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Saving Up for a Rainy Day? Climate Events, Human-Induced Processes and Their Potential Effects on People's Coping Strategies in the Mycenaean Argive Plain, Greece

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Abstract

The abstract is published online only. If you did not include a short abstract for the online version when you submitted the manuscript, the first paragraph or the first 10 lines of the chapter will be displayed here. If possible, please provide us with an informative abstract.

Considerable research has been devoted to the relationship of climate change and the Late Bronze Age (LBA) Aegean 'collapse' in ca. 1200 BCE. Less attention has been paid to other factors that may have contributed in this crisis. Here we investigate the risk management strategies of the LBA people against the changing climate and another potential stress factor, monumental construction. Our case study area, the Argive Plain (Greece), accommodated several palatial centres which were active in monumental construction during the LBA. Since agriculture was the predominant subsistence strategy, resource-demanding building efforts may have affected the local economies profoundly. Simultaneously, changes in climate could have added pressure to maintain livelihood. Our study examines the area through a cross-craft interactions perspective, describing how different human activities were co-dependent. Our results emphasize the adaptive skills of the local population to the wide range of demanding tasks they faced in the LBA.

Keywords

Monumental construction
Risk management
Subsistence agriculture
Mycenaean Greece
Labour cost studies
Cross-craft interactions

Introduction [AB]

This chapter investigates, first, the pressure that changing climatic conditions and other potential stress factors, such as monumental construction programmes, could have brought upon the Late Bronze Age (LBA) people. Second, it explores the resilience and risk management strategies against such stress factors. Through our case study of the Argive Plain (northeast Peloponnese, Greece), we aim to contribute to the overall understanding of socio-political and economic networks of past East Mediterranean societies which ended up in large-scale crises and eventually to a socioeconomic and political 'collapse' around c. 1200 BCE. The relationship of climate change and the LBA Aegean 'collapse' has been a popular study arena for decades (e.g. e.g., Bryson et al. 1974; Weiss 1982; Diamond 2005; Drake 2012; Kaniewski et al. 2013; Finné et al. 2017). What such studies often lack is the consideration of the other potential factors that may have contributed in crises, and a question of the extent of the 'collapse'. These factors can be external such as natural disasters (including draughts, crop failure) diseases and changing birth/mortality rates), or disrupted inter-regional trade networks and war, as well as internal, such as social unrest and war, human and natural resource exhaustion due to overbuilding, overpopulation, or overconsumption (Bennet 2013). The question whether the long-term and large-scale building activities in the plain, resulting in impressive citadels and fortification walls, awe-invoking engineering projects and tholoi

Shelmerdine 1997), and it is very relevant to a discussion about the multi-cause crises in the region (Brysaert 2013, 2017; Brysaert et al. 2018) (see section “[Research History](#)”). If changes in the climatic conditions emerged, how were these perceived by an individual or a community? Whom did these changes affect and to what extent, and how were ancient populations trying to overcome the problems they faced (Middleton 2012; Weiberg and Finné 2018)?

For this paper we aim to contribute to the following issues:

1. What was the agricultural potential of the LBA Argive Plain?
2. What were the minimum resource inputs in the prolonged building programmes? Did these building programmes affect human and environmental resources in the region towards 1200 BCE, and if so, to what degree?
3. How much pressure could a potential climate event combined with large-scale and long-term building activities have exerted on the Argive Plain’s agricultural potential, and how did people cope with such potential pressures?

Methodologically, this paper bases itself on a critical review of archaeobotanical, archaeozoological, climatic, landuse and ancient economy literature (Timonen: in prep.), as well as on presenting published labour cost and timing data for architectural and agricultural activities that took place in the final century of the LBA (Brysaert 2013, 2015a, 2020). These data in themselves are based on critically used ethnographic accounts and published ratios. In doing so, cross-craft interaction practices emerge as the result of various *chaînes opératoires* practices that are combined. These practices coincided with people going about their daily tasks (Brysaert 2007). Specific methods for labour cost and timing are explained in the following section.

Research History

Climate in the Argive Plain Region [RT]

The current climate in the Aegean is characterized by strong seasonality, which produces warm and arid summers, and mild, humid winters. Annual precipitation is concentrated in the winter months between October and March, and reaches ca. 500 mm in the Argive Plain (Hellenic National Meteorological Service 2017). Based on a variety of datasets such as stable-isotope analyses of speleothems and sediments, it has been proposed that in the Bronze Age, the climate in the Eastern Mediterranean was generally moving towards drier conditions (Finné et al. 2011). Shorter fluctuations between wetter and drier conditions were, however, occurring within the drying trend, and they likely also took place sub-regionally. These long- and short-term climatic patterns could have influenced the success of the local agriculture.

In recent years, the Peloponnese has yielded a large number of high definition data of the LBA climate (Unkel et al. 2014; Boyd 2015; Finné et al. 2017; e.g. Emmanouilidis et al. 2018; Katrantsiotis et al. 2018, 2019; Norström et al. 2018). Most of these studies confirm the slow drying climatic trend of the Bronze Age but it seems that during the LBA, also referred to as the Late Helladic period (LH, c. 1600–1100/1070 BCE), climate was generally wet (Finné et al. 2017) offering a good basis for the local agriculture. Furthermore, recent data in the central and north-eastern Peloponnese suggest relatively stable and humid climate from ca. 1300 BCE onwards and during the last decades before the ‘collapse’ in ca. 1200 BCE (Unkel et al. 2014; Katrantsiotis et al. 2019). However, stable isotope data of the speleothems in the Mavri Trypa and Alepotrypa caves in southern and western Peloponnese unanimously indicate the presence of a severe dry period in ca. 1250 BCE (3200 yrs BP) (Finné et al. 2017; Boyd 2015). The length of this period was ca. 20 years. Currently, these data can be considered as the most reliable paleoclimatic records in the area (Finné et al. 2017). The speleothem data furthermore expresses the beginning of a more intensively dry period from ca. 1150 BCE (3100 yrs BP) onwards. Such drastically drier climate after the ‘collapse’ could have enhanced any ongoing societal and subsistence crisis. In order to understand, however, the scale of impact climatic changes may have had on the society, we must examine its level of sustainability.

Labour Cost Studies and the Argive Plain [AB]

The Argive Plain is renowned for its Mycenaean palatial centres (Mycenae, Tiryns and Midea) whose communities were active in monumental construction, craftsmanship and inter-Mediterranean trade during the LBA (e.g., Pullen 2013; Brysaert and Veters 2010, 2013). Building programmes took place in the 13th c. BCE and resulted in awe-evoking citadels, burial monuments, waterworks, roads and bridges (e.g., Simpson and Hagel 2006). It was said already early on (e.g., Müller 1930 and many after him), that these programmes likely mobilized substantial labour forces over sustained periods of time. Since agriculture and animal husbandry were the predominant subsistence strategies for most people in the Greek LBA, such resource-demanding intensive and prolonged building efforts may have affected local economies, and food provisions and intake profoundly. If present, drastic or consistently returning severe changes in the climate that resulted in consecutive years of food shortage could potentially have added extra pressure to maintain sufficient levels of livelihood during the periods of intensive construction. The potentially detrimental nature of long-term building (resource exhaustion) to the sustainability of the socio-political structures towards c. 1200 BCE has been expressed (e.g., De Fidio 2001; Galaty and Parkinson 2007; most recently Bintliff 2016). Shelmerdine (1997, 566) stated that in order to understand the complexity of the Mycenaean’s system ‘collapse’, the effects of monumental building programmes need to be investigated.

In approaching the building efforts expended by human and other resources, architectural energetics is a useful measuring tool before its results can be interpreted. The method is best summarized as the expenditure of human and animal energy extracted from calculating the masses and volumes of building materials (after Abrams 1994). These latter are used to calculate cost-estimates per construction task per material and are then combined with labour time-units invested, expressed in person days/hours. The method has been applied in many settings (see AIAA Bonn 2018: <http://www.aiaa2018.de/>). Old World applications are best known through

Burford (1960), DeLaine (1997), De Haan (2009) and Pakkanen (2009, 2013). In the Aegean Bronze Age such research is fairly new: Devolder (2013: on Minoan architecture), Fitzsimons (2011: Mycenaean tombs), Brysbaert (2013, 2015a: Mycenaean fortifications, 2020) and Harper (2016: various structures in Mycenae), and this is now also expanded upon by data collected in the field (Boswinkel, forthcoming; Turner 2020; Pakkanen et al. 2020).

In recent work carried out for the Argive Plain, Brysbaert (2013) argued that the non-specialized builders involved in such tasks were likely also the local farmers in the region. There are no Linear B tablets from the Argive Plain supporting builders working on this scale receiving remuneration from the palace although the local tablet record is very scarce. Wall builders are known from Pylos, though, and they were working at Pylos and Leuktron (Nakassis 2012). If there is a separate group of builders and labourers for building in the Argive Plain, that would imply that they (and their families?) would need to be supported long-term with food rations (by the palace or the local communities) so other workers would have to provide for them if they were building non-stop throughout the year. In any case, building throughout the year was seasonally not possible—working with oxen for both builders and farmers during the wet winter days, for example, would have been impossible due to mud slides—(Brysbaert 2013), so they would have free time to carry out other tasks. Also, the tablets show that other tasks, such as military duty, could be asked by the palace authorities as duty and tax contributions (Nakassis 2013). A similar situation can be assumed for building efforts. While the Pylos tablets refer to specialized builders (wall builders, carpenters, foremen), several other skills needed in the tasks for building may have been similar or at least compatible to agricultural tasks, thus making farmers good builders and unskilled workers when large amounts of them were needed. First, their familiarity and work with oxen and several transport tools such as sledges (which can also be used for threshing) would come in very handy. Second, being used to levelling terrain, encountering (large) stones, making terraces, digging and other work on the land would suggest strong and healthy workers, and would provide them with skills useful in building. Finally, the construction style of the citadels in the Argive Plain is very different than the palace of Pylos construction which means that the specialized and the unskilled labour needed in these two places (Pylos versus Argive Plain with three palaces) would be hard to compare.

Construction [AB]

A complete overview of all construction work that took place in the LH III A-B period (c. 1400–1100/1070 BCE) in the Argive Plain is beyond the scope of this paper. Iakovidis (1983) largely follows a three-phase division of the citadel constructions of Mycenae and Tiryns while we are aware of further sub-phases (esp. Maran 2010; French 2002, 2010). In any case, most, if not all, of these phases will have needed substantially large and organized groups of people, and similar building and stone working techniques were employed in erecting all phases (details in Wright 1978; Küpper 1996; Loader 1998). We limit ourselves to monumental construction undertaken in LH IIIB, roughly corresponding to the thirteenth century BCE and considered the acmé of building efforts undertaken by the palatial centres, and of which the results are published. The buildings concerning us here are: the citadels of Mycenae, Tiryns and Midea (Iakovidis 1983; Loader 1998; Demakopoulou and Divari-Valakou 1999), the tholoi of Atreus and Clytemnestra (Loader 1998; Cavanagh and Mee 1999; Wace 1955) and the dam and canal located four km east of Tiryns (Balcer 1974; Knauss 1996: 84–86; Loader 1998: app. 4). The tholos of Tiryns (only one of two is published) is left out because there is no consensus on its date of construction. Wace (1921–1923) dated the tomb on stylistic grounds and differential use of stone to LH IIB while several other authors (Müller 1975: 4; Pelon 1976) prefer to see an LH III date, based essentially on similar grounds. The full raw data on the architectural energetics for these monuments are presented elsewhere (Brysbaert 2015a and 2013 [for Tiryns citadel], under review), but an overview of the combined published results (Table 8.1) suffices for the points we want to make and their subsequent discussion.

Table 8.1

Labour costs for 6 major 13th c BCE building works in the Argive Plain, with basic dimensions of a simplified circumference or shape

	Dimensions	Work efforts in individual person years (py)		Efforts in c. 100 py, i.e. 100 people employed simultaneously	
		Brysbaert based on Brysbaert 2015a, 2013	Loader 1998 [†] Cavanagh and Mee 1999 [*]	Brysbaert 2015a, 2013 Harper 2016 [Ⓐ]	Loader 1998 ^{††} Cavanagh and Mee 1999 ^{**}
Tiryns Citadel	725 m L wall	c. 60 py	55.26 py [†]	5.5	0.55 ^{††}
Tiryns Dam	100m L × 9m H × 65m W (av.)	-	144 py [†]	1.45 ^{††}	1.44 ^{††}
Mycenae Citadel ^{†††}	980 m L wall	c. 75 py	-	7.4	-
Mycenae Atreus treasury	13.5m H × 13.5m diam	-	20,000 pd [*] = 54.8 py ^{**}	267,570 / 162,240 [Ⓐ] = 1.65 × larger than Cavanagh and Mee (1999) = 0.9 [Ⓐ]	0.55 ^{**}
Mycenae Clytemnestra tholos ^{**}	13.5m H × 13.5m diam	-	20,000 pd ^{**} = 54.8 py ^{**}	267,570 / 162,240 [Ⓐ] = 1.65 × larger than Cavanagh and Mee (1999) = 0.9 [Ⓐ]	0.55 ^{**}
Midea Citadel	462 m L wall	c. 15 py	14.16 py [†]	1.4	0.14 ^{††}
TOTAL WORK EFFORTS FOR 100 PEOPLE				17.6 years	

Data combined from Brysbaert (2013, 2015a), Loader (1998[†]), Cavanagh and Mee (1999^{*}) and Harper (2016[Ⓐ]). [Ⓐ]Extrapolated data from Cavanagh and Mee (1999) by AB. [Ⓐ]Extrapolated from Harper (2016) by AB. ^{††}Extrapolated from Loader (1998) by AB. When compared, the right two columns show an 8–10 times difference in effort scale between Loader's and Brysbaert's work and a 1.65 times difference between Cavanagh and Mee's versus Harper's work

Table 8.1 expresses the published dimensions of the monuments taken into account, and the work load carried out in person-years based on Brysbaert (2013, 2015a) and Loader (1998: app. 3) who both carried out calculations for the citadel of Tiryns. These are compared with older data compiled by Loader (1998: app. 3) who also included data on Midea. A comparison of the Tiryns data from

both Loader and Brysbaert indicated a difference of c. 8–10 times lower numbers estimated by Loader. No data for Mycenae were available in past publications so these were extrapolated from the Tiryns data (by Brysbaert) rather than the Midea data since both Mycenae and Tiryns followed a more similar construction history in terms of phases, materials and size (Mylonas 1966; Iakovidis 1983). The Tiryns dam calculations are based on Loader's (1998: app. 4) work since she is, so far, the only one who did these. Her earth moving rates are based on Wright (1987: 174) who adopted a cost of one man digging 1 m³ per day. This rate was also followed by Fitzsimons (2011) for all Mycenaean tholoi and by Knauss (1996: 86) for the dam. While there are some issues with 1 m³ rate (Brysbaert 2015a) Loader's calculations contain some wider problems as well, and have been partially reassessed (ongoing work, also: Brysbaert 2020). The data for the Atreus tholos are based on Cavanagh and Mee (1999) as the only published data on the monument so far. From these, the figures of the Clytemnestra tholos were extrapolated on the basis of its similar dimensions even though the stone use, size and level of finish were different. DeLaine's (1997) instrumental calculations for the Baths of Caracalla mention the use of 220 working days in a 365-day year. In those numbers she calculated that no substantial building could have been undertaken in winter months when bad weather would inhibit it. Cavanagh and Mee (1999) worked with man-days which have been transferred into person years by their full amount, i.e. 365 days/year. Loader (1998: 70) also refers to 365 days/year and eight hours work/day which has been kept in the figures of Table 8.1, thus converting Brysbaert's (2013, 2015a) ten hour working days to eight hour working days, for matter of consistency with the other sources (Cavanagh and Mee 1999; Loader 1998).

LBA Agriculture

LBA Agricultural Production and Its Organization [RT]

The Argive plain was intensively used for agriculture throughout the LBA (Bottema and Woldring 1990; Jahns 1993). Cereals, leguminous plants, vine and olive were the main crops of the local agricultural economy. The most common cultivated cereals in the Argive Plain were barley, einkorn, emmer and free-threshed (bread) wheat (Hopf 1961; Kroll 1982; Shay et al. 1998). Similar to most of the Bronze Age communities in the Mediterranean, sheep, goats, cattle and pigs were the most common domestic animals in the LBA Argive Plain (Gejvall 1969; von den Driesch and Boessneck 1990; Reese 1998, 2008). Besides meat, these animals were exploited for their secondary products (Halstead 1987).

Such wide variety of plant and animal species is typical for mixed agricultural farms in which cereal cultivation and animal husbandry are practiced on a small scale, and who aim at subsistence production instead of a large surplus (Jones 1987; Cherry 1988; Hansen 1988; Halstead 1992, 1995). However, the LBA textual evidence, deriving mainly from Pylos and Knossos, suggests that large-scale specialized production of items such as wheat, wool and flax was practiced by the Mycenaean palatial centres (Halstead 1992). Evidence of wool production is also provided by the linear B texts recovered at Mycenae (Varias Garcia 2012). However, due to the fragmentary nature of the Argive Plain textual evidence, the extent of the palatial control over other types of agricultural production is difficult to estimate. Furthermore, since there are differences in the land use and administrative practices between the palaces of Pylos and Knossos (Shelmerdine 1999), extrapolating these practices to the palatial centres of the Argive Plain is equally problematic. Here we assume that the LBA Argive Plain agriculturalists consisted essentially of small-scale subsistence farmers, but that palatial production of wool, and other products, such as cereals, could have taken place simultaneously.

The agriculture in the LBA Aegean was based on rainfed cultivation, to which the intensity and timing of the winter rains is of crucial importance. Acknowledging the the regularly commonly fluctuating rainfall, a farmer would have ensured the success of his crops by cultivating a variety of species with different water requirements (Garnsey 1988). The palatial interest to the surplus production of a single species (e.g., wheat) could have thus increased the risk of a total crop loss in a bad rainfall year. The relatively equal amount of cereals and legumes in the LBA archaeobotanical assemblages may indicate the practice of cereal-legume rotation (Halstead 1992). Crop rotation either with bare fallow, or the alternation between cereals, legumes and fallow, enabled the restoring of important soil nutrients and prevented soil exhaustion functioning as a risk management strategy. Domestic animals could have roamed free outside the cultivated areas, or on the fallow land while manuring the fields (Halstead and Jones 1997). Part of the crop yield was likely saved for fodder, particularly for the large individuals used as draft animals in agriculture (Halstead 1995) and construction (Brysbaert 2013).

Agricultural products were stored either in storerooms of individual dwellings, or, in few cases, in larger communal storages (Jones et al. 1986). The LBA storage spaces included large pithoi, usually for storing grain or olive oil, and smaller containers of different types for various other agricultural products (Jones et al. 1986; Jones and Halstead 1995; Palaiologou 2015). Crop seeds found in storage contexts suggest most species were grown and stored separately (Jones et al. 1986; Jones 1987). Cereals and legumes were processed before being packed away, although glume wheats (i.e., emmer and einkorn) were usually stored with chaff which protected the seed from decomposing (Jones 1995; Sarpaki 2001). Ethnographic accounts suggest that households tend to store goods for maximum two years (Forbes 1982). Most evidence of LBA storage points to such small storage capacities aiming at supporting single households or small agricultural communities. Larger communal storage spaces are exceptional, even in the large palatial centres (Sjöberg 2004; Privitera 2014). This supports arguments for small-scale subsistence farming, as well as a decentralized economic model suggested by Halstead (1992). We return to this topic in the discussion.

Agricultural Cycle Data [AB]

The timing and intensity of agricultural practices may vary between years depending on climate, labour available, and the land itself. Equally, agricultural know-how and changing technologies influence choices in husbandry practices and in other skilled activities. For example, working with animals in ploughing, threshing and harvest transportation may have led to very different outputs in

demonstrate that packages of changing technologies all influenced each other and may thus have had a serious impact on how agriculture was conducted from very early on. Ethnographic sources make clear that agricultural work is very time-consuming around the year (Brysbart 2020). Table 8.2 sums up the most important tasks in the *chaîne opératoire* of the pre-industrial agricultural cycle for crop rearing and animal husbandry per season. As far as crop production and processing are concerned, many activities run over several seasons and overlap with each other throughout the year, while other activities clearly need to be undertaken step by step in a specific order of the operational chain. Table 8.2 illustrates which agricultural practices are conducted per season for south Greece (excluding Crete) because the timing of many activities depended strongly on the regionally seasonal and climatic conditions. These would have been different for regions higher north (e.g. e.g., Pindus mountains: Halstead 2014).

Table 8.2

Time table indicating which activities took place per season

	Tilling Ploughing	Sowing	Harvest	Crop processing	Land management	Animal husbandry
SPRING	Yes	Yes	Late spring		Yes	Sheer sheep Calving
SUMMER			Grain, then pulses/beans	Grain, then pulses	Manure after harvest	August: Cull old sheep, goat, cattle
AUTUMN					Manure before sowing	Spin, weave, hunt, fish
WINTER	Yes	Yes			Clear new fields	Milk new lambs

Based on and adapted from Forbes (1982), Halstead (2014), Blitzer (1990), Koster (1977), Dahl and Hjort (1976), by AB

Table 8.3 shows a *chaîne opératoire* of producing and processing, from sowing to grinding into flour, for an area of 1 ha. Halstead's (2014: Table 4.1) on emmer forms the basis of Table 8.3, but figures are adapted for a more convenient 1 ha calculation rate. The calculated rates are left in ranges rather than absolute numbers to reflect better the reality which includes more or less productive days.

Table 8.3

Agricultural cycle tasks for crop rearing, labour cost rates and labour efforts needed per task, with totals

Task	Labour cost rate	Labour in person days (pd)
Tilling-sowing 1 ha	0.01–0.03 ha/pd	34–100
Reaping 1 ha	0.1 ha/pd	10–13
Manual threshing of 1000 kg	100–300 kg/pd	3.75–10
Dehusking of 1000 kg	100–300 kg/pd	3.75–10
Crop cleaning	Variable/person	25
Total without grinding		76.25–157.5
Grinding flour (c. 1000 kg grain)	3 h/day (2 kg?)	162.6

Adapted from Halstead (2014), by AB

Climate's Impact on Rainfed Agriculture [RT]

The sustainability of an area is commonly defined through its carrying capacity. In the context of early agricultural societies, it usually emphasizes the maximum amount of agricultural production the land can provide, i.e., the agricultural potential (Cook 2004). The agricultural potential is directly related to population numbers since it results in a maximum number of people who can be sustained by this production (Brush 1975). In Aegean archaeology, estimations of agricultural potential have centred around two cereals, wheat and barley (see references in table 8.4). Table 8.4 presents a selection of yields used for the Bronze Age and Classical Greece. Estimations for the Classical period are often used for the Bronze Age with the assumption that crop growing conditions did not considerably change in time (e.g., Van Wersch 1972; Palmer 1992). Both Jardé (1925), and Osborne (1987) argued that the modern climatic conditions are well comparable with the climate of the past (according to Osborne for the past 3–4 millennia). While the interannual variability (i.e., winter rains, summer drought) may have remained similar, modern paleoclimatic studies are producing increasing amounts of data of changing climatic trends since prehistory. These new data should be better incorporated in the studies of agricultural economies in the Aegean.

Table 8.4

Selected yield estimations for Bronze Age and Classical Greece. Weight kg/ha is transformed from original figures (e.g., hectolitre, *oka*, *medimnos*, *stremma*) by RT

Period and area	Wheat kg/ha	Barley kg/ha	Source
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Period and area	Wheat kg/ha	Barley kg/ha	Source
Classical Attica	436	742	Garnsey (1998)
Early Helladic Tsoungiza (Nemea)	500	400	Hansen and Allen (2011)
Classical Greece	624–936	1,024–1,280	Jardé (1925)
Classical Greece	1,000–1,500	–	Osborne (1987)
Classical and Hellenistic Messenia	772	1,157	Roebuck (1945)
Late Helladic Messenia	900	750	van Wersch (1972)

In **rainfed** systems, rainfall has an influential role in the agricultural production. Garnsey (1988: 10) indicates that the lack of rainfall at essential moments of the plant's growth cycle is strongly related **to crop failure**. In the Mediterranean, winter is the most essential period for crop growth, since then the majority of the annual rainfall is stored in the soil (Shiel 1999: 69). Depending on the beginning and length of winter rains, crops may ripen at different times. If the rainfall is particularly low, or the season short, plants will not mature (Forbes 1976: 129–130). Already the loss of one year's harvest could cause difficulties in maintaining sustenance. Crop loss in two consecutive years could lead **to famine** without proper risk **management strategies** (Hanson 1998; Hansen and Allen 2011). The annual rainfall of 300 mm is commonly suggested as the limit for drought. With a lower precipitation, water accumulation in the soil ceases, making it unavailable for plant roots (Sarpaki 1992: 63). However, different species have different requirements for water intake. Thresholds presented by Arnon (1972) indicate that wheat needs ca. 300 mm rainfall during the crucial growing months, while barley can tolerate 200–250 mm. Legumes, however, usually require 350–400 mm.

Crop failures are familiar phenomena in **rainfed** agricultural communities. In central Turkey Hillman (1973) recorded a 30% reduction **to yield** in a "bad harvest" year which the area witnessed every four or five years. In cases of "near failure", which happened on average every 17 years, the total loss would have been 55%. With **adequate risk management**, such as irrigation, the total annual loss was reduced to only 9%. Garnsey (1988) compared Arnon's rainfall thresholds to the early twentieth century precipitation in Attica, and suggested that wheat would have failed once every four years, legumes almost three out of four years, but barley only once in every 20 years. Halstead (1989) observed similar variability in the coastal plains of modern Thessaly, where within ten years, three winters experienced a rainfall of 300 mm or less, and one winter a severe drought with only a 150 mm rainfall. Interestingly, during the 300 mm rainfall years, pulses compensated some of the losses of wheat and barley, although they have the highest need for water. This discrepancy could be explained by additional irrigation. The stable isotope values measured in crop remains in Neolithic Kouphovouno, Peloponnese (Vaiglova et al. 2014) and LBA Assiros Toumba, **northern Greece** (Wallace et al. 2015) suggest that pulses were irrigated already in prehistory, while wheats and barley most likely survived with natural precipitation. Pulses, as well as wheats, were likely also manured (Vaiglova et al. 2014). Such practices could explain the abundance of pulses in the archaeobotanical samples despite the unfavourable rainfall fluctuation.

In summary, the LBA people were presumably familiar with single years of drought. They had effective means to reduce the damage brought on crops by the climate and a vast understanding over the variety of growth requirements of different species. A period of drought lasting several subsequent years would have been exceptional, and therefore people may have not had the means to cope with it. The **consequent subsistence** pressure could have had an influence in a wider societal crisis.

Discussion

Agricultural Production and Crop Failures in the Argive Plain [RT]

With an annual rainfall of minimum 300 mm, the LBA Argive Plain would have provided a fertile platform for crop cultivation. The quality of the prehistoric alluvial soils resembled that of today, and these soils were among the most productive **in Greece** (Finke 1988). The maximum area for cultivation in the LBA would have been ca. 20,000 hectares (Lehmann 1937, Timonen in prep., Bintliff 2020). With a one-year fallow/legume **rotation** (usually about 50% is left fallow) the area under cultivation annually would have been max. 10,000 ha.

Table 8.5 presents the agricultural potential of the LBA Argive Plain, calculated by using **the yield** estimates for Classical and Bronze Age presented in table 8.4. On average, the area would have supported ca. 35,000 people. The number agrees well with the earlier calculation of Bintliff (1977: 697, Table 8.4; 2019), who estimated the **maximum carrying capacity** of the area as ca. 31–32,000, and the LBA population as ca. 20,000. As a comparison, in 1928 the population of the Argive Plain was ca. 36,000 (Lehmann 1937). Using the crop reduction rates of Hillman a bad crop year would reduce the Argive Plain agricultural potential with more than 10,000 people. However, the area would still be within **its subsistence** limits. A 55-percent reduction **to yields** (delete "the yield") **the yield** would have been catastrophic to the subsistence without risk **management strategies** (Table 8.6).

Table 8.5

Population estimates for the Argive Plain based on **different yield and yields** consumption rates presented in the selected studies (i.e., 'Source'). The land area under cultivation is calculated as 20,000 ha with 50% fallow

Barley yield kg/ha	Wheat yield/ha	Barley/wheat ratio	Consumption kg/person/yr	Population	Source
750	900	1/4	235	36,700	Van Wersch (1972)

Barley yield kg/ha	Wheat yield/ha	Barley/wheat ratio	Consumption kg/person/yr	Population	Source
1,024–1,280	624–936	4/1?	230	40,200–52,000	Jardé (1925)
400	500	70/30	300	14,300	Hansen and Allen (2011)
742	436	4/1	175	38,000	Garnsey (1988)

Table 8.6

The estimated agricultural potential of the LBA Argive Plain during a year of normal rainfall, and years with 30% and 55% crop failures (after Hillman 1973). Calculations are based on the crop yields and consumption rates presented in tables 8.4 and 8.5

'Normal' year	'Bad year' –30%	'Total destruction' –55%	Used reference
36,700	25,700	16,500	Van Wersch (1972)
32,600	22,900	14,700	Amemiya (2007)
40,200–52,000	28,100–36 300	18,000–23,400	Jardé (1925)
14,300	10,000	6,500	Hansen and Allen (2011)
38,000	26,600	17,100	Garnsey (1988)

Numbers Related to Labour Involved in Building and Agricultural Activities [AB]

The building figures of the six major constructions illustrate that these took several years to be executed. Unfortunately, Loader's numbers are a serious underestimation of the work involved (Table 8.1). Both Loader (1998) and Cavanagh and Mee (1999) agree, however, that many other factors would enlarge these figures. The Tiryns fortification walls form a good example. While its full length has been included in the calculations of Loader, the two faces bring the number up to minimally 55 person years. This does not account for the fill of these walls although separating fill and two faces is not ideal for the stability of such a wall construction as field observations have shown (Brysbart 2015a). Brysbart (2013, 2015a) collected the data for the Tiryns Unterburg wall over a length of 375 m. These calculations of many, partly overlapping, steps of the *chaîne opératoire* of building multiplied Loader's by of 8–10 times (Table 8.1: indicated in blue), indicating her scale of underestimation. For example, Brysbart's calculations distinguish between minimally three block-size categories which add significantly to the cost estimations (contra Loader). Moreover, the walls at Tiryns, Mycenae and Midea also consisted of well-worked stone corners, towers and two sets of galleries and the niches in Tiryns were constructed with the corbeled technique. This would have taken longer than constructing walls, thus adding to the cost again. Numbers by Loader are given per courses but the irregular stone size cannot be matched to courses, in turn influencing the entire trajectory of transporting to building the walls, and adding to the cost once more. Many additional cost factors could be added for each of the six monuments and are done for the Mycenae citadel (Boswinkel: forthcoming) and for the Tiryns tholos tomb (Brysbart et al. forthcoming; Pakkanen et al. 2020). Unpublished data (Harper 2016: 243) indicate for the Atreus tholos an augmentation of the numbers by Cavanagh and Mee (1999) by either 1.65 or even 2.64 times, based on an eight or five hour working day, respectively (Table 8.1: indicated in green). Another sign for error in both Loader and Cavanagh and Mee's work is the fact that the labour numbers for the Tiryns citadel (Loader 1998) and the Atreus Tholos (Cavanagh and Mee 1999) seem the same (Table 8.1: indicated in grey). Even observing both monuments by naked eye illustrates that this is not possible.

The more realistic figures, based on the Tiryns calculations, therefore, provide labour costs whereby Midea, Tiryns and Mycenae citadels together would have taken, for example, 100 people to build continuously for 14.4 years (or less people for more years, or more people for less years). Following Loader, who takes the digging rate by Wright (1987), would leave the Dam calculation as expressed in Table 8.1, taking 100 people 1.4 years. If we base the labour costs for both Atreus and Clytemnestra tholoi on Harper's figure which is 1.65 times greater (8 h working day) than Cavanagh and Mee's figures (1999), these two together would have taken 100 people 1.8 years. The total building time of all would be 17.6 years for 100 people. This more solid recalculation would also solve the similar but problematic figures obtained by Loader and Cavanagh and Mee for both Tiryns citadel and the tholoi.

Table 8.2 brings the range of tasks of the working agriculturalists per season to the forefront. These tasks, as a whole, will have regularly involved the entire family unit of about 5 people together (after Halstead 2014; Gallant 1991). It shows especially the periods of intensive work to be done such as tillage/sowing and harvest which take up the late winter, spring and the entire summer. There is more slack time once the harvest has been successfully collected, but animal husbandry would have taken additional time, especially again in the winter, spring and summer months. Table 8.3 shows in more detail the labour cost of producing and preparing a mixed crop on a 1 ha plot of land, which is certainly not enough to feed a family. One would have to multiply that number by 2–3 ha (Halstead 1995), and thus also the cost factor. Halstead (2014) refers to man-days for all tasks outlined here while he mentions the labour input by women, sub-adults and children, and the elderly. Hence, man-days are replaced by person-days in table 8.3 to reflect everyone's input better.

Tables 8.1, 8.2, and 8.3 clearly demonstrate that there is very little time free during any yearly cycle for building if the farmers of any region were also the construction workers. Since one could simplistically assume that elite members of the Mycenaean societies would be sensible to leave the farmers to collect their harvest in time for their own and the farmers' sake (see Brysbart 2020), this would

leave farmer families only the autumn to double up as builders. While this may be an exaggeration—not everyone will have been 100% involved in the farming activities throughout the other seasons—it is nevertheless interesting to realize that the working time for building would easily have doubled, if not tripled for the 100 people involved. This would have meant c. 35 or 52.8 years of constant building. Furthermore, we can also assume that more than 100 people may have been involved in building in order to speed up the process. Practical limitations such as space in quarry areas and on the actual building site, however, were in place in various parts of the *chaînes opératoires* that may have restricted this (Brybaert 2015a).

Resilience Strategies [AB & RT]

People may have adopted various risk management strategies in order to survive adversity in daily life. Here we focus on various storage strategies. *Material food storage* is designed to provide long- and short-term preservation of agricultural food produce beyond its natural period of availability. (Christakis 2008–9). Storage can also be *social* when food is exchanged as a ration against social obligations (e.g., crafts), which, in hard times, can be reconverted into food. Finally, *indirect storage* of well-fed animals (e.g., with failed crops and surplus) can be converted into food during hard times (Christakis 2008–9–10). Despite potential debilitating instances from mild food shortage to full-fledged famine, ancient populations were not powerless in the face of rapidly changing climate, and our awareness of their resilience and adaptive skills is increasing. Modern data suggest that harvest failure, for example, is considerably more likely to happen in a single year rather than two consecutive ones. Shortage, rather than acute famine is the more frequent but we cannot project this scenario to any past context (Garnsey 1988–17). The two years threshold, however, is clearly linked to storage issues and unless food was brought in from elsewhere, this could affect a larger region, including central places with additional storage space. Because of the well-known risk for crop failure people knew very well how to minimize that risk, i.e., by crop diversity cultivation, as noted, for example, also at Lerna, Dimini and Kastanas (Jones 1987–120) as and as presented also earlier in this paper.

The evidence of material storage in the Argive Plain settlements is fragmentary. For LH IIIB2, Sjöberg (2004: 140–141) recognized storage at the citadels of Mycenae, Tiryns and Midea although their capacities were limited and likely only served the citadel inhabitants themselves. At Mycenae, a large storage complex was built in the vicinity of the Lion Gate in LH IIIB (ca. 1250 BCE) (Privitera 2014, citing Iakovidis 2006, latter one not seen), but destroyed, after only a few decades of use. Privitera (2014, p. 444) estimates the volume of this complex as min. 700,000 L. He suggests that it was used as a grain silo. With a grain consumption of 200–250 L per person per year (Table 8.5), such capacity could support 2,800–3,500 people. Other LH IIIB storage spaces at Mycenae are small and dispersed, and often targeted to keep large amounts of special items such as wool or oil (Tournavitou 1995; Shelmerdine 1997). In at Midea Midea, a larger storage space was located by the West Gate. Demakopoulou (1995: 157) suggests that it was used to keep the agricultural products deriving from the surrounding plain. In other words, it could have functioned as a central storage. In At Tiryns, the galleries added to the Upper Citadel in mid-thirteenth century BCE could have functioned as a larger storage (Maran 2009). Maran (2009: 248) suggests that the construction of storage spaces inside the citadel walls may reflect political changes, i.e., the increasing control and centralization over agricultural production by the palace. On the contrary, Whitelaw (2001: 58) suggests that the palatial stores were mainly targeted for the collection of foodstuffs offered at local feasts or festivals. The (admittedly scarce) evidence of the storage capacity of the Argive Plain settlements suggests they were not sufficient to serve the inhabitants of the citadels, or the plain.²

Outside the citadels, storage spaces are mainly found dispersed in individual dwellings (Jones et al. 1986). At the small settlement of Chania, 3 km south of Mycenae, three buildings along both sides of the M7 and west of the M4 consisted of storerooms for agricultural produce, stored in large pithoi. The smallest storeroom contained complete storage vessels and had no windows, likely to preserve the stored goods against light and temperature changes. This storage complex was used by the small agricultural community living in the house complex. However, the agricultural production was most likely monitored and exploited by the palace of Mycenae (Palaiologou 2014; 2015: 57–58, 73, Figs. 3a, 6a). This could confirm Halstead's (1992) decentralized model for the agricultural economy in the region.

Numbers Related to Climate, Agriculture and Construction [AB & RT]

As discussed in the beginning of this chapter, the climate in the Peloponnese underwent a drying climatic trend during the BA. The local agriculture could have adjusted to such a gradual change. However, a rapid period of drought with several consecutive years of low rainfall could have caused a subsistence crisis. The dry spell of c. 20 years in c. 1250/1200 BCE visible in the speleothem records of western and southern Peloponnese (Boyd 2015; Finné et al. 2017), may have included such years of drought, although this cannot be verified by the current evidence. More paleoclimatic data in the northeast Peloponnese are needed to firmly connect this event to the Argive Plain, but we can hypothetically examine the consequences of such a drought event in the area.

Several consecutive years of very low rainfall could have resulted in failing risk management strategies through storage because storage surplus would not have had the time to accumulate. Furthermore, material storage is usually designed to support a household for 1–2 years maximum (Forbes 1982) and any storage beyond that would have to deal with possibly moulding and infestations (Halstead 2014). Therefore, if we compare Arnon's (1972) rainfall thresholds to the storage thresholds, wheat growth would have suffered with two or more years of rainfall less than 300 mm. Additional years of less than 200 mm rainfall would have influenced the growth of drought-tolerant barley, which has been commonly used as famine food (Garnsey 1988). Therefore, besides the lack of storage surplus, abnormally dry years would have hindered the risk management strategy through crop variability.

Earlier in this paper we suggested that, in LH IIIB, the Argive Plain could have supported ca. 35,000 people with its agricultural production. The real number of population was likely less than this, and we can assume that about 20,000–25,000 people were comfortably sustained in the period when the monumental construction programmes reached their high point (Bintliff 2020; Timonen in prep.). In this paper we assume that the vast majority of a population (80%) was involved in agricultural tasks at several crucial periods (ploughing, sowing, harvesting and post-processing of crops) throughout the year. If this population was divided into households of ca. 5 people (Halstead 1995; Gallant 1991), and we assume that the main workforce consisted of two members of that household (the adults), the available adult workforce could have been 8,000–10,000 people. However, since children and elderly members of these households would most likely participate in labour activities in a diminished capacity per head, the total workforce was likely higher but hard to estimate. For the purpose of this paper, however, the minimal number based on adults seems reasonable.

We cannot be sure whether building happened simultaneously at different sites or whether builders moved from place to place. The architectural similarities between Mycenae and Tiryns and their specialized knowledge of working specific materials indicates the latter in at least some cases (Brysaert 2015b with references). The Dam was built in the very last decade of the thirteenth century BCE (Maran 2010) while the two tholoi are chronologically the earliest constructions, at most contemporary with the second, and largest, building phase at Mycenae. However, if construction workers were recruited among the common farmers, they would have most likely not worked throughout the year, but rather returned their fields during the busiest times of the year (see Brysaert 2013). If construction workers were a separate group from the farmers, though, they would have to be fed by either their own community or the palace. Linear B tablets from Pylos refer to paying specialized wall builders in kind and Nakassis (2012: 278–279), basing himself on historical parallels, suggested that the specialist builders (master builder, foremen, carpenters) could potentially have been travelling groups, of maximum 25 people, who would then locally hire the rest of the needed workers (see also Brysaert: under review).

If we consider that sowing, harvesting and crop processing took maximum 160 person days per year for 1 ha, and the average size of land per BA household is estimated as 2–3 ha (Halstead 1995), two adults could have grown and processed their own crops in about 160–240 days. For a family with adolescents, this would have taken less. Theoretically, 105–205 days are then left for building or other activities. These day ranges fall close to the suggested doubling (205 days = 1.8 times) or even more than tripling (105 = 3.5 times) of the years needed for 100 people to construct the six monuments. This converts into respectively 31.32 years based on 205 days or 61 years for 105 days of adult workforce availability (Brysaert 2020).

If the available workforce of the Argive Plain consisted of several thousand people as presented above, 100 workers involving themselves with construction for part of the year would not have overloaded the economy although at certain moments in the construction process, many more may have been needed (Boswinkel: forthcoming). However, a period of crop failures caused by prolonged drought could have created stress on the subsistence if the construction programmes had to continue with as many people as possible to speed up the process. We considered that scenario unlikely, however (see also above). We saw that a year of total destruction (55%) of crops would reduce the agricultural carrying capacity of the area down to about 15,000 people. At the same time, we, and others (e.g., Ludlow and Manning: this volume) have demonstrated that agrarian communities may suffer crop failure of wheat and barley at regular intervals when rainfalls drop below specific thresholds. Risk management strategies, such as stored goods and animal resources could help to recover from one or maximum two years of crop failure. However, subsequent bad crop years would diminish surplus production the latter which could have been used, for example, to support the builders during construction. Recovering from one or maximum two years of crop failure if storage was in place, was thus feasible. Garnsey (1988: 10) also indicates that the lack of rainfall at essential moments of the plant's growth cycle is more important than annual threshold figures, and Erdkamp (this volume) asserts that rainfall can vary largely, even at a regional scale. For our region, this seems confirmed by Lavery (1995) and by personal accounts from current olive farmers who need rain at very specific weeks of the year, beyond the larger and long-term winter rainfall, for a successful olive harvest (H. Sader 2019: pers. communication with AB). To our knowledge no data set, so far available, would be able to be that precise within an agricultural year-cycle.

Conclusions

Some general conclusions can be presented here. Single years of low rainfall, or even drought, were not enough to cause a subsistence crisis in the LBA Argive Plain. Unless the monumental construction programmes had to be finished in a very short amount of time (most evidence goes against this) and involved, therefore, several hundred people more than what was calculated, they seemed to have played a minor role in the potential resource exhaustion of the Argive Plain if there ever was such an exhaustion (see also Brysaert 2020). The biggest threat to the subsistence economy of the Argive Plain would have been a period consisting of consecutive poor rainfall years, such as the ca. 20 year period visible in the recent paleoclimatic datasets, which, in themselves, will not have been uniform throughout the full 20 years. In order to have more than the usual impact, such a period should include at least 2–3 years of rainfall less than 300 mm, and one or more years of rainfall less than 200 mm, and to form 2–3 subsequent years in order to also annihilate potential storage strategies. A hypothetical climate change of the scale sketched above here could have caused a subsistence crisis even if the monumental construction was not ongoing, although Garnsey (1988) and others have shown how rare this would have been (see above). Moreover, agricultural strategies in changing crop-growing to less risky choices when rainfall dropped will have played a role in people's survival strategies too (Erdkamp: this volume).

We thus need to keep asking ourselves whether any climate shift noticed so far, can in fact be correlated to crisis data archaeologically, and whether it was sufficiently severe to have had a major impact on society as a whole (see Erdkamp: this volume). In the exceptional case of such a climatic catastrophe, however, it is reasonable to think that construction would have ceased, since all focus had to be turned to survival. The various risk management strategies of the LBA people were aimed at supporting the population over one or two years of poor rainfall but were ineffective if prolonged bad climate would occur. The effects of political changes, such as the

centralization of agricultural storage, and the increasing control over production, could have influenced the existing risk management strategies negatively, thus making the society more vulnerable. The dating of the drought event in ca. 1250 BCE does not collide exactly with the LBA collapse. When combined with poor political decisions as an aftermath, this could have left the society bare for any kind of negative changes (as already proposed by Weiberg et al. 2018 for Pylos), such as natural catastrophes, invasion or any over-exertion of human and other resources. However, our current results emphasize the resilience and adaptive skills of the Argive Plain population to the wide range of demanding tasks that came their way in LH IIIB. In light of the evidence presented in this paper, the monumental construction programmes of the six largest monuments combined do not seem to have contributed in a major way to the socio-political and economic crises that accumulated around 1200 BCE (see also Brysbaert 2020 for additional efforts undertaken). Furthermore, we observe how risk management such as agricultural and storage strategies, and well-organized planning of large-scale construction efforts helped people to adapt to rapidly changing climatic conditions when they occurred. On the other hand, the risk management strategies would have failed quickly during prolonged periods of unusual climate which have been considered as rare.

People were also prepared to carry out highly demanding building tasks which had to be fitted, if all went well and if allowed, around intensive farming all year round. Especially people at the bottom of the food chain, such as farmers, may have planned the many tasks well ahead, and may have even seen an additional source of income in joining the building works when time allowed it. Equally, it seems that people were perfectly capable in transferring skills from farming work (e.g., ploughing with oxen) into building activities (e.g., guiding oxen in moving heavy blocks) as another adaptive strategy, and many more examples can illustrate this resourcefulness. Especially such cross-craft interaction capacities and adaptive strategies likely saw them through their daily lives. As this is work in progress, new high-definition data of regional climatic patterns and labour costs may, however, bring new light to the challenges of Mycenaean subsistence strategies and people's work patterns as a whole.

Acknowledgements Please do not delete Brysbaert A., D. Turner and E. Vikatou forthcoming in Bibliography. The deletion is a mistake, the intention was to remove "s" in eds.

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¹ Harper (2016: 243) makes an error in the percentage calculations. The correct multiplication factor of Cavanagh and Mee's (1999) total figure is 1.65 for an eight hour day.

² The population of Mycenae is estimated as 6400 by Bennet (2007). The carrying capacity of the territory of Mycenae was estimated as 2250 by Bintliff (1977), although his revised calculations suggest only 695 inhabitants for the same area in LBA (Bintliff 1989). The corresponding numbers for Tiryns are 4600 (Brysbaert 2013), 1875 (Bintliff 1977), and 579 (Bintliff 1989).