CONSTRUCTING CITIES AND RECONSTRUCTING DIET

Investigating dietary changes from the Early Iron Age into the Classical and Hellenistic Period at two sites in Thessaly and Macedonia through stable isotope analysis

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Cover figure: Terracotta fish-plate, ca. 350-325 BCE. The Metropolitan Museum of Art (https://www.metmuseum.org/art/collection/search/247404)

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Chapter 1: Introduction

1.1 Greece in the Early Iron Age

Neolithic Period	Early Neolithic	6500-5800 BCE
	Middle Neolithic	5800-5300 BCE
	Late Neolithic	5300-3200 BCE
Bronze Age	Early Bronze Age	3200-2200 BCE
	Middle Bronze Age	2200-1700 BCE
	Late Bronze Age	1700-1100 BCE
Early Iron Age		1100-750 BCE
Archaic Period		750-500 BCE
Classical Period		500-323 BCE
Hellenistic Period		323-146 BCE

Table 1: The periodization of ancient Greece, from the Neolithic until the Hellenistic Period. After Martin, 2000.

Ancient Greece is a thoroughly studied subject, from the earliest beginnings of Cycladic culture in the Early Bronze Age all the way to Roman times and beyond (e.g. Cartledge, 2011; Martin, 2000). There is one time period, however, that remains quite elusive. At the very end of the Late Bronze Age (1700-1100 BCE, see also Table 1 for future reference to time periods), large urban centers were relatively suddenly abandoned all throughout the Aegean and the Near East. This is known as the Late Bronze Age Collapse. In Greece, this collapse starts around 1200 BCE and is complete by 1000 BCE. The period that follows, the Early Iron Age, is known as the 'Greek Dark Ages'.

These 'Dark Ages' lasted for approximately 350 years. During this time, the Palatial Civilizations that existed during the preceding Mycenaean period in Central and Southern Greece are replaced by small rural settlements. The period is characterized by population migrations, and long-distance trade is present on a much reduced scale. The 'Greek Dark Ages' are also characterized by the loss of writing, such as the apparent vanishing of the writing system known as Linear B (Morris, 2006, p. 77). Only at the end of the Early Iron Age does writing re-emerge in Greece, with the spreading of the Phoenician alphabet in the eighth century BCE (Drake, 2012, p. 1862-1863; Morris, 2006, p. 77).

Because practically no literary sources survive in the Aegean during the Early Iron Age, any information gleaned on this period comes from either archaeological or biological sources. Since population levels declined, the small rural communities that existed in the four centuries following the Late Bronze Age Collapse left only a limited archaeological record (Drake, 2012, p. 1862; Morris, 2006, p. 73-74). Athens was the biggest settlement during this time, and its population was likely never greater than between 2.500 and 5.000 individuals (Morris, 2006, p. 74). Due to the scarcity of archaeological evidence, it is still uncertain what exactly caused the Late Bronze Age Collapse. Various economic, military and climatic causes have been suggested that could have contributed to the Collapse, but there is not one clear, proven theory (Drake, 2012, p. 1863).

In the Archaic period following the Early Iron Age, settlement size increased again. By the beginning of the seventh century BCE, Athens had a population count anywhere between 5.000 and 10.000, and many other settlements had between 1.000 to 5.000 inhabitants. This urban growth continued, resulting in Athens' population reaching approximately 20.000 by 480 BCE (Morris, 2006, p. 74-75).

Additionally, starting around 750 BCE, temples were being built across Greece. In the following two centuries, thousands of such temples were constructed. This happened after the Early Iron Age, a period with no monumental architecture to speak of (Morris, 2006, p. 76).

Trade existed during the Early Iron Age, but while long-distance trade with the Near East and modern-day Italy must have been extensive during the Bronze Age to supply Greece with metals necessary for metallurgy, these contacts diminished greatly following the Collapse. Trade returned with the arrival of the Phoenicians in the tenth century BCE, but any trading beyond the Aegean only properly got started again after 800 BCE. Approximately two centuries later, Greek cities were at the center of a vast trading network that extended beyond the scope of its Bronze Age equivalent (Morris, 2006, p. 78).

1.2 Changing subsistence strategies and diet

Research into climate proxies suggests that at the end of the Late Bronze Age, a centuries-long megadrought began in the Aegean and the Near East, that lasted into the beginning of the Early Iron Age (Drake, 2012, p. 1862). The drought worsened the problems during the Late Bronze Age Collapse, as crop failure made recovery difficult and disease increased. Wetter conditions only returned around 900 BCE (Morris, 2006, p. 83).

The drought, paired with the degeneration of strong urban centers, led communities in the Early Iron Age to change their subsistence strategies. Instead of homogeneous cereal cultivation and sheep herding, inhabitants of Early Iron Age settlements diversified their agriculture to include different animals and plants more resistant to aridity, such as goats and olive trees (Dibble & Finné, 2021, p. 59). The change in diet was a response to the changing environment, both in terms of the political situation and the natural climate.

Seeing as climate conditions gradually improved toward the Archaic Period, the question arises if this was once again paired with a change in subsistence strategies and diet, and how this relates to the regeneration of urban centers. Were there changes in diet from the Early Iron Age to later periods that can explain the reorganization of communities into centralized urban settlements? If subsistence strategies changed, was this in response to a return of wetter climate conditions? Could a change in diet have contributed to the development of cities? Or was it the other way around, and did the changing political landscape dictate a shift in subsistence strategies?

As archaeological evidence from the Early Iron Age is scarce, this thesis will address these issues by looking at the osteological record. The reason why human skeletal remains are a good source of information on subsistence strategies, is that they can be studied to gain insight into the diet of populations. As the saying goes, 'you are what you eat'. This is quite literally true, as the human body is built up of atoms that are derived from food. This of course includes the skeleton. Because of this, studying an individual's bones on an atomic scale can provide information on that person's diet. In an archaeological context, this can be done using stable isotope ratios from skeletal material for a group of individuals from one location, to gain insight into the dietary habits of its population. This is incredibly useful, especially for time periods from which no or few literary sources survive, such as the Greek Early Iron Age.

1.3 Research questions

To gain insight into possible changes in the diet and subsistence strategies from the Early Iron Age into later times, this thesis will compare skeletal material from two sites in modern-day Greece. One is the site of Halos in Thessaly, the other is the site of Makrigialos in Central Macedonia. From both sites, isotopic nitrogen and carbon data from osteological material is available dating to both the Early Iron Age and later periods. Therefore, studying changes in isotopic data from these sites can provide a unique insight into changing subsistence strategies and living conditions from the Early Iron Age to following time periods.

In comparing the isotopic data from both sites, an attempt will be made to answer the research question:

How did diet change from the Early Iron Age to the Classical and Hellenistic periods at the Greek and Macedonian sites of Halos and Makrigialos, as seen through stable isotopes?

The sub-questions that this thesis will address are:

- *How do $\delta^{13}C$ and $\delta^{15}N$ values differ between the Early Iron Age Halos and the Hellenistic New Halos skeletal assemblages?*
- *How do $\delta^{13}C$ and $\delta^{15}N$ values differ between the Early Iron Age Makrigialos and the Classical Makrigialos skeletal assemblages?*
- *How do $\delta^{13}C$ and $\delta^{15}N$ values differ between Halos and Makrigialos, both in the Early Iron Age and in the later periods?*

1.4 Approach

In order to answer the research questions, stable carbon and nitrogen isotope ratios will be examined from the archaeological sites of Halos and Makrigialos. The reason these places have been selected, is that human skeletal remains have been found at both sites dating to the Early Iron Age, with the skeletons at Halos dating between 1100 and 900 BCE, and those at Makrigialos dating between 1100 and 700 BCE (Panagiotopoulou et al., 2016, p. 212; Triantaphyllou, 1999, p. 3). From both sites, skeletal material dating to later periods has also been excavated. For Halos, the later skeletons date to the early Hellenistic period (302-265 BCE) and the skeletal remains from Makrigialos date to the Classical period (500-300 BCE) (Sparkes, 2017, p. 54; Triantaphyllou, 1999, p. 235).

Furthermore, both sites are located on the east coast of contemporary mainland Greece, which means both communities at least had the Aegean Sea as a resource that could have provided them with food and a possible point of contact with the wider region. Both sites are also situated near the roads that lead from north to south, which places them along the same corridor of trade via land.

Diet of past populations can be assessed by determining ratios of stable isotopes, in this case carbon and nitrogen. Within an individual's skeleton, the ratio between different isotopes of the same element will reflect the ratio of those isotopes in the food they ate. Diets based on certain foodstuffs will have a different ratio of stable isotopes than diets based on other foodstuffs. Therefore, past diet can be examined through stable carbon and nitrogen isotope analysis (Katzenberg, 2008, p. 415).

For the skeletal assemblages at both Halos and Makrigialos, the relevant carbon and nitrogen isotope ratios have been determined and are freely accessible through IsoArcH, an open database containing isotopic data of both human and animal skeletal material from archaeological contexts

(Salesse et al., 2018, p. 2-3). Previous research on stable carbon and nitrogen isotopes for Makrigialos has already been done by Dr. Sevasti Triantaphyllou (1999), in her PhD thesis: *A Bioarchaeological Approach to Prehistoric Cemetery Populations from Central and Western Greek Macedonia.* However, while Triantaphyllou briefly touches upon the material from the Classical period, the main focus of her work is on prehistoric material. She uses the skeletal remains from Early Iron Age Makrigialos alongside those from eight other burial locations dating between the Early Neolithic and the Early Iron Age. In her thesis, she analyzes stable carbon and nitrogen isotopes from bone collagen alongside paleopathology and burial contexts to sketch an image of diet and social roles (Triantaphyllou, 1999).

Similar work has been done for Halos. Panagiotopoulou et al. (2016) have written a paper in which stable carbon and nitrogen isotope analysis from bone collagen is combined with burial context and estimated age-at-death to reconstruct diet and social differentiation (Panagiotopoulou et al., 2016, p. 212). This research was quickly picked up by Dr. Hillary Sparkes, who briefly touched upon the results from that paper in her own PhD thesis: *Taking a Bite out of History: Hellenistic Dietary Reconstruction and Population Mobility at the Site of New Halos, Thessaly, Greece*. Her paper is focused on New Halos, which is the name given to the Hellenistic town of Halos, to separate it from earlier phases of habitation at the same place. Sparkes analyzed stable carbon and nitrogen isotopes from both bone collagen as well as enamel carbonate to reconstruct diet at New Halos. She also uses stable strontium and oxygen isotopes from enamel apatite to investigate patterns of mobility (Sparkes, 2017).

In this thesis, previous research at both sites will be expanded upon by comparing both Early Iron Age Makriaglos with its Classical counterpart, comparing Early Iron Age Halos to Hellenistic New Halos, and comparing the two locations to each other.

1.5 Thesis outline

In Chapter 2, the historical background of the Late Bronze Age Collapse will be discussed for both the Aegean and the region that would become the kingdom of Macedonia. Next, the concept of the 'Greek Dark Age' will be discussed and criticized. This is followed by a description of the regeneration of urban centers after the Early Iron Age. Chapter 2 will continue with an explanation of stable carbon and nitrogen isotope analysis in human bones with regards to diet reconstruction, and it will conclude with a brief summary of work previously done regarding stable isotope analysis for diet assessment in ancient Greece. Chapter 3 will outline the materials and methods used for this research, including detailed descriptions of the sites of Halos and Makrigialos and their osteological assemblages, followed by an explanation of the analytical methods that will be employed. Chapter 4 will show the results of the research, in which the isotopic data from and between both sites will be compared. In Chapter 5, these results will be interpreted and discussed with the works by previous researchers in mind, and the results will be placed within the context of regeneration of urban centers after the Early Iron Age. Finally, in Chapter 6, a conclusion will be drawn and the research questions will be answered. The thesis will end with suggestions for further research.

Chapter 2: Background

This chapter will first present the historical context concerning the Late Bronze Age Collapse in both Greece and Macedonia. The concept of a 'Greek Dark Age' will be explained and problematized. Then, the regeneration of complex societies after the Early Iron Age will be discussed. This is followed by an explanation of dietary reconstruction using stable carbon and nitrogen isotopes in human bones. Finally, a brief overview of previous work concerning assessment of past diet using stable isotope analysis in ancient Greece will be given.

2.1 The Late Bronze Age Collapse

2.1.1 The Collapse of Mycenaean civilization

In the Late Bronze Age, during the second millennium BCE, a culture known as the Mycenaean civilization developed on the southern mainland of modern-day Greece. The civilization was named by archaeologists after its most prominent site, Mycenae. Although the term "Mycenaean Greece" is often used to describe the situation during the second millennium BCE, Bronze Age Greece was never a united state, but instead consisted of independent settlements (Martin, 2000, p. 26).

Beginning in the fifteenth century BCE, Mycenaeans started constructing tholos tombs. These are monumental domed burial chambers. The architectural style of the tombs and the grave goods found in them show that Mycenaean settlements maintained contact with the Near East, and Egypt especially (Martin, 2000, p. 27). Mycenaean pottery has also been found in Sardinia, Sicily and southern Italy. An important purpose of the trade network was to facilitate metallurgy (Morris, 2006, p. 77-78).

Mycenaeans were also in close contact with Crete, where Minoan culture was thriving. Minoans were known for building monumental maze-like palaces. The Mycenaeans of the mainland traded extensively with Minoan Crete, and starting in the fourteenth century BCE, the mainlanders started building palaces as well, which were ruled by 'kings'. At this time, the Mycenaeans also appear to have taken over control of Crete from the Minoans. The Mycenaeans founded colonies along the Mediterranean coast, and their civilization became the most powerful one in the Aegean (Martin, 2000, p. 27-28).

Starting around 1200 BCE, however, the political systems that had been in place in the eastern Mediterranean and the Near East started to unravel. By 1000 BCE, Mycenaean palace culture and the

Hittite kingdom in Anatolia were destroyed, the New Kingdom in Egypt was falling apart, and political turmoil disrupted civilizations in Mesopotamia. The cause of this 'Late Bronze Age Collapse' is debated, but it was most likely a multitude of factors. The most important ones are internal strife between political centers, overexploitation of natural resources, earthquakes and possibly a drought, all of which led to widespread migrations (Drake, 2012, p. 1862-1863; Martin, 2000, p. 30-31).

Internal problems caused peoples from Mycenaean Greece, the Aegean islands, Anatolia, Cyprus and the Near East to abandon their homes and to migrate to Egypt and the Levant. Some groups of people only traveled away from their homeland to conduct raids with the intention to return, while others permanently moved. These widespread migrations and attacks further disrupted the political and economic systems of the territories that they moved into (Drake, 2012, p. 1862-1863; Martin, 2000, p. 31-32).

Meanwhile, major earthquakes added to the difficulties. Mycenaean palaces depended on redistribution of agricultural products. Warfare already stressed this economic system, but with the addition of earthquakes, recovery was even further hindered (Martin, 2000, p. 34). It has also been shown that a centuries-long period of drought at the end of the Late Bronze Age and into the Early Iron Age added to the existing stress (Drake, 2012, p. 1862-1863).

By 1000 BCE, the Late Bronze Age Collapse was complete and Mycenaean civilization was gone. In the Early Iron Age population fell, and settlements were fewer and less organized (Martin, 2000, p. 39; Morris, 2006, p. 80; Sparkes, 2017, p. 11-12). Contact with the Near East continued, but on a much smaller scale (Martin, 2000, p. 37; Morris, 2006, p. 78).

Because the population declined, there were fewer people to cultivate the land. This resulted in a decrease in the food supply, which in turn made the population fall further. It has therefore been suggested that pastoralism became a more important form of subsistence, and partially replaced cereal cultivation (Martin, 2000, p. 38-39; Sparkes, 2017, p. 11-12).

However, recent research comparing faunal remains and pollen data from the Late Bronze Age to those from the Early Iron Age show that Greece did not switch to pastoralism. Instead, both Mycenaean Greece and Early Iron Age Greece were agropastoral. The difference is that the Mycenaeans made use of strategies of intensification, whereby food production was fairly homogeneous between settlements. The focus was on cereal production and sheep farming (Dibble & Finné, 2021, p. 53 and 57). In contrast, the more arid conditions caused by climate change and the decentralization after the fall of palatial societies, caused a switch in food strategies whereby intensification was replaced by diversification (Dibble & Finné, 2021, p. 51). Different settlements used different food strategies. Sheep were no longer necessarily the most numerous animal. Goats, cattle and pigs appeared at settlements in greater numbers (Dibble & Finné, 2021, p. 55). Meanwhile, agriculture continued, and olives began to be cultivated in greater numbers. The areas most affected by the drought tended toward goat husbandry. Both the emphasis on goats and on olive trees can be interpreted as a response to the dryer climate, as both are better adapted to such an environment (Dibble & Finné, 2021, p. 59).

2.1.2 The Collapse and Macedonia

During the Bronze Age, the region that would become the kingdom of Macedonia was situated north of the Mycenaean civilization, and south of the political centers in the Balkans. It was not a part of 'Mycenaean Greece' and therefore did not have the same palatial culture. However, Macedonia did have close contact with the south and the north. The highest amount of sites were inhabited at this time in Central Macedonia. New settlements were being built, mostly in the form of dwelling mounds known as *toumba* sites (Bahyrycz, 2019, p. 124). The Thessalian equivalent of this settlement type is called a *magóula*. Although there is no clear evidence for highly organized political centers similar to those in Mycenaean Greece, the toumba sites do show that agricultural products could be stored in amounts that were much larger than the inhabitants of the settlement required (Bahyrycz, 2019, p. 124).

In the valley of the river Vardar, these Late Bronze Age settlements belonged to the Ulanci culture. This culture had its own customs and material culture such as monochrome pottery, but was also strongly influenced by Mycenaean civilization. Pottery of local shapes are often decorated with imitations of Mycenaean painting patterns, and bronze objects from the south are common grave goods (Mitrevski, 2007, p. 444-445).

When Mycenaean civilization started to collapse, the parts of Mycenaean culture that had integrated into local Macedonian communities continued to exist and develop for a time. This process was interrupted however, when several waves of migrations took place from the north into Macedonia during the twelfth century BCE. These migrations were often violent, as burned layers can be found in many Macedonian settlements dating to this time. Some Macedonian communities chose to move to more defensible areas, abandoning their previous settlements. Artefacts native to the Northern and Central Balkans now appeared in Macedonia, and burial customs changed. Previously, inhumation had been the norm. With the influx of people from the north, this changed to cremation (Mitrevski, 2007, p. 447).

Similarly to the rest of the wider area, there is evidence that Macedonia experienced several earthquakes during the Late Bronze Age (Hošek et al., 2021, p. 1009). The proposed drought that took place into the Early Iron Age was also affecting Macedonia at this time (Hošek et al., 2021, p. 1003). Research by Dibble and Finné (2021) indicates that the same trend in the south toward a food strategy of diversification as opposed to intensification also took place in Macedonia, although it must be mentioned that this is only based on evidence from one archaeological site (Dibble & Finné, 2021, p. 56).

During the Early Iron Age, influence from the north remained important, although burial customs did switch back to inhumations in cist graves. Economic power was reduced as a consequence of the turmoil during the Late Bronze Age, resulting in a sharp reduction of settlements and depopulation in Early Iron Age Macedonia. To the west of the Vardar Valley, the Hallstatt culture from the eastern Alps spread into Macedonia. From there, Hallstatt material culture (mainly jewelry) was introduced into the wider Macedonian region (Mitrevski, 2007, p. 449).

2.1.3 'Greek Dark Ages?'

The term 'Greek Dark Ages' was used by early scholars to describe the Early Iron Age in Greece, because little to no writing survived from that period. It was seen as an interlude between the well-documented Bronze Age and the later Archaic Period. Additionally, the Early Iron Age followed the collapse of Mycenaean civilization, which was seen as complex. This made the following period seem 'dark' in comparison. However, the term 'Dark Ages' is increasingly rejected, as it implies a period of inferiority. It also implies pause, as if nothing took place during those centuries. For those reasons, scholars nowadays prefer to simply use the term 'Early Iron Age' (Kotsonas, 2012).

The concept of 'Dark Ages' was practically never applied to the region that would become the ancient kingdom of Macedonia. This is most likely because the Late Bronze Age palatial society in the Aegean did not extend to Macedonia, and so no 'grand civilization' fell here during the Late Bronze Age Collapse. Furthermore, little written text survives from Bronze Age Macedonia, and so the Bronze Age is perceived as equally as 'dark' as the Early Iron Age (Kotsonas, 2012).

Even though both the south of Greece and Macedonia experienced destructive and disruptive migrations during the Early Iron Age and both were affected by the reduced contact within the wider Aegean overall, scholars used to approach the two regions entirely separately. The term 'Greek Dark Ages' was limited only to the south, and so Macedonia was excluded from any research connecting it to the Aegean (Kotsonas, 2012).

Because in reality Macedonia was never cut off from the Aegean and the two experienced similar economic, political and climatic turmoil, for this thesis both a site from Thessaly and from Macedonia will be examined. Seeing as the term 'Dark Ages' has outdated implications, in this thesis, it will not be used beyond this chapter. Instead, the much more inclusive and widely accepted term 'Early Iron Age' will be used to describe the centuries between 1100 and 700 BCE.

2.1.4 Regeneration

Population started to increase again starting in the eighth century BCE. At this time, contact with Egypt and the Near East also intensified again (Morris, 2006, p. 78; Sparkes, 2017, p. 12). Greek colonies were founded on Sicily and in Italy, which enabled the Greeks to cultivate more land and to import the produce, reducing stress on settlements in the homeland and allowing for growth (Morris, 2006, p. 78). Starting in the Archaic Period (750-500 BCE), the concepts of the city-state or *polis* and associated citizenship developed (Martin, 2000, p. 51; Sparkes, 2017, p. 12). The Greek polis consisted of a usually fortified urban political center, surrounded by a wider area of agricultural land and smaller settlements. A polis was often dedicated to a certain deity of the Greek pantheon, and the citizens were united in communal rituals for this deity (Martin, 2000, p. 51). With this, monumental architecture returned to Greece in the form of temples, thousands of which were being constructed in the Archaic Period (Morris, 2006, p. 76). During the Classical Period (500-323 BCE), poleis were at the height of their influence. While all Greeks worshipped the same pantheon and spoke the same language, poleis were politically independent from each other and often engaged in wars for control over a region (Sparkes, 2017, p. 13).

This regeneration of strictly organized societies in ancient Greece can partially be explained by an improvement in climatic conditions. In the ninth and eighth centuries BCE, the drought came to an end and due to the cooler, wetter environment, crops were less likely to fail and living conditions improved. Another factor was the arrival of the Phoenicians in the late tenth century BCE. Phoenician merchants were driven into the Aegean by Assyria, which demanded tribute from them. This contact with the Phoenicians gave an impulse to renewed interregional trade (Morris, 2006, p. 83).

Also at the end of the eighth century BCE, Perdiccas of Argos became the founder of a united Macedonian kingdom, with Aegae as its capital city (Sprawski, 2010, p. 128). This kingdom would continue to grow in power. By the late Classical Period, the Macedonian king Philip II conquered Thessaly. He continued to gain territory from the Phokians, Thebans, Illyrians and the Chalkidian League. In doing so, he united the Greeks against common enemy Persia, and he assigned land in Macedonia to those who wanted to become Macedonian. This assured stability within the kingdom. Philip II's son, Alexander the Great, continued his father's conquests and expanded the Macedonian kingdom into Persia, Asia Minor, Northern Syria and Egypt. The spread of Hellenized, Macedonian culture in the Late Classical Period laid the foundations for the Hellenistic Period (Sparkes, 2017, p. 14).

The death of Alexander the Great marks the beginning of the Hellenistic Period. The Macedonian empire fell apart into three separate kingdoms: Macedonia and Greece were ruled by the Antigonid dynasty, Egypt was ruled by the Ptolemaic dynasty, and Syria and Persia by the Seleucid dynasty (Martin, 2000, p. 199). The three kingdoms engaged in conflicts over their borders. This was more or less resolved around the middle of the third century BCE (Martin, 2000, p. 200-202). During the Hellenistic Period, Greek culture became widespread and the Eastern Mediterranean became a multicultural society (Sparkes, 2017, p. 14). This happened for a large part due to the movement of Greek peoples into newly founded cities in the Hellenistic kingdoms. Increased contact between territories within the Eastern Mediterranean strengthened the interregional trade networks, which existed both on land and overseas (Martin, 2000, p. 198-199).

2.2 Stable isotope analysis

Each atomic element (such as carbon or nitrogen) has different variations or 'isotopes', which are determined by the number of neutrons the atom has in its core (Katzenberg, 2008, p. 415). For example, there are carbon atoms with twelve neutrons in their core (carbon-12, also written as ^{12}C), and carbon atoms with thirteen neutrons in their core (carbon-13, or ^{13}C). These two variations of carbon are different carbon isotopes. Isotopes can be unstable (also known as radioactive) or stable. Unstable isotopes decay over time, while stable isotopes do not (Katzenberg, 2008, p. 415). The ratio between the different stable isotopes present in an individual's skeleton will reflect the ratio of those isotopes in the food they ate. Certain diets will have a different ratio of carbon and/or nitrogen isotopes than others. Therefore, analyzing the carbon and nitrogen isotope ratios present in human bones can give information on past diet (Katzenberg, 2008, p. 415). In the case of this thesis, stable carbon and nitrogen isotope ratios will be analyzed.

2.2.1 Stable carbon isotope analysis for diet reconstruction

The two stable carbon isotopes used in analyses of past diet are the very common ^{12}C and more rare ^{13}C. Because ^{13}C has one more neutron in its core than ^{12}C, it is slightly heavier. As a result, ^{13}C tends to react more slowly in chemical reactions than its lighter counterpart. This is also the case during photosynthesis, the process through which plants fix carbon in the form of glucose from atmospheric

CO_2. Therefore, the ratio between ^{13}C and ^{12}C in plants differs from that of the atmosphere. This change in the ratio between stable isotopes within a sample and the source the isotopes came from, is called fractionation (Katzenberg, 2008, p. 415-416). The stable carbon isotope abundance ratio in a sample is calculated against an international standard (the Vienna Pee Dee Belemnite), which results in a $\delta^{13}C$ value of parts per thousand (‰) (Katzenberg, 2008, p. 422; Richards, 2015, p. 18).

The ^{13}C : ^{12}C ratio in the atmosphere has an average $\delta^{13}C$ value of -7 to -8‰. Due to fractionation, plant tissue has a more negative $\delta^{13}C$ value. However, not all plants discriminate against ^{13}C in equal measures. Plants can be divided into C_3 and C_4 plants, according to the photosynthetic pathway they follow. The C_3 pathway discriminates the strongest against ^{13}C, which means the $\delta^{13}C$ value of C_3 plants is the most negative, and ranges between -20‰ to -35‰. C_4 plants discriminate against ^{13}C to a lesser degree, which results in a $\delta^{13}C$ value between -9‰ and -14‰. In ancient Greece, C_3 plants are the most common and include trees and cereals. C_4 plants are associated with arid environments, and include grasses and millet (Katzenberg, 2008, p. 423; Richards, 2015, p. 18-19).

The $\delta^{13}C$ value of terrestrial plant tissue will also differ from that of marine or freshwater plant tissue. The bicarbonate in ocean water from which marine plants derive their carbon, contains a higher percentage of ^{13}C than the atmosphere. This results in a $\delta^{13}C$ value of ocean water that is around 10‰ higher than it is in atmospheric CO_2, and therefore the $\delta^{13}C$ value of marine plants is also around 10‰ higher than that of terrestrial plants (Richards, 2015, p. 19).

Freshwater plants also derive their carbon from the water. However, the source of this dissolved carbonate can vary. It could be derived from the atmosphere, or it could have a geological origin. This results in a wide range of $\delta^{13}C$ values within freshwater plant tissue. Usually, atmospheric CO_2 is the main source of dissolved carbonate in freshwater. Therefore, the $\delta^{13}C$ values of freshwater plants tend to be similar to those of terrestrial plants (Richards, 2015, p. 19).

Because the $\delta^{13}C$ value within plant tissue varies according to what type of plant it is and animals higher on the food chain (including humans) derive their carbon from those plants, studying the $\delta^{13}C$ values within human skeletal material can provide information on a population's diet.

2.2.2 Stable nitrogen isotope analysis for diet reconstruction

The stable nitrogen isotopes used when analyzing past diet are ^{14}N and ^{15}N, of which ^{14}N occurs much more commonly. Similarly to carbon isotopes, the ratio of ^{14}N : ^{15}N in a sample can be compared to that of an international standard (the AIR standard), and expressed as $\delta^{15}N$ in parts per thousand (‰). The AIR standard is considered to have a $\delta^{15}N$ value of 0‰ (Richards, 2015, p. 19).

Most plants derive all their nitrogen from decomposing organic matter. Leguminous plants such as lentils form the exception: they have a symbiotic relationship with certain bacteria that live in their roots and can fix atmospheric nitrogen for them. Although leguminous plants do still obtain nitrogen from the soil, a part of their nitrogen intake is derived from the atmosphere (Katzenberg, 2008, 425; Richards, 2015, 19-20). Leguminous plants therefore have a $\delta^{15}N$ value closer to that of the atmosphere than non-leguminous plants. Non-leguminous plants rely fully on decayed organic matter for their nitrogen, and this source is more enriched in ^{15}N (Katzenberg, 2008, p. 425).

As mentioned before, lighter isotopes tend to react more than heavier ones. Therefore, organisms break ^{14}N down faster than ^{15}N, leaving their tissue enriched in ^{15}N. The $\delta^{15}N$ value of herbivores is around 3‰ higher than that of the plants they consume. With every subsequent step in the food chain, the $\delta^{15}N$ value goes up by another 3‰ on average. Therefore, the higher the trophic level, the higher the $\delta^{15}N$ value (Katzenberg, 2008, p. 425).

Due to denitrification, seawater has a higher $\delta^{15}N$ value than the atmosphere. The $\delta^{15}N$ value of dissolved deep ocean nitrate lies between 6-8‰. For this reason, marine plants and other organisms tend to have an elevated $\delta^{15}N$ value compared to terrestrial organisms (Richards, 2015, p. 20). Marine food chains are also much longer than terrestrial ones, which means the trophic level effect on $\delta^{15}N$ tends to be greater in marine environments as well. Nitrogen isotopes can therefore be used to distinguish between terrestrial and marine-based diets, but this is only possible when the local food web is established. In order to do so, faunal isotopic data can be used alongside isotopic data derived from human bones (Richards, 2015, p. 20-21).

2.2.3 Skeletal material for stable isotope analysis

To assess diet of past populations, stable carbon and nitrogen isotopes can be obtained from skeletal material. Both bone collagen and bone bioapatite contain the isotopes. The carbon isotope values in bone collagen mostly reflect the source of dietary protein, rather than the total of all carbon consumed by an individual. Similarly, the nitrogen isotope values also reflect dietary protein, but unlike carbon, there is no other source of nitrogen to be considered as nitrogen is only present in dietary protein. The fractionation of $\delta^{13}C$ from dietary protein to collagen, is around 5‰. The same fractionation for $\delta^{15}N$ is around 3‰. The isotope values in collagen reflect all dietary protein that was consumed over the past 10 to 20 years of life (Richards, 2015, p. 17).

Bone bioapatite is present in the mineral component of bone. The $\delta^{13}C$ of this carbonate reflects the entirety of dietary carbon, including protein, lipids and carbohydrates. This means that carbonate potentially provides more information on the complete diet of an individual. However, bone carbonate has been found to be severely altered by the surrounding soil after deposition. Mainly for this reason, bone collagen is more commonly used for diet reconstruction (Richards, 2015, p. 17-18).

2.3 Previous work

Over the last few decades, research into ancient Greek diet using stable carbon and nitrogen isotopes has been done. Before 2000, this research was mostly limited to the south mainland, Crete, and the Cyclades. Starting in the late 1990s, a study of isotopes was done on remains from central and western Greek Macedonia (Triantaphyllou, 2015, p. 58).

An overview of previous studies using skeletal remains for diet reconstruction in ancient Greece was published in Volume 49 of *Hesperia Supplements* (Papthanasiou et al., 2015). Most research within this volume focuses on prehistory, but some chapters include studies into later periods. For example, a chapter by Lagia is focused on Athens and Laurion from the Classical to Imperial Roman Periods, and work by Bourbou and Garvie-Lok examines diet in Byzantine Greece (Lagia, 2015, p. 119-145; Bourbou & Garvie-Lok, 2015, p. 171-194).

Chapter 3: Materials and Methods

In order to better understand the questions that this thesis attempts to answer, the context of the sites that will be examined in this thesis must be provided. In this chapter, the historical, archaeological and geographical background of each site will be described, as well as the skeletal assemblages that will be used for analysis. The following two subchapters will discuss Early Iron Age Halos and New Halos respectively. Subchapter 3.3 and 3.4 provide the background of Early Iron Age Makrigialos and Classical Makrigialos. Finally, subchapter 3.5 will discuss the methods used regarding the sample selection and analysis of the stable carbon and nitrogen isotopic data.

3.1 Early Iron Age Halos

3.1.1 Neolithic Period to Bronze Age

Halos is located on the east coast of southern Thessaly (Figure 1). It is situated on the border between two plains: the Almirós Plain to the northwest, and the Soúrpi Plain to the southeast. Directly west of Halos are the Othris Mountains, and roughly two kilometers to the east is the Pagasetic Gulf and therefore access to the sea (Sparkes, 2017, p. 42). Other important strategic features of the area are the saltmarsh to the east and the river Amphrysos that flows through the valley near Halos (Figure 7) (Halos/University of Groningen, 2014).

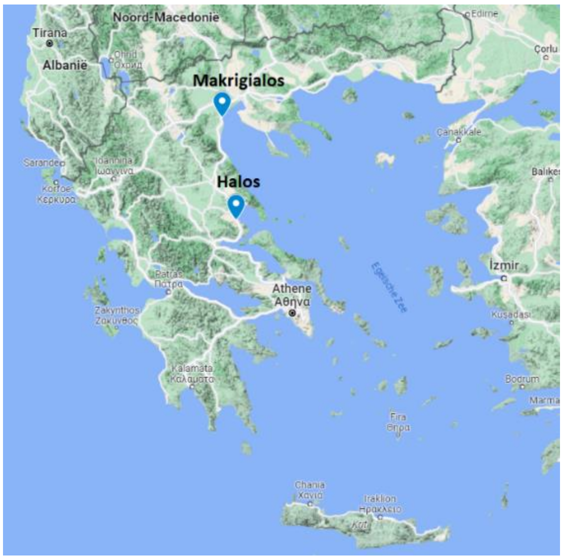

Figure 1: The locations of Makrigialos and Halos in mondern-day Greece. Image by author, using Google Maps.

The Almirós and Soúrpi plains were already inhabited during the Neolithic Period. In total, five Neolithic sites are known across both plains (Halos/University of Groningen, 2014a; Reinders, 2016, p. 7). *Magoúlas* are found throughout Thessaly. They are prehistoric dwelling mounds, consisting of a gently sloping platform on which occupational waste material is piled up (Reinders, 2016, p. 13). In the Bronze Age, more magoúla sites are known in the Almirós and Soúrpi area, such as Magoúla Soúrpi (Figure 2) (Halos/University of Groningen, 2014b).

Figure 2: Magóula Soúrpi (Halos/University of Groningen, 2014b).

In 1990, a Bronze Age site was found in the Voulokaliva area, near the Amphrysos river (see its location in Figure 7). This site is notably not a magóula. It was occupied during the Early Bronze Age. Later, it was reoccupied in the Late Bronze Age and Early Iron Age (Reinders, 2016a, p. 20; Agnousiotis & Wiersma, 2016, 166).

This part of Greece belonged to the northern margins of the Mycenaean civilization, which existed during the Late Bronze Age. Halos was located near important trade and travel routes, both on land and on sea. The land routes ran from the north to the south of the mainland, and the maritime routes ran along the Pagasetic Gulf. Therefore, during the Late Bronze Age Collapse, Halos was affected by the abandonment of the large Mycenaean settlements (Panagiotopoulou et al. 2016, 212).

3.1.2 Voulokaliva cemetery

Not far from the Voulokaliva Bronze Age site was a cemetery, in use from Bronze Age until the Archaic Period (Agnousiotis & Wiersma, 2016, p. 164). The Voulokaliva cemetery was discovered during excavations starting in 1998, in preparation of the expansion of the National Road from Athens to Salonica (Agnousiotis & Wiersma, 2016, p. 164; Malakassioti, 2006, p.122). Altogehter, the cemetery contained 141 graves (Malakassioti, 2006, p. 123). However, only a limited number of them could be confidently dated. These were 22 graves dating to the end of the Bronze Age, 38 dating to the Early Iron Age, and 11 graves were added in the Hellenistic Period, when the cemetery was reused (Tsiouka, 2008, p. 6). Some of the graves form clusters of 2 to 7, but others are singular. The tomb types include pits, cists, burial jars and a circular construction, within which both single and double inhumations were found. The majority of the bodies was buried in (semi-)contracted position, but 6 were buried in extended position (Panagiotopoulou et al., 2016, p. 214).

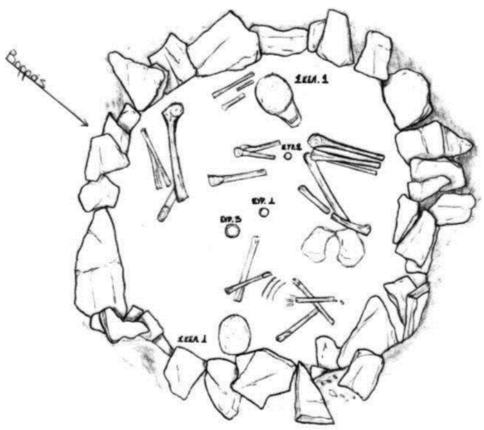

Figure 4: Grave 8 from the Voulokaliva cemetery. Protogeometric. Vaulted structure made out of flat stones, pebbles and earth. Contained two skeletons facing each other in semi-contracted positions (Tsiouka, 2008, p. 54). Image from Tsiouka, 2008, p. 238.

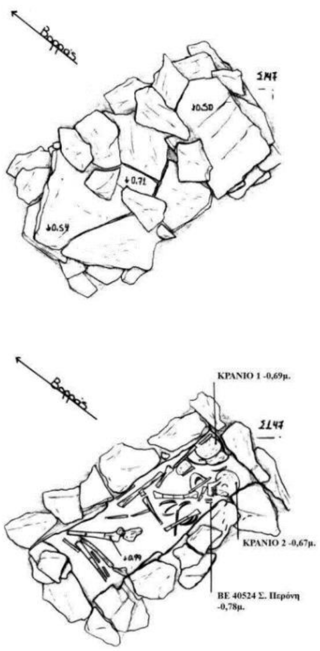

Figure 3: Grave 11 from the Voulokaliva cemetery. Protogeometric. Covering (upper image) and case (lower image) of limestone slabs. It contained two skeletons: one in contracted and one in extended position (Tsiouka, 2008, p. 27). Image from Tsiouka, 2008, p. 2.

Panagiotopoulou et al. (2016) took 32 Early Iron Age (1050-900 BCE) bone collagen samples from individuals from the Voulokaliva cemetery for stable isotope analysis. This yielded 26 usable results. The other 6 samples were excluded because they either did not yield any collagen at all, or they did not fall within the acceptable range of the quality parameters (Panagiotopoulou et al., 2016, p. 215). The breakdown of the sexes of the individuals can be seen in Table 2. This table also shows the number of non-adults (individuals below 18 years of age), as their sex cannot accurately be determined.

Voulokaliva cemetery	M/M?	F/F?	I	Non-adult
n	7	5	5	9

Table 2: The number of individuals (n) from Voulokaliva cemetery, with the number of adult male/probable male individuals (M/M?), the number of adult female/probable female individuals (F/F?), adult individuals of indeterminate sex (I) and non-adults (non-adult) (Panagiotopoulou et al., 2016, p. 215).

3.1.3 Kephalosi cemetery

Also discoverd during the same rescue excavations in preparation of the road expansion was the Early Iron Age (1100-900 BCE) cemetery of Kephalosi. This cemetery was located within the city walls of the later Hellenistic settlement of New Halos (Panagiotopoulou et al., 2016, p. 213). Next to it were the remains of a settlement, also dated to the Early Iron Age. These consist of an apsidal building and three walls that were probably part of other buildings. It is quite likely that the Kephalosi cemetery belonged to this settlement. The Voulokaliva cemetery, which is located 1 km to the north, might have belonged to the Kephalosi settlement as well (Karouzou, 2017, p. 348).

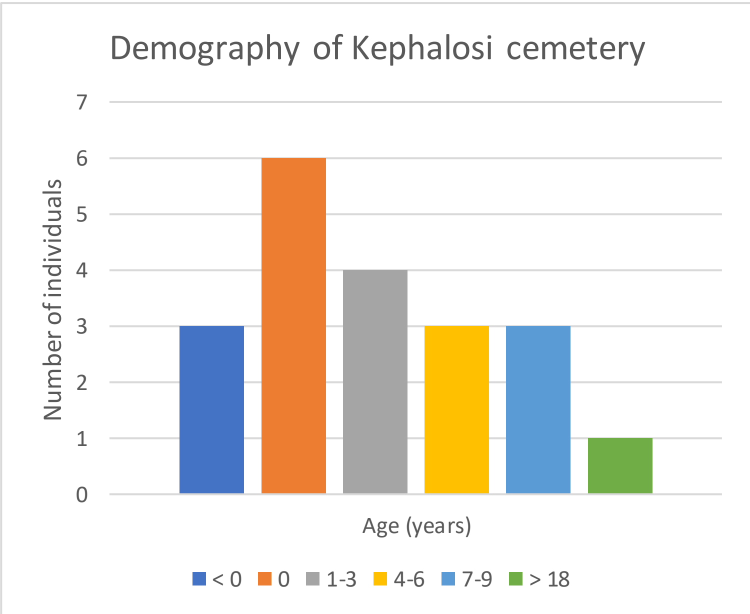

Figure 5: A bar graph showing the age in years of the individuals from Kephalosi cemetery who yielded a valid collagen sample.

What makes it more likely that both cemeteries could be linked to the same settlement, is the fact that all but one inhumations from the Kephalosi cemetery were children, all under the age of 10, including three foetuses (Panagiotopoulou et al., 2016, p. 213-215). Kephalosi might therefore have been an intramural cemetery exclusively used for burying children.

The cemetery contained 22 graves in total, all of which were simple cist graves with singular burials. The individuals were buried in either (semi-)contracted or extended position. Panagiotopoulou et al. (2016) used all 22 individuals for stable isotope analysis. This resulted in 20 usable bone collagen samples, as 2 of them did not yield collagen (Panagiotopoulou et al., 2016, p. 213). No sex could be determined, since 21 individuals from the cemetery were of non-adults. The only adult sampled was of indeterminate sex (Panagiotopoulou et al., 2016, p. 215). For the 20 individuals that yielded valid collagen samples, the demographic breakdown between age groups is shown in Figure 5.

3.2 Hellenistic New Halos

3.2.1 Classical and Hellenistic Period

In the Classical Period, a town named Halos existed very close to the coast of the Pagasetic Gulf. Around 346 BCE, a Macedonian army besieged the city. The sieged was stopped by an Athenian embassy, after which a peace treaty between Athens and Macedonia was established. Unfortunately for the citizens of Halos, their town was excluded from the treaty. The people of Halos were expelled from the city, and the city itself was destroyed (Sparkes, 2017, p. 41). The territory now belonged to the city of Pharsalos, which was allied with the Macedonians. Classical Halos counted around 2.000 inhabitants before its destruction (Halos/University of Groningen, 2014c).

In Hellenistic times, around 302 BCE, a new city was established roughly 2 km inward from the location of the Classical town of Halos. This city is referred to as 'New Halos'. It had an upper and a lower town and was fortified with a city wall. The upper city contained the Acropolis with public buildings, while the lower part was used for housing (Figure 6). The houses numbered around 1.400 and they were laid out in a grid along straight streets. New Halos had an estimated population of around 9.000 inhabitants (Dijkstra et al., 2017, p. 151-152).

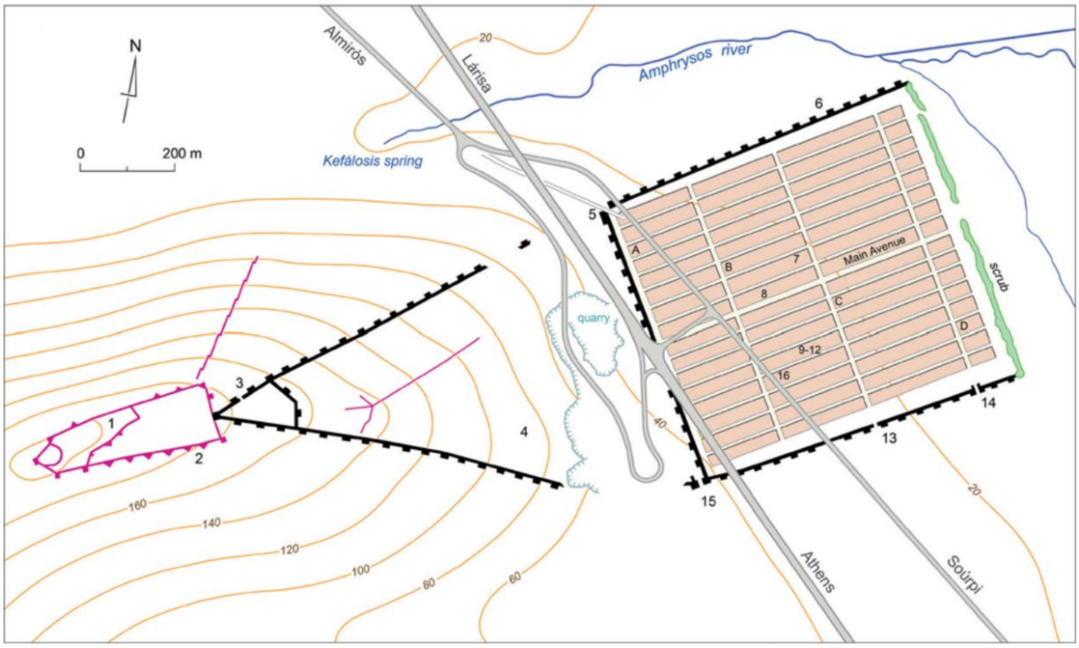

Figure 6: The layout of New Halos with the upper town west from the modern road and the lower town with houses east from the modern road. The structures in purple to the west date to Byzantine times (Dijkstra et al., 2017, p. 152).

As organized and expansive as New Halos was, it was only briefly inhabited, from 302 BCE until 265 BCE. It is likely that the city was abandoned after an earthquake, as the Almiros area is susceptible to seismic activity. Most of the city fell out of use, but there is proof that the Southeast Gate (number 13 in Figure 6) was converted into a farmhouse and remained occupied until 220 BCE (Dijkstra et al., 2017, p. 154).

3.2.2 Kaloerika cemetery

During excavations in 1984, 1990 and 1991, a cemetery belonging to New Halos was investigated. This cemetery is called Kaloerika. Its use coincides with the occupation of New Halos. All graves in Kaloerika were cist graves lined with limestone slabs, and all contained one to three individuals in extended position (Sparkes, 2017, p. 53-54).

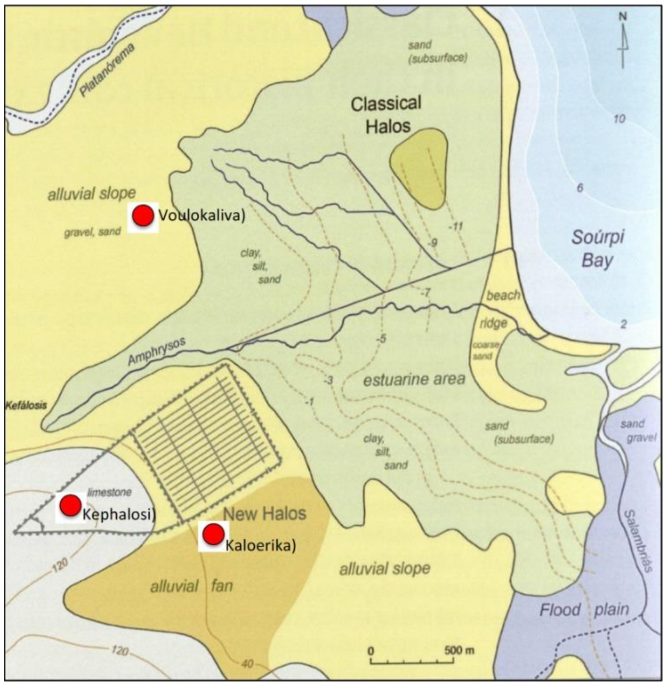

Figure 7: The locations of the cemeteries of Voulokaliva, Kephalosi and Kaloerika in relation to each other and the landscape of the Almiros area (Sparkes, 2017, p. 53).

Sparkes (2017) used 142 skeletal samples for stable isotope analysis. These samples included both bones and teeth. Of the bone collagen samples, 61 passed the quality tests to be used in stable isotope analysis (Sparkes, 2017, p. 91).

In Table 3, the sampled individuals from Kaloerika cemetery are grouped according to their biological sex in the case of adults, or grouped under 'non-adult' when the sampled individual was below the age of 18 (Sparkes, 2017, p. 131).

Kaloerika cemetery	M/M?	F/F?	I	Non-adult
n	16	11	30	4

Table 3: The number of individuals (n) from Kaloerika cemetery, with the number of adult male/probable male individuals (M/M?), the number of adult female/probable female individuals (F/F?), adult individuals of indetermin ate sex (I) and non-adults (non-adult) (Sparkes, 2017, p. 131).

3.3 Early Iron Age Makrigialos

3.3.1 Neolithic Period to Bronze Age

Makrigialos is located in the region of Pieria, in Central Macedonia, on the east coast of mainland modern-day Greece. It is situated roughly 140 km to the north of Halos (see Figure 1). Pieria is separated from Thessaly by Mount Olympus. Makrigialos is located on a hilly terrain. Two kilometers to the east of Makrigialos lies the Thermaic Gulf, and roughly fifteen kilometers to the west lie the Pieria mountains (Pappa & Besios, 1999, p. 179). Because of alluviation and fluctuating sea levels, the coastline of the Thermaic Gulf has changed drastically. It is therefore possible that sites in the Makrigialos area that were directly on the coast, have been eroded by the sea (Triantaphyllou, 1999, p. 42-44).

The Makrigialos area was already inhabited in the Late Neolithic Period. At that time, a flat, extensive site (as opposed to a toumba-type site) existed on two sides of a hill (Pappa & Besios, 1999, p. 177). The earliest activity at the site was around 5450 BCE (Maniatis & Pappa, 2020, p. 479). In total, the Neolithic settlement covered an area of 50 ha (Pappa & Besios, 1999, 179). At that time, Makrigialos must have already had extensive contact with Thessaly to the south, because "Classical Dimini" pottery was found at Neolithic Makrigialos. This type of pottery comes from the site of Dimini, which like Halos was situated along the Pagasetic Gulf (Vlachos, 2002, p. 119-120).

In the Late Bronze Age, the settlement of Pydna was first occupied. Pydna is located near the modern-day village of Makrigialos. It remained constantly inhabited until early Christian times (Douitsi, 2017, p. 4). Pydna would become an important harbor city within the kingdom of Macedonia (Hatzopoulos & Paschidis, 2004, p. 806). This will be discussed further in subchapter 3.4.

3.3.2 Early Iron Age cemetery of Makrigialos

In 1989 and 1990, rescue excavations at Makrigialos revealed a cemetery associated with Early Iron Age Pydna. During the excavations, 54 graves were found. Similarly to Voulokaliva cemetery, the deceased were buried in a variety of grave types. These include cist graves, pit graves, small wooden coffins, and two chamber tombs. Most bodies were laid out in extended position (Triantaphyllou, 1998, p. 354-355).

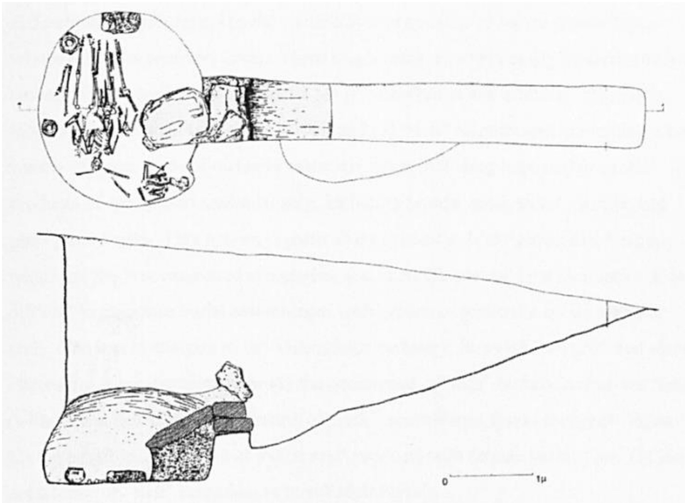

Figure 8: Plan of one of the chamber tombs from the EIA Makrigialos cemetery (Triantaphyllou, 1999, p. 66). For a picture of the same chamber tomb, see Figure 9.

Within the cemetery, there were very few infants and young children, while the number of young women was high. The lack of infants is most likely due to poor preservation, and the high frequency of young women could be explained by a higher mortality rate due to health complications during and after pregnancy (Triantaphyllou, 1998, p. 357).

Triantaphyllou (1999) used the skeletal assemblage from Early Iron Age Makrigialos for stable isotope analysis. A total of 14 samples fell within acceptable quality parameters (Triantaphyllou, 1999, p. 240). In Table 4, the individuals are grouped according to biological sex. The one non-adult in this group had an estimated age-at-death of 8 years old (Triantaphyllou, 1998, 358).

Early Iron Age Makrigialos cemetery	M/M?	F/F?	I	Non-adult
n	4	9	0	1

Table 4: The number of individuals (n) from EIA Makrigialos cemetery, with the number of adult male/probable male individuals (M/M?), the number of adult female/probable female individuals (F/F?), adult individuals of indeterminate sex (I) and non-adults (non-adult).

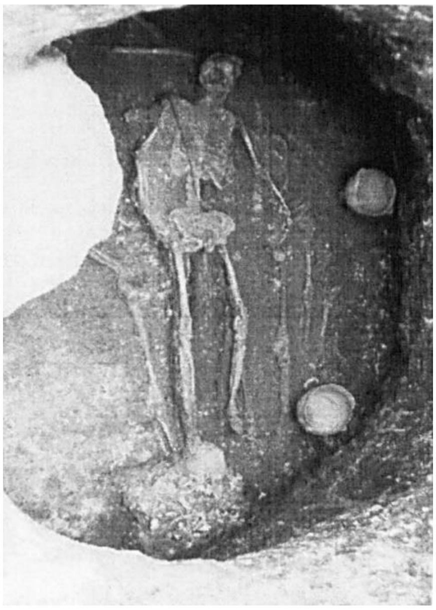

Figure 9: Picture of one of the chamber tombs from EIA Makrigialos cemetery (Triantaphyllou, 1999, p. 63). For a plan of the same chamber tomb, see Figure 8.

Figure 10: Picture of one of the cist graves from EIA Makrigialos cemetery (Triantaphyllou, 1999, p. 65).

3.4 Classical Makrigialos

3.4.1 Classical and Hellenistic Period

Similarly to Halos, the Makrigialos area was located along essential roads that ran from the north to the south. During the Classical Period, the city of Pydna in the Makrigialos area became the most important port of the kingdom of Macedonia (Gatzolis & Psoma, 2021, p. 134; Tsokas et al., 1997, p. 124). At that time, the greater territory of the polis might have covered around 200 km^2. In 410 BCE, Pydna rebelled against Macedonian king Archelaus and successfully seceded from the kingdom. However, after a long siege the city was recaptured. At that point, the population of Pydna was moved roughly 4 km inland. The abandoned city was reoccupied very quickly in the fourth century BCE. While a handful of power struggles took place over Pydna's territory, the Macedonian king Philip II successfully besieged and recaptured Pydna for the last time in 357 BCE. After that, the city remained under Macedonian rule throughout the following Hellenistic period (Gatzolis & Psoma, 2021, p. 134; Hatzopoulos & Paschidis, 2004, p. 806).

3.4.2 Classical cemetery of Makrigialos

Because the cemeteries in the Makrigialos area are associated with Pydna and Pydna was abandoned for a brief time, the graves there stop around the end of the fifth century BCE, and reappear again with the reoccupation of the city in the early fourth century BCE (Gatzolis & Psoma, 2021, p. 134).

Triantaphyllou (1999) used skeletal material from twelve individuals dating between 500 and 300 BCE for stable isotope analysis (Triantaphyllou, 1999, p. 240). Unfortunately, no information on burial context, estimated sex or estimated age-at-death was available. Only data on stable nitrogen and carbon isotopes for the twelve individuals was accessible.

3.5 Methods

3.5.1 Sample selection

This thesis will use the data on stable carbon and nitrogen isotopes from the research described above: Panagiotopoulou et al. (2016) for Early Iron Age Halos, Sparkes (2017) for New Halos, and Triantaphyllou (1999) for Makrigialos.

The data from that research was accessed and selected through IsoArcH. As described in Chapter 1, IsoArcH is an open database for isotopic data on skeletal archaeological remains (Salesse et al., 2018, p. 2-3). This thesis is focused on the change between the Early Iron Age and the Classical/Early Hellenistic Period in Greece, in order to examine possible explanations in regards to diet and climate for the regeneration of complex societies following the Late Bronze Age Collapse. Therefore, the data from IsoArcH was first filtered to only show Greece. Next, the remaining entries were filtered to show only samples dated between 1100 and 700 BCE, and samples dating between 500 and 200 BCE. After that, the two lists were compared. At Halos and Makrigialos, both time periods were present. Furthermore, the two were comparable in terms of location (both are located on the east coast of the Greek mainland, and along the roads leading from north to south). For those reasons, the samples as described in the previous subchapters was selected. The full dataset is supplied in Appendix A.

3.5.2 Collagen extraction

In all research described above, stable carbon and nitrogen isotopes were obtained from bone collagen. This has to be done in a laboratory. Each researcher has used a slightly different approach. Their individual laboratory procedures are cited in Appendix B.

In general, isotopic data is obtained from bone collagen by adhering to the following steps. First, dirt has to be washed off the bone. Next, the bone has to be demineralized. In order to do so, usually a small chunk of bone between 1 g and 3 g is placed into a hydrochloric acid solution of between 1-5%. To remove any remaining organic matter from the environment, the sample can be soaked in sodium hydroxide. Afterward, the sample should consist of only collagen, and gets freeze-dried. To make sure that the sample really is collagen, quality indicators exist. One such indicator is the carbon-to-nitrogen ratio. This C/N ratio should fall between 2,9 and 3,6. Other indicators are the %C and %N in the sample. The %C should be around 45%, while the %N should be around 15% (Richards, 2015, p. 16). This is measured within a mass spectrometer, which also provides the $\delta^{13}C$ and $\delta^{15}N$ values of each sample (Katzenberg, 2008, p. 418). This is done by first converting the sample into a gaseous form by heating it up in a furnace, before letting the gasses run through the mass spectrometer (Katzenberg, 2008, p. 420).

3.5.3 Methods for data analysis

In order to glean information from the isotopic data obtained through IsoArcH, statistical analysis must be done. This will be done using IBM SPSS statistics 29. The first step toward this, is to determine whether all data is normally distributed. If this were to be the case, parametric tests could be used to determine significant differences between the data sets (Fletcher & Lock, 1991, p. 74). By running a one-sample Kolmogorov-Smirnov test in SPSS, it was determined that most, but not all data sets were normally distributed. Therefore, only non-parametric tests will be used to analyze the isotopic data. In Appendix C, the results of the Kolmogorov-Smirnov test are provided.

When only two data sets at a time are being analyzed during a comparison between two time periods or between two sites, a Mann-Whitney U test can be used to determine significant differences between the data sets (Fletcher & Lock, 1991, p. 88). When more than one data set at a time is analyzed during a comparison between multiple sites, a Kruskal-Wallis H test must be used instead (Corder & Foreman, 2009, pp. 99–100).

Chapter 4: Results

In this chapter, the isotopic carbon and nitrogen data from all five assemblages (Voulokaliva, Kephalosi, Kaloerika, Early Iron Age Makrigialos and Classical Makrigialos) will be analyzed. First, the mean $\delta^{13}C$ and $\delta^{15}N$ values within the Halos assemblages will be compared to each other. Next, the same will be done for the two Makrigialos sites. Finally, the two locations will be compared to each other. This will first be done broadly, followed by a comparison between the Early Iron Age assemblages and lastly a comparison between the assemblages from later time periods.

4.1 Halos

4.1.1 Voulokaliva

A total of 26 individuals from Voulokaliva cemetery was analyzed. Of this group, 7 were male, 5 were female, 5 were of indeterminate sex and 9 were non-adults. Overall, the group has a mean $\delta^{13}C$ value of -19.081‰ with a standard deviation of 0.791. The mean $\delta^{15}N$ value is 8.412‰ with a standard deviation of 0.850.

4.1.2 Kephalosi

A total of 20 individuals was analyzed from Kephalosi cemetery. No sex estimation could be done for this group, as it was composed entirely of non-adults (with the exception of one individual of indeterminate sex). This group has a mean $\delta^{13}C$ value of -18.910‰ with a standard deviation of 0.603. The mean $\delta^{15}N$ value is 9.705‰ with a standard deviation of 0.908.

4.1.3 Kaloerika

A total of 61 individuals was analyzed from Kaloerika cemetery. Of this group, 16 individuals were male, 11 were female, 30 were of indeterminate sex and 4 were non-adults. This group has a mean $\delta^{13}C$ value of -19.815‰ with a standard deviation of 0.418. The mean $\delta^{15}N$ value is 9.310‰ with a standard deviation of 0.808.

4.1.4 Comparison within Halos

Voulokaliva and Kephalosi date to the same time period. To determine if the two can be grouped together as one assemblage representing Early Iron Age Halos, a Mann-Whitney U test must be performed to detect significant differences in $\delta^{13}C$ and $\delta^{15}N$ values. A difference is considered statistically significant if the p-value is lower than 0.05 ($p < 0.05$). The test shows that there is no statistically significant difference in $\delta^{13}C$ values ($U = 186.000$, $p = 0.100$, $n = 46$). However, it does show a statistically significant difference in $\delta^{15}N$ values ($U = 63.500$, $p < 0.01$, $n = 46$). Therefore, Voulokaliva and Kephalosi will not be grouped together, but treated as separate groups from the same location and time period.

Next, a Kruskal-Wallis H test will be used to determine if there are statistically significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between the three Halos sites (Voulokaliva, Kephalosi and Kaloerika). The test shows a statistically significant difference in $\delta^{13}C$ values ($H(2) = 49.212$, $p < 0.001$, $n = 107$). To determine where this significant difference lies, pairwise comparisons between the sites must be used. The results of the pairwise comparison are shown in Table 5.

	Site comparison	H(2)	p	n
$\delta^{13}C$	Kaloerika – Voulokaliva	-36.023	<0.001	87
	Kaloerika – Kephalosi	-48.769	<0.001	81
	Voulokaliva – Kephalosi	12.746	0.166	46

Table 5: Results of pairwise comparisons from a Kruskal-Wallis H test showing differences in $\delta^{13}C$ values between the Halos sites.

As Table 5 shows, the significant difference in $\delta^{13}C$ values lies both between Kaloerika and Voulokaliva, and Kaloerika and Kephalosi. The mean $\delta^{13}C$ value of Kaloerika is significantly more negative than those of both Voulokaliva and Kephalosi. The Mann-Whitney U test performed before already showed no statistically significant difference in $\delta^{13}C$ values between Voulokaliva and Kephalosi, which the Kruskal-Wallis H test confirms. A boxplot showing the results from $\delta^{13}C$ comparison between the Halos sites is presented in Figure 11. As the boxplot shows, the mean $\delta^{13}C$ value of Kaloerika is the lowest, and that of Kephalosi is the highest. Voulokaliva has the widest range of $\delta^{13}C$ values, with a minimum value of -20.0‰ and a maximum of -17.0‰.

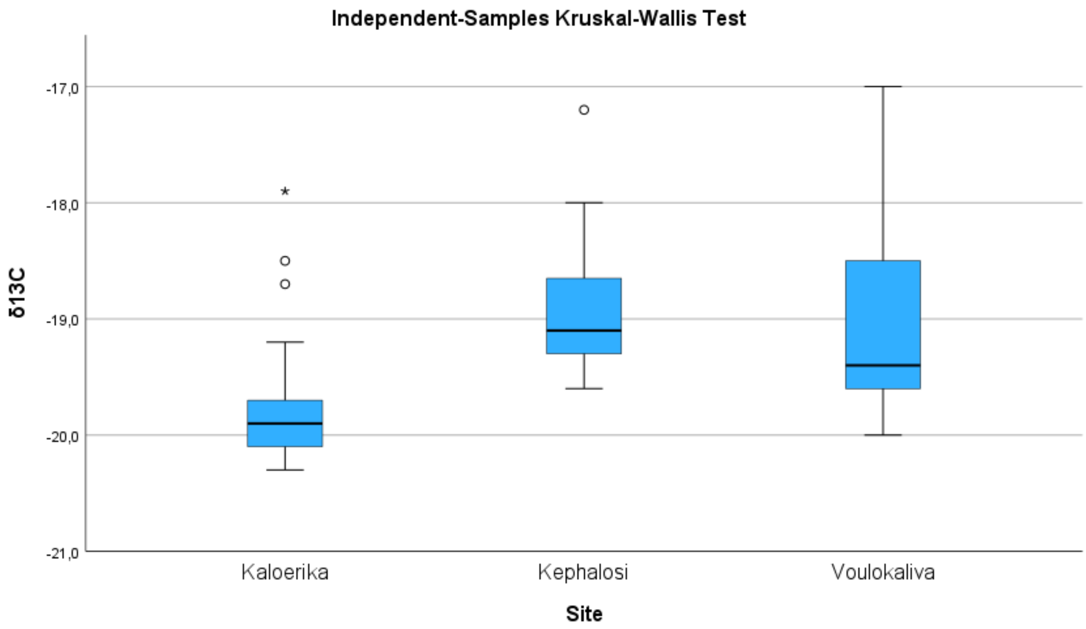

Figure 11: A boxplot showing the δ^{13}C values in ‰ of all individuals from all three Halos sites.

The Kruskal-Wallis H test also shows a statistically significant difference between the δ^{15}N values of the three Halos sites (H(2) = 25.802, p < 0.001 , n = 107). The results of the pairwise comparisons of this test are shown in Table 6.

	Site comparison	H(2)	p	n
δ^{15}N	Kaloerika – Voulokaliva	30.812	<0.001	87
	Kaloerika – Kephalosi	-12.253	0.125	81
	Voulokaliva – Kephalosi	43.065	<0.001	46

Table 6: Results of pairwise comparisons from a Kruskal-Wallis H test showing differences in δ^{15}N values between the Halos sites.

Table 6 shows that the statistically significant difference in δ^{15}N values lies between Kaloerika and Voulokaliva, and between Voulokaliva and Kephalosi. Again, the Mann-Whitney U test performed earlier already showed that there was a significant difference in δ^{15}N values between Voulokaliva and Kephalosi, which the Kruskal-Wallis H test confirms. A boxplot of the δ^{15}N values is presented in Figure 12. It shows that the mean of the δ^{15}N values in Voulokaliva is lower than that of Kaloerika and Kephalosi. Kaloerika has the largest range of δ^{15}N values if outliers are ignored, with a maximum value of 11.1‰ and a minimum of 7.3‰.

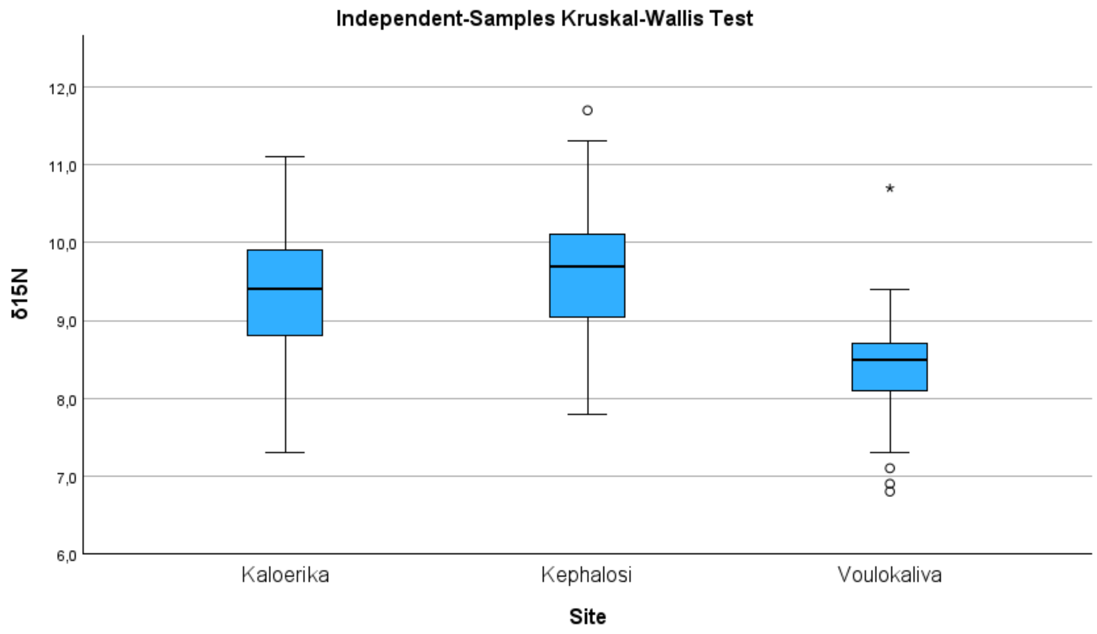

Figure 12: A boxplot showing the $\delta^{15}N$ values in ‰ of all individuals from all three Halos sites.

4.2 Makrigialos

4.2.1 Early Iron Age Makrigialos

A total of 14 individuals was analyzed from the Early Iron Age cemetery of Makrigialos. Of this group, 4 individuals were male, 9 were female and 1 was a non-adult. In total, this group has a mean $\delta^{13}C$ value of -18.893‰ with a standard deviation of 0.492. The mean $\delta^{15}N$ value is 7.100‰ with a standard deviation of 0.596.

4.2.2 Classical Makrigialos

A total of 12 individuals was analyzed from the Classical cemetery of Makrigialos. No sex has been estimated. This group has a mean $\delta^{13}C$ value of -19.025‰ with a standard deviation of 0.273. The mean $\delta^{15}N$ value is 8,225‰ with a standard deviation of 0.832.

4.2.3 Comparison within Makrigialos

In order to determine whether there are statistically significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between the Early Iron Age assemblage and the Classical assemblage, a Mann-Whitney U test will be performed. The test shows that there is no significant difference in $\delta^{13}C$ values ($U = 89.500$, $p = 0.781$, $n = 26$). A boxplot showing a comparison between the $\delta^{13}C$ values of Early Iron Age and Classical Makrigialos is presented in Figure 13. As shown, the mean values of both sites are comparable. If outliers are ignored, Early Iron Age Makrigialos has a wider $\delta^{13}C$ range with a maximum value of -18.4‰ and a minimum value of -19.5‰.

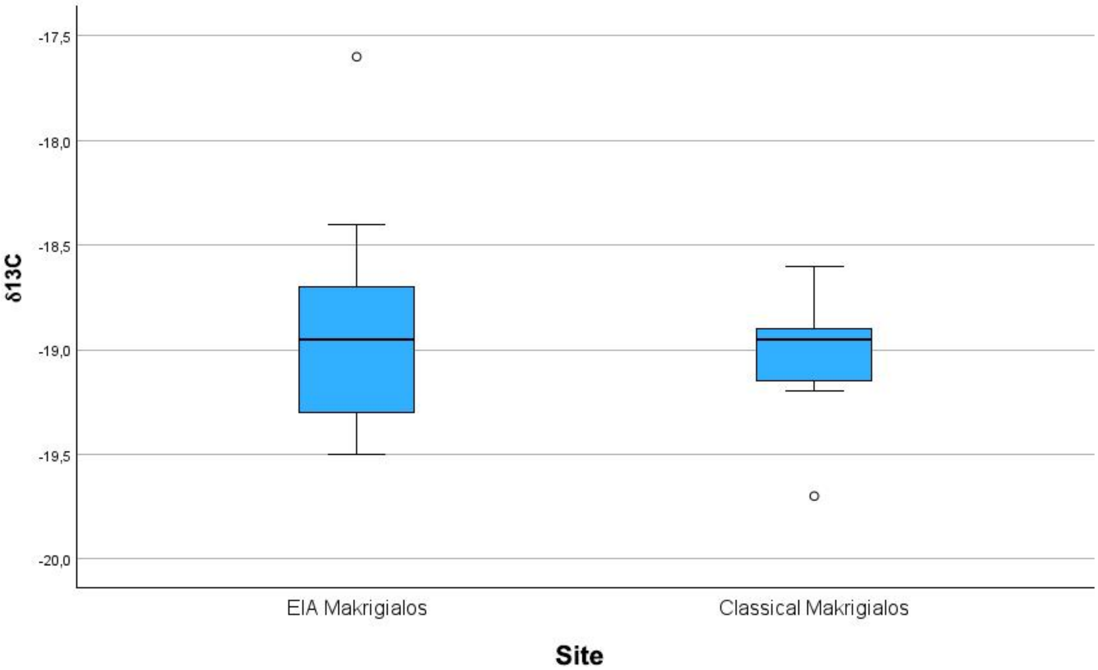

Figure 13: A boxplot showing the $\delta^{13}C$ values in ‰ of all individuals from both Makrigialos sites.

The Mann-Whitney U test shows that there is a statistically significant difference in $\delta^{15}N$ values between the Early Iron Age assemblage and the Classical assemblage ($U = 27.000$, $p = 0.003$, $n = 26$). A boxplot showing a comparison between the $\delta^{15}N$ values of Early Iron Age and Classical Makrigialos is presented in Figure 14. As shown, the Early Iron Age assemblage has a lower mean than the Classical assemblage. The ranges of $\delta^{15}N$ are comparable, but that of Classical Makrigialos is slightly larger with a maximum value of 9.1‰ and a minimum value of 6.7‰.

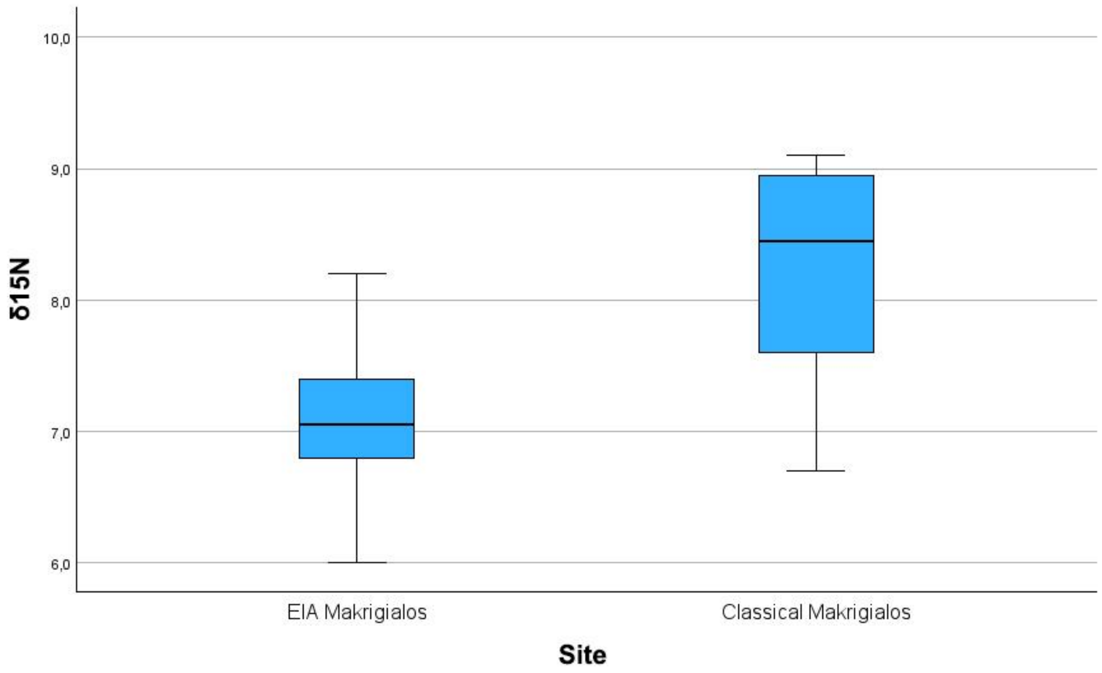

Figure 14: A boxplot showing the $\delta^{15}N$ values in ‰ of all individuals from both Makrigialos sites.

4.3 Comparison between Halos and Makrigialos

4.3.1 Overview of all groups

In Table 7, an overview of the means for each group is provided for both $\delta^{13}C$ and $\delta^{15}N$ values. Early Iron Age Makrigialos has both the highest mean $\delta^{13}C$ value and the lowest mean $\delta^{15}N$ value of all groups. Kaloerika has the lowest mean $\delta^{13}C$ value, and Kephalosi has the highest mean $\delta^{15}N$ value.

			$\delta^{13}C$		$\delta^{15}N$	
		n	Mean (‰)	SD	Mean (‰)	SD
Halos	Voulokaliva	26	-19.081	0.791	8.412	0.850
	Kephalosi	20	-18.910	0.603	9.705	0.908
	Kaloerika	61	-19.815	0.418	9.310	0.808
Makrigialos	Early Iron Age Makrigialos	14	-18.893	0.492	7.100	0.596
	Classical Makrigialos	12	-19.025	0.273	8,225	0.832

Table 7: An overview of all groups, with the number of individuals (n) and the mean $\delta^{13}C$ and $\delta^{15}N$ values with standard deviation (SD). The highest values of both $\delta^{13}C$ and $\delta^{15}N$ are highlighted in green, while the lowest values are highlighted in red.

All $\delta^{13}C$ and $\delta^{15}N$ values for every individual of every group is also displayed in a scatterplot in Figure 15. This visualizes the comparatively low $\delta^{15}N$ values for Makrigialos, as their dots are clustered toward the lower half of the graph. Makrigialos overall also appears to have a tighter range of $\delta^{13}C$ values compared to Halos. With the exception of an outlier, the $\delta^{13}C$ values of Makrigialos are clustered around -19,0‰, while those of the Halos sites are more spread out.

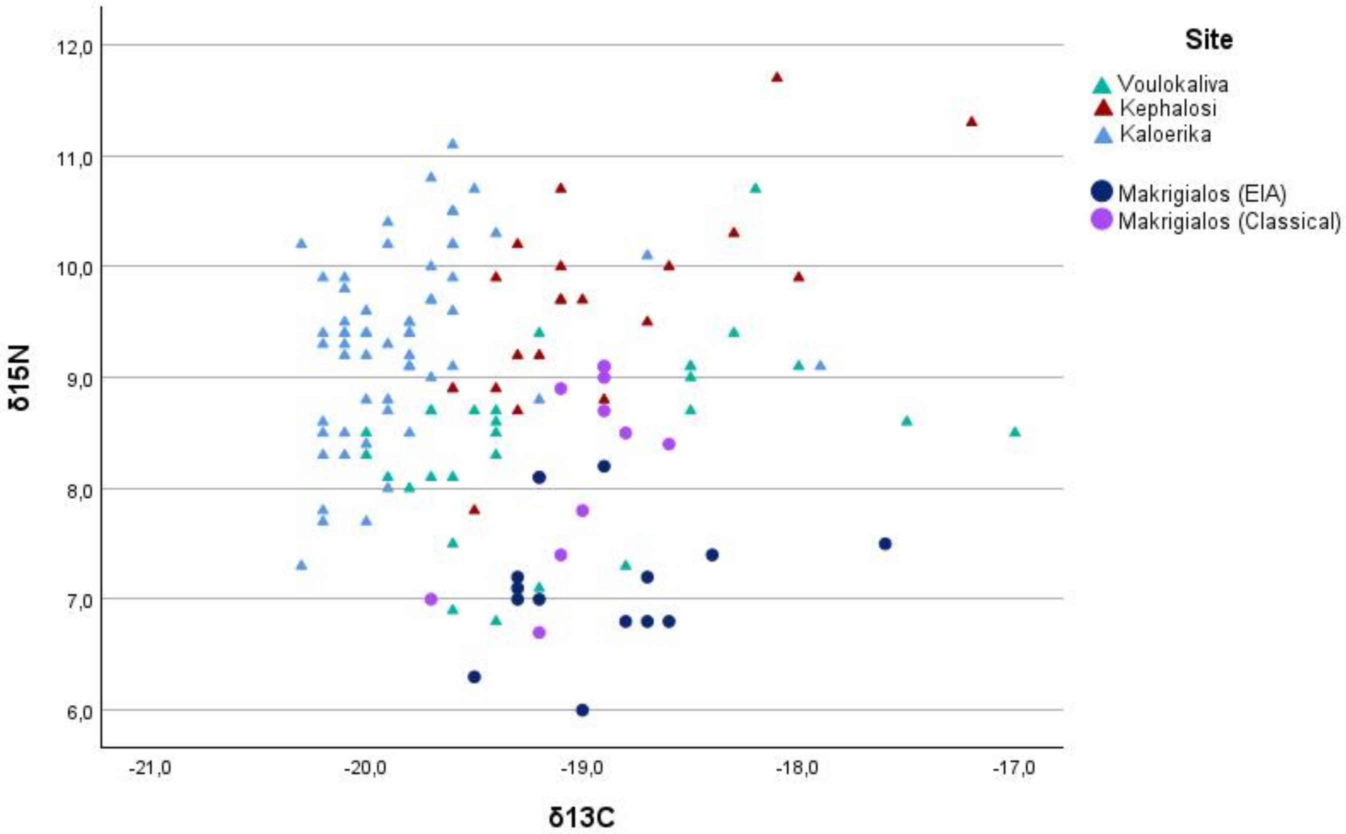

Figure 15: A scatterplot of the $\delta^{13}C$ and $\delta^{15}N$ values of all individuals of all groups in ‰. Every point represents one individual. Individuals from Halos are represented with a triangle, while individuals from Makrigialos are represented with a circle. The points are colored by site.

4.3.2 Comparison between Early Iron Age sites

In order to determine whether there are statistically significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between the Early Iron Age assemblages, a Kruskal-Wallis H test will be performed on the assemblages from Voulokaliva, Kephalosi and Early Iron Age Makrigialos. As previous tests have already shown the differences between Voulokaliva and Kephalosi, the focus here will be on comparing the Early Iron Age Halos sites to the Early Iron Age Makrigialos group. The test shows there is no significant difference in $\delta^{13}C$ values between the three sites ($H(2) = 3.802$, $p = 0.149$, $n = 60$). A pairwise comparison between only Makrigialos and the Halos sites shows that the smallest difference in mean $\delta^{13}C$ value lies between Early Iron Age Makrigialos and Kephalosi (Table 8).

	Site comparison	H(2)	p	n
$\delta^{13}C$	Voulokaliva – EIA Makrigialos	9,783	0.090	40
	Kephalosi – EIA Makrigialos	-1,746	0.774	34

Table 8: Results of pairwise comparisons from a Kruskal-Wallis H test showing differences in $\delta^{13}C$ values between the Early Iron Age Halos sites and Early Iron Age Makrigialos.

A boxplot showing a comparison between the $\delta^{13}C$ values of all Early Iron Age sites is presented in Figure 16. As shown, the mean values of all sites are comparable, but Voulokaliva has a much larger range than the other two sites.

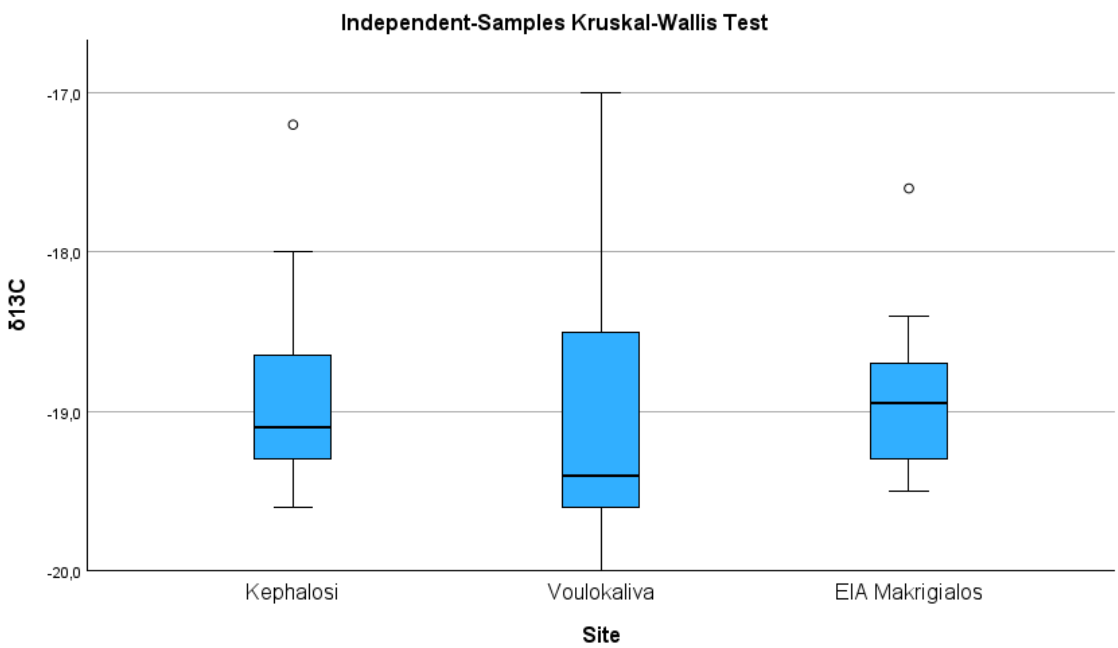

Figure 16: A boxplot showing the $\delta^{13}C$ values in ‰ of all individuals from both all three Early Iron Age sites.

The Kruskal-Wallis H test shows there is a statistically significant difference in $\delta^{15}N$ values between the Early Iron Age assemblages ($H(2) = 37.259$, $p < 0.001$, $n = 60$). A pairwise comparison between only Makrigialos and the Halos sites shows that the significant difference lies both between Early Iron Age Makrigialos and Voulokaliva, and Early Iron Age Makrigialos and Kephalosi. The biggest difference in $\delta^{15}N$ values lies between Makrigialos and Kephalosi (Table 9).

	Site comparison	H(2)	p	n
δ15N	Voulokaliva – EIA Makrigialos	-18.014	0.002	40
	Kephalosi – EIA Makrigialos	36.796	< 0.001	34

Table 9: Results of pairwise comparisons from a Kruskal-Wallis H test showing differences in $\delta^{15}N$ values between the Early Iron Age Halos sites and Early Iron Age Makrigialos.

A boxplot showing a comparison between the $\delta^{15}N$ values of all Early Iron Age sites is presented in Figure 18. As shown, the $\delta^{15}N$ values of Kephalosi are much higher than those of Voulokaliva, which in turn are higher than those of Makrigialos.

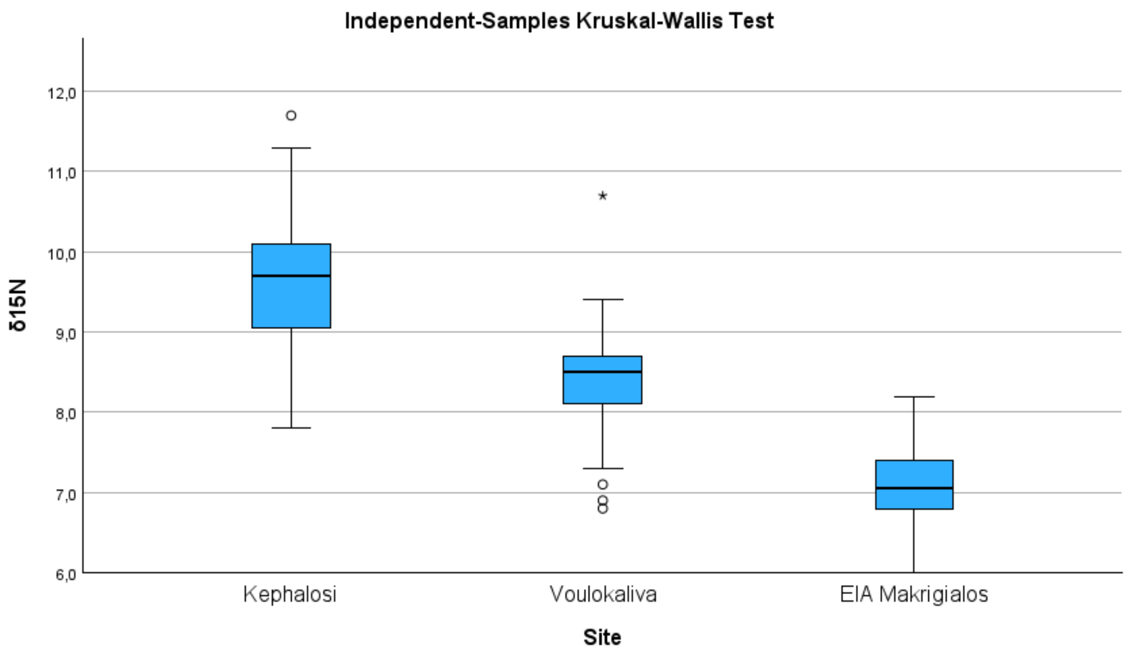

Figure 17: A boxplot showing the $\delta^{15}N$ values in ‰ of all individuals from all Early Iron Age sites.

4.3.3 Comparison between the sites from later time periods

In order to determine whether there are statistically significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between the assemblages from the Classical and Hellenistic Period, a Mann-Whitney U test will be performed on the assemblages from Kaloerika and Classical Makrigialos. The test shows that there is a statistically significant difference in $\delta^{13}C$ values ($U = 51.000$, $p < 0.001$, $n = 73$). As the boxplot in Figure 18 shows, the mean $\delta^{13}C$ value of Classical Makrigialos is much higher than that of Kaloerika.

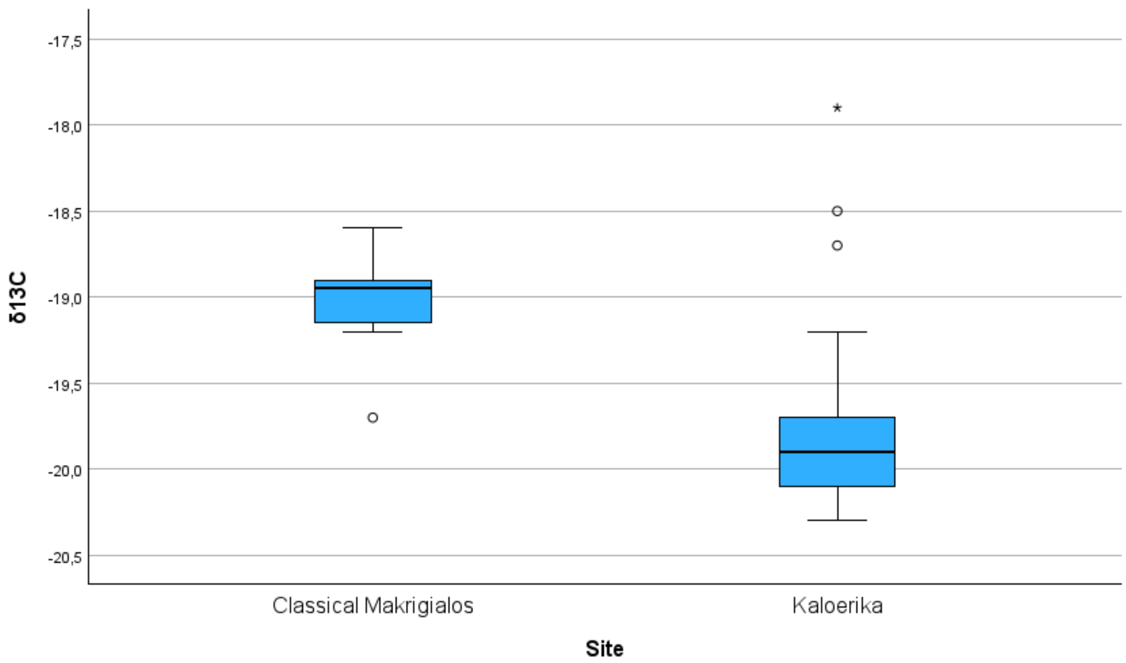

Figure 18: A boxplot showing the $\delta^{13}C$ values in ‰ of all individuals from the Classical and Hellenistic assemblages.

Additionally, the test shows that there is a statistically significant difference in $\delta^{15}N$ values ($U = 613.500$, $p < 0.001$, $n = 73$). As the boxplot in Figure 19 shows, the mean $\delta^{15}N$ value of Kaloerika is higher than that of Classical Makrigialos. Kaloerika also has a larger spread of values.

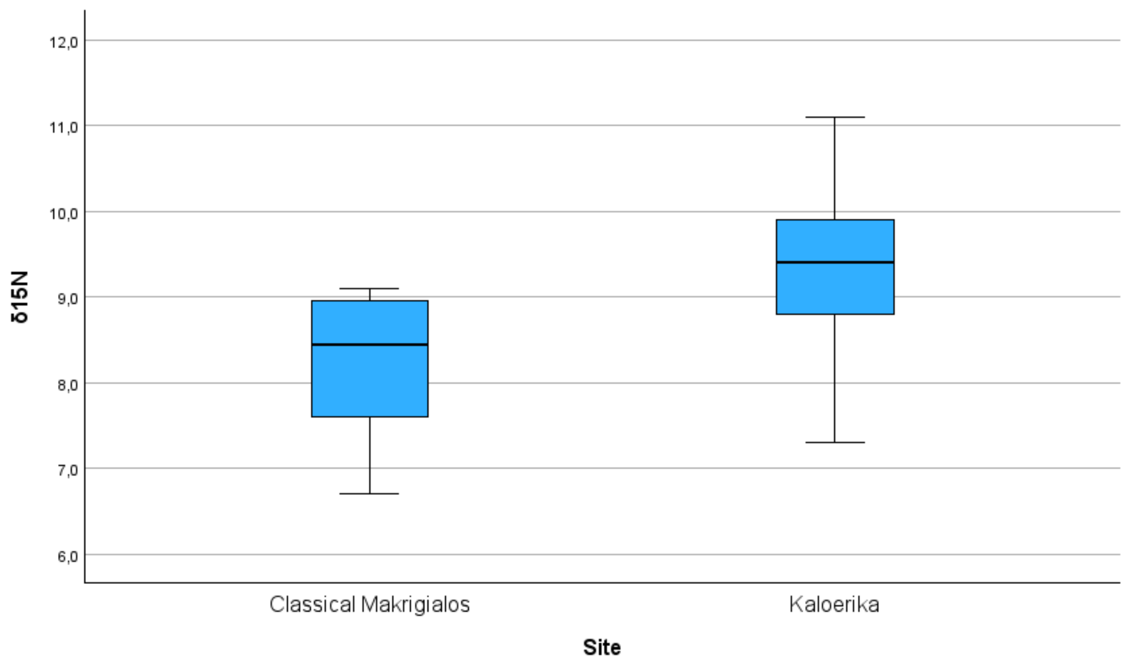

Figure 19: A boxplot showing the $\delta^{15}N$ values in ‰ of all individuals from the Classical and Hellenistic assemblages.

4.4 Summary of the results

The stable carbon and nitrogen isotopic data has been analyzed within and between both locations (Halos and Makrigialos), and within and between both time periods (Early Iron Age and later). First, a comparison of $\delta^{13}C$ values within Halos showed that the mean value of Kaloerika is significantly lower than those of both Voulokaliva and Kephalosi. A comparison of the $\delta^{15}N$ values showed that the mean of Voulokaliva is significantly lower than those of both Kaloerika and Kephalosi.

Next, a comparison of $\delta^{13}C$ values within Makrigialos showed that there was no significant difference between the Early Iron Age and the Classical assemblages. There was however a significant difference in $\delta^{15}N$ values, as the Early Iron Age assemblage has a significantly lower mean than the Classical assemblage.

A broad comparison between all five sites showed that Makrigialos has an overall lower mean $\delta^{15}N$ value than the Halos assemblages. In addition, the range of $\delta^{13}C$ values is much tighter for Makrigialos as compared to Halos.

Within all three Early Iron Age sites, there was shown to be no significant difference in $\delta^{13}C$ values. There was however a statistically significant difference in $\delta^{15}N$ values, with the value of Makrigialos being significantly lower than those of both Halos assemblages.

Finally, a comparison between the two sites from later time periods revealed that there was a statistically significant difference in $\delta^{13}C$ values, with the mean value of Classical Makrigialos being significantly higher than that of Hellenistic Kaloerika. There was also a significant difference in $\delta^{15}N$ values, with the mean value of Kaloerika being significantly higher than that of Classical Makrigialos.

Chapter 5: Discussion

In this chapter, the results obtained in Chapter 4 will be discussed, interpreted and placed within the context of changes in diet from the Early Iron Age into later periods. First, differences in diet among the sites from Halos will be discussed, followed by the same approach for the two Makrigialos sites. Then, differences in diet between the two locations will be discussed. Throughout the interpretation of the data, previous work by other researchers on all sites will be used to provide a more complete image.

5.1 Halos

5.1.1 Early Iron Age Halos

For the two Early Iron Age sites from Halos, the first important consideration that must be made before interpretation of the data can begin is the demography of the individuals from Kephalosi cemetery. Of the twenty individuals analyzed, only one was an adult. Moreover, three individuals were foetuses and another ten individuals had an age between 1 and 3 years. That means that of the twenty individuals sampled, over half were 3 years old or younger. Foetuses do not reflect their own diet, as they do not have one. Instead, they reflect the diet of their mother. This is also the case for infants up to around the age of 2, as they are fully to highly dependent on breastmilk. However, the trophic level effect as discussed in Chapter 2, causes the $\delta^{15}N$ value in the tissue of foetuses and infants to lie an average of 3‰ above that of their mother.

Of the twenty-six Voulokaliva individuals analyzed, nine were non-adults, only two of which were infants. It is worth noting that one of those two infants is visible as the high outlier in the boxplot of Figure 12 in Chapter 4, with a $\delta^{15}N$ value of 10.7‰. With this demographic difference in mind, it is understandable that the mean $\delta^{15}N$ value for the individuals from Kephalosi is significantly higher than that of Voulokaliva (respectively 9.705‰ and 8.412‰). It is therefore still possible that the Kephalosi and Voulokaliva cemeteries were used by inhabitants of the same settlement, as the difference in $\delta^{15}N$ values does not necessarily reflect a difference in diet of the adult population in this case.

The notion that Kephalosi and Voulokaliva belong to the same settlement is further supported by the fact that the mean $\delta^{13}C$ values are not significantly different. The mean $\delta^{13}C$ value is -19.081‰ for Voulokaliva, and -18.910‰ for Kephalosi. Since these values lie close together, this suggests that the diet of the people associated with both sites was similar. C_3 plants have a $\delta^{13}C$ value between -20‰ to -35‰. C_4 plants have a $\delta^{13}C$ value between -9‰ and -14‰. Therefore, the mean carbon isotope ratios for the Early Iron Age cemeteries of Halos fall just above the upper limit of the range of C_3 plants. Bearing in mind that fractionation of $\delta^{13}C$ from dietary protein to collagen is around 5‰, it is plausible that the main source of dietary protein for the population of Early Iron Age Halos consisted of C_3 plants such as cereals like wheat and barley, vegetables and fruit, or animals that were fed on C_3 plants. However, since the human carbon isotope ratios are higher than a range for a purely C_3-based diet, it is possible that some C_4 flora such as millet was also consumed.

In order to assess to what degree animal products played a role in the dietary habits of Early Iron Age Halos, the nitrogen isotope ratios must be examined. For this interpretation to be successful, the $\delta^{15}N$ value of faunal remains must be used to establish the food web. Panagiotopoulou et al. (2016, p. 216) show that the mean nitrogen isotope ratio of contemporary animal remains of herbivores such as goats and cattle is 4.9‰. The nitrogen isotope ratios of Kephalosi will be disregarded for comparison, since these are highly influenced by a trophic level effect from breastmilk consumption. The remains from Voulokaliva however do represent a wider demography. Seeing as the mean $\delta^{15}N$ value from Voulokaliva is 8.412‰ and the trophic level effect causes a fractionation of on average 3‰, it is very likely that the diet of people from Early Iron Age Halos was supplemented with meat and/or other animal products, as the nitrogen isotope ratio in humans lies approximately one level above that of the faunal remains.

A few individuals have an elevated carbon isotope ratio (with a maximum of -17.0‰), which could be explained by a diet supplemented with C_4 plants such as millet, or animals fed on C_4 grasses. Another possible cause for the elevated carbon isotope ratios is marine intake. In order to determine what the most likely cause is, the carbon and nitrogen isotope ratios from faunal remains must be compared to the ones from the humans.

The faunal remains have an average $\delta^{13}C$ value of -19.4‰ (Panagiotopoulou et al., 206, p. 216). This suggests that the herbivores mostly fed on C_3 flora. Elevated carbon isotope ratios in humans is therefore more likely to be caused by direct C_4 plant consumption rather than consumption of C_4-fed animal products.

For individuals with a relatively high $\delta^{13}C$ value but a more average $\delta^{15}N$ value, the elevated carbon isotope ratio is more likely to be caused by regular consumption of C_4 plants. If both the carbon and nitrogen isotope ratios are elevated, marine food intake could be the cause. There are five human individuals across both sites with a $\delta^{13}C$ value of -18.0‰ or higher. Of these five, two also have a comparatively high $\delta^{15}N$ value. This could indicate marine food intake. However, one of the two is an infant, which means the high nitrogen isotope ratio cannot reasonably be interpreted as anything other than breastmilk consumption. This leaves one sample that suggests possible marine food intake. The other individuals (or their mothers) with a $\delta^{13}C$ value of -18.0‰ or higher likely had a regular intake of C_4 plants such as millet.

In summary, the main source of dietary protein for all individuals from Early Iron Age Halos consisted of C_3 plants such as wheat and barley, fruits such as olives, and vegetables. A significant portion of their diet was made up of animal products such as meat or milk. This diet might have been supplemented with consumption of C_4 plants such as millet, but this differed from individual to individual. Signs of marine food intake are practically absent from the isotopic data.

5.1.2 Hellenistic New Halos

The mean nitrogen isotope ratio of all individuals from Kaloerika cemetery is 9.310‰, with a minimum value of 7.3‰ and a maximum value of 11.1‰. The mean $\delta^{15}N$ value of the sampled animals is 5.2‰ (Sparkes, 2017, p. 146). The nitrogen isotope ratios of the humans are approximately one trophic level higher than those of the animals, which suggests that terrestrial animal products played a significant role in the diet of Hellenistic New Halos.

The mean carbon isotope ratio of all individuals from Kaloerika cemetery is -19.815‰. The minimum value is -20.3‰ and the maximum value is -17.9‰. Similarly to the Early Iron Age Halos assemblages, the carbon isotope ratio for Kaloerika suggests a diet based primarily on C_3 plants, or meat and secondary animal products from C_3-fed animals.

However, the mean carbon isotope ratio for the people of New Halos is too high for a diet consisting of only C_3 plants. The relatively higher mean $\delta^{13}C$ value can be interpreted in different ways. A first possible explanation is significant consumption of C_4 plants, or significant consumption of C_4-fed animal products. Faunal remains from New Halos have a mean $\delta^{13}C$ value of -20.8‰ (Sparkes, 2017, p. 146). The diet of herbivores at New Halos was therefore based on C_3 plants. Direct human consumption of C_4 plants is therefore more likely than human consumption of C_4-fed animals. There are three individuals at New Halos with high $\delta^{13}C$ values (between -19.2‰ and -17.9‰), but below average $\delta^{15}N$ values (between 8.8‰ and 9.1‰). These individuals might have regularly consumed C_4 plants such as millet.

A second interpretation is marine food intake. The comparatively long food chain in marine environments as opposed to terrestrial ones would cause an elevated $\delta^{15}N$ value in people who consume marine food regularly. A high carbon isotope ratio caused by consumption of marine food would therefore be paired with a high nitrogen isotope ratio. There are thirteen individuals from Kaloerika cemetery with a $\delta^{15}N$ value above 10.0‰ (all adults, with a range of 10.1‰ to 11.1‰). At New Halos, a large amount of mollusk shells have been found within the city (Sparkes, 2017, p. 149). Considering this, it is likely that these were consumed regularly to at least some extent by a portion of the population, especially those individuals on the higher end of both the $\delta^{15}N$ and the $\delta^{13}C$ spectrum.

Sparkes (2017, p. 149 & 160) argues that non-protein foodstuffs might have been a relatively large contributor to the overall caloric intake of the people of New Halos. This is suggested because the mean carbon isotope ratio of New Halos is quite low compared to that of other sites of which the population also mainly relied on C_3 plants. When proteins form a relatively small portion of the overall caloric intake, it is possible that the carbon isotope ratios of other types of food becomes visible in bone collagen, which would show as a low mean $\delta^{13}C$ value. Lipids such as from olive oil or fatty dairy products, and carbohydrates such as those from cereals could have been eaten in significant quantities. Another contributing form of sustenance could have been wine (Sparkes, 2017, p. 149 & 160).

To summarize, the diet at New Halos was mainly based on consumption of C_3 plants and C_3-fed animal products. Some millet might have supplemented the diet of select individuals, but it is unlikely to have played a large role in the diet of the overall population. Marine resources were plausibly utilized by at least a portion of the population. Mollusk shell finds suggest that marine intake mostly consisted of shellfish. A significant portion of the calories consumed at New Halos could have been from foodstuffs other than protein, such as wine, fats like oil and dairy products, and carbohydrates such as grains.

5.1.3 Early Iron Age Halos compared to Hellenistic New Halos

When comparing the assessed diets of Early Iron Age Halos and Hellenistic New Halos, the following can be said. At both time periods, a diet based on C_3 plants and terrestrial animal products was the standard. However, isotopic data suggests that millet could have been regularly consumed by a significant portion of the Early Iron Age individuals, while there is little evidence of this among the Hellenistic population. As discussed in Chapter 2, C_4 plants such as millet are associated with drier climates. Seeing as a centuries-long draught took place during the Early Iron Age across the Eastern

Mediterranean, it is possible that millet formed an alternative for wheat and barley at this time. When the climate became wetter again, millet consumption went down.

A second difference in subsistence strategies between the two time periods, is the use of marine resources. Isotopic data does not show strong evidence for regular consumption of marine food among the Early Iron Age population. A portion of the Hellenistic population, however, does show a possible marine signal. This is supported by the large quantity of mollusk shell finds at New Halos. A lot of mollusks have to be consumed for shellfish to form a significant contribution to the daily caloric intake of a population. This means that at New Halos, mollusk gathering would have been done on quite a substantial scale. Gathering big quantities of shellfish would have taken a large amount of time, effort and energy per calory in comparison to making use of terrestrial food sources.

In Hellenistic times, political power was more centralized, with kings ruling over large territories. New Halos was an urban center, while Early Iron Age Halos was likely a smaller settlement as was typical for that time. This means that New Halos was more likely to be integrated into a larger trading network than its Early Iron Age equivalent, especially since interregional contact was diminished during the Early Iron Age. Therefore, New Halos possibly had more available means to import food from other places. This would have alleviated stress on the inhabitants of New Halos in terms of food production, which would have allowed them to allocate time and resources into gathering mollusks to add variety to their diet.

The final difference between diet in Early Iron Age Halos and Hellenistic New Halos as suggested by isotopic evidence, is that a larger portion of overall caloric intake could have been from non-protein sources among the Hellenistic population. Wine and olive oil might have played a more substantial role in diet during the Hellenistic Period at Halos. In comparison to foodstuffs such as wheat, vegetables and animal products, large quantities of wine and olive oil are more luxury. This would suggest that New Halos and its inhabitants were doing well financially.

It is also possible that a larger amount of lipids was consumed at New Halos through milk, or through processed dairy products such as cheese and yoghurt. Similarly to the mollusk gathering discussed above, the processing of secondary animal products required a relatively high amount of effort. Again, this suggests that steady import of staple foods may have allowed for more high-effort subsistence strategies. While both Early Iron Age Halos and Hellenistic New Halos consumed C_3-fed animal products, it could be argued that the Early Iron Age population relied more on meat while the Hellenistic population went through the effort to produce secondary animal products.

5.2 Makrigialos

5.2.1 Early Iron Age Makrigialos

The mean carbon isotope ratio of the individuals from Early Iron Age Makrigialos is -18.893‰, with a minimum value of -19.5‰ and a maximum value of -17.6‰. This carbon isotope range suggests a diet based mainly on C_3 plants or C_3-fed animals, but is remarkably high with five out of fourteen individuals displaying a $\delta^{13}C$ value of -18.7‰ or above.

In order to assess the cause of the elevated mean carbon isotope ratio, faunal remains from the site must be examined. The only available faunal isotopic data from Makrigialos date to the end of the Late Neolithic Period, and consist in equal parts of data from red deer, domesticated pigs, and wild boar. The mean $\delta^{13}C$ value of this group is -20.85‰, while the mean $\delta^{15}N$ value is 4.23‰ (Triantaphyllou, 1999, p. 241). The faunal assemblage therefore has a carbon isotope ratio consistent with consumption of C_3 plants. Especially red deer, the only herbivores in this group, have a low mean $\delta^{13}C$ value of -21.67‰, suggesting a C_3 plant-based diet (Triantaphyllou, 1999, p. 241). If the comparatively high carbon isotope ratios in humans was caused by C_4 consumption, it would therefore be more likely that this was consumed directly in the form of millet rather than through meat or secondary products of C_4-fed or grazing animals.

It must be kept in mind though that the Late Neolithic Period ended over 2000 years before the Early Iron Age began. It is therefore not unthinkable that the diet of local fauna had changed considerably by the time Early Iron Age Pydna used Makrigialos cemetery. In fact, Bronze Age faunal sheep, goat and cattle isotopic data from various other locations in Northern Greece have a mean $\delta^{13}C$ value of -18.57‰, suggesting that domesticated animals fed on C_4 plants during the Bronze Age, which is closer in time to the Early Iron Age Makrigialos assemblage (Triantaphyllou, 2015, p. 65).

The mean $\delta^{15}N$ value of the individuals buried at Early Iron Age Makrigialos is 7.100‰, with a minimum value of 6.0‰ and a maximum value of 8.2‰. This is certainly not high enough to support evidence of marine intake, ruling that option out as the cause for the high human carbon isotope ratios. Some individuals have such a low stable nitrogen isotope ratio, that selective consumption of legumes is plausible.

The human nitrogen isotope ratios also suggest consumption of terrestrial animal products, since the mean value is approximately one trophic level higher than that of the Late Neolithic faunal assemblage. However, the mean $\delta^{15}N$ value of domesticated pigs is considerably higher than the overall faunal assemblage, with a value of 5.25‰ (Triantaphyllou, 1999, p. 241). Furthermore, the Bronze Age faunal remains from other sites in Northern Greece have a $\delta^{15}N$ value of 5.20‰ (Triantaphyllou, 2015, p. 65). Therefore, the mean human nitrogen isotope ratio does not fall a full trophic level above the mean value for domesticated pigs, which would have been kept specifically for meat consumption, and domesticated animals from the Bronze Age. This suggests that meat may have been eaten infrequently, thus forming a less substantial portion of the overall dietary protein intake than plant-based food.

A diet based on plants rather than meat is supported to a degree by dental palaeopathology. Triantaphyllou (1999) examined 846 teeth from skeletal remains from Early Iron Age Makrigialos (obviously representing a much larger assemblage than the fourteen individuals sampled for stable isotope analysis). The teeth had a prevalence of caries of 9.92%, and a prevalence of dental calculus of 6.97% (Triantaphyllou, 1999, p. 211 & 217). When it comes to dietary causes, caries is mainly associated with a diet high in carbohydrates such as cereals and fruits, while calculus is associated with a diet high in proteins, particularly meat (Triantaphyllou, 1999, p. 220). The prevalence of caries being higher than that of calculus among the larger Early Iron Age Makrigialos assemblage, could therefore indicate that meat was consumed to a lesser extent than plants.

In summary, the people of Early Iron Age Pydna who were buried in Makrigialos likely consumed a diet based on C_3 plants such as cereals, fruits and vegetables, supplemented with considerable additions of millet and possibly some legumes. Terrestrial animal products were consumed, although the overall diet was likely more plant-based, with only occasional meat consumption. There is no isotopic evidence of marine food intake.

5.2.2 Classical Makrigialos

The mean $\delta^{13}C$ value of the analyzed individuals from Classical Makrigialos cemetery is -19.025‰, with a minimum value of -19.7‰ and a maximum value of -18.6‰. This once again suggests dietary protein intake was based mainly on consumption of C_3 plants or C_3-fed animal products, although the mean $\delta^{13}C$ value is too high for a purely C_3-based diet. It is therefore possible that millet was consumed in addition to C_3 plants, especially by individuals on the higher end of the spectrum. Whether this was in the form of direct millet consumption by the people buried at Makrigialos or by consumption of C_4-fed or grazing animal products, is difficult to determine.

The mean $\delta^{15}N$ value of the sampled individuals is 8,225‰, with a minimum value of 6.7‰ and a maximum value of 9.1‰. Four out of twelve individuals had a stable nitrogen isotope ratio of 8.9‰

or higher. The mean $\delta^{15}N$ value is too low to suggest a substantial role for marine food in the diet. In fact, it could indicate legume consumption among individuals toward the lower end of the spectrum. The mean $\delta^{15}N$ value is in line with regular consumption of terrestrial animal protein, especially toward the higher end of the spectrum. Although, it has to be stressed that the only comparable faunal data from Makrigialos dates to the end of the Late Neolithic Period, and the only data from elsewhere in Northern Greece dates to the Bronze Age. When this is applied to a Classical human assemblage, any conclusion really must be taken with a grain of salt. Because the diet of animals at this time cannot accurately be assessed and therefore a food web cannot be established with certainty, further interpretation of the dietary habits of the individuals from Classical Makrigialos remains limited.

To summarize, diet of the Classical individuals at Makrigialos was mainly based on consumption of C_3 plants, and/or products of animals that were fed C_3 plants. This could have been supplemented with C_4 plants such as millet, and/or products of animals that ate C_4 plants. Regardless of what type of plants local animals were eating, terrestrial animal protein consumption by human individuals is likely, especially for the individuals with a relatively high $\delta^{15}N$ value. Legumes may have been eaten, especially by individuals with a relatively low $\delta^{15}N$ value. A marine signal was absent from the isotopic data.

5.2.3 Early Iron Age Makrigialos compared to Classical Makrigialos

Comparison of the Early Iron Age Makrigialos individuals with the Classical ones, indicates the following possible assessments. Firstly, there is a significant difference in mean $\delta^{15}N$ values, as the ratio for the Classical assemblage is significantly higher than the ratio for the Early Iron Age assemblage. This would suggest an increase in animal protein intake toward the Classical Period, although in what form is difficult to say.

Secondly, the mean $\delta^{13}C$ values of the two time periods are both around -19‰ and not significantly different. This suggests that both groups relied on consumption of C_3 plants, with additions of millet. However, when outliers are disregarded, the range for the Classical assemblage is both tighter and on the higher end compared to the range for the Early Iron Age assemblage (as seen in Figure 13, the range without outliers is -19.5‰ to -18.4‰ for the Early Iron Age group, compared with -19.2‰ to -18.6‰ for the Classical group).

This could suggest that millet was more regularly eaten among the Classical population of Pydna, either directly or via animal protein, as opposed to only selective consumption among the

Early Iron Age population. Millet was first introduced in Greek Macedonia in the Late Bronze Age (Triantaphyllou, 2015, p. 67). Perhaps it was not quite as established yet as a crop in the Early Iron Age as it was in the Classical Period. Given the context that Pydna became the most important port in the Macedonian kingdom at this time, it would have had access to trade routes along the Thermaic Gulf and possibly beyond. Moreso than the Early Iron Age population, Classical Pydna could have imported foodstuffs. This might indicate that millet could have been increasingly imported.

In this regard, only assessing the diet of the two populations using the mean stable carbon isotope ratios is somewhat misleading, as the inclusion of outliers brings the mean value of the Classical assemblage below that of the Early Iron Age group. The two outliers could be interpreted as an individual with a personal preference for millet at Early Iron Age Pydna, and an individual with a personal preference against millet at Classical Pydna.

This is however mostly speculative, as the stable carbon isotope ratios do not differ strongly enough between both assemblages to clearly make this distinction. Furthermore, the sample size of both sites is small (n = 14 for Early Iron Age Makrigialos, and n = 12 for the Classical assemblage). Therefore, any conclusions drawn on diet for the two groups is only based on a fraction of the population, which is not necessarily representative. In fact, women are disproportionally represented among the Early Iron Age group. Nine out of fourteen individuals were assessed as female, while only four were assessed as male (and one was a non-adult). For the Classical assemblage, no demographic information is available at all, so it is impossible to tell how well this group represents Classical Pydna as a whole.

5.3 Comparison between Halos and Makrigialos

In order to assess whether subsistence strategies changed in similar ways from the Early Iron Age into later periods across the two locations, Halos and Makrigialos must be compared to each other. A first observation is that all assemblages examined have a diet based mainly, but not purely on C_3 plants. All groups also consumed a significant amount of animal protein within their diet. In other words, all communities examined were agropastoral.

A difference between Early Iron Age Halos and Early Iron Age Makrigialos, is that the mean nitrogen isotope ratios from Kephalosi and Voulokaliva are significantly higher than that of Makrigialos. As has been discussed, the low nitrogen isotope ratios at Makrigialos can be interpreted as a more plant-based than animal-based diet, with a focus on carbohydrates such as from cereals, vegetables and fruits, and low meat consumption. Some consumption of legumes could also be possible at Makrigialos, while isotopic analysis does not show any evidence for this at Halos.

The mean stable carbon isotope ratios at both places do not differ significantly during the Early Iron Age, and millet consumption has been suggested as a possibility for both. Millet was likely first introduced into Macedonia from the north (Triantaphyllou, 2015, p. 68). Faunal remains from Bronze Age Macedonia suggest that domesticated animals may have consumed more C_4 plants than in Southern Greece, which means millet was likely more readily available to the individuals from Makrigialos than to individuals from Thessalian Halos.

Halos experienced quite a noticeable shift in diet from the Early Iron Age to the Hellenistic Period. Millet all but disappeared from the isotopic record, marine resources were added to the diet, and non-protein foods such as fats and carbohydrates possibly became more prevalent. This has been explained by a wetter climate rendering millet no longer necessary, and possibly by trade networks providing a steady import of food which allowed for effort to be put toward diversification of the diet with luxury additions such as secondary animal products and mollusks. Halos therefore went from a subsistence strategy mostly focused on survival to one focused on greater variety.

Such a shift is not visible in the osteological isotopic record at Makrigialos. The mean $\delta^{13}C$ value of Classical Makrigialos is significantly higher than that of Hellenistic New Halos, while $\delta^{15}N$ is significantly lower. This indicates subsistence strategies at Pydna remained more focused on cultivation and gathering of plants than they were at New Halos, and millet, once introduced, remained a significant contributor to dietary protein in Macedonia. The only shift in diet between the Early Iron Age and the Classical Period at Pydna that can be deduced to a reasonably certain degree from isotopic evidence alone, is one towards a more substantial contribution of animal protein to daily caloric intake. But even with this shift towards greater animal protein consumption, the mean $\delta^{15}N$ value of Classical Makrigialos remained below that of New Halos.

From historical sources, it is known that Classical Pydna must have had extensive contact with the greater area, considering it became the most influential port of the Macedonian kingdom at that time. Yet a shift in diet caused by trade, as has been suggested for New Halos, is not directly visible in the isotopic record at Makrigialos. An explanation is the small size and possible bias of the sample from Classical Makrigialos. Only twelve individuals were analyzed, and there is no demographic information or burial context available. Perhaps these individuals, buried quite a ways outside of Pydna proper, were of a social status that did not benefit much from any increase in interregional trade. The citizens buried closer to or within the city walls of Pydna may have had a higher socioeconomic status, and therefore more access to luxury goods than the people buried at

Makrigialos. Another explanation is that trade is simply difficult to detect within osteological isotope data alone.

Chapter 6: Conclusion

In this thesis, an attempt was made to investigate changes in diet from the Early Iron Age in Greece into later time periods. Considering diet and subsistence strategies changed in the Aegean from the Late Bronze Age into the Early Iron Age, and the association of this change with both a drought and the collapse of political centers, the question arose in what ways diet changed again with new shifts in the climate and the rise of new urban hubs in the form of poleis. In an effort to address these issues, stable nitrogen and carbon isotope analysis of human skeletal remains from the Thessalian site of Halos and the Macedonian site of Makrigialos was done. Diet was assessed and compared at both locations during the Early Iron Age and the later Classical and Hellenistic Period, in the hopes of answering the main research question: "how did diet change from the Early Iron Age to the Classical and Hellenistic periods at the Greek and Macedonian sites of Halos and Makrigialos, as seen through stable isotopes?" In this final chapter, this question will be answered. Afterward, this thesis will conclude with suggestions for future research.

6.1 Answering the research questions

In order to answer the main research question, first all three sub-questions must be addressed. The first sub-question was: "how do $\delta^{13}C$ and $\delta^{15}N$ values differ between the Early Iron Age Halos and the Hellenistic New Halos skeletal assemblages?" Stable carbon isotope ratios during both periods suggest a main reliance on C_3 plants such as wheat, barley, fruits and vegetables. The mean $\delta^{15}N$ values during both time periods was in line with substantial consumption of animal proteins among the adult population.

The $\delta^{15}N$ was higher in New Halos than it was among the adults of the Early Iron Age assemblage. This has been interpreted as the addition of marine food, mainly in the form of mollusks, into the diet during Hellenistic times. At Kephalosi, one of the Early Iron Age cemeteries, the mean $\delta^{15}N$ value was not significantly different from that of the Hellenistic assemblage. However, as Kephalosi contained a high number of infant burials, its high mean $\delta^{15}N$ has been interpreted as breastmilk consumption.

The mean $\delta^{13}C$ value during the Hellenistic Period was significantly lower than it was during the Early Iron Age. This has been interpreted as the disappearance of millet from the diet, and the increased consumption of products such as wine, lipids such as oil and dairy products, and carbohydrates such as fruits and cereals.

The second sub-question was: “how do $\delta^{13}C$ and $\delta^{15}N$ values differ between the Early Iron Age Makrigialos and the Classical Makrigialos skeletal assemblages?” The mean $\delta^{13}C$ values during both the Iron Age and the Classical Period are indicative of C_3 plants as the most important source of dietary protein. This diet was likely supplemented with some degree of millet consumption. The stable carbon isotope ratio did not differ significantly between the two time periods, which suggests that the type of plants consumed did not change dramatically between the Early Iron Age and the Classical Period, although personal preference may have dictated more or less millet consumption among certain individuals.

During the Early Iron Age, the mean $\delta^{15}N$ value was a little less than one trophic level above that of the best available domesticated faunal remains. This has been interpreted as a more plant-based diet, possibly containing some legumes and only occasional consumption of meat. The stable nitrogen isotope ratio was significantly higher during the Classical Period, which has been interpreted as an increase in animal protein consumption.

The final sub-question was: “how do $\delta^{13}C$ and $\delta^{15}N$ values differ between Halos and Makrigialos, both in the Early Iron Age and in the later periods?” Across all sites, $\delta^{13}C$ and $\delta^{15}N$ values indicate a diet based on C_3 plant consumption, with considerable additions of terrestrial animal-based protein in the form of either meat or secondary animal products. This means all analyzed groups were agropastoral.

The mean $\delta^{13}C$ values did not significantly differ between the Early Iron Age locations. At both Halos and Makrigialos, millet might have been consumed to some degree. In the later periods, however, the stable carbon isotope ratio of Makrigialos is significantly higher than that of New Halos. The mean $\delta^{15}N$ value of Makrigialos is lower than that of Halos across both time periods. The combination of these factors has been interpreted as the following differences: millet disappeared from the diet at New Halos, while it continued to be consumed in Classical Makrigialos; and the diet of Makrigialos was on average more plant-based and less animal protein-based than in Halos across both time periods. Overall, based on stable carbon and nitrogen isotopic data alone, a more dramatic shift in diet is detectable at Halos, while diet at Makrigialos did not visibly change too much over time.

Finally, the main research question can be answered as follows. During the Early Iron Age and into the Classical and Hellenistic Period, the people living at Halos and Pydna (to which the Makrigialos cemeteries belong) were agropastoral. Their main source of dietary protein was formed by C_3 plants such as vegetables, wheat and barley. A second important resource for all groups was animal protein.

Isotopic data indicate that diet changed throughout time at both Halos and Makrigialos, although this was more visibly dramatic at Halos than at Makrigialos. These changes can be put into context of both a shift in climate, the establishment of urban centers and associated trade networks, and local cultural differences.

During the period of aridity at the beginning of the Early Iron Age, drought-resistant millet was introduced into Northern Greece. While this resource was used throughout the Early Iron Age at the settlement of Pydna as well as at Halos, when the climate became wetter in later periods, millet fell away as a partial substitute for wheat and barley in the south. It remained in use in Macedonia.

Out of all assemblages examined, Early Iron Age Makrigialos had the most plant-based diet. During Classical times, consumption of animal protein at Makrigialos increased somewhat, but the local preference toward plant-based subsistence strategies remained in comparison to New Halos.

At Halos, diet became more diverse during the Hellenistic Period. The inhabitants of New Halos made use of resources that were less cost-effective, such as mollusk gathering and production of dairy products such as yoghurt or cheese. There is also an indication of more use of luxury products. These are the kinds of dietary strategies associated with a population that is overall doing well socio-economically, and can afford to focus less on immediate survival and more on variety. This could indicate import of food, as this would alleviate stress on food production.

6.2 Suggestions for future research

In this thesis, the scope of research was limited to shifts in diet throughout time across overall settlement populations, rather than detecting differences between specific demographic groups. This is because the original publications from which the isotopic data for this thesis was sourced, had already made an effort toward this goal. According to the those, no conclusive differences between the sexes and between age groups could be detected at any of the assemblages used in this thesis. Another reason that differences between demographic groups was not addressed, is the fact that the sample groups were very small, especially at Makrigialos. Demographic data on Classical Makrigialos was completely absent. Trying to use such fragmentary data to find differences in diet between sex or age groups would more often than not lead to insufficiently supported claims.

Therefore, a first suggestion for additional research is sampling more skeletal remains for stable isotope analysis if possible, especially from around Pydna. There are other cemeteries at Pydna that could perhaps yield more collagen samples. A bigger sample size would decrease bias and make for a completer overall representation of the populations. Samples could also be taken from other

Greek cemeteries dating to the Early Iron Age and later, to assess dietary changes across a wider geographic scope.

A second suggestion for further research is to examine the assemblages for signs of palaeopathology, especially dental. This has been done for Early Iron Age Makrigalos, but not for the other assemblages used in this thesis. Considering New Halos has the largest number of sampled individuals, it would be particularly interesting to see what a paleopathological study of this group would indicate in terms of diet.

Abstract

Toward the end of the Late Bronze Age, conflicts, widespread migrations and climate change culminated in the collapse of centers of political power across the Aegean and the Near East. The period that followed, the Early Iron Age, was marked by a decrease in settlement size, population, and interregional contact. These large changes are associated with a change in diet, toward a subsistence strategy of diversification rather than intensification. During the Archaic Period, climate improved, poleis start to form and a period of regeneration begins. By the Hellenistic Period, centralized power in the form of large kingdoms and highly populated urban centers exist, and long distance contact with Egypt and the Near East reaches an unprecedented scale. The question arises therefore if these large societal changes once again are mirrored by a change in diet within Greece. In order to investigate this, stable carbon and nitrogen isotope analysis is done on human skeletal remains from the Early Iron Age sites of Halos in Thessaly, and Makrigialos in Greek Macedonia. From those same locations, skeletal material dating to the Hellenistic Period in the case of Halos and the Classical Period in the case of Makrigialos is also investigated. Using stable carbon and nitrogen isotope analysis, assessment and comparison of diet within and between the sites is done. Diet reconstruction based on skeletal isotopic data suggests that diet did indeed change from the Early Iron Age into later periods. All examined groups were agropastoral, with a diet based on C_3 plant consumption and terrestrial animal products. At Halos, millet was consumed during the Early Iron Age, but not in the Hellenistic Period. As the climate became wetter, millet was no longer a necessary food source. Instead, there is evidence of marine food intake and increased consumption of processed secondary animal products, and possibly greater consumption of luxury goods. This could indicate import of food, as this would alleviate stress related to food production and allow for effort to go toward a more varied diet with luxury additions. At Makrigialos, millet remained a substantial dietary component from the Early Iron Age into the Classical Period, but animal protein intake increased.

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Appendix A: Isotopic dataset

	Site	City	Ref. nr. IsoArch	Sex	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
1	Kephalosi	Halos	6685	N/A	-19,1	9,7
2	Kephalosi	Halos	6686	N/A	-18,0	9,9
3	Kephalosi	Halos	6688	N/A	-18,7	9,5
4	Kephalosi	Halos	6689	N/A	-18,1	11,7
5	Kephalosi	Halos	6690	N/A	-19,1	10,0
6	Kephalosi	Halos	6691	N/A	-18,6	10,0
7	Kephalosi	Halos	6692	N/A	-19,4	9,9
8	Kephalosi	Halos	6693	N/A	-18,9	8,8
9	Kephalosi	Halos	6694	N/A	-19,3	10,2
10	Kephalosi	Halos	6695	Indeterminate	-19,1	9,7
11	Kephalosi	Halos	6696	N/A	-19,3	8,7
12	Kephalosi	Halos	6697	N/A	-19,3	9,2
13	Kephalosi	Halos	6698	N/A	-18,3	10,3
14	Kephalosi	Halos	6699	N/A	-19,6	8,9
15	Kephalosi	Halos	6700	N/A	-17,2	11,3
16	Kephalosi	Halos	6701	N/A	-19,4	8,9
17	Kephalosi	Halos	6703	N/A	-19,0	9,7
18	Kephalosi	Halos	6704	N/A	-19,1	10,7
19	Kephalosi	Halos	6705	N/A	-19,2	9,2
20	Kephalosi	Halos	6706	N/A	-19,5	7,8
21	Voulokaliva	Halos	6707	Indeterminate	-19,2	9,4
22	Voulokaliva	Halos	6708	Indeterminate	-19,4	8,7
23	Voulokaliva	Halos	6710	Male	-20,0	8,5
24	Voulokaliva	Halos	6711	Female	-19,4	8,6
25	Voulokaliva	Halos	6712	N/A	-19,4	8,5
26	Voulokaliva	Halos	6713	N/A	-18,5	9,0
27	Voulokaliva	Halos	6715	N/A	-19,9	8,1
28	Voulokaliva	Halos	6716	N/A	-18,2	10,7
29	Voulokaliva	Halos	6717	Male?	-19,4	6,8
30	Voulokaliva	Halos	6718	N/A	-20,0	8,3
31	Voulokaliva	Halos	6720	Female?	-19,6	8,1
32	Voulokaliva	Halos	6721	N/A	-19,2	7,1
33	Voulokaliva	Halos	6722	Male?	-18,5	8,7
34	Voulokaliva	Halos	6724	Male	-19,5	8,7
35	Voulokaliva	Halos	6726	Indeterminate	-19,6	7,5
36	Voulokaliva	Halos	6727	Indeterminate	-19,4	8,3
37	Voulokaliva	Halos	6729	Male	-19,7	8,1
38	Voulokaliva	Halos	6730	N/A	-19,6	6,9
39	Voulokaliva	Halos	6731	N/A	-18,3	9,4
40	Voulokaliva	Halos	6732	Female	-17,5	8,6
41	Voulokaliva	Halos	6733	Indeterminate	-19,7	8,7

42	Voulokaliva	Halos	6734	Male	-18,5	9,1
43	Voulokaliva	Halos	6735	Female	-17,0	8,5
44	Voulokaliva	Halos	6736	N/A	-18,0	9,1
45	Voulokaliva	Halos	6737	Indeterminate	-19,8	8,0
46	Voulokaliva	Halos	6738	Female	-18,8	7,3
47	Kaloerika	New Halos	9296	Indeterminate	-19,6	9,6
48	Kaloerika	New Halos	9297	Female	-20,1	8,5
49	Kaloerika	New Halos	9298	Indeterminate	-20,1	9,8
50	Kaloerika	New Halos	9302	Indeterminate	-20,1	9,4
51	Kaloerika	New Halos	9303	Indeterminate	-19,8	9,1
52	Kaloerika	New Halos	9305	Male?	-19,7	10,8
53	Kaloerika	New Halos	9307	Indeterminate	-19,5	10,7
54	Kaloerika	New Halos	9308	Indeterminate	-19,7	8,7
55	Kaloerika	New Halos	9309	Indeterminate	-19,6	10,2
56	Kaloerika	New Halos	9310	Indeterminate	-20,0	8,4
57	Kaloerika	New Halos	9311	Indeterminate	-19,6	8,9
58	Kaloerika	New Halos	9312	Male	-19,9	10,2
59	Kaloerika	New Halos	9313	Male	-20,0	9,4
60	Kaloerika	New Halos	9315	Indeterminate	-19,9	8,8
61	Kaloerika	New Halos	9317	Indeterminate	-19,6	11,1
62	Kaloerika	New Halos	9318	Male	-19,9	10,4
63	Kaloerika	New Halos	9320	Indeterminate	-18,7	10,1
64	Kaloerika	New Halos	9321	Indeterminate	-19,7	10,0
65	Kaloerika	New Halos	9326	Male	-19,6	10,2
66	Kaloerika	New Halos	9327	Male	-19,8	9,4
67	Kaloerika	New Halos	9328	Male	-20,0	9,2
68	Kaloerika	New Halos	9329	Indeterminate	-19,9	8,0
69	Kaloerika	New Halos	9330	Indeterminate	-19,8	9,1
70	Kaloerika	New Halos	9331	Female	-20,1	9,9
71	Kaloerika	New Halos	9332	Male?	-20,1	9,3
72	Kaloerika	New Halos	9333	Indeterminate	-19,8	9,5
73	Kaloerika	New Halos	9334	N/A	-20,2	8,6
74	Kaloerika	New Halos	9335	Male	-19,6	10,5
75	Kaloerika	New Halos	9337	Indeterminate	-20,3	10,2
76	Kaloerika	New Halos	9338	N/A	-19,8	8,5
77	Kaloerika	New Halos	9339	Indeterminate	-20,2	7,8
78	Kaloerika	New Halos	9340	Indeterminate	-19,2	8,8
79	Kaloerika	New Halos	9342	N/A	-18,5	9,1
80	Kaloerika	New Halos	9343	N/A	-19,6	9,1
81	Kaloerika	New Halos	9344	Male?	-19,7	9,7
82	Kaloerika	New Halos	9346	Male	-17,9	9,1
83	Kaloerika	New Halos	9348	Indeterminate	-20,2	9,9
84	Kaloerika	New Halos	9349	Female	-20,1	9,5
85	Kaloerika	New Halos	9350	Male	-20,3	7,3
86	Kaloerika	New Halos	9352	Female	-19,7	9,0
87	Kaloerika	New Halos	9353	Female	-19,9	9,3

88	Kaloerika	New Halos	9354	Female?	-20,2	8,5
89	Kaloerika	New Halos	9355	Female?	-20,2	8,3
90	Kaloerika	New Halos	9356	Indeterminate	-19,8	9,2
91	Kaloerika	New Halos	9357	Female	-20,1	9,2
92	Kaloerika	New Halos	9359	Female	-20,0	9,6
93	Kaloerika	New Halos	9360	Indeterminate	-19,8	9,4
94	Kaloerika	New Halos	9361	Indeterminate	-20,2	9,4
95	Kaloerika	New Halos	9362	Male	-19,4	10,3
96	Kaloerika	New Halos	9363	Male	-19,8	9,5
97	Kaloerika	New Halos	9364	Female	-19,6	10,5
98	Kaloerika	New Halos	9365	Indeterminate	-20,1	8,3
99	Kaloerika	New Halos	9366	Female	-20,1	9,4
100	Kaloerika	New Halos	9367	Indeterminate	-19,9	8,7
101	Kaloerika	New Halos	9368	Indeterminate	-20,0	7,7
102	Kaloerika	New Halos	9369	Male	-19,7	9,7
103	Kaloerika	New Halos	9371	Indeterminate	-19,6	9,9
104	Kaloerika	New Halos	9372	Male	-20,0	9,4
105	Kaloerika	New Halos	9373	Indeterminate	-20,0	8,8
106	Kaloerika	New Halos	9375	Indeterminate	-20,2	7,7
107	Kaloerika	New Halos	9377	Indeterminate	-20,2	9,3
108	Makrigialos (EIA)	Pydna	6748	Female	-19,0	6,0
109	Makrigialos (EIA)	Pydna	6749	Female	-19,3	7,0
110	Makrigialos (EIA)	Pydna	6750	Female	-19,2	8,1
111	Makrigialos (EIA)	Pydna	6751	Female	-18,7	6,8
112	Makrigialos (EIA)	Pydna	6752	Male	-18,4	7,4
113	Makrigialos (EIA)	Pydna	6753	Female	-19,5	6,3
114	Makrigialos (EIA)	Pydna	6754	Female	-18,8	6,8
115	Makrigialos (EIA)	Pydna	6755	Female	-19,2	7,0
116	Makrigialos (EIA)	Pydna	6756	Male	-18,9	8,2
117	Makrigialos (EIA)	Pydna	6757	Female	-18,6	6,8
118	Makrigialos (EIA)	Pydna	6758	Female	-18,7	7,2
119	Makrigialos (EIA)	Pydna	6759	Male	-19,3	7,2
120	Makrigialos (EIA)	Pydna	6760	Male	-17,6	7,5
121	Makrigialos (EIA)	Pydna	6761	N/A	-19,3	7,1
122	Makrigialos (Classical)	Pydna	6762	?	-19,2	6,7
123	Makrigialos (Classical)	Pydna	6763	?	-19,1	8,9
124	Makrigialos (Classical)	Pydna	6764	?	-18,6	8,4
125	Makrigialos (Classical)	Pydna	6765	?	-18,9	9,1
126	Makrigialos (Classical)	Pydna	6766	?	-19,7	7,0
127	Makrigialos (Classical)	Pydna	6767	?	-19,0	7,8
128	Makrigialos (Classical)	Pydna	6768	?	-18,8	8,5
129	Makrigialos (Classical)	Pydna	6769	?	-19,1	7,4
130	Makrigialos (Classical)	Pydna	6770	?	-18,9	8,7
131	Makrigialos (Classical)	Pydna	6771	?	-18,9	9,0
132	Makrigialos (Classical)	Pydna	6772	?	-18,9	9,1
133	Makrigialos (Classical)	Pydna	6773	?	-19,2	8,1

Appendix B: Laboratory analysis methods per study

Early Iron Age Halos (Voulokaliva and Kephalosi): Panagiotopoulou et al., 2016, p. 214:

"The carbon and nitrogen stable isotope analysis of bone collagen from the two cemeteries of Halos was carried out at the Center for Isotope Research at the University of Groningen. The collagen was extracted following an improved version of the Longin method (Longin, 1971). First the samples were cut to the appropriate size and weight. Loose soil and dirt were removed mechanically and the samples were placed in acid (1% HCl) to demineralize the bone. A weaker than usual acid solution was used because of the preservation state of the samples. A 1% NaOH bath removed humic acids. Next, the samples were first placed in slightly acidic demineralized water and then in an oven in order to solubilize the organic part, that is the collagen fraction of the bone. The solution was filtered (50 μm) in order to collect the pure collagen solution. Finally, the solution was dried into solid collagen.

The collagen was combusted and purified into gas (CO_2 and N_2 for ^{13}C and ^{15}N analysis, respectively) using an Elemental Analyser (EA), coupled to an Isotope Ratio Mass Spectometer (IRMS). We used two instruments, a Carlo Erba/Optima and an Isocube/Isoprime EA/IRMS combination.

The instruments provide the isotope ratios $^{13}R = {}^{13}C/{}^{12}C$ and $^{15}R = {}^{15}N/{}^{14}N$ as well as the C and N yields of the collagen. The isotope ratios are expressed in permil deviations from a reference material, reported as delta values:

$$\delta = [R_{sample}/R_{reference}] - 1 \ (x\ 1000‰)$$

The reference materials are the internationally recommended compounds VPDB (belemnite carbonate) for $\delta^{13}C$ and ambient air for $\delta^{15}N$ (DeNiro, 1987; Mook, 2006). The analytical precision is 0.1‰ and 0.2‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively.

For bone collagen, quality parameters are widely accepted values for the carbon content, nitrogen content and the atomic C/N ratio. These values should be in the range 30–45%, 11–16% and 2.9–3.6, respectively (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999). When these values differ significantly, the bone is considered (partly) degraded, and this may produce deviating isotope ratios, and lead to possibly erroneous conclusions."

New Halos (Kaloerika): Sparkes, 2017, p. 94-95:

"The UCT method was selected for this study because various comparative methodological studies have shown that it provides reliable results (Jørkov et al., 2007; Sealy et al., 2014). The first step is to wash all samples with ultrapure water and place them in a sonicator to remove surface contaminants. Each sample was sonicated three times for five minutes each. Samples would be sonicated a fourth time if the water was still cloudy after the third wash indicating contaminants were still present. When the water was clear the samples were removed and left to air dry for 48 hours. Once clean and dry each sample was weighed and placed into its own glass container ready for further processing. Sample demineralization was accomplished by soaking the samples in a 1% HCl solution that was changed every two days. The samples were checked at each HCl solution change for softness and transparency. A fully demineralized sample is soft throughout, is transparent or translucent, and will cease producing bubbles in the acid solution. Once a sample was fully demineralized, it was rinsed in purified water until its pH level reached neutrality and then it was soaked overnight in purified water.

Next, the samples were placed in a 20 hour 0.125M NaOH soak. Following this the samples were once again rinsed and soaked in purified water until they reached neutrality. The water was removed and the samples were then frozen. The samples were freeze-dried and the resulting collagen for each sample was then weighed for comparison to the initial bone weight to calculate collagen yield. 1 mg of dry collagen for each sample was packed in tin capsules using a microbalance. The samples were then run using a EuroEA Elemental Analyzer coupled with an Isoprime Mass Spectrometer in the Biogeochemical Analytical Service Laboratory directed by Dr. Mingsheng Ma in the Department of Biology at the University of Alberta."

Early Iron Age and Classical Makrigialos: Triantaphyllou, 2000, p. 234:

Unfortunately, Triantaphyllou does not provide the exact laboratory procedures used. Instead, her explanation is limited to the following:

"The current work represents a limited pilot analysis of stable carbon and nitrogen isotopes conducted by Dr G. J. van Klinken in the Oxford Research Laboratory for Archaeology and History of Art."

Appendix C: One-sample Kolmogorov-Smirnov test

To determine whether or not the sets of data were normally distributed, a one-sample Kolmogorov-Smirnov test was run in IBM SPSS statistics 29. The results are provided in the table below. A set of data is considered normally distributed when the asymptotic significance (or p-value) is higher than 0.05. As the table shows, $p < 0.05$ for the $\delta^{13}C$-values of Kephalosi, Voulokaliva and Kaloerika. Therefore, those values are not normally distributed and only non-parametric tests can be used for data analysis.

	Site name	**Kolmogorov-Smirnov**		
		N	Test statistic	Asymp. Sig. (2-tailed)
$\delta^{13}C$	Kephalosi	20	0.224	0.010
	Voulokaliva	26	0.234	< 0.001
	Kaloerika	61	0.205	< 0.001
	Makrigialos (EIA)	14	0.162	> 0.200
	Makrigialos (Classical)	12	0.178	> 0.200
$\delta^{15}N$	Kephalosi	20	0.123	> 0.200
	Voulokaliva	26	0.136	> 0.200
	Kaloerika	61	0.086	> 0.200
	Makrigialos (EIA)	14	0.165	> 0.200
	Makrigialos (Classical)	12	0.167	> 0.200