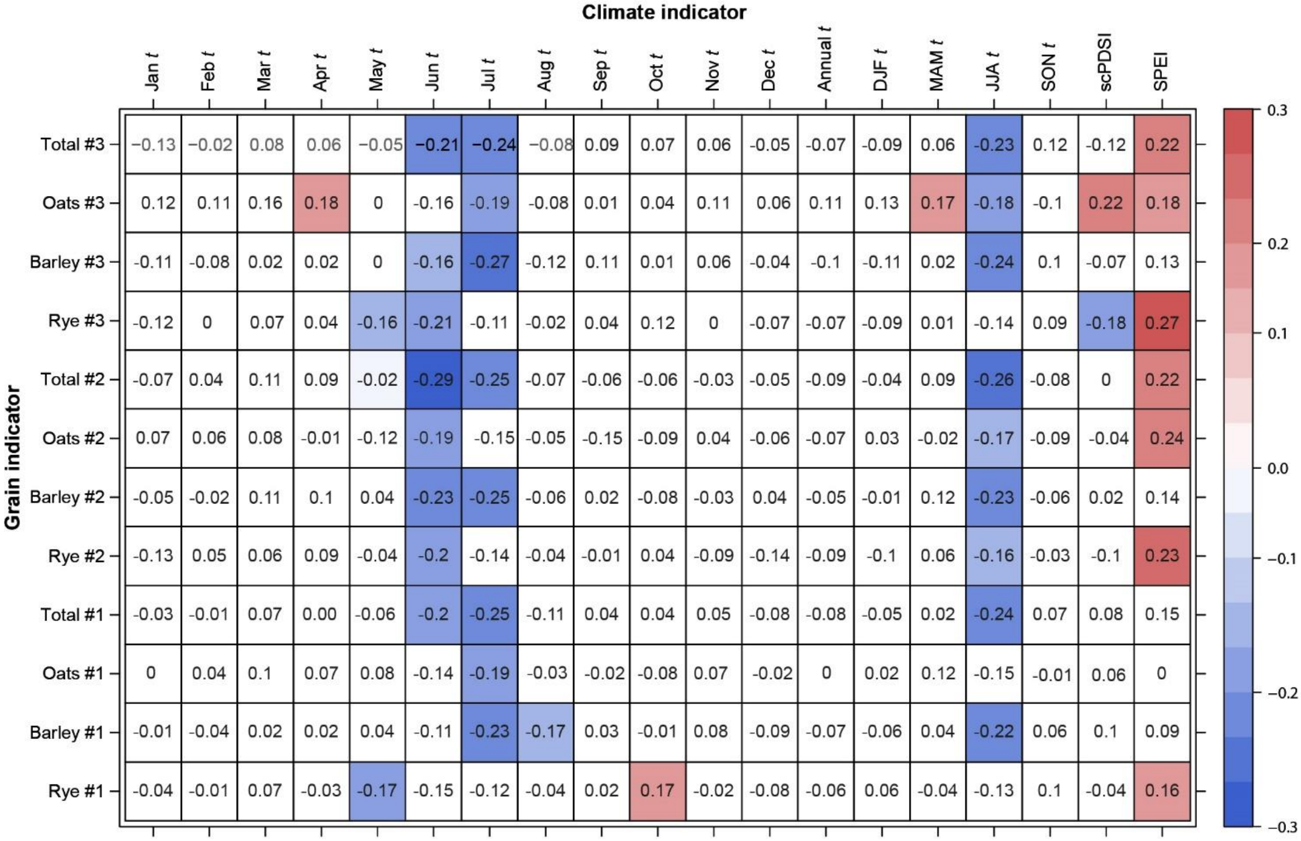

Figure 9: Correlations of grain series vs temperature and hydroclimate indicators, c. 1702-1865. Sources: see section 2.1-2.3.

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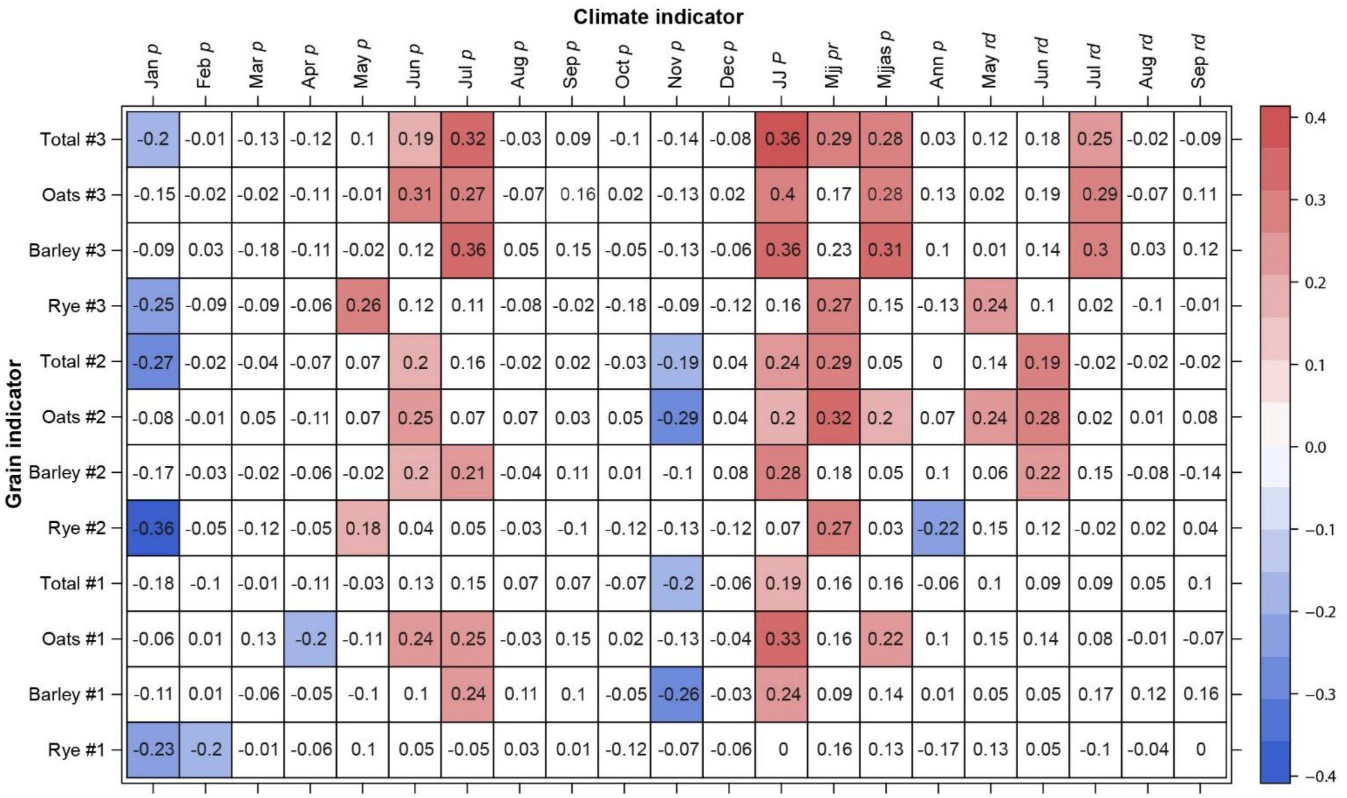

Figure 10: Correlations of grain series vs precipitation indicators, c. 1748-1865. Sources: see section 2.1-2.3.

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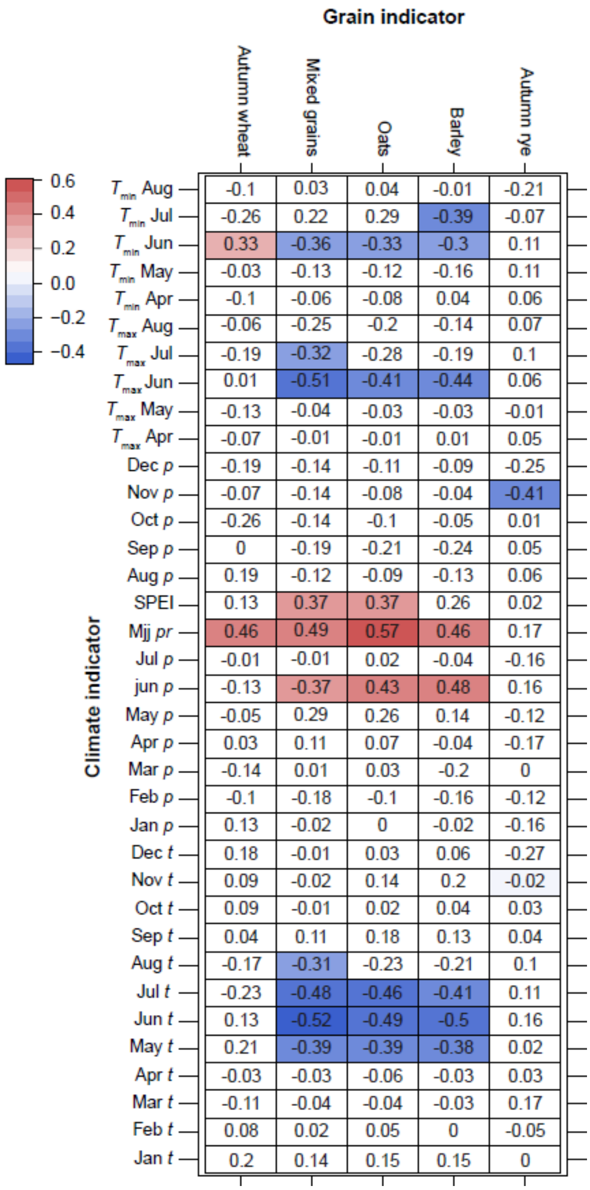

Figure 11: Correlations of grain series vs climate indicators 1865-1911. Sources: see section 2.1-2.3.

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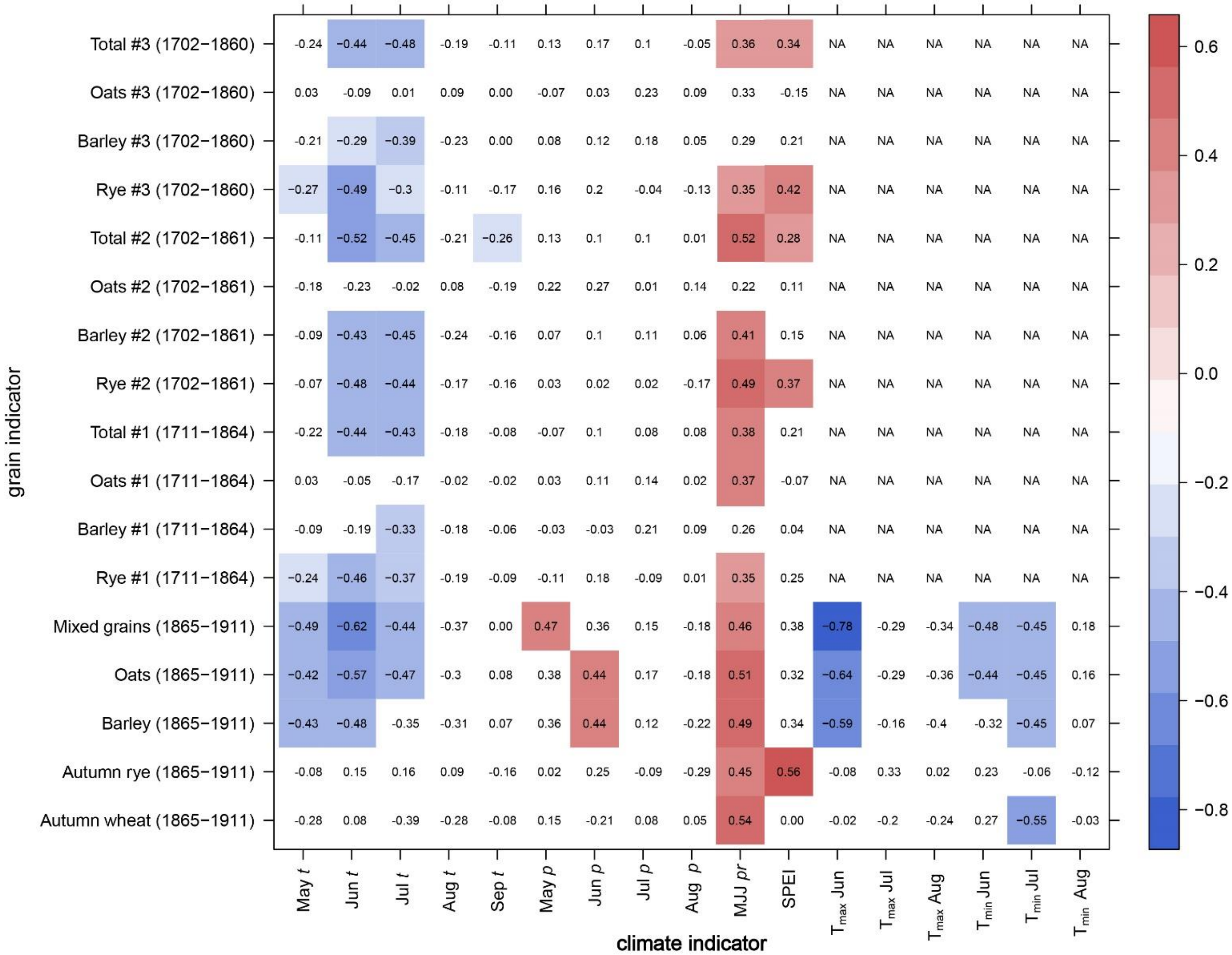

Figure 12: Correlations of grain series vs climate indicators c. 1702-1865/1865-1911 during relatively dry years. Sources: see
965 section 2.1-2.3.

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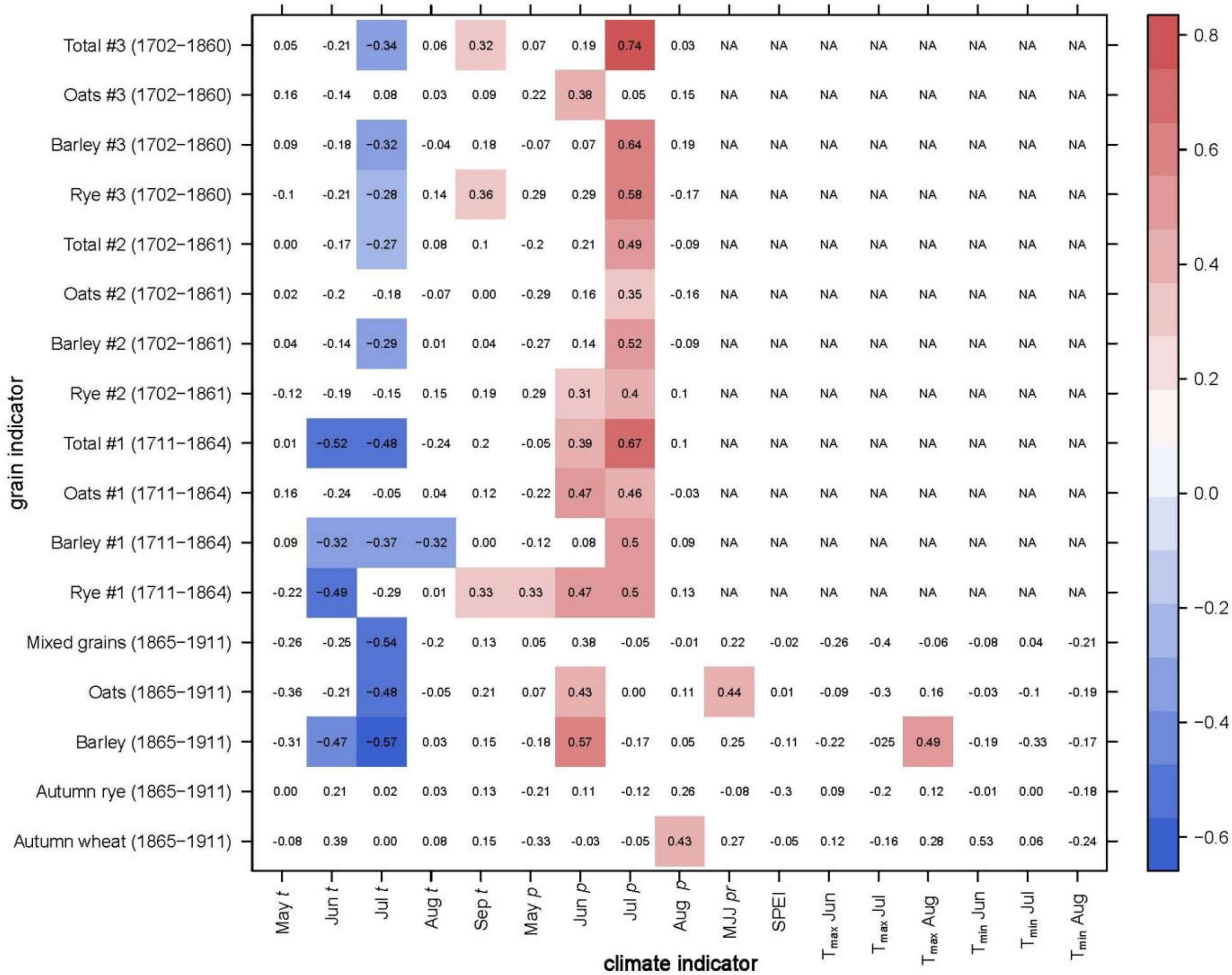

Figure 13: Correlations of grain series vs climate indicators c. 1702-1865/1865-1911 during relatively wet years. Sources: see section 2.1-2.3.

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