THE SHOTGUN METHOD 2.0
ESTIMATING POPULATION NUMBERS FOR SECOND-CENTURY AD SAGALASSOS

Abstract: During the last 150 years archaeologists and historians attempted to estimate the population sizes of cities and regions in the past via the application of a large variety of formulae. Most of these formulae were, however, heavily criticised, or had to rely on guesstimates. In 2006, Mogens Herman Hansen presented the 'shotgun method' as an alternative. Here, different calculation formulae were applied on the same context and the final result consisted of the total range of all the estimates. These ranges, however, are often too broad to make further inferences. Therefore, this paper aims — in the spirit of the 'shotgun method' — at surveying the population estimates to come to distributions which make it possible to select a population range with a specific probability. This refined method makes it possible to calculate both the carrying capacity and the population of a specific region or city. Consequently, inferences can be made on the population pressure and relation between an urban centre and its territory. The ancient site of Sagalassos (SW Anatolia) during the second century AD is chosen as a case study to obtain an estimate for the urban and territorial population.

I. Introduction

In 2006, Mogens Herman Hansen published a small book on 'The Shotgun Method'. His main goal was to estimate "how many ancient Greeks lived in all the poleis"[1]. One very interesting component is the method he proposed:

> To study ancient history is like hunting hares. The hunter uses a shotgun instead of a rifle. His weapon does not hit the bull's eye and is not constructed for big game, but the spreading out of the pellets to cover a broader field is very efficient when used against smaller animals. Similarly, the quantifications presented by the ancient historian are never precise, but within certain limits they can provide us with extremely valuable information about ancient societies.[2]

Hansen thus contrasted two different methods. The rifle method, on the one hand, implies that a single shot is fired in a very directed, precise

[1] Hansen (2006) 2.
[2] *Ibid.* 1; a similar method was already applied by Zorn (1994) 31-48.

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way, but that it might hit very far from the target. The shotgun method, on the other hand, increases the impact area, thus enlarging the chance of hitting whatever is in range. In practice, for estimating population numbers, Hansen used many different methods to calculate the ancient Greek population to conclude with a total range starting from the lowest estimate and ending up with the highest[3]. For the archaeological site of Sagalassos (SW Anatolia), both methods have been applied in the past. In 2008, Femke Martens and colleagues[4] chose a single method based on a formula by Josiah C. Russel[5]. To quantify the population of Sagalassos they multiplied the urban area with an estimated population density of 150 inhabitants/ha. Rinse Willet and Jeroen Poblome applied the shotgun method of Hansen for estimating the urban and territorial population of this city[6]. The range they obtained for the urban population, however, was extremely broad (between 1,500 and 5,000 individuals[7]). The question can be asked whether this range is still meaningful. What remains to be learned from a range which covers 70 per cent of the maximum number?

The goal of this paper, therefore, is to design a method that allows the estimation of population numbers of an ancient city or region as accurately as possible without obtaining a very broad range. This method will be tested on the case study of second-century AD Sagalassos. The site of Sagalassos is located in the Taurus mountains in southwest Anatolia, *c*. 100 km north of Antalya (fig. 1). The site was inhabited from late Achaemenid / early Hellenistic times until the early 13th century AD, after which community life came to an end. Within this time range, the settlement formed part of different empires and kingdoms, featuring Achaemenid, Hellenistic, Roman and Byzantine overlords. During its heydays in the early and middle Roman imperial periods, the city of Sagalassos as well as its territory reached their full extent. Since many research efforts have focussed on these heydays, important datasets are available for the second century. This chronological frame is thus chosen for practical, analytical reasons. This paper aims to estimate the population numbers of both the city and its territory to get a better understanding of the relationship between the two.

[3] *Ibid*. 73.
[4] Martens e.a. (2008) 137.
[5] Russell (1958) 68.
[6] Willet & Poblome (2015) 134-139.
[7] *Ibid*. 137.

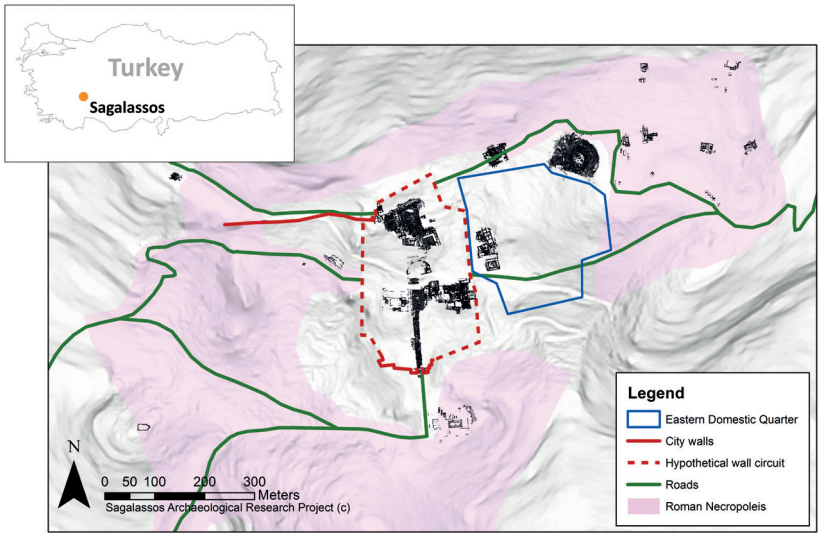


Fig. 1: A map of second century AD Sagalassos enclosed by its *necropoleis* with the eastern domestic quarter indicated in blue.

II. Methodology

The methodology proposed here consists of three parts. The first calculates as many estimates as possible using different formulae. While discussing these, the focus will mainly be on those established within the discipline of archaeology, with an emphasis on ancient sites. The second part deals with data representation to study the distribution of population estimates. Finally, the third part will distil a limited estimation range from the data distribution. As this paper also aims at comparing urban and rural populations, it is important to make a distinction between the methods for both.

In literature, a broad variety of techniques for calculating the amount of inhabitants of settlements and regions are discussed[8]. Thomas H. Hollingsworth[9] proposed a hierarchy of the sources best used for calculating population estimates. The first non-written sources only end up at place 13 out

[8] E.g. Wilson (2011) 170; Schacht (1981) 119-140; Zorn (1994) 31-48; Kolb e.a. (1985) 581-599; Willigan & Lynch (1982) 40-42; Hollingsworth (1969); Chamberlain (2006) 126-132; Hassan (1978) 49-103; Drennan e.a. (2015); Hassan (1981).

[9] Hollingsworth (1969) 43-44.

of 19. Other authors too state that the use of archaeological sources for demography "(…) may well be a hopeless task"[10]. In this regard, many case studies have shown the value of the application of written sources in ancient demography[11]. Nevertheless, for many sites — such as Sagalassos — the proposed historical sources are not available or are insufficient for deducting population numbers. The use of archaeological sources is thus a necessity in many cases, albeit a problematic one. The main problem in this regard is probably best described by Albert J. Ammerman and colleagues:

> In modern census practice, the aim is to count all of those people living over a brief period of time or even ideally at a given point in time. In contrast, the archaeologist normally has to deal with material remains that from a census point of view have accumulated over a substantial time period[12].

Other historical demographers, such as Thomas H. Hollingsworth, are even more negative about the use of non-written sources:

> Unwritten evidence, in fact, is rarely as valuable as the written word or figure. (…) the evidence is always indirect at best, and has to be amplified by fairly bold assumptions to produce any actual estimates of demographic levels or rates at all. The main value of the unwritten evidence is as corroboration of what can be suggested from other sources. On its own, it could be very misleading[13].

Yet, archaeologists in their own right have proposed a series of techniques to estimate population numbers. Most of these are based on the extent of a specific settlement or region which is multiplied by an estimate of the population density[14]. Such calculations are applied on sites all around the globe: they often rely on an estimate for the population density which is specific for the site/region under study. Indeed, the area can often easily be measured, but the population density, in the words of Robert M. Schacht, is "(…) seldom more than a guess"[15]. Fekri A. Hassan stated that "[t]he poor correlation between site area and residential population size does not seem to provide a firm basis for demographic estimates"[16]. Similarly,

[10] van de Walle & Kantrow (1974) 614.
[11] E.g. Bagnall & Frier (1994); Beloch (1886); Duncan-Jones (1974) 259-287.
[12] Ammerman e.a. (1976) 32.
[13] Hollingsworth (1969) 294.
[14] Hassan (1978) 58-59; Schacht (1981) 128-131; Chamberlain (2006) 128; De Roche (1983) 187-192; Drennan e.a. (2015) 105-108.
[15] Schacht (1981) 128.
[16] Hassan (1978) 59.

Jeffrey R. Zorn[17] listed all estimated population densities he could find for ancient populations. The highest estimate is 1,000 individuals per ha, while the lowest is 100-125 persons for the same ha. More recently John W. Hanson and Scott G. Ortman have listed a number of opportunities and pitfalls of this method[18]. It can thus be concluded that, although this method is very often applied, it is also one of the most chancy ones, because it is both case-specific and the population density is too often based on assumption.

A second technique relies on house counts which are multiplied by an estimate for the average household composition. However, an archaeological site is seldom documented to such an extent that a total house count is possible, let alone of houses which were occupied contemporarily[19]. Another serious issue is household size. Robert M. Schacht wrote on the estimates of household size: "Usually this is a guess, perhaps based on a minimally researched ethnographic analogy, and treated as a constant"[20], a critique which is supported by many other scholars[21]. Treating household size as a constant is problematic as it does not take the varying family structure across time/space into account, nor does it reckon the household cycles over generations[22]. An often cited paper by Christy G. Turner II and Laurel Lofgren[23] tried to overcome the problem of the unknown average household size of the western pueblo Indians by dividing the volume of cooking vessels by that of consumption bowls. This method, however, cannot be applied for most ancient sites, because of the wide variation in consumption wares and attitudes, and diets and practices, as well as the uncertainty that households always dined together (e.g. a family and their servants living under the same roof probably ate separately). Here, historical sources — if these are available for the site or region under study — can give some solace.

Many other, albeit less practiced, techniques are proposed in literature: the seating capacity of (amphi)theatres[24], the size of water supply[25] and necropolis data[26]. As for theatres, not all provided space for all inhabitants

[17] Zorn (1994) 34.
[18] Hanson & Ortman (2017) 303-304.
[19] *Ibid*. 33; Schacht (1981) 126.
[20] Schacht (1981) 125.
[21] Kolb (1985) 582; Zorn (1994) 33; Willigan & Lynch (1982) 41-42.
[22] Drennan e.a. (2015) 101-102. See for example Ian Morris' reconstruction of the family developmental cycle in Vroulia (Morris (1992) 196-197).
[23] Turner & Lofrgen (1966) 117-132.
[24] Wilson (2011) 170; Duncan-Jones (1974) 261.
[25] Lloyd & Lewis (1977) 35-40.
[26] Asch (1976).

in the city. Moreover, other factors might have caused theatres to be equipped with more seats than the size of the urban population. One possible reason can be the organization of the Imperial cult in a specific urban centre, causing a temporary influx of people from the wider region. Sagalassos itself can be considered as such an example[27]. Indeed, theatres were not only built for the inhabitants of a city, but also for visitors from the wider region. This total, even if it can be calculated, can therefore not be used for estimating population numbers. As already indicated by Richard Duncan-Jones[28], water supply to the city is not a good estimate for the urban population either, because not all of the water was used as drinking water, but for bathing facilities and nymphaea as well. Moreover, drinking water was not always gathered from public fountains but could be obtained from wells, springs or rain barrels too. Skeletal data in the past were considered unreliable for making population estimates, especially because of issues related with calculating average life expectancy[29]. More recently, however, they are praised for their purposes in studying demographic structure, mortality and fertility patterns, as well as sex and age distributions[30].

The notion of agricultural carrying capacity has always been regarded as an important aspect in demographic studies[31]. The term 'carrying capacity' originally derives from the discipline of ecology, where it is defined as "the maximum population of a given organism that a particular environment can sustain", indicated with the letter *K*[32]. Although between the 1970s and '90s this concept was popular under the influence of New Archaeology conceptualizations, some authors were quite critical when it came to its application: "The practical problems involved in measuring and using 'carrying capacity' have proven the concept to be deficient in theory, unrealistic in implementation, and impossible to measure"[33], Brian Hayden stated. This critique was mainly influenced by the practical pitfalls of the concept: knowledge of the diet of the inhabitants, an exact outline of the catchment area, a reconstruction of the past environment, the area needed to support a household, seasonal cycles and

[27] Waelkens & Poblome (2011) 120; Talloen & Waelkens (2004) 171-216; Talloen & Waelkens (2005) 217-250.

[28] Duncan-Jones (1978) 51; Duncan-Jones (1974) 261.

[29] Hollingsworth (1969) 43; Schacht (1981) 122.

[30] Chamberlain (2006) 81-126; Bocquet-Appel (2008) Drennan e.a. (2015) 11.

[31] Beloch (1886) 29-33; Zorn (1994) 33; Hassan (1978) 63-67; Hansen (2006) 77; Wilkinson (1999) 45-64.

[32] 'Carrying capacity' in the Oxford dictionary of ecology.

[33] Hayden (1975) 11.

so on. All of these aspects are in need of a detailed study and often result in speculative outcomes, which makes the eventual range of the population that can be sustained too broad to work with[34]. More recently, due to more detailed studies of the natural environment and the widespread application of bioarchaeological analyses, archaeologists dealing with demography get more interested again in the application of catchment analysis[35]. An important aspect of carrying capacity is that it is no measure for the number of people living in a specific region, but it describes the maximum population that could be sustained[36]. Therefore, in this paper, carrying capacity will be regarded separately from the population estimates and will be used to define the upper limit of the population size.

For estimating regional population numbers, calculations based on the total area and the carrying capacity are very similar to those discussed above. Two formulae, however, are specific for regional populations. The first one uses site counts and multiplies these by a population estimate per site type. Robert D. Drennan and colleagues gave an overview of such techniques[37], while Robin Osborne presented some applications in the Mediterranean world[38]. This method, however, is criticized for a variety of reasons[39]: some sites go unnoticed during archaeological survey or might have been erased from the archaeological record due to erosion or quarrying. It is also unlikely that all sites within the same time period were simultaneously occupied. On top of that, multi-period sites make it hard to distinguish their extent during each phase of their occupation[40]. The main critique is similar to the method applying site areas, where the population density remains a 'black box'. The same is true for average site population numbers, similarly deriving from estimated guesswork[41]. The second method is based on aDNA. The technique for measuring population sizes through genetic analysis developed in conservational ecology, because it "(…) can inform management and help predict the extinction risk of populations"[42]. In general, two estimates can be distinguished: the census

[34] Critiques by Zorn (1994) 33; Hayden (1975); Hassan (1978) 66.
[35] Chamberlain (2006) 12, stating "calculations of carrying capacity (…) constitute essential sources of evidence for archaeological demography".
[36] Hayden (1975) 11-21; Hassan (1978) 66; Hassan (1981) 164.
[37] Drennan e.a. (2015).
[38] Osborne (2004) 163-172.
[39] Listed throughout Drennan e.a. (2015).
[40] Catling (2002) 205; Bintliff (1997) 231-252.
[41] Schacht (1981) 126.
[42] Luikart e.a. (2010) 355.

population size (N_c)[43] and the effective population size (N_e)[44]. As the census population size only takes adult individuals into account — because these can procreate and are thus more interestingly in conservational ecology — in archaeology the effective population size is used[45].

After applying these methods, often resulting in very differing population ranges, there are three different ways to deal with the results. Mogens Herman Hansen[46] encourages scholars to use the maximum range of all outcomes combined, while Jeffrey R. Zorn[47] gears the different results to each other. For example, if one is investigating a settlement with 200 houses and a surface of 1.7 ha[48], an estimated population density of 200 individuals per ha results in a household size of only 1.7 people, which is considered too low. The population density thus needs to be higher. Similarly, John W. Hanson and Scott G. Ortman[49] first calculated the population density based on the amount of houses per hectare, multiplied by an average household size of five people. In a second step they multiplied this constant with the total domestic area of a city or town. This paper will make use of a fourth method, which scrutinizes the data distribution to deduce the probability of specific population ranges. Five distributions (fig. 2) will be taken into account:

(1) The total range: All estimates between the lowest and the highest population number define this range. This method is the one proposed by Hansen in his 'shotgun method'[50]. These ranges are very broad to work with.
(2) The total range limited by the carrying capacity: As was discussed above, the carrying capacity does not result in a population estimate, but in a maximum population. The total range can thus be limited by the carrying capacity.
(3) Range of most overlapping methods: By applying as many methods as possible, a variety of partly overlapping population ranges is

[43] "The number of adults in a study area or population", Luikart e.a. (2010) 356.
[44] "The number of individuals that would give rise to the sampling variance or the rate of inbreeding appropriate to the conditions under consideration, if they bred in the manner of the idealised population", Falconer (1960) 68. Developed by Wright (1931).
[45] E.g. Cann (2001) 1742-1748.
[46] Hansen (2006) 73.
[47] Zorn (1994) 44.
[48] Data from Zorn (1994) 31-48
[49] Hanson and Ortman (2017).
[50] Hansen (2006) 32.

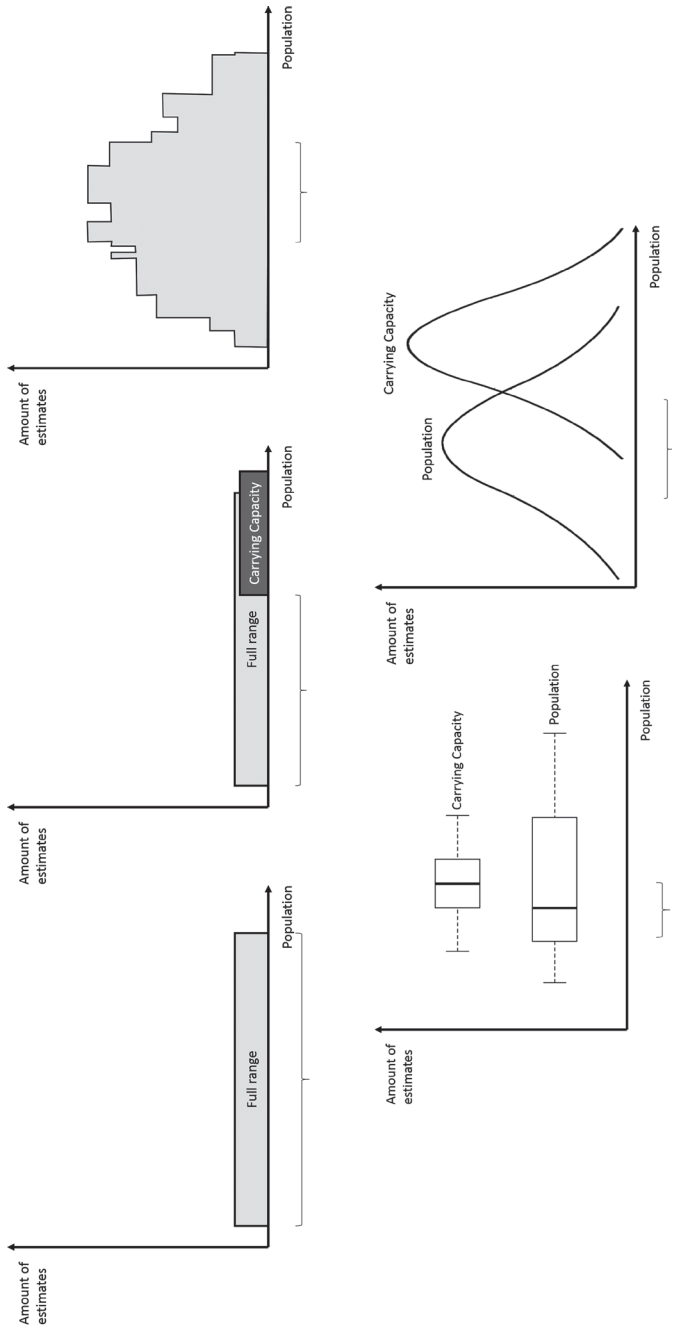


Fig. 2: The five data distribution methods for the population estimates (fltr. total range, range limited by the carrying capacity, overlap of estimates, quartiles, Gaussian function).

obtained. The more ranges overlap, the larger the probability that these approximate the actual population size.

(4) The quartiles: The data distribution can also be visualized as a box-plot. When the quartiles of the population estimates are calculated, the range of highest probability lies between the 1st and 3rd quartile. This range can further be bound from the mean of the carrying capacity data onwards.

(5) The normal distribution: A normal distribution with a mean and standard deviation has the advantage that a range of a predetermined probability can be chosen (e.g.: 1σ is 68.2 per cent and 2σ is 95,4 per cent). This range can be further limited by the intersection between the population gauss curve and the curve of the carrying capacity, since this is the point where the probability of reaching the maximum population exceeds the probability of the population estimates. The problem here is that the data distribution is simplified into a fixed form, the gauss curve. In fact, this can be considered as a simplification of the data, ruling out tails.

Finally, after reaching five different ranges, these can be balanced against each other. A comparison between the ranges for the urban and rural population, as well as between the population and the carrying capacity, can be executed. This method will now be tested on second-century AD Sagalassos.

III. Urban population

As was referred to in the above-mentioned methods, historical sources are often considered very reliable for estimating population numbers. Many attempts in this direction, especially focusing on army numbers, have been made in the past[51]. If the Sagalassos case is looked into, historical sources seem to be of lesser use. The sole two ancient authors referring to demographics in Sagalassos and the wider region are Livy and Justinian. Livy, discussing the situation in the second century BC, mentions the following:

> Then they entered the country of the Sagalassenes, rich and abounding in all kinds of crops. Pisidians inhabit it, by far the best warriors in this

[51] E.g. Beloch (1886) Hansen (2006) 4-11; Hollingsworth (1969) 229-232; Willet (2012) 137-141.

> region. This circumstance gave them courage, as well as the fertility of the soil and their large population and the situation of their fortified town in a land where such strongholds were few.[52]

Discussing the fertility of the soil and the large population of its territory, Hellenistic Sagalassos and environs seemed to be flourishing. The account of Justinian dating to *c*. AD 535-536, points in the same direction:

> We have investigated the origin of the Pisidians, and have learned from ancient writers that this people formerly exercised dominion over a large portion of the earth, and now that this province needs a powerful and energetic magistracy (for it contains a great number of villages, and a large population who are especially seditious when it comes to the payment of taxes) (…)[53]

Although both authors, for two different time periods, mentioned the occurrence of many villages, fertile fields and large populations, these accounts are not specifying the population numbers. Therefore, other sources are needed, which will be found in the archaeological and geographical record.

City area

Thanks to the urban surveys, geophysical prospection and archaeological excavations by the Sagalassos Archaeological Research Project[54], it was possible to define the surface of the urban area of Sagalassos during its heyday in the middle Imperial period. This surface, circumscribed by the necropoleis, was set on 31.5 ha, of which 23.5 ha was considered to have served habitational purposes[55]. Adding the 6 ha surface of the Eastern Suburbium results in an urban area of 37.5 ha[56]. An often applied method consists of multiplying the residential area (23.5 ha) by a constant which is an assumption of the population density. A first constant is given by Josiah C. Russel, who stated that the population density of Roman "[m]edium-sized cities, well populated and prosperous" ranged between 100 and 150 inhabitants per ha[57]. Applying this to Sagalassos gives popula-

[52] Livy, *Ab Urbe Condita* 38.15, translated by Sage (1936).
[53] Justinian, *Novella* 24.1, translated by Scott (1932).
[54] Martens e.a. (2012).
[55] Martens e.a. (2008) 137; other numbers for the urban area are given too: more than 40 ha (Waelkens & Poblome (2011) 59); 37.5 to 40 ha (Willet & Poblome (2015) 135).
[56] Willet & Poblome (2015) 135.
[57] Russel (1958) 68.

tion numbers between 3,750 and 5,625[58]. Similar constants were given by Donald W. Engels and John D. Grainger for domestic areas. Engels proposed a population density between 100 and 160 inh/ha on Roman Corinth[59], while Grainger used a rather high density estimate of 200 inh/ha for the Pamphylian coastal settlements in Roman times[60]. Multiplying these density estimates by the residential area ends up with a range between 2,350 and 3,760, and 4,700 inhabitants respectively. Far lower population densities between 40 and 60 inhabitants per ha were proposed by Simon Price for unplanned Classical and Hellenistic Greek city-states[61], basing himself on Ottoman-era Greek *comparanda*[62]. Sagalassos, although a Roman provincial city in the second century AD, can be classified as unplanned in the sense that it does not follow a Hippodamian grid. Multiplied by the urban area, this gives a range of 1,500 to 2,250 citizens.

Both John Bintliff and later Mogens Herman Hansen used a constant percentage of the walled area that is reserved for habitational purposes in Greek poleis. Bintliff[63] proposed a percentage of 56 per cent of habitational space in which per hectare 225 individuals resided. Hansen[64], on the other hand, suggested that for middle-sized poleis half of the urban area was reserved for domestic purposes, with *c*. 150 people per ha. Although the residential area represented *c*. 63 per cent of the urban area of Sagalassos, the methods of Bintliff and Hansen are nevertheless useful to apply. This results in a range between 2,813 and 4,725 inhabitants for Sagalassos. An important note on these constant population numbers is that these often remain mute on whether these are assuming single- or multi-storeyed houses[65], while at Sagalassos most houses are expected to consist of only a ground floor[66].

Another method was first proposed by Raoul Naroll[67], seeking a relationship between house floor area and the amount of inhabitants for

[58] This method was already applied for Sagalassos by Martens e.a. (2008) 137.
[59] Engels (1990) 82.
[60] Grainger (2009) 234.
[61] Price (2011) 23.
[62] A critique posed by Josiah Ober, arguing that the Ottoman context was too distinct from a Hellenistic one to apply such figures (Ober (2015) 81, n. 16).
[63] Bintliff (1997) 235.
[64] Hansen (2006) 61.
[65] Hanson & Ortman (2017) 308.
[66] Only for the so-called urban mansion at Sagalassos is a second floor documented (Putzeys e.a. (2007) 212, 225-228).
[67] Naroll (1962) 587-589.

sedentary populations. His study, which was based on the anthropological records of 18 communities, resulted in the so-called "Naroll's constant"[68] of one person per 10 m² of floor area. Later, Polly Wiessner[69] altered this method to make it applicable for calculating the population sizes of settlements. Both Naroll's[70] and Wiessner's[71] techniques were severely criticised for being too much of a generalisation, and it remains unclear how multi-storeyed houses would influence the formula. Yet, they offer the opportunity to use a method which is not based on an arbitrary estimate of the population density. Wiessner created the formula *residential area* = $a \cdot$ *population size*^{b}, with a being a constant value close to 0 for which here a range between 0.1 and 0.25 is chosen, and $b = \frac{2}{3}$ for urban societies[72]. For Sagalassos, the formula thus is: 23,5 ha = $0.1 - 0.25 \cdot$ *population size*$^{\frac{2}{3}}$, resulting in a population between 911 and 3,602.

House count

Many authors[73] discussed the use of house count in estimating population size. For Sagalassos, thanks to extensive geophysical surveying[74], the layout of the city is fairly well known, especially for the eastern part of the city. Within this area, the well-surveyed neighbourhood southwest of the theatre was selected. The surface of this area measured 8.7 ha and counted 92 edifices which were interpreted as houses. Per hectare stood an average of 11 houses. When this is multiplied by the total residential area of 23.5 ha, a total of 249 houses can be assumed in Sagalassos. The small amount of houses and their large surfaces, however, indicate that this quarter was reserved for the urban upper classes, thus diminishing its representativeness. Whether middle and lower class people lived mainly in the southwestern residential quarters is difficult to say. Apart from the issue with representation, Robert M. Schacht[75] also pointed out the problem with turning house counts into population sizes with household sizes remaining unknown. Especially for the Sagalassos-case this problem is crucial: the

[68] Brown (1987).
[69] Wiessner (1974) 343-350.
[70] Hassan (1978) 55-58; Kolb e.a. (1985) 581.
[71] Kramer (1982) 163; Chamberlain (2006) 128.
[72] Wiessner (1974) 349.
[73] Zorn (1994) 32-33; Schacht (1981) 125-126; Kolb (1985) 582.
[74] Martens e.a. (2012); Martens (2004).
[75] Schacht (1981) 125

30 houses of which the surface was calculated range from 70 to more than 2,500 m². The differences in floor area hinder the simple application of an average household size. As other neighbourhoods are not thoroughly prospected via geophysical survey, this paper needs to find a way to deal with the data of this more residential quarter. Such varying household sizes are referred to in literature. Hansen[76], for example, mentions 3-7 members per household for the Classical and Hellenistic Poleis, while Beryl Rawson[77] states that in Imperial Rome, average households consisted of *c*. 2-3 children resulting in a household size of 4-5, and Roger Bagnall and Bruce Frier argued, based on tax records from Roman Egypt, that *c*. 4.04-5.31 people made up a lower class household in the cities[78]. For the larger dwellings in Sagalassos a housekeeping of slaves and freedmen is expected. One Roman comparison can be found with the site of Cosa, where 24 large and 244 small houses are found with a ratio of 1:10[79]. Luuk de Ligt estimated that 5-6 people lived in the former, while the latter housed 10-12[80].

Rinse Willet and Jeroen Poblome[81] applied these numbers to the Sagalassos case, resulting in a population between 1,356 and 1,583 inhabitants. With the broad range of house sizes, it seems better to model household numbers. One way to do so is to assume that the household size grows at the same rate as the floor area. For this method, for the smallest house, the range of 3-7 inhabitants is chosen and then multiplied by $\frac{house\ size_i}{house\ size_{i-1}}$. A second calculation is to plot the 3-7 household size for houses of *c*. 50 m², the 10-12 for the 500 m² — matching the 1:10 ratio — and 20-30 for a 2,000 m² mansion. Thus the relationship between house and household size can be modelled through correlation curves. The first correlation is linear, resulting in the following formulae: $household = 0.0082 \cdot size + 4.0288$ ($R^2 = 0.9606$) for the lower ranges and $household = 0.0118 \cdot size + 6.2638$ ($R^2 = 0.9998$) for the upper ones. This formula assumes the rising number of slaves when living space increased. When a logarithmic correlation is sought — assuming that more living space was one of the pleasures of being rich — this results in the formulae $household = 4.4496 \cdot \ln(size) - 15.293$ ($R^2 = 0.9416$) for the lower ranges and

[76] Hansen (2006) 53-60.
[77] Rawson (1986) 8.
[78] Bagnall & Frier (1994) 68.
[79] Fentress & Bodel (2003) 25.
[80] de Ligt (2012) 220.
[81] Willet & Poblome (2015) 136.

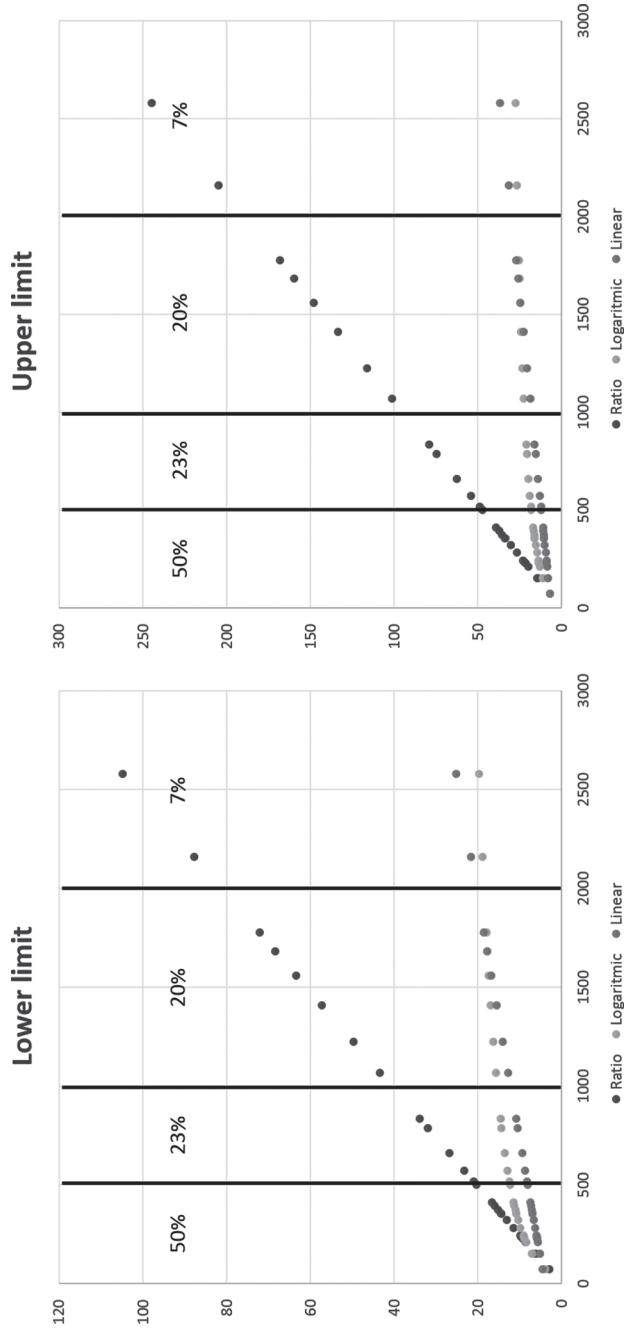


Fig. 3: Modelling of the house floor area to household sizes.

household = 5.8234 · ln(*size*) – 18.078 (R^2 = 0.8046) for the upper ones. These curves now allow for the calculation of the household size for each of the 30 houses of which the surface areas were measured. Since it was not feasible to measure the floor area of all 249 houses, it seemed best to categorize the houses according to their surface area. This resulted in four categories: A) < 500 m²; B) 500-1,000 m²; C) 1,000-2,000 m²; D) > 2,000 m². For each of these categories, per modelling technique (constant ratio, linear and logarithmic; fig. 3) the average household size can be calculated, which is multiplied by the percentage of houses belonging to this category and by the total house count. By then making a sum of these calculations of each of the categories, a total population size can be established. For the first technique (constant ratio), this results in a range of 2,174-5,072 inhabitants, for the linear modelling 2,486-3,693 and for the logarithmic 3,080-4,512. As stated above, it can be questioned whether, by taking a probably elite neighbourhood as basis, the amount of people residing in Sagalassos is not underestimated. Similarly, the problem emerges that the amount of high class residents is overestimated.

Necropoleis

Although cemetery data are considered by Thomas H. Hollingworth as the "most unreliable sources for making any demographic estimate"[82], using them in a thoughtful manner can produce valuable results. In most cases, when archaeological demography makes use of skeletal evidence, the application of palaeodemography is meant, focussing on mortality and fertility patterns, age and sex distribution[83], not the reconstruction of population sizes. In this case, the burial density will be used to estimate the amount of individuals buried at Sagalassos. This method has already been applied by William W. Howells in 1960 on the native American settlement Pecos[84], albeit on a more completely excavated burial site. The starting point is the premise that all individuals that once lived — and thus died — in Sagalassos were also buried there. So far 77 burials — inhumations and cremations — dating between Hellenistic and Late Roman times were unearthed at Sagalassos, all in the eastern necropolis. The ratio of the amount of skeletons per site and the excavated area[85],

[82] Hollingsworth (1969) 43.
[83] Chamberlain (2006) 81-126; Seguy & Buchet (2013); Bocquet-Appel (2008).
[84] Howells (1960) 158-176.
[85] These sites are Site F, Site D, Site PQ1 and Site PQ4.

resulted in an overall burial density of 0.13 skeletons/m². However, there are indications for tombs which were looted or found empty and for which the removal of skeletal remains is assumed. These are counted in as the maximum amount of individuals per area, resulting in a burial density of 0.15 skeletons/m². The total area of the Sagalassos' necropoleis was measured to be 620,000 m² [86]. The total of buried individuals can be calculated as the *burial density* · *necropolis area*, resulting in a range from 80,600 to 93,000 burials. However, to calculate how many people were living at the same time in the second century AD, this number has to be divided by the total timespan the necropoleis were in use (*c*. 700 years) and then multiplied by the average life expectancy for this time period. For the early and middle Roman imperial period, an average life expectancy was used of *c*. 23.6 years, matching the estimates from elsewhere in the Roman empire[87]. This calculation ($population = necropolis\ area \cdot \frac{average\ life\ expectancy}{use\ life\ necropoleis}$) results in a range between 2,722 and 3,135 individuals.

Carrying capacity

Sagalassos can be found within a one to three-hour walking distance north of two fertile valleys which are named after the modern villages that lie there: Ağlasun and Yeşilbaşköy. If these valleys are considered as the primary catchment area for the city of Sagalassos[88], its valley bottom surface of *c*. 29 km² serves as the basis for the carrying capacity calculations. A first technique for calculating the carrying capacity of a region is based on the yield of wheat and barley. This technique has a long history as it was already applied by Karl Julius Beloch[89] and Adolf Holm[90]. Beloch lists the surface as well as wheat and barley yields for specific regions known for producing these crops in Hellenistic Greece. Later, he discusses the number of *medimnoi* grain equivalent which were needed to sustain an average individual on a yearly basis, i.e. six

[86] Köse (2005) 17-23 counted a total area of 33.2 ha. How he exactly calculated this surface is not specified in his study. Here the surface is based on the distribution of the Roman imperial funerary contexts.

[87] E.g. Bagnall & Frier (1994) 109.

[88] Willet & Poblome (2015) 137; Eva Kaptijn, personal communication.

[89] Beloch (1886) 29-33.

[90] Holm (1965 [1886-1901]) 173-175.

medimnoi[91]. Yet, if one applies his figures and thus divides the yield per area by the volume of grain needed per person, the resulting population that can be sustained by the Ağlasun and Yeşilbaşköy valleys is too low to feed the population of Sagalassos: only 1,148 people. Beloch based his research on the total area of the territories of these ancient *poleis*[92], while for Sagalassos only the fertile valley bottoms are selected as catchment area. Given that only 20-50 per cent of the Attica was suitable for crop cultivation[93], the carrying capacity for Sagalassos can easily be multiplied by a factor 2 to 5. This means that a population of 2,269 to 5,672 people can be fed. More recently Donald Engels[94] came up with a more complex formula, which takes the energy intake needed on a yearly basis, the calorific value per kilogram of wheat and barley, the percentage of arable land and the average yield per km² into account[95]. This formula implied that a total of 2,119 to 4,238 individuals can be sustained:

$$\frac{Area \cdot {Yield}/{Area} \cdot year \cdot \%\ Arable\ land \cdot {Mass}/{Yield} \cdot {Calories}/{Mass}}{{Calories}/{Person} \cdot 365\ days} = \frac{29km^2 \cdot \frac{1200hl}{km^2} \cdot 50\% \cdot 61.8kg/hl \cdot 2{,}185kcal/kg}{1{,}500 - \frac{3{,}000kcal}{p} \cdot 365days}$$
$$= 2{,}119 - 4{,}238\ individuals$$

For the nearby territory of Balboura (*c*. 110km southwest of Sagalassos) in southern Lykia the carrying capacity was established according to a similar calculation method[96]. Here, the possible wheat yield is compared to the estimated need of cereal intake per person. Although a far too simplistic diet is assumed, the used formula takes into account the amount of grains reserved as fodder, sowing seed and taxation goods. It was concluded that a population of *c*. 10,000 to 20,000 people could be sustained from the yield of the fertile valley bottoms in the territory, measuring 10,040 ha. This corresponds with 1 to 2 individuals that could live

[91] Beloch (1886) 32-33.
[92] *Ibid.* 31-32.
[93] Garnsey (1988) 91.
[94] Engels (1990) 27-28.
[95] The mean of 3,000 kcal is based on the average energy intake for adults following the FAO-formulae for caloric needs, assuming a mean stature of 1.66m for men and 1.56 for women, a normal Body Mass Index (BMI) and a Physical Activity Level (PAL) reflecting non-mechanic work in a pre-industrial society (FAO (2001)). The other numbers are based on Engels (1990) n. 30.
[96] Wagstaff & Erdentuğ (2012) 36-41.

from one hectare of arable fields. When this number is applied on the 29 km² valley bottom of the Ağlasun-Başköy system, a carrying capacity of 2,900 to 5,800 people is obtained.

Most formulae, however, are based on the area which is needed to sustain a household of 5 individuals. Franco De Angelis[97] argued that in previous attempts to calculate the number of people that can be sustained by a specific catchment area, only cereal yields were taken into account — as in the previous paragraph — while a broader spectrum of foods needs to be incorporated too. Therefore, he looked into ancient and modern crop yields, dietary practices and family labour data from Italy and Greece to come up with a surface of 3-4 ha to sustain a group of 5 people. Applying this number results in an estimate of the population that can be sustained for Sagalassos: 3,625 to 4,833 people. John Bintliff[98] was more specific in the surface needed to support a group of 5, stating that 3.6 ha were necessary in Iron Age Greece. This comes down to 4,028 individuals which could have been sustained.

IV. Population In The territory

From the reign of Augustus onwards, the city of Sagalassos administered over a *c.* 1,200 km² territory[99]. The borders of this area were inferred from boundary markers and topographical observations[100].

Territorial area

The most common formula for calculating the population within a territory is — just as for the urban area — to multiply the surface by an assumption of the population density. Walter Scheidel and Bruce Frier[101] estimated that the population density for Anatolia during the Roman Imperial period was 14-15 individuals per km², which results in a population of between 16,800 and 18,000 for the Sagalassos territory. These numbers are rather low, because they are based on the general estimate

[97] De Angelis (2000) 118.

[98] Bintliff (2002) 158.

[99] Waelkens & Poblome (2011) 11; an area of 1,800 km² was mentioned in Waelkens e.a. (2003) 62.

[100] For a full description of the evidence see: Waelkens (1995) 11-12; Waelkens (1997) 97-99; Waelkens e.a. (2003) 60-62.

[101] Scheidel (2007) 48; Frier (2000) 812.

for population density in Roman Anatolia. For the territory of Sagalassos, however, a denser population is expected[102]. When this number is compared to the present density of *c*. 78.1 people per km² in the region[103], resulting in a population of 93,720 for the territory of Sagalassos, the contrast is quite distinct. Similarly, for Classical Athens Peter Garnsey[104] proposed a density of 50-104 persons per km², which comes down to a total population of 60,000-124,800. Two other estimates are proposed by John Bintliff and Anthony Snodgrass[105] for the region of Boeotia in Classical times. In a first formula, they propose a population density between 38 and 70 individuals per km², resulting in a total population for the territory of between 45,600 and 84,000 inhabitants.

The second formula is more elaborate. Here, only the part of the territory suitable for agriculture is taken into consideration. As was already acknowledged, ancient authors referred to Pisidia and the Sagalassos territory as a very fertile region. Hartwin Brandt[106] argued that in the Pisidian Lake District, 70 per cent of the valley bottoms were suitable for agriculture. However, Sagalassos is located in the foothills of the Taurus mountain range, a rather mountainous region where valley bottoms are less frequent. Hannelore Vanhaverbeke[107] published the areas of some of the valley bottoms within the territory, which in total cover an area of *c*. 450 km² of the total territory of 1,200 km² (*c*. 40 per cent). If the 70 per cent of arable area of the valley bottoms is accepted, *c*. 25 per cent of the total territory (*c*. 315 km²) was suitable for agriculture. A safety factor of 10 per cent is built in, resulting in a range between *c*. 20 and 35 per cent arable space. John Bintliff and Anthony Snodgrass[108] proposed for Classical Boeotia that within the arable areas the population density was 95/km². When applying this on the Sagalassos territory, a population of 22,158-38,118 individuals is obtained.

[102] Justinian, *Novella* 24.1; Livy, *Ab Urbe Condita* 38.15.

[103] http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tgs00024&plugin=1 (last issued 03 May 2016); the number of 2014 for the region 'Antalya, Isparta, Burdur' is used. Note that the densely populated city of Antalya is located within the selected region.

[104] Garnsey (1988) 89-91.

[105] Bintliff & Snodgrass (1985) 143.

[106] Brandt (1992) 10.

[107] Vanhaverbeke & Waelkens (2003); for the surface of the Ağlasun-Başköy valley system, Willet & Poblome (2015) 137.

[108] Bintliff & Snodgrass (1985) 143.

Site count

During the extensive survey campaigns under the guidance of Marc Waelkens and Hannelore Vanhaverbeke, 68 sites dating to Roman imperial times were documented in the territory, of which 41 are characterized as villages and 27 as farms or hamlets[109]. Richard W.V. Catling[110] applied this technique to the Laconia region. He started by attributing an average of 5 people to farmsteads, considering a household, while in villages each household needed a space of 0.05 ha. A city, on the other hand, is supposed to have a population density of 150 to 300 people per hectare, which is rather high compared to previously proposed numbers. When applying these numbers to the Sagalassos territory, supposing that the surface of villages is somewhere between 1 and 5 ha, one obtains a range between 7,760 and 27,685 inhabitants. Based on this technique and the different applications cited in Robin Osborne's work[111], other numbers can be used too. Starting with the same 41 villages and 27 farms or hamlets, but assuming a similar population density in a village and a city of 100-160, and a range of 5-10 housing in a farm, the formula results in a population range of 6,585 to 36,830 inhabitants.

aDNA

Up till now, 40 skeletal samples from Sagalassos were successfully analysed for mtDNA. These data were analysed by Claudio Ottoni and colleagues[112] to simulate possible events of population contraction in the Sagalassos territory, based on the changes in genetic variation. Ottoni and colleagues tested four different models: in the first, no reduction in population size occurred; the second assumed a decrease associated with the Justinian plague (AD 541-543); the third model associated decline with the seventh-century earthquake[113]; the last selected event was the attested early 13th-century abandonment of the site[114]. Only the last event seemed to have had a major influence on the population size, probably even halving the number of people residing in the former territory. The population size for any demographic contraction was determined by the posterior

[109] Vanhaverbeke & Waelkens (2003) 241-246.
[110] Catling (2002) 206.
[111] Osborne (2004) 163-172.
[112] Ottoni e.a. (2016).
[113] Waelkens e.a. (2000); Sintubin e.a. (2003).
[114] Poblome e.a. (2017).

median values for female effective population size (N_s). Ottoni e.a. concluded that before the first decline in population, between *c*. 26,000 and 32,000 had lived in the territory. Although "[t]hese results should be treated with caution, due (…) to the limited power of demographic reconstructions based on a single genetic locus"[115], an ancient-DNA perspective is a valuable supplementation of the demographic data.

Carrying capacity

The total area of the Sagalassos territory consisted, as mentioned before, of *c*. 1,200 km². This area can also be considered as the total catchment area of all settlements within the territory and thus serves as the basis for the calculations on the carrying capacity. In fact, all methods used for calculating the carrying capacity of the city of Sagalassos can be used for its territory too. When Beloch's[116] method is applied on the Sagalassos-territory, this results in 46,944 people that can be sustained. Engels' method[117], on the other hand, provides a population of 17,538 to 52,615 inhabitants which can be fed from the territory. In analogy with the Balboura-territory, the territory of Sagalassos would be able to support a population of 24,000-84,000 souls[118]. As seen above, these techniques are more recently replaced by formulae focussing on a diet more varied than one consisting of only grains. When applying the formula of De Angelis, a range between 29,155 and 66,873 people is obtained, while Bintliff's technique gives a number of 32,394-55,728 inhabitants. Gert Verstraeten and Maarten Van Loo, whose research considers erosional processes, soil fertility and grain yields, estimated for the territory of Sagalassos that around 40,000 souls could be sustained[119].

V. Results

A number of techniques have now been applied, but the individual results are not necessarily meaningful due to their quite distinct outcomes (fig. 4; table 1). As Hansen proposed in his shotgun method, a combination of these results is needed to reach a valuable outcome. Although he

[115] Ottoni e.a. (2016); Ottoni, personal communication.
[116] Beloch (1886) 29-33.
[117] Engels (1990) 27-28.
[118] Wagstaff & Erdentuğ (2012) 36-41.
[119] Verstraeten & Van Loo, personal communication.

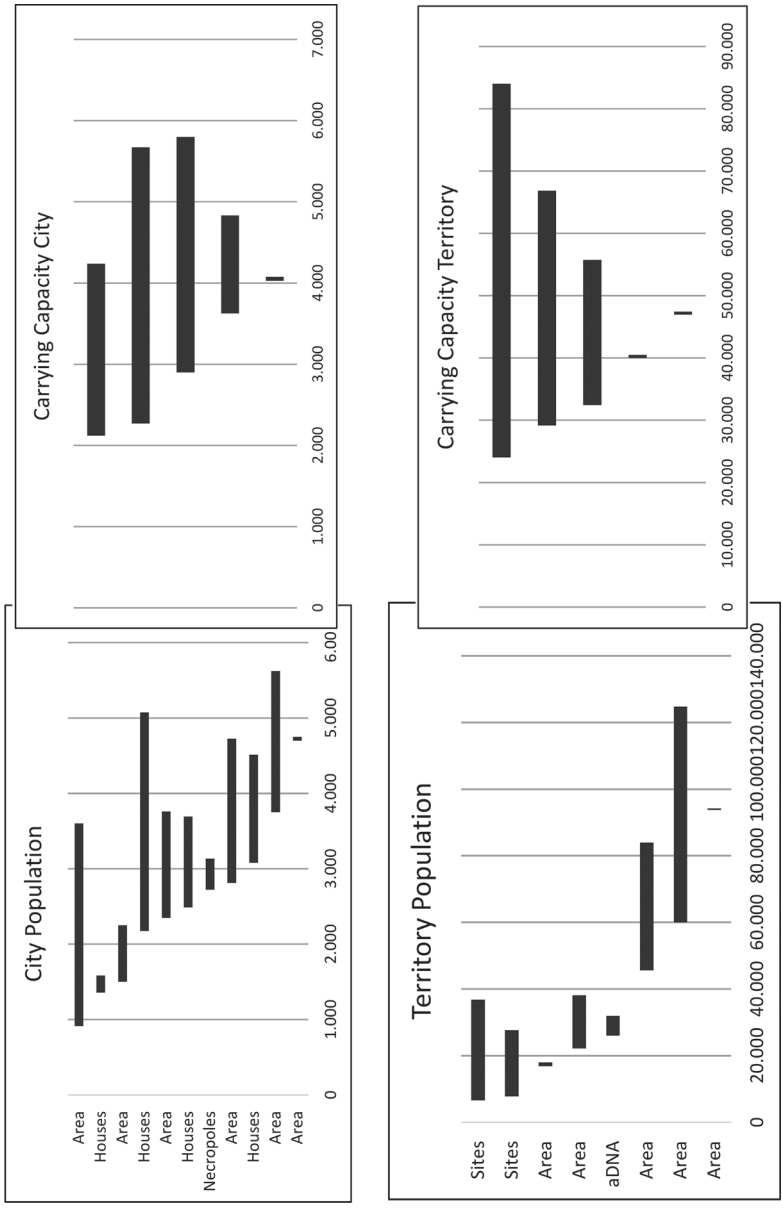


Fig. 4: The ranges of the applied estimation methods.

Table 1 – Summary of the ranges obtained for population and carrying capacity estimates

Scale	Base	Formula	Lower range	Upper range	Reference
City	Area	Residential area × population density	3.750	5.625	Russel (1958) 68
City	Area	Urban area × percentage of residential area × population density	2.813	4.725	Bintliff (1997) 235; Hansen (2006) 61
City	Area	Urban area × population density for an unplanned city	1.500	2.250	Price (2011) 23
City	Area	Residential area × population density	2.350	3.760	Engels (1990) 82
City	Area	Residential area × population density	4.700	4.700	Grainger (2009) 234
City	Area	Area = a × population^b	911	3.602	Wiessner (1974) 343-350
City	Houses	(Housing units/area) × residential area × sum (perc. Housetype × household size(analogy))	1.356	1.583	Willet & Poblome (2015) 136
City	Houses	(Housing units/area) × residential area × sum (perc. Housetype × household size(ratio))	2.174	5.072	
City	Houses	(Housing units/area) × residential area × sum (perc. Housetype × household size(linear))	2.486	3.693	
City	Houses	(Housing units/area) × residential area × sum (perc. Housetype × household size(logaritmic))	3.080	4.512	
City	Necropoleis	(((Excavated skeletons/excavated area) × surface necropoleis)/time span) × life expectancy	2.722	3.135	

Scale	Base	Formula	Lower range	Upper range	Reference
City	Carrying Capacity	(Area× (yield/area)× household size)/personal need	2.269	5.672	Beloch (1886) 29-33
City	Carrying Capacity	People/ha× Area	3.625	4.833	De Angelis (2000) 125
City	Carrying Capacity	People/ha× Area	4.028	4.028	Bintliff (2002) 158
City	Carrying Capacity	(Area× (yield/(area× year))× perc. arable land× mass/vol× calories/mass)/ (calories/person× 365 days)	2.119	4.238	Engels (1990) 27-28
City	Carrying Capacity	People/ha× Area	2.900	5.800	Wagstaff & Erdentug (2012) 36-41
Territory	Area	Area× population density	16.800	18.000	Frier (2000) 812; Scheidel (2007) 48
Territory	Area	Area× population density	93.720	93.720	Analogy with the current population density in the area
Territory	Area	Area× population density	45.600	84.000	Bintliff & Snodgrass (1985) 143
Territory	Area	Area× population density	60.000	124.800	Garnsey (1998) 89-91
Territory	Area	Area× population density× perc. arable area	22.158	38.118	Bintliff & Snodgrass (1985) 143
Territory	Sites	Sum(amount of sites per type× perc. sites per type× population density per type)	6.585	36.830	Osborne (2004) 163-172

Scale	Base	Formula	Lower range	Upper range	Reference
Territory	Sites	Sum(amount of sites per type × perc. sites per type × population density per type)	7.760	27.685	Catling (2002)
Territory	aDNA		26.000	32.000	Ottoni e.a. (2017)
Territory	Carrying Capacity		40.000	40.000	Maarten Van Loo & Gert Verstraeten
Territory	Carrying Capacity	(Area × (yield/area) × household size)/personal need	46.944	46.944	Beloch (1886) 29-33
Territory	Carrying Capacity	People/ha × Area × arable area	29.155	66.873	De Angelis (2000) 125
Territory	Carrying Capacity	People/ha × Area × arable area	32.394	55.728	Bintliff (2002) 158
Territory	Carrying Capacity	(Area × (yield/(area × year)) × perc. arable land × mass/vol × calories/mass)/(calories/person × 365 days)	17.538	52.615	Engels (1990) 27-28
Territory	Carrying Capacity	People/ha × Area × arable area	24.000	84.000	Wagstaff & Erdentug (2012) 36-41

claims that "(…) we must remember that we cannot expect precision. We have to use the shotgun method with its considerable gap between maximum and minimum"[120], this paper advocates that the obtained results can end up in more precise population estimates. Indeed, applying the shotgun method often ends up in very broad population ranges[121].

Ranges of the urban and territorial populations

If this total range is applied to Sagalassos with the previously mentioned populations estimates as its basis, a total of 911-5,625 individuals formed the urban population and 6,585-124,800 the territorial one. These ranges, however, are so broad that they become impossible to work with. Even if from these the rural population is extracted (territorial population minus the city population), this would result in numbers between 960 and 123,889 people. Any study relating to population estimates — from the pressure on the landscape to the relation between city and territory or even in urban *versus* rural economy — becomes impossible to execute with such broad ranges as basis.

By applying the five different above mentioned techniques, this paper hopes to limit these broad ranges. A first possibility to limit the total range is by taking the carrying capacity into account. This factor does not — as was discussed above — give any estimates for population numbers, but sets an upper limit for the population that can be sustained. Since for the city population the largest overlap in the ranges for the carrying capacity lies between 3,625 and 4,238 individuals, the upper limit for the population of Sagalassos lies somewhere within this range, instead of at 5,625. The same is true for the territory, where most of the carrying capacity estimates give results somewhere between 32,394 and 52,615 individuals, with the highest probability around 44,000. Between 38,118 and 45,600 lies a gap in the territorial population estimates. Since this hiatus falls within the peak of the carrying capacity, the population estimates over 45,600 souls can be excluded.

A following method consists of taking the overlap of most population estimates into account. Most methods for calculating the urban population

[120] Hansen (2006) 73.

[121] E.g. City of Sagalassos 1,500-5,000 and Sagalassos territory 6,000-25,000 (Willet & Poblome (2015) 137 and 139); City of Corinth 30,000-50,000 and Corinthian territory 40,000-60,000 (Willet (2012) 151); City of Balboura 850-1,400 (Coulton (2012) 76); Greek world 7.5-10 million (Hansen (2006) 32).

range between 2,813 and 3,525 individuals (fig. 5), which is just below the average carrying capacity of 3,625-4,238. The Ağlasun-Yeşilbaşköy valley bottoms was taken as the catchment area of Sagalassos, but given the fact that the rural population residing in this valley needs to be sustained from this same area, the population numbers for Sagalassos will tend to point to the lower limit of this range. In case of the Sagalassos territory, the highest overlap of methods can be found for a population between 22,158 and 32,000 individuals (fig. 6). Additionally, the range falls just below the carrying capacity of 32,394-52,615.

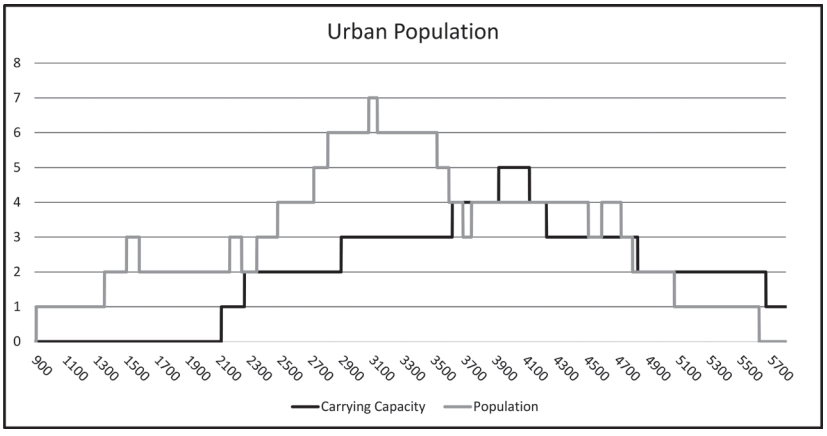


Fig. 5: The distribution of urban population estimates.

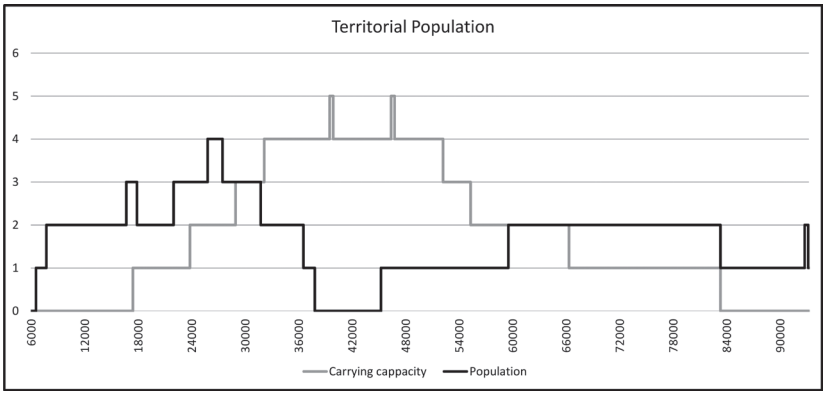


Fig. 6: The distribution of territorial population estimates.

In the previous methods, the upper and lower limits of the ranges are still directly adopted from the outcomes of the estimates discussed above. The complete data distribution is not taken into account. To this end, statistical methods such as the use of quartiles and Gaussian statistics can be applied. A first way of visualizing the ranges is by drawing box plots for the population and carrying capacity, which allows for a comparison between the two. When the urban population data are examined, the mean value of all estimates is 3,320, while the first quartile is set on 2,660 and the third on 4,110. This means that the highest probability ranges between the two quartiles (2,660-4,110). However, when the carrying capacity is considered, the mean is calculated as 3,944, and the range between the first and the third quartile is 3,248-4,615. By limiting the population numbers from the mean of the carrying capacity onwards are considered unsustainable, the urban population of Sagalassos ranges between 2,660 and 3,944 individuals (fig. 7). When it comes to the territorial population, the estimates higher than 45,600 individuals are not taken into account for reasons discussed above. Here the mean of the population estimates is 22,986, and the quartiles range between 16,339 and 29,539. As the mean of the carrying capacity is set on 46,800, the territorial population consisted of 16,339-29,539 individuals (fig. 8). In this way they seemed to remain safely within the carrying capacity of the region. Unsurprisingly, the urban population thus experienced a larger population pressure with a population reaching closer to the carrying capacity of its primary catchment area.

A last method starts with the assumption that the population estimates are normally distributed, or at least closely resemble this patterning. With close resemblance, a "batch that is single peaked and symmetrical"[122] is meant. However, when the normal distribution of each of the population or carrying capacity estimates is tested, none are really normally distributed[123]. Nevertheless, since all consist of a single peak and are more or less symmetrical, their mean and standard deviation can be applied in the calculations as if dealing with a normal distribution. In order to calculate the highest probability for the population estimates, a 1σ-probability is chosen. For the urban population, the range given by μ = 3,320 and σ = 1,038 for a 68 per cent chance is 2,283-4,358 people. However, as

[122] Drennan (2010) 59.

[123] Tested with a Kolmogorov Smirnov test and visually surveyed with a Q-Q plot using R©.

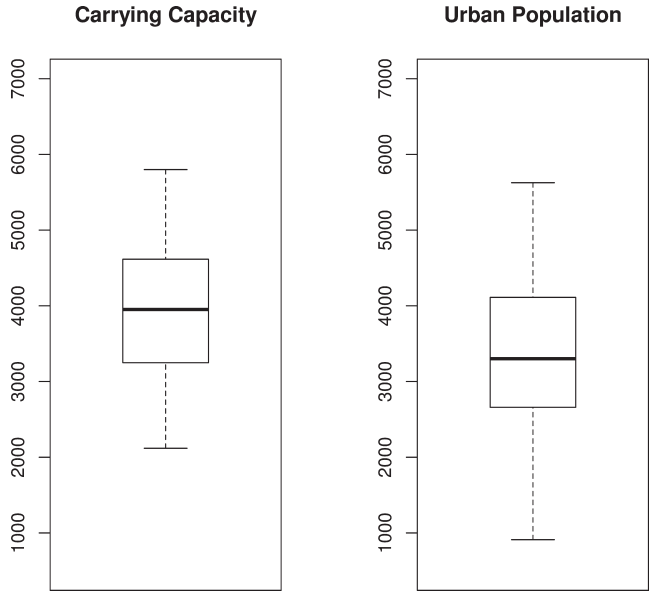


Fig. 7: Boxplots of the urban population estimates.

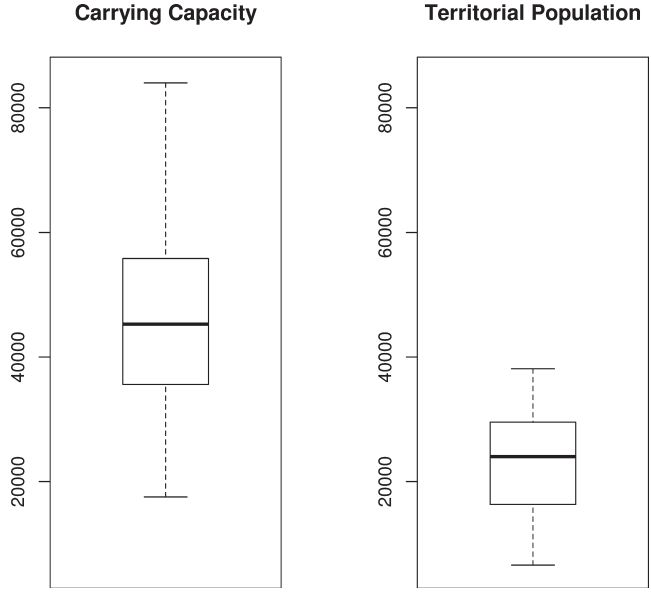


Fig. 8: Boxplots of the territorial population estimates.

seen before, the upper range falls within the range of the carrying capacity and therefore needs to be limited. The choice was to limit the population estimates where the probability of the carrying capacity overgrows that of the population, or in other words on the intercept of the two curves. This intercept can be found on 3,458 and thus the population for urban Sagalassos can be considered as between 2,283 and 3,458 individuals (fig. 9). For the territorial population the same logic can be followed, resulting in a range of 14,733-31,238 people (fig. 10), which is not limited by the carrying capacity since the intercept lies beyond the $\mu + 1\sigma$ on 34,222 individuals.

Comparison of the urban and the rural population

After the above discussed methods for data analysis have been applied, they can be compared to each other. So far, we are still dealing with five population ranges for both the urban and the territorial population.

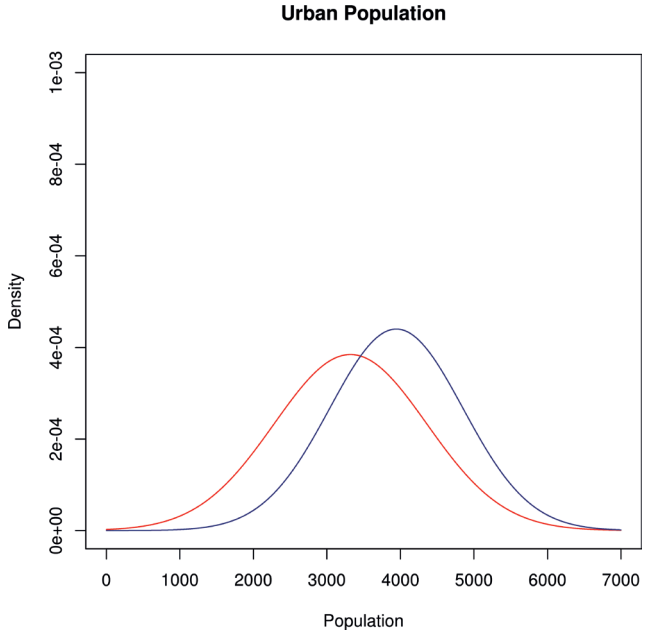


Fig. 9: Normal distribution of the urban population (red) and carrying capacity (blue) estimates.

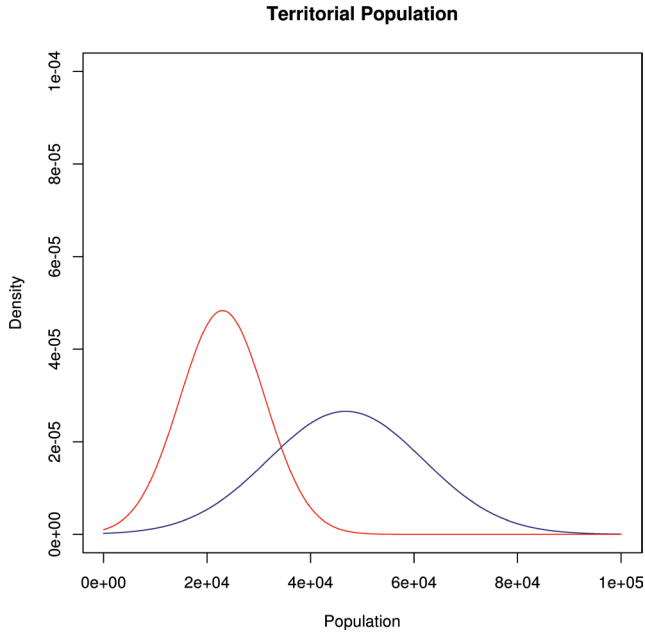


Fig. 10: Normal distribution of the territorial population (red) and carrying capacity (blue) estimates.

Therefore, it is best to weigh the value of each of the methods. The first two always result in a broad range, as they are not or barely limited. The following three methods are limited both in their upper as well as in their lower limit, which narrows the total range down. For example, the average range of the last three methods for the urban population is only 25 per cent of the total range (method 1). It thus seems more efficient to make use of the last three methods than of the former two. When the mean of the latter three methods is calculated, the urban population of Sagalassos ranges between 2,585 and 3,642 inhabitants, while the territorial population lies between 17,743 and 30,926 people. The rural population, or all people who are residing in the territory of Sagalassos, but not in the city itself, can thus be calculated as the territorial population minus the urban population, resulting in a range between 15,158 and 27,283 individuals.

An interesting aspect of these numbers is the relation of the urban to the rural population. This relation informs us on processes such as food

production and distribution, governance and regionalism. In literature, some attempts are made to come up with a fixed ratio between the urban and rural population. Within a Greek polis context, John Bintliff[124] estimated that urban:rural was in the ratio of 4:1, while for the same geopolitical situation, Mogens Herman Hansen[125] proposed a 2:1 ratio. Second-century AD Sagalassos, however, was not a Greek polis, but a Roman provincial city. For the Roman world, Peter de Graaf[126] proposed an alternative model where urban population percentages are between 10 and 25 per cent (1:9 to 1:3) of the total population, stressing the demographic importance of the countryside. A similar ratio was proposed by Stephen Mitchell[127], who came up with a ratio of 1:10-1:8 for (central) Anatolia. Frank Kolb and Andreas Thomsen[128] mention a ratio of 1:5.2 for the southern Lykian town of Kyaneai and its territory. Similarly, the estimates of the rural and urban population of Balboura is in the ratio of 1:14-1:12[129]. For the estimates discussed in this paper the ratio of urban:rural is 1:7.5 to 1:5.9, meaning that only *c.* 11 to 15 per cent of the population lived in the city of Sagalassos while the rural population was much larger. The ratio proposed by Peter de Graaf thus seems to correspond best with the Sagalassos case. Yet, the comparison with the Lykian towns of Balboura and Kyaneai indicates that the relation between town and hinterland can differ extensively from case to case.

The shotgun method 2.0 can be regarded as a heuristic tool, which makes it possible to calculate population numbers. The ultimate goal, however, is to interpret these numbers within the appropriate historical context. One interesting inference can be found by comparing these numbers to the carrying capacity. During the second century AD, the calculations above proved that the carrying capacity of the territory was still far removed from the population estimates, in contrast to the city, where the urban population was just less than its carrying capacity. The population pressure was thus more tangible in the city than in the country. In the calculations for the carrying capacity of the urban population, it was assumed that the Ağlasun-Yeşilbaşköy valley system served as its primary catchment area. The role of the immediate surroundings of

[124] Bintliff (1997) 235.
[125] Hansen (2006) 23-24.
[126] De Graaf (2012) 91-92.
[127] Mitchell (1993) 244.
[128] Kolb & Thomsen (2004) 40-41.
[129] Coulton (2012) 76; Wagstaff & Erdentuğ (2012) 40.

Sagalassos for food production — even for herding — in the second century was already attested in the high pollution in sheep and goat bones from this period, indicating that these animals lived close to the settlement itself[130]. Yet, the population pressure must have been even greater as the inhabitants of the valley itself were not taken into account. Therefore, it can be assumed that not only the Ağlasun and Yeşilbaşköy valleys served as the catchment area, but that the rest of the territory assisted in sustaining the urban population too, albeit to a lesser extent than the immediate valleys.

Problems and pitfalls

In this paper, the shotgun method 2.0 has been represented as a more precise way to deal with demographic data than by simply taking the total range of all applied estimates. This resulted in an urban population estimate for Sagalassos between *c*. 2,600 and 3,650 inhabitants and between *c*. 17,700 and 31,000 individuals residing in the total territory (including the city of Sagalassos itself). Indeed, the method tested in this paper provided plausible and interpretable results, but this does not mean that the work is finished. During the calculations and literature study some generic problems arose:

– GIGO: To archaeological GIS, the adage GIGO (originating from the computer sciences) — Garbage In, Garbage Out — is often applicable[131]. This term refers to the idea that the basic data used in whatever tool, be it statistics, GIS or computing, need to be of sufficient quality to ensure that the outcome is feasible, independent of the quality of the method. Minor changes in the input data, such as the choice for another surface for the residential area, already have a major influence on the outcome.
– Guesstimation: The term ‘guesstimate’ is often used in articles concerning ancient demography[132], indicating that the given number is as much based on gut feeling as it is on scientific data. Yet, some authors argue that guesstimates can be very useful if applied to problems for which an exact number is not a necessary outcome[133], such as population numbers. If their use in population estimates in archaeology is

[130] Degryse e.a. (2004) 2819-2834.
[131] Conolly & Lake (2006) 11.
[132] E.g. Hassan (1978) 68.
[133] Weinstein & Adam (2008).

scrutinized, the guesstimates, however, tend to differ to such extent that their usefulness lapses. One example is in the application of the method where the urban population is calculated by multiplying the area by the 'guesstimate' of the population density: Russel[134] proposes a population density of 100 to 150 individuals, while Grainger[135] suggests 200 people. These numbers, although both valuable guesstimates, are so different that the choice for the one or the other would double the population outcome.

– The omnipresent unknown: Of the two just-mentioned problems, the first can be settled by evaluating all input-data. The second problem, on the other hand, is less easily tackled. Within each of the calculations for estimating the urban and territorial population of Sagalassos, always at least one unknown — and thus guesstimated — value is present: be it the population density, household size, average age at death, soil surface needed for sustaining a household, or the number of people living in a hamlet. Because an unknown value is always present, a guesstimate is necessary to overcome this problem, with all problematic side effects mentioned.
– Methods from other case studies: Most of the here-used techniques are originally proposed by scholars working in other spatial and/or temporal contexts: the Greek polis, Boeotia, the Pamphylian coastal cities, Laconia, or even native American sites. Not all of these methods can be transferred to other contexts. One example which was already discussed was the ratio between urban and rural population proposed by Hansen[136] and Bintliff[137] for the Greek polis, which were totally different than those for Roman Imperial Sagalassos. Therefore, in the best possible scenario, the methods applied should either be neutral of any context, or specific for the studied site.

The different methods discussed above and applied to the Sagalassos-case do not approximate the final number equally well. In particular, three of the methods for calculating the territorial population were so high that they surpassed the carrying capacity[138]. Other techniques

[134] Russell (1958) 68.
[135] Grainger (2009) 234.
[136] Hansen (2006) 23-24.
[137] Bintliff (1997) 235.
[138] These methods are the one using the population density of present-day southwest Anatolia, the one for Attica (Garnsey (1988) 89-91) and the first method of Bintliff & Snodgrass (1985) 143.

approximate the final population ranges much better. By comparing the deviation of the lower and upper limit of the population range resulting from each of the methods with the final ranges for the urban and territorial population, the most accurate methods can be indicated. For the urban population, the method using house counts by which the household size was modelled linearly deviated less from the final range of 2.585 to 3.642 inhabitants. The method using a population density between 100 and 160 people per ha[139] was second best. The most differing results are Grainger's proposition of a population density of 200 inhabitants[140] and the method on house counts by Willet and Poblome[141]. For the territorial population, the methods that are based on multiplying the area by an estimate of the population density in general obtains the results that are farthest removed. A single exception is the method by Bintliff and Snodgrass[142] which takes the arable area into account. The method which deviated least was the one based on the aDNA by Claudio Ottoni[143]. Consequently, the methods which are independent from a specific context (e.g. aDNA) or which are to a lesser extent based on guesstimates (e.g. necropolis and housing units), often score better.

During the last 150 years, archaeologists and historians aimed at estimating the population sizes of cities and regions in the past because of the important consequences the number of people has on both the environment and society itself[144]. Most techniques, however, were criticised and never seemed to come close to a clear population estimate. This resulted in a limited interest in demographic studies over the past two decades. Instead of creating yet another formula, suffering the same problems, this paper aimed – in the spirit of Hansen's 'shotgun method' – at exploring and combining the existing techniques to come to a population range of highest probability. For the case study of second-century AD Sagalassos this resulted in an estimated urban population of 2,600-3,650 and a territorial one of 17,700-31,000 individuals.

[139] Engels (1990) 82.
[140] Grainger (2009) 234.
[141] Willet & Poblome (2015) 136.
[142] Bintliff & Snodgrass (1985) 143.
[143] Ottoni e.a. (2016); Ottoni, personal communication.
[144] E.g. Malthus (1798); Boserup (1981); for a survey of the importance of population estimates, see Hassan (1978) 69-87; Chamberlain (2006) 4-10.

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