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Mulder, Sophie

UNIFORM OR DIVERSE?

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Cover figure: Mosaic from a villa near Tor Marancia, Rome (2nd century AD). Located at the Vatican Museum (https://commons.wikimedia.org/wiki/File:Still_life_Tor_Marancia_Vatican.jpg).

Uniform or diverse?

Ancient Roman diet compared between three Imperial Roman cities using stable isotope analysis

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Chapter 1. Introduction

1.1 The culture of Roman Italy

Italy has a long and well-known history that has been studied thoroughly. Its capital Rome grew from a village in central Italy to a powerful empire spreading from the British Isles to the Levant. The Italian peninsula had a central position in the Roman Empire, which gave it a strong connection to the city of Rome itself. Rome profited from the alliances with the diverse Italian peoples for their power and resources (Lomas, 1996, p. 1). The Roman Conquest had gained control over the entire peninsula by 264 BC, when the First Punic war was initiated and warfare within the peninsula was not as frequent anymore (Bradley & Hall, 2017, p. 204). But for the peoples on the Italian peninsula, being under the same rule did not mean having the same identity. On the contrary, the Italian peninsula held many culturally diverse groups with their own name and identity, even during the Imperial period between 31 BC and 476 AD (Lomas, 1996, p. 2).

It is probable that these groups adapted to the cultural influence of the Roman rule differently. Therefore, the question rises if it is possible to speak of a uniform Roman Italian or even Roman culture. Moreover, the process of Romanization, that has been used to describe the adaptation of "non-Roman" cultures to the influence of the Roman rule, is being doubted. The term suggests that an inherent Roman culture is brought upon non-Roman peoples, that is accepted and taken over by them (Terrenato, 2008, p. 235). This ignores the fact that cultural continuity could have been present for the non-Roman peoples. Moreover, it conflicts with the possibility of there being cultural influence from the non-Roman upon the "pure" Roman culture. This one-way view of cultural change has been questioned and a more interactive model of cultural change has been suggested. In this model, non-Roman cultural influence plays a more important role. Culture change is then understood as a combination of Roman and non-Roman influences interacting with each other, keeping in mind that cultures are not closed off concepts (Terrenato, 2008, p. 236).

To test if a uniform Roman culture existed, or if culture differed more locally, it should be studied if common cultural features existed in the Roman Empire in any way. Were there similar cultural patterns throughout the empire, or did this differ based on local factors? If a uniform Roman culture existed, it would probably find its origin in the centre of the empire: the Italian peninsula with Rome as its beating heart. The further away from the centre of the empire, the bigger the cultural differences are expected to be. The Italian peninsula would therefore be the most uniform in cultural features. If local cultural differences can be found there, it can question the existence of a uniform Roman culture. The research area of this thesis will therefore be narrowed down to the Roman Italian peninsula.

Cultural differences in Roman Italy could especially have been notable between different cities. Cities are centres of dense population and can therefore have distinct cultural features. The countryside around the cities less so. Differences could be based on many factors, such as regional, social or economic factors. As Roman Italy has been abundantly researched in the past, especially its cities, there are many possibilities to study these factors. Historical literary sources can give a large amount of information on daily life in a Roman city, but these are often biased by their writers. These writers were often males from elite social classes, that do not represent the lifestyle of an ordinary Roman citizen (Erdkamp & Holleran, 2019, p. 6). Archaeological excavations, on the other hand, can uncover information on cultural aspects of daily life in a Roman city that is much less biased. Domestic, religious and commercial architecture leave physical traces behind, but burial practices and the use of common objects are also uncovered through archaeology.

Essential parts of every culture that can be studied archaeologically are food and diet. Studying diet can give a very specific insight into a common Roman citizen's life. Food production, preparation and consumption are all vital aspects of everyday life and essential for survival. Cultural differences can be reflected in all of these aspects. The importance of food in everyday life therefore makes it a suitable topic for studying cultures.

1.2 Diet research in Roman Italy

In Roman Italian archaeology, a lot of research has been done on the food that was commonly eaten. It is difficult to generalize the diet of a people that was spread out over such a large area and over such a large timespan, but the 'Mediterranean triad' is often used as characterization of the Roman diet. It consists of cereals, olive oil and wine. A large proportion of the Roman diet could be ascribed to this triad, especially for the Romans with a lower living standard (Rowan, 2019, p. 129). In higher classes, pricier foods like fresh animal products were more commonly eaten, while the elites also used exotic imported products in their diet (Donahue, 2019, p. 94).

The question rises, however, if diet was uniform throughout the Italian peninsula. Can we speak of a standardized diet that minimally differs between the different cities in Roman Italy? Or can nuances in diet be seen when looking more closely at different cities? As explained in section 1.1, the cultures of the many different peoples that inhabited the Italian peninsula before the Roman conquest could have influenced the "Roman" culture that ultimately became widespread. Moreover, local factors such as availability of food resources, but also geographical restrictions for trade could affect the diet of different cities' inhabitants. What is crucial, is if these differences are in such a way significant that

they are reflected through diet. If that is not the case, it would be likely that a more uniform diet existed in Roman Italy.

Researching diet can be done in different ways. In archaeology, botanical and zoological traces in areas of past habitation can give information on *what* was eaten. But knowing what foods were common does not give direct information on their proportion in the diet of a Roman citizen. That is where isotope analysis could be of use. This technique uses the isotopic composition of human bone to reconstruct the diet of an individual (Larsen, 2015, p. 301). Dietary reconstructions using isotopic data have been done for sites all over Italy. The data from these studies can be used to compare the diet in different cities to each other.

1.3 Research questions

To address the research problem, this thesis will compare the diet of the three cities Rome, Ostia and Pompeii. This will allow for an analysis of dietary differences on a local, city-internal level as well as on a Roman regional level. For the purpose of keeping the research domain feasible, only data from between 0 and 300 AD – roughly the Roman Imperial Period – will be used. The following research question has been formulated:

"To what extent do local and regional factors influence the human diet in Roman Italy between 0 and 300 AD, as seen through stable isotopes?"

The following sub-questions will be answered to help answering the research question:

1. *"What differences are observed in $\delta^{13}C$ ratios within and between the archaeological sites in Rome, Ostia and Pompeii?"*
2. *"What differences are observed in $\delta^{15}N$ ratios within and between the archaeological sites in Rome, Ostia and Pompeii?"*
3. *"What differences are observed between the sexes within and between the archaeological sites in Rome, Ostia and Pompeii?"*

1.4 Approach

To study possible differences in diet, a comparison will be made of isotopic data from archaeological sites on the Italian peninsula. The three Imperial Roman cities Rome, Ostia, and Pompeii will be the focus. First, two archaeological sites in Rome will be studied: Casal Bertone, close to Rome's centre, and Castellaccio Europarco, further to the suburbs. Casal Bertone is a site containing an industrial

complex accompanied by buildings and a necropolis. These were used during the Imperial Period (31 BC – 476 AD) (Killgrove, 2010, pp. 73–75). Castellaccio Europarco is a site located next to the Via Laurentina, a large road to Rome's city centre. The site contained several buildings and a necropolis dated between 50 and 175 AD (Killgrove, 2010, pp. 82–85). Then for Ostia, a coastal harbour city, the Isola Sacra site will be studied. This is an island located in the Tiber near the river's mouth. The island was used as a necropolis by the inhabitants of Ostia and the adjacent town Portus Romae during the 2nd and 3rd century AD (Prowse, 2001, pp. 85–86). Finally Pompeii, the city that thrived until it was covered under the ashes of the 79 AD Vesuvius eruption. Due to the eruption's destruction, skeletal material was found scattered across in the city. The material that is used in this study was dated to the 1st century AD up to 79 AD (Pate et al., 2016, p. 128).

The isotopic data from these three cities will be studied in order to get an insight into the diet of the cities' inhabitants. Isotopic data can be extracted from human skeletal remains that are found in burials at archaeological sites. This data is analysed to give an impression of the different components in a person's diet. That is because the isotopes that are present in food are reflected in the composition of human bone. Two different types of isotopes are used to gain this information: stable carbon isotopes and stable nitrogen isotopes. Both have their own properties that can give information on the types of food a person ate (Larsen, 2015, p. 302).

The isotopic data that is used in this thesis comes from several isotopic studies that were carried out in the last two decennia. The data for the Rome sites was retrieved from Killgrove (2010), Killgrove & Montgomery (2016) and Killgrove & Tykot (2013). The data from the Ostia site Isola Sacra was retrieved from Bruun (2010), Crowe et al. (2010), Prowse (2001), Prowse et al. (2004) and Prowse et al. (2007). The data from Pompeii was retrieved from Nitsch (2012) and Pate et al. (2016). All raw isotopic data from these sites was accessed through www.IsoArch.eu, an open access database for isotopic data from all over the world (Salesse et al., 2018, 2020).

1.5 Thesis Outline

After this introductory chapter, the theoretical background for the thesis will be discussed in chapter 2. It will focus on what is already known about diet in Roman Italy and how it can be studied using stable isotope analysis. In addition, previous studies using stable isotope analysis for dietary reconstruction will be reviewed to provide context for this approach. Chapter 3 begins with background information on the three Roman Italian cities that will be studied in this thesis. Then it discusses the specifics of the sample selection and the methods that were used. Chapter 4 presents the results of the research. First,

the city-internal analyses will be reported, in which a key focus is on possible differences between the sexes. Next, the comparisons between the cities will be described, in which the groups as a whole are compared to each other, but also the males and the females separately. Chapter 5 presents a discussion of the results and puts these into context. It addresses both similarities and significant differences within and between the cities, and considers possible causes for these occurrences. Chapter 6 concludes this thesis with an answer to the research questions. Suggestions for future research will be provided as well, that could improve on the current research.

Chapter 2. Background

This chapter introduces the concept of diet reconstruction in the Roman Empire and presents a general overview of the most common foods that were eaten. Next, the science behind isotope analysis will be explained. Which isotopes can be used for diet reconstruction, and how diet is reflected in human bone. At the end of this chapter, the usefulness of isotope analysis for diet reconstruction is illustrated by the discussion of some successful studies that have been done in the past.

2.1 Diet reconstruction in the Roman Empire

The food that ancient Romans ate has been studied using different sources. Literary sources have long been the standard for studying Roman food consumption. Ancient recipes hold detailed information on different types of Roman food that were eaten. When the research focus started moving from individual Roman foods to a more holistic concept of Roman diet, sources beyond literature were used more and more (Erdkamp & Holleran, 2019, pp. 2–3). Archaeological evidence can be used as a primary source for reconstructing diet and can give a more representative image of diet. Especially for the lower classes this is an essential development, as these are usually not represented well in literary sources. Types of archaeological remains that are primary evidence of dietary preferences are for example remains of food, such as fruit seeds and animal bones. Other types of archaeological evidence that can reveal aspects of diet are objects for food preparation or consumption, such as pottery and grinding stones, but also imagery and art that show food-related activities (Erdkamp & Holleran, 2019, p. 3). Finally, human skeletal remains and teeth can give an indication of the nutrition and components of an individual's diet (Erdkamp & Holleran, 2019, p. 3).

Important to note before beginning this chapter is that the documentation of diet in Roman Italy is not the same for all social classes. Primary literature is often biased and focuses mainly on the higher classes. The study of archaeological remains solves this problem only to a certain degree, as remains of higher classes are often still preserved better than those of lower classes (Erdkamp & Holleran, 2019, p. 7). However, the present data are still valuable to get a general idea of the diet in Roman Italy. Below, examples of foods that Romans commonly ate will be given to serve as context for the data collected in this thesis.

2.2 Most common foods in the Roman Empire

Centuries of studies from many different sources have brought us to a fair knowledge of the foods that were often eaten in the Roman world. The foods and drinks that were most commonly consumed in Roman Italy can be divided into three categories: plant-based foods like cereals and pulses, animal products like meat, fish and cheese, and lastly wine and olive oil. Below, these foods and their importance in the diet of different social classes will be discussed per category.

2.2.1 Cereals and pulses

Cereals and pulses commonly made up a large portion of the Roman diet. Cereals are plants from which the grains are used for consumption. Examples of cereals that were available in the Roman world are wheat, barley, oats, millet and sorghum (Heinrich, 2019, pp. 101–103). Cereals are very versatile and can be used to create a variety of products, which likely contributed to their popularity. After processing the cereal grains into for example meal, flour or groats, both semiliquid and solid products could be made. Fermenting, boiling and baking were methods for creating finished products like porridge, stew and of course bread (Heinrich, 2019, pp. 104–105). The proportion of cereals in the Roman diet has been estimated to be around 60%. Caution should be taken with generalized assumptions like these as diet can differ greatly with social class, but the importance of cereals in Roman diet is nevertheless stressed (Heinrich, 2019, p. 107). Roman writers like Martial and Pliny the Younger have described the Roman breakfast, lunch and afternoon snack in their works, which all included bread as an important component (Donahue, 2019, p. 95).

Pulses are foods like chick peas, lentils and faba beans. These and other pulses were commonly mentioned in Roman literature and also found in archaeology in both wealthy and poor contexts. Just like cereals, pulses can be consumed either in semi-liquid form or in solid form using similar production methods. In addition, pulse flour was often mixed with cereal flour to create hybrid dishes, as they were also sold as mixes. Bread made from a mix of cereal and pulse flower was therefore not uncommon (Heinrich & Hansen, 2019, pp. 119–120).

2.2.2 Animal products

Animal products were not eaten as consistently as plant based staple foods like cereals and pulses. Their availability was not always guaranteed and varied during the year. Moreover, availability was dependent on location and social context. Average Romans ate meat mainly for dinner and sometimes for lunch, but the latter was usually only possible for the wealthier classes (MacKinnon, 2019, pp. 150–

151). The meat consumption consisted mainly of domestic livestock like cattle, pig, sheep, goat and fowl. Pork was by far the most popular meat in Roman Italy, as an average of 45% of animal bone material found at archaeological sites in this area was of pig (MacKinnon, 2019, p. 154). The consumption of fresh fish and rarer types of animal products like wild game was more limited, comprising of on average only 5% of the zooarchaeological record at Roman sites (MacKinnon, 2019, p. 153). However, literary sources suggest that smaller and lower quality types of fresh fish were also consumed by the lower classes. Moreover, fish and other marine products that were salted for preservation were even more common for the lower classes. These are thought to be consumed by all social classes (Marzano, 2018, pp. 440–441). The elite class ate the most exotic foods: because of their wealthy and sometimes even extravagant lifestyle, feasts were not out of the ordinary. Here, luxurious foods like shellfish, exotic birds and stuffed dormice were served (Donahue, 2019, p. 94). Cheese and eggs were more broadly available, also to the lower classes that could often not afford meat. These and other cheaper products were often eaten at local *tabernae,* that were convenient for Romans without a kitchen. These Roman 'fast food bars' served several products for the middle and lower classes. Epigraphic evidence from one of these bars gives a pricelist containing not only bread, porridge, onion, leek, dates, oil and wine, but also animal products like sausage, fish and cheese (Donahue, 2019, p. 96; MacKinnon, 2019, p. 156). Milk from several different types of animals was considered nutritious and was consumed by those who could afford it, but its limited preservability made that it was not drunk on a daily basis (Broekaert, 2019, p. 141).

2.2.3 Wine and other drinks

Wine is considered a central drink in the Roman world, as it occurs very often in different forms of documentation. Wine became popular, among other things, because of its long shelf life and the possibility to be shipped over large distances. There was a high variety in the types of wine that were consumed, as production methods, taste and alcohol percentage differed widely based on location and social factors (Broekaert, 2019, pp. 140–141). In addition, wine consumption differed largely with social class. In upper classes, higher quality wines could be afforded in larger quantities. Ancient writers were often part of the elite class and were thus biased in their description of Roman wine consumption. The lower classes are therefore represented much less in ancient sources (Broekaert, 2019, p. 140). The lower classes could in fact not, or only occasionally afford to buy wine. Estimations of the wage of an average urban labourer have been made, which would only allow consumption of 0,18 litre of wine a day (Broekaert, 2019, p. 143). This tells us that wine was perhaps not such a vital part of the average Roman diet.

Other drinks that might have been more important in the Roman diet were milk and water. As mentioned earlier, milk was drunk where it was available, mostly by lower classes. The consumption of water by Romans would seem evident, but in urban contexts the water was not always clean enough to drink. However, especially in Imperial times, the supplying of water through waterways and aqueducts had advanced to deliver clean water in the cities. Rural settlements relied more on natural water sources, that were usually clean enough to drink (Broekaert, 2019, pp. 141–142).

2.2.4 Olive oil

As mentioned earlier, olive oil is considered part of the Mediterranean triad of foods, together with wine and cereals. These foods are thought to be the most important basis for the Roman, and in broader sense, the Mediterranean diet (Rowan, 2019, p. 129). Olive trees could be grown all around the Mediterranean coast and more inland in some regions. In every region where olive trees were able to grow, olive processing tools have been found (Rowan, 2019, p. 133). Olive oil was a versatile ingredient included in many recipes. It was used for cooking, but also for marinating meat and fish and conserving foods. Moreover, it was often used for drizzling on many types of foods like bread, vegetables and finished meals (Donahue, 2016, p. 610). The importance of olive oil is supported by the widely accepted estimate that an average Roman citizen consumed 20 litres of olive oil per year. This estimate is based on ethnographic comparisons, and is still being debated by some scholars that suggest a much lower or even a higher intake. Nevertheless, it shows the importance of olive oil for Roman diet, as the current average olive oil intake in Italy is around 12 litres per year (Rowan, 2019, p. 135). Table olives were also consumed by a broad range of Roman citizens, and were popular as an appetizer and in salads (Donahue, 2016, p. 610).

2.2.5 Towards regional and individual diet reconstruction

In conclusion, a broad knowledge of the diet in the Roman world is available. We know that cereals and pulses – especially bread – are present in almost every meal that an average Roman would eat in a day. Meat and other animal products were a bit harder to come by, especially for the lowest classes. The higher classes, however, could afford eating meat in more than one meal a day. Eggs and cheese were more accessible for lower classes. Fish and marine products were, especially further away from the coast, more expensive and less available to lower classes. Wine was widely drunk in the Roman world, but was often limited to middle and high classes. For lower class citizens water and milk were

mostly drunk where accessible. Olive oil was used in many contexts, especially for cooking and garnishing meals. A significant amount of the Roman diet therefore consisted of olive oil.

These are mainly general impressions of diet in the Roman Empire. They do, however, not tell us much about individual diets and regional differences. If we want to study dietary differences on a more regional scale, a more precise approach is necessary. An example of a technique that can show more specific dietary preferences on an individual level is the study of dental caries. Erosion of the dental enamel, the upper layer of the tooth, can give an indication of which foods were common in an individual's diet. More carbohydrate-rich diets can give a higher risk of caries. That is because carbohydrates are broken down by bacteria in the mouth that produce acid. This acid can cause cavities that remain visible even ages after an individual has been buried (Larsen, 2015, p. 314). The study of dental caries is therefore an accessible way to study diet from human remains. It is however not insightful enough to tell us what types of food were consumed, only if they were predominantly carbohydrate-rich or not. More advanced techniques to study diet from human remains exist as well: isotope analysis has often been used to study ancient human diet. By taking samples from bone and studying the isotope ratios within, a broad idea of the diet can be reconstructed. Just like the study of dental caries, it is a technique that directly reflects a person's diet. This makes it more accurate than studying, for example, food waste or pottery remains (Lee-Thorp, 2008, p. 925). Isotope analysis can go beyond the study of dental caries, because it can give a more detailed insight in the types of foods a person ate. The consumption of plant or animal products, marine foods, and specific plant types can be distinguished with isotope analysis (Tykot, 2004, pp. 434–437). In the following sections, a theoretical background will be given on isotope analysis regarding diet.

2.3 Stable isotope analysis: the theoretical background

At a microscopic level, the world around us is made up of atoms. Every atom consists of protons, neutrons and electrons. Atoms can be of different chemical elements based on the amount of protons that they have in their core. Isotopes are atoms of the same chemical elements, and thus with the same amount of protons, but with a different amount of neutrons. The amount of neutrons only influences the weight of the atom and does not change its chemical function. Isotopes are therefore atoms of the same element, but with a different weight. To illustrate: a carbon atom has 6 protons, but can occur with an atomic mass of 12 and 13 (and even more or less) based on the amount of neutrons that are present in the core (Alexandre, 2020, pp. 3–4). This has consequences for the way the different isotopes interact with their environments. For instance, heavier isotopes move more slowly than lighter isotopes (Lee-Thorp, 2008, p. 927). This affects how different isotopes act in an

organism's metabolism that is responsible for the build-up of tissues. The composition of tissues in different plants and animals can therefore differ in the ratio of heavier and lighter isotopes. This also means that different foods have different isotope ratios. When a person eats plants and animals, the isotope ratio is transferred into the person's tissues. It will therefore also leave a signature in the bone composition of humans. Thus, diet can really be read from one's bones (Larsen, 2015, p. 302). For diet reconstruction, carbon and nitrogen isotopes are used. Below, the way these are used for studying diet from bone remains will be explained.

2.3.1 Carbon stable isotopes for diet reconstruction

The element carbon exists in several isotopic forms, of which two are stable isotopes that do not decay radioactively. The ^{12}C isotope is the most prevalent and makes up 98.9% of the stable carbon atoms on earth. The heavier isotope ^{13}C is much less prevalent and makes up 1.1% of the stable carbon atoms (Farquhar et al., 1989, p. 504). The presence of the two different carbon isotopes varies in different types of food. One instance in which this is the case is between so-called C_3 and C_4 plants. These plants differ in their photosynthetic processes. The photosynthetic process in C_3 plants favours ^{12}C over ^{13}C, causing there to be less ^{13}C isotopes in C_3 plants than in C_4 plants. The ratio of ^{13}C isotopes to ^{12}C isotopes is measured using the $\delta^{13}C$ value. This value is calculated by comparing the $^{13}C/^{12}C$ ratio measured in a sample to an international standard, giving a negative parts per mille (‰) value. Because there are less ^{13}C isotopes in C_3 plants, these have more negative values than C_4 plants. The $\delta^{13}C$ value of C_3 plants varies between –22‰ and –36‰, whereas the value of C_4 plants varies between –9‰ and –21‰ (Larsen, 2015, p. 303). Examples of C_3 plants are wheat, barley, oats, rice and potato, and examples of C_4 plants are maize, sorghum, millet and cane sugar. Marine plants have a signature $\delta^{13}C$ value as well,

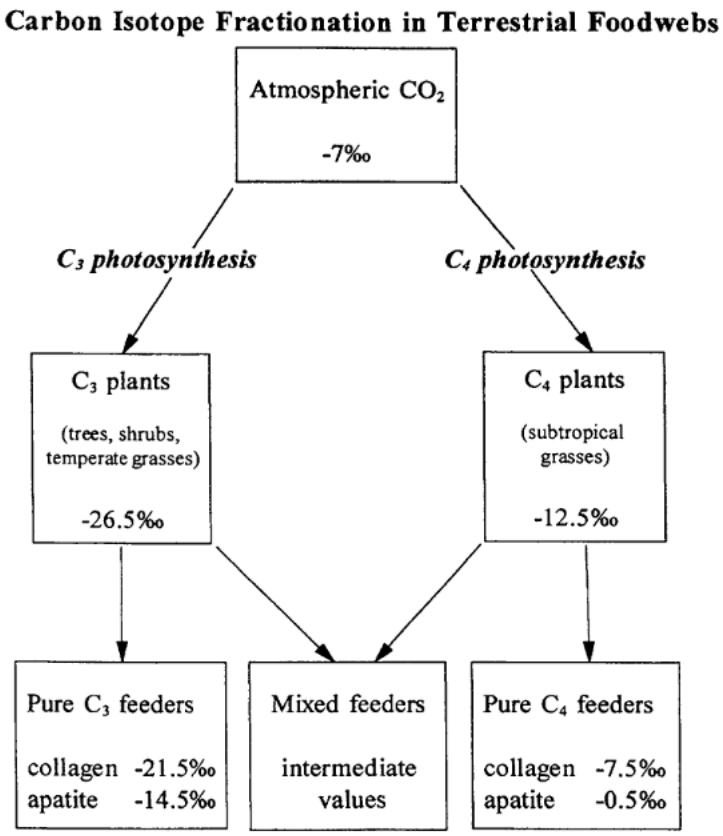

Figure 1: Flowchart with the $\delta^{13}C$ values for C_3 and C_4 plants, and the reflection into their consumers' bone composition for different diets (Tykot, 2004, p. 435).

averaging around –20‰. These include phytoplankton and algae, which are a source of food for many marine organisms (Lee-Thorp, 2008, p. 927). When humans eat these types of foods, the $\delta^{13}C$ value that is reflected in their bones will differ slightly: around +5‰ in samples taken from bone collagen (Tykot, 2004, p. 435). Figure 1 shows how these values differ for different plant based diets.

2.3.2. Nitrogen stable isotopes for diet reconstruction

Just like carbon, the element nitrogen exists in several isotopic forms. Two of these are stable isotopes that do not decay radioactively. The ^{14}N isotope is the most prevalent and makes up 99.6% of the stable nitrogen atoms on earth. The heavier isotope ^{15}N makes up 0.4% of the stable nitrogen atoms (Cartigny & Busigny, 2018, p. 1). These nitrogen isotopes naturally occur in all organisms, but the ratio of ^{15}N to ^{14}N varies. This is dependent on the trophic level that the organism occupies in the ecological food chain. When an organism digests food, its metabolism breaks down molecules containing nitrogen. Molecules containing the lighter ^{14}N break down faster than molecules with ^{15}N. Consequently, more ^{14}N than ^{15}N is excreted from the organism's body after the molecules are decomposed, leaving a relatively higher amount of ^{15}N in the body behind. This process repeats itself with every step in the food chain, leaving behind a higher amount of ^{15}N every time. Just like with carbon isotopes, the ratio of ^{15}N to ^{14}N is calculated by setting a sample against an international standard. This gives the $\delta^{15}N$ value in parts per mille (‰) (Larsen, 2015, p. 320). With every trophic level in the food chain, an increase of 2‰ to 6‰ of the $\delta^{15}N$ value can be measured in the tissues of organisms. The higher up the food chain, the higher the $\delta^{15}N$ value. A human diet containing meat and animal products like eggs and milk will therefore cause a higher $\delta^{15}N$ value than the consumption of a purely plant-based diet (Lee-Thorp, 2008, p. 928). The tissues of herbivores usually have a $\delta^{15}N$ value of around 6‰, while carnivores have an average around 9‰. The $\delta^{15}N$ value of omnivores like humans usually lie between these values. An even higher $\delta^{15}N$ value is caused by the consumption of marine products: food chains in marine ecosystems are often considerably longer than terrestrial food chains. However, these values can differ based on the conditions an organism lives in. Therefore, human $\delta^{15}N$ values should be compared to those of local flora and fauna in order to determine the trophic level in the local food web (Larsen, 2015, pp. 320–321).

2.3.3 Bone remains for stable isotope analysis

Carbon and nitrogen are both important components of human tissues. As explained above, the $\delta^{13}C$ and $\delta^{15}N$ values that are present in the foods consumed by humans will therefore be reflected in the

composition of their tissues. This also includes bones, which is often the only thing that is preserved of a person in archaeology. During a person's life, bone tissue is constantly remodelled. It takes on average 10 years for a bone to completely remodel. For archaeological bone remains, this means the $\delta^{13}C$ and $\delta^{15}N$ values in bone reflect the diet of the last 10 years of life the person lived (Lee-Thorp, 2008, p. 927). To study the $\delta^{13}C$ and $\delta^{15}N$ values in bone, collagen is used most often, as it is the largest component of bone tissues (Larsen, 2015, p. 302). The $\delta^{13}C$ and $\delta^{15}N$ values in bone collagen can be measured by analysing a sample with a mass spectrometer. A full elaboration of this technique can be found in section 3.5. Altogether, human bone found in an archaeological context makes a valuable source for the reconstruction of ancient human diet.

2.4 Previous stable isotope analysis studies on diet reconstruction

Many previous studies have successfully applied stable isotope analysis to reconstruct ancient diets. To illustrate their success, three examples will be presented. The first example is of the Wetwang slack site in the UK. The local diet at this Iron Age site was reconstructed using stable isotope analysis by Jay and Richards (2006). They found an average $\delta^{13}C$ value of –20.5±0.3‰ and an average $\delta^{15}N$ value of 9.6±0.5‰ for the 61 studied individuals. They attributed these values to a diet containing mainly terrestrial animal foods like meat, milk and eggs, but not a large amount of marine foods. In regions that have not been archaeologically researched much, stable isotope analysis can be valuable as well. Kuzmin et al. (2018) have researched the diet of individuals from the far eastern Russian site Cherepakha 13. Of the 11 studied individuals, the average $\delta^{13}C$ value was –10.2±0.8‰ and the average $\delta^{15}N$ value was 12.4±0.3‰. The $\delta^{13}C$ values are much higher for Cherepakha 13 than for Wetwang Slack, which can be ascribed to the high intake of C_4 plants, like millet, and marine foods at Cherepakha 13. The higher $\delta^{15}N$ value is also suggested to be caused by a high intake of marine foods. But not only on a local level can stable isotope analysis be applied. Recently, Pérez-Ramallo et al. (2022) have applied stable isotope analysis to several medieval northern Iberian sites. They studied and compared the dietary preferences at sites in the wider region, mainly focusing on social class. The $\delta^{13}C$ and $\delta^{15}N$ values differed significantly between rural, urban and elite populations. Elite populations had higher $\delta^{15}N$ values, suggesting higher animal and marine protein intake. These larger scale studies on isotopic data can be valuable for investigating the uniformity of diet in a broader region. The following chapter will discuss how this same method was used in this thesis, focusing on three Imperial Roman Italian cities.

Chapter 3. Materials and methods

In this chapter, the materials and methods will be discussed that were used to carry out the research. First, a description of the sites that are studied will be given. The location of the three cities that are studied are given in figure 2: Rome, Ostia and Pompeii. Each city and the sites that are studied within them will be discussed one by one. Context will be given on the environment and the location where the studied archaeological material was retrieved from. After that, the database will be presented that was used to retrieve the data on stable carbon and nitrogen isotopes from the sites, followed by the sample selection of this data. The methods that were used to carry out the stable isotope analysis by the consulted previous studies are discussed next. The chapter is concluded with a description of the tests used for data analysis.

Figure 2: Location of the Roman cities that are the subject of this research.

3.1 Rome: Casal Bertone and Castellaccio Europarco

The city of Rome was the beating heart of the Roman Empire, and had almost 1 million inhabitants during the Imperial period. The suburbs of Rome were also densely populated. In the suburbs, two sites are located that will be studied in this thesis. The *Casal Bertone* site lies close to the Roman centre, while the *Castellaccio Europarco* site lies more to the south of the suburbs. The location of the sites can be seen in figure 3. Below, both sites and their archaeological contexts will be discussed.

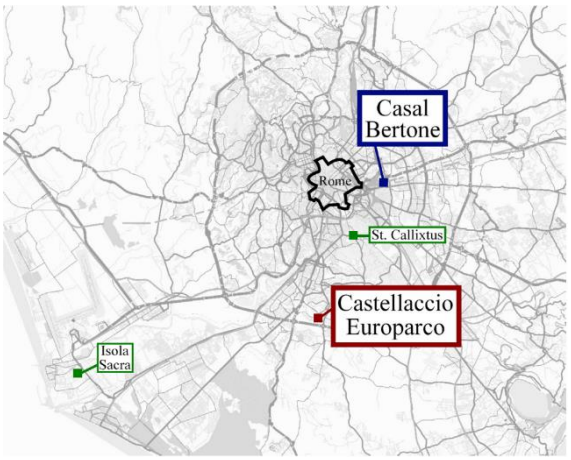

Figure 3: Locations of the Casal Bertone and Castellaccio Europarco sites in Rome. Isola Sacra, the site that is studied for Ostia, is also given. A fourth site, St. Callixtus is given, but is not studied in this thesis (Killgrove & Tykot, 2013, p. 30).

3.1.1 Casal Bertone

Casal Bertone is an archaeological site named after a present-day neighbourhood in Rome. It is located close to the centre of Rome, about 2 km from the ancient city centre walls. In the late '90s and early 2000s the site underwent several excavations. The most important findings were a mausoleum, a necropolis, an industrial complex and a villa, all dated to the Imperial period (31 BC – 476 AD). The villa was built with high quality building materials and accompanied by a nymphaeum, a set of decorated fountains. This lead the excavators to believe that its owners were quite wealthy. The industrial complex contained a building of more than 1000 m^2, with almost 100 basins that could be filled with water from pipes. It is therefore interpreted as a fullery or a tannery (Killgrove, 2010, pp. 73–75). A fullery, or Latin *fullonica,* was a workplace where clothing was dry cleaned and where woollen products were finished using basins to soak the clothing (Bradley, 2002, pp. 21, 24). A tannery, or Latin *officina coriarorum*, was a workplace where leather was tanned by soaking it in a basin using vegetable extracts (Van Driel-Murray, 2009, p. 2). It is thought that the mausoleum and necropolis on the site were closely related to the industrial complex.

The mausoleum consisted of a building with two rooms with mosaic floors and an underground burial chamber, dated between the 2nd and 3rd century AD (figure 4). The underground burial chamber contained 13 grave niches that were first excavated in 2003, revealing 38 individuals. Many of the niches contained several individuals. Later excavations uncovered even more skeletons, but these were not studied. The graves contained minimal grave goods (Killgrove, 2010, pp. 75–76). The burial of individuals in a mausoleum is usually linked to higher socioeconomic status. However, cases of lower class citizens being buried in mausolea are not out of the ordinary (Killgrove, 2010, p. 66).

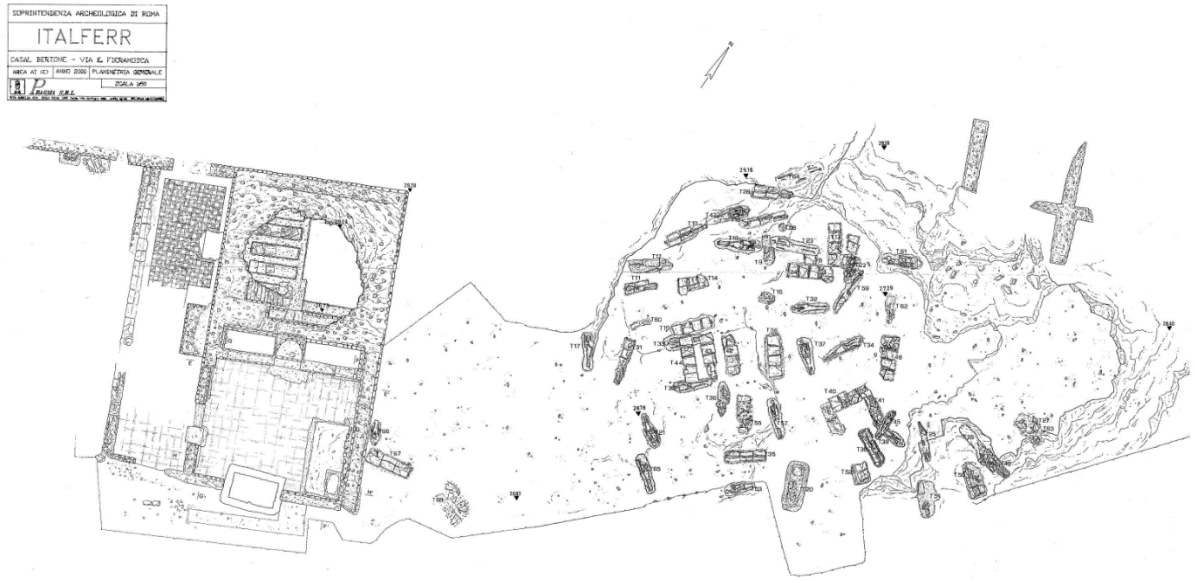

Figure 4: Map of the excavated mausoleum (left) and necropolis (right) at Casal Bertone (Killgrove, 2010, p. 77).

The necropolis was located right next to the mausoleum, containing around 70 graves (figure 4). The graves were of different types and had no similar spatial orientation. Over half of the graves were so-called *cappuccina* burials, that consist of a body covered in tiles, resembling a small tomb (Figure 5). This type of burial is associated with the lower classes of Roman society, such as laborers, slaves and freed slaves. One third of the graves were pit burials, and the rest of the graves were child burials in amphorae. The graves again contained minimal grave goods. In total, 100 individuals from the necropolis were studied osteologically (Killgrove, 2010, pp. 65, 76–78).

Figure 5: Cappuccina burial at Osteria del Curato, a region in Rome (Killgrove, 2010, p. 66).

The total amount of individuals found in the mausoleum and the necropolis is 138. Age categories from 0-5 years to 61-70 years are represented. More represented are individuals from the age categories 6-16 and 31-50. From the adults of which the sex could be determined, 54 were male and 24 were female. The underrepresentation of females could be due to several factors. Differences in burial practices between males and females could cause the latter to be underrepresented, but also the better preservation of male bones because of higher density. Maybe males more often used to work at fulleries and tanneries, causing them to be more represented at this site (Killgrove, 2010, pp. 78–81).

3.1.2 Castellaccio Europarco

Castellaccio Europarco is a site about 11 km outside ancient Rome's city center. Excavation of the site took place between 2003 and 2007, during which several buildings were uncovered next to the Via Laurentina (figure 6). This large road connected the southern Roman suburbs with the centre. The buildings that were found seemed to have had functions like storage, protection of animals and the processing of grapes and olives. A necropolis was found to the south of the buildings, containing almost 100 graves from three different time periods. The graves from the last phase belonged to the Imperial period and were dated between 50 and 175 CE. A total of 50 graves from this phase revealed 45 skeletons and 3 cremations. Most graves were pit burials with minimal grave goods, but some *cappuccina* burials were present as well. Like in Casal Bertone, this is a sign these burials were from individuals from the lower classes (Killgrove, 2010, pp. 82–85).

The total amount of studied individuals from the Imperial phase of the necropolis is 45. Age categories from 0-5 years to 41-50 years are represented. Most represented is the age category of 31-40 years. From the adults of which the sex could be determined, 24 were male and 7 were female. Again, this underrepresentation of females could be due to different burial practices between males and females or the better preservation of male bones because of higher density (Killgrove, 2010, pp. 86–87).

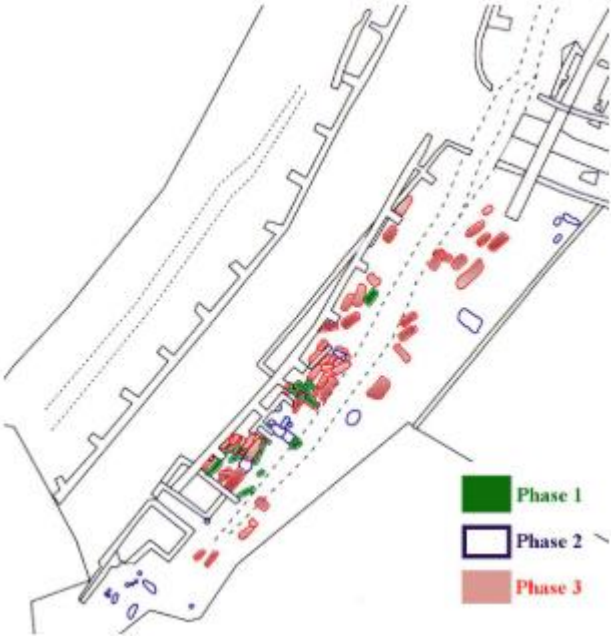

Figure 6: Map of the necropolis along the Via Laurentina at Castellaccio Europarco. The legend shows three phases, of which the third is the focus of this thesis (Killgrove, 2010, p. 82).

3.2 Ostia: Isola Sacra

Ostia was a coastal city located 23 km outside of Rome. It was situated at the mouth of the Tiber river that connected it to Rome. This made it an important city for both maritime trade and the distribution of products to Rome. Next to Ostia, the city *Portus Romae* is located, that also functioned as a harbour city connected to Rome. Both towns were thought to be inhabited by middle class traders (Lockau et al., 2019, p. 3). A necropolis that is located on the *Isola Sacra, "*sacred island", was situated between the two cities. This island was human made in 103 AD. It was used as a necropolis during the 2nd and 3rd century AD. Extensive excavations of the cemetery have taken place from 1925 onward, uncovering tombs and burials with over 1600 individuals (Prowse, 2001, pp. 85–86). A collection of skeletons this large is of tremendous importance for Roman osteoarchaeology, and has therefore been used in several studies (Bruun, 2010; Crowe et al., 2010; Prowse, 2001; Prowse et al., 2004; and Prowse et al., 2007).

The burials in the Isola Sacra necropolis consisted of tomb burials, but also cappuccina burials, simple pit burials and burials in amphorae, which mostly contained non-adults. The burials were located along the Via Flavia that connects Ostia with Portus Romae. It is thought that apart from the tomb burials, there was a 'field of the poor' where the poorer citizens were buried. A map of the necropolis is given in figure 7. None of the graves contained more than minimal grave goods like coins and lamps (Prowse, 2001, pp. 89–90).

The Ostia skeletal sample consists, as mentioned above, of more than 1600 individuals. Sources even estimate that there are 2000 individuals represented in the sample. A large part of the collection, however, consists of commingled remains. This leaves a total of about 1000 complete skeletons in the sample. Research on these skeletons is usually done on only parts of the collection, which makes it difficult to get a grasp of the demographics of the sample as a whole. Clear is however that the mortality rate in the population buried at Isola Sacra was high. This means that the buried individuals had a quite low average age-at-death (Prowse et al., 2007, p. 512).

Figure 7: Map of the Isola Sacra necropolis (Prowse, 2001, p.88).

3.3 Pompeii

Pompeii was a coastal city that was located about 200 km to the southeast of Rome. It was situated close to the Vesuvius volcano that caused its demise in 79 AD. The city was exceptionally well preserved by the ashes that covered it after the eruption. Because of this, the city has been subject to extensive research during the last centuries and it is still being excavated today. Excavations show habitation in the area from as early as the 7th century BC (Flohr & Wilson, 2017, p. 4). The city however only became a Roman ally at the beginning of the 3rd century BC, and was made a Roman colony in 80 BC (Guzzo,

2007, pp. 3–4). A substantial amount of Pompeiian inhabitants could afford more than just subsistence, which makes Pompeii a quite wealthy city. There was a lower class, that lived in modest houses or apartment buildings. About 25% of Pompeii's inhabitants were sub-elite, living in larger houses and regularly buying some types of elite goods. The richest 5% of Pompeii lived in the largest houses with ample access to luxurious goods (Flohr, 2017, pp. 79–80). Pompeii's hinterland was mainly used for agriculture to support the needs of the city, wine being the most produced agricultural product (De Simone, 2016, p. 35).

The skeletal sample that was used for the stable isotope analysis of Pompeii individuals differs from the skeletal samples from Rome and Ostia. The Pompeii skeletal sample does not come from a burial context, as the Vesuvius eruption caused people to die and immediately be buried under layers of volcanic ash. The individuals were thus retrieved from houses and streets. The skeletal material was, especially in the early days of Pompeii's excavation, not kept in their original context. After excavation, the skeletons were sorted by bone type and stored in already excavated houses. This makes the interpretation of skeletons and their context difficult. The skeletal material was generally preserved well, but some bones underwent discolouring by extreme heat from the volcanic ashes (Henneberg & Henneberg, 2006, pp. 24–25; Pate et al., 2016, p. 128).

The Pompeii skeletal sample consists of at least 500 skeletons. Previous studies of the skeletal material showed that the distribution of sex in the sample was about equal, males being represented slightly more (Lazer, 2017, p. 138). The age distribution cannot be compared one-on-one with the Rome and Ostia samples. The individuals in this sample did after all not die of natural causes, but of the Vesuvius eruption. The ages of the individuals will therefore represent a living population, and include younger ages than the Rome and Ostia samples. The sample included individuals of all ages, only infants were not represented. This occurs more often in archaeology and could be due to vulnerability of the smaller bones or to a lack of recognition of the smaller bones by excavators (Lazer, 2017, pp. 137–139).

3.4 Sample selection: isotopic data

The data on stable isotopes that is used for this research is retrieved from www.IsoArch.eu. This is an online open access database for isotopic data collected from archaeological studies from all over the world and from many different time periods. It is compiled with data on several different types of isotopes from human, animal, botanical and other organic samples that were analysed in archaeological research. Every entry is provided with all sources it was published in. Anyone visiting the database can start a query and select the region, time period, specifications on sex or age, and the

desired isotopic data. The outcome is a spreadsheet with all available data under the selected criteria (Salesse et al., 2018, p. 1051; Salesse et al., 2020). IsoArch is a helpful tool to gather and compare isotopic data from several different studies in the same region or same time period. It contributes to making isotopic data more accessible to a broader academic public.

For this research, IsoArch is a suitable tool to gather isotopic data from Rome, Ostia and Pompeii. A query was done by limiting the search region to Italy and the time period between 0 and 300 AD. The desired category of the samples was set to human without restrictions to the type of bone. As isotopic criteria, the $\delta^{13}C$ and $\delta^{15}N$ ratios were selected. This created a spreadsheet with all sites from the Imperial period in Italy with the desired isotope data. To research Rome, Ostia and Pompeii in particular, the data from the sites located in these cities was selected and extracted from the spreadsheet.

In order to obtain the most accurate results, a selection should be made of the collected data. The selection was made based on availability of data suitable for answering the research questions. To answer sub-question 1 and 2, data for both $\delta^{13}C$ and $\delta^{15}N$ from bone samples is necessary. To answer sub-question 3, data on sex is necessary, therefore only adults for whom sex could be estimated are included. Differences between adults and non-adults will not be studied in this thesis, because not all isotopic studies included data on non-adults. Non-adults will therefore be left out as a whole to avoid skewing of the results. Below, a description of the sample selection per city will be given. The final sample can be found in table 1.

The isotopic data on individuals from Rome originates from Killgrove (2010). Individuals of all ages were represented in the sample, but most were estimated older than 40 years. Data on non-adults was also collected, but not included in the sample for this thesis. Not all individuals could be determined for sex, therefore only the individuals of which the sex was determined were included in the sample. The data by Killgrove was used by several other studies that are referenced in table 1.

The isotopic data on individuals from Ostia originates from two studies. Prowse (2001, pp. 108–109) collected data from individuals between 15 and >45 years of age, most being from the >45 years category. Data on non-adults was also collected, but not included in the sample for this thesis. Sex could not be determined for all individuals, so only the individuals of which the sex was determined were included in the sample. The data by Prowse was used by several other studies that are referenced in table 1. Crowe et al. (2010, pp. 358–361) used the same sample as Prowse (2001), but also included data on new individuals from the same site. They collected data from individuals between 15 and 50+ years of age, most being of the 40-50 years category. Sex could not be determined for all individuals, so only the individuals of which the sex was determined were included in the sample.

The isotopic data on individuals from Pompeii originates from Pate et al. (2016, p. 182). Unfortunately, there were no age estimates for the individuals from this study. As there was no data on non-adults for the Pompeii site, it was decided to leave out non-adults as a whole for this thesis. On top of the data from Pate et al. (2016), the IsoArch database presented isotopic data on an additional 22 individuals from Pompeii by Nitsch (2012). These, however, did not have any sex specification and could therefore not be used for this thesis.

Table 1: Number of individuals studied per city and site (n), number of male individuals (M) and number of female individuals (F). The original source the data on the individuals is given in the last column.

Site	n	M	F	source
Rome	**24**	**13**	**11**	Killgrove, 2010; Killgrove & Montgomery, 2016 and Killgrove & Tykot, 2013.
Casal Bertone	16	9	7	
CB Necropolis	9	6	3	
CB Mausoleum	7	3	4	
Castellaccio Europarco	8	4	4	
Ostia	**156**	**109**	**47**	Bruun, 2010; Crowe et al., 2010; Prowse, 2001; Prowse et al., 2004 and Prowse et al., 2007
Pompeii	**31**	**12**	**19**	Pate et al., 2016

3.5 Methods for stable isotope analysis

The studies considered in this thesis applied laboratory procedures to the skeletal material to obtain the data on stable carbon and nitrogen isotopes per individual. The exact procedures differed slightly per study, but did contain the same main elements. The full procedures as described by the authors of the original studies are included in appendix B. Here, a short description of the main methods they carried out will be given.

First, bone collagen needed to be extracted from the skeletal material. The type of bone that was used for the extraction of bone collagen was not specified in every study. (Killgrove, 2010) and Prowse (2001) used femora, while Crowe et al. (2010) and Pate et al. (2016) did not specify the bone type they used. In general, the process of collagen extraction begins with the superficial cleaning and breaking into smaller pieces of the bone. Specimens of about 1-3 grams of bone are used for the further process. The bone specimens are demineralized using a concentration of hydrochloric acid (HCl) in water. Next, the bone specimens are soaked in a sodium hydroxide (NaOH) solution to remove contaminants. The specimens are then dried, either by freeze-drying them or by placing them in a drying oven, usually at low heat. After drying, the specimens are analysed with a mass spectrometer that measures the $\delta^{13}C$ and $\delta^{15}N$ values.

3.6 Data analysis

The analysis of the isotopic data was done using statistical tests in IBM SPSS statistics 27. Prior to the application of tests to search for significant differences, a normality test was done on all groups. This was done to make sure either parametric or non-parametric tests should be used. Parametric tests can be used when the data is normally distributed, while non-parametric tests are used for data that is not normally distributed (Fletcher & Lock, 1991, p. 74). As several of the groups were not normally distributed, it was decided that only non-parametric tests will be used. The results of the normality tests can be found in appendix C.

Two different types of tests were used to analyse and compare the isotopic data from the different cities. For comparisons between the sexes, a test of difference between two independent groups had to be used. The non-parametric test that is suitable for this type of analysis is the Mann-Whitney U test (Fletcher & Lock, 1991, p. 88). For comparisons between the three cities, a test of difference between three independent groups had to be used. The non-parametric test that is suitable for this type of analysis is the Kruskal-Wallis H test (Corder & Foreman, 2009, pp. 99–100).

Chapter 4. Results

This chapter will present the results of the analysis of the isotopic data from Rome, Ostia and Pompeii. Both stable carbon and nitrogen isotope data were studied for every city. First, differences between the sexes within every city are studied. Then, the data from the three cities are compared to each other to see if there are significant differences per city. Finally, a comparison of the sexes between the three cities is made. The entire dataset that was used for this thesis is presented in appendix A.

4.1 Rome

4.1.1 Casal Bertone: mausoleum

From the mausoleum at the Casal Bertone site in Rome 7 individuals, 3 male and 4 female, were analysed. The $\delta^{13}C$ values of the group as a whole had a mean of -18.300‰ with a standard deviation of 0.651. The $\delta^{15}N$ values had a mean of 9.429‰ with a standard deviation of 1.739.

4.1.2 Casal Bertone: necropolis

From the necropolis at the Casal Bertone site in Rome 9 individuals, 6 male and 3 female, were analysed. The $\delta^{13}C$ values of the group as a whole had a mean of -18.189‰ with a standard deviation of 0.501. The $\delta^{15}N$ values had a mean of 10.367‰ with a standard deviation of 1.316.

4.1.3 Castellaccio Europarco

From the Castellaccio Europarco site in Rome 8 individuals, 4 male and 4 female, were analysed. The $\delta^{13}C$ values of the group as a whole had a mean of -17.763‰ with a standard deviation of 2.208. The standard deviation is large, because there is one outlier with reference number 2623. This outlier has a $\delta^{13}C$ value of -12.5‰, which is much higher than the other individuals in the Rome sample. The $\delta^{15}N$ values had a mean of 9.425‰ with a standard deviation of 1.265.

4.1.4 Comparison of the Rome sites

From Rome, individuals from three separate contexts were analysed. To determine beforehand if these contexts are similar, the individuals from the three contexts are compared and tested for significant

differences. The three groups were compared using an independent samples Kruskal-Wallis test using pairwise comparisons. Both for $\delta^{13}C$ and $\delta^{15}N$, there were no significant differences between any of the groups (table 2). Because the three groups were not significantly different from each other, they will from now on be taken as one group to represent Rome.

Table 2: Pairwise statistical comparisons of $\delta^{13}C$ and $\delta^{15}N$ values between the Rome sites.

	Site	H(2)	p	n
$\delta^{13}C$	CB Mausoleum – CB Necropolis	0.135	0.969	16
	CB Necropolis – Castellaccio Europarco	0.715	0.833	17
	Castellaccio Europarco – CB Mausoleum	0.580	0.872	15
$\delta^{15}N$	CB Mausoleum – CB Necropolis	-4.889	0.784	16
	CB Necropolis – Castellaccio Europarco	5.889	0.086	17
	Castellaccio Europarco – CB Mausoleum	1.000	0.170	15

From the entire sample for Rome, 24 individuals were analysed. The $\delta^{13}C$ values for the entire group had a mean of -18.635‰ with a standard deviation of 1.317. The values ranged between -19.5‰ and -17.2‰, with one outlier of -12.5‰. The $\delta^{15}N$ values had a mean of 9.997‰ with a standard deviation of 1.447. The values ranged between 7.0‰ and 11.6‰. A total of 13 male and 11 female individuals were analysed. The males had a mean $\delta^{13}C$ value of -17.715‰ with a standard deviation of 1.659, and a mean $\delta^{15}N$ value of 9.939‰ with a standard deviation of 1.273. The females had a mean $\delta^{13}C$ value of -18.509‰ with a standard deviation of 0.561, and a mean $\delta^{15}N$ value of 9.590‰ with a standard deviation of 1.674.

A Mann-Whitney U test was performed to see if the stable carbon and nitrogen isotope values differed between male and female individuals. The test did not give a statistically significant difference between the sexes for the $\delta^{13}C$ values (U= 46.500, p = 0.142, n = 24), nor for $\delta^{15}N$ values (U = 64.000, p = 0.664, n = 24). This suggests that there was no apparent difference in diet between male and female individuals buried in the Casal Bertone and Castellaccio Europarco cemeteries in Rome.

4.2 Ostia

From the Isola Sacra site in Ostia 156 individuals were analysed. The $\delta^{13}C$ values of the group as a whole had a mean of -18.733‰ with a standard deviation of 0.341. The values ranged between -19.9‰ and -17.3‰. The $\delta^{15}N$ values had a mean of 11.099‰ with a standard deviation of 1.105. The values ranged between 7.5‰ and 15.3‰. A total of 109 male and 47 female individuals were analysed. The males

had a mean $\delta^{13}C$ value of -18.706‰ with a standard deviation of 0.364, and a mean $\delta^{15}N$ value of 11.141‰ with a standard deviation of 1.109. The females had a mean $\delta^{13}C$ value of -18.794‰ with a standard deviation of 0.275, and a mean $\delta^{15}N$ value of 11.000‰ with a standard deviation of 1.102.

A Mann-Whitney U test was performed to see if the stable carbon and nitrogen isotope values differed between male and female individuals. The test did not give a statistically significant difference between the sexes for the $\delta^{13}C$ (U= 2107.500, p = 0.077, n = 156), nor for $\delta^{15}N$ values (U = 2448.000, p = 0.661, n = 156). This suggests that there was no apparent difference in diet between male and female individuals buried in the Isola Sacra cemetery of Ostia.

4.3 Pompeii

From Pompeii a total of 31 individuals were analysed. The $\delta^{13}C$ values of the group as a whole had a mean of -18.610‰ with a standard deviation of 1.420. The values ranged between -20.1‰ and -14.4‰. The $\delta^{15}N$ values had a mean of 9.507‰ with a standard deviation of 1.177. The values ranged between 5.9‰ and 10.6‰. A total of 12 male and 19 female individuals were analysed. The males had a mean $\delta^{13}C$ value of -17.875‰ with a standard deviation of 1.861, and a mean $\delta^{15}N$ value of 9.600‰ with a standard deviation of 0.678. The females had a mean $\delta^{13}C$ value of -19.074‰ with a standard deviation of 0.809, and a mean $\delta^{15}N$ value of 9.447‰ with a standard deviation of 1.421.

A Mann-Whitney U test was performed to see if the stable carbon and nitrogen isotope values differed between male and female individuals. The test did not give a statistically significant difference between the sexes for the $\delta^{15}N$ values (U= 100.500, p = 0.589, n = 31). The test did however give a statistically significant difference for the $\delta^{13}C$ values (U = 62.000, p = 0.035, n = 31). These values were significantly higher for male individuals than for female individuals. This suggests that there was a difference in diet between male and female individuals from Pompeii.

4.4 City comparisons: general

The stable carbon and nitrogen isotope values were compared between the three cities to see if there were significant differences. First, the three groups as a whole were compared, which will be presented in this section. An overview of all means and standard deviations that were presented in the previous sections is given in table 3 below. In the scatter plot in figure 8, the stable carbon and nitrogen isotope values of each analysed individual are plotted in a graph. This scatter plot clearly shows all studied individuals from the three cities with shape and colour marked points. Slight differences in distribution

can be seen in this plot. For example, individuals from Ostia seem to have higher $\delta^{15}N$ values than those from Rome and Pompeii. Also, individuals from Pompeii, males in particular, seem to have higher $\delta^{13}C$ values than those from Rome and Ostia. To test if these differences are significant and if other differences are present, statistical analyses to compare the groups were carried out. These will be presented in the following sections.

Table 3: Mean values and standard deviations of the samples from Rome, Ostia and Pompeii, also divided between male and female groups.

		$\delta^{13}C$		$\delta^{15}N$	
	n	**Mean (‰)**	**SD**	**Mean (‰)**	**SD**
Rome	**24**	**-18.635**	**1.317**	**9.997**	**1.447**
Rome males	13	-17.715	1.659	9.939	1.273
Rome females	11	-18.509	0.561	9.590	1.674
Ostia	**156**	**-18.733**	**0.341**	**11.099**	**1.105**
Ostia males	109	-18.706	0.364	11.141	1.109
Ostia females	47	-18.794	0.275	11.000	1.102
Pompeii	**31**	**-18.610**	**1.420**	**9.507**	**1.177**
Pompeii males	12	-17.875	1.861	9.600	0.678
Pompeii females	19	-19.074	0.809	9.447	1.421

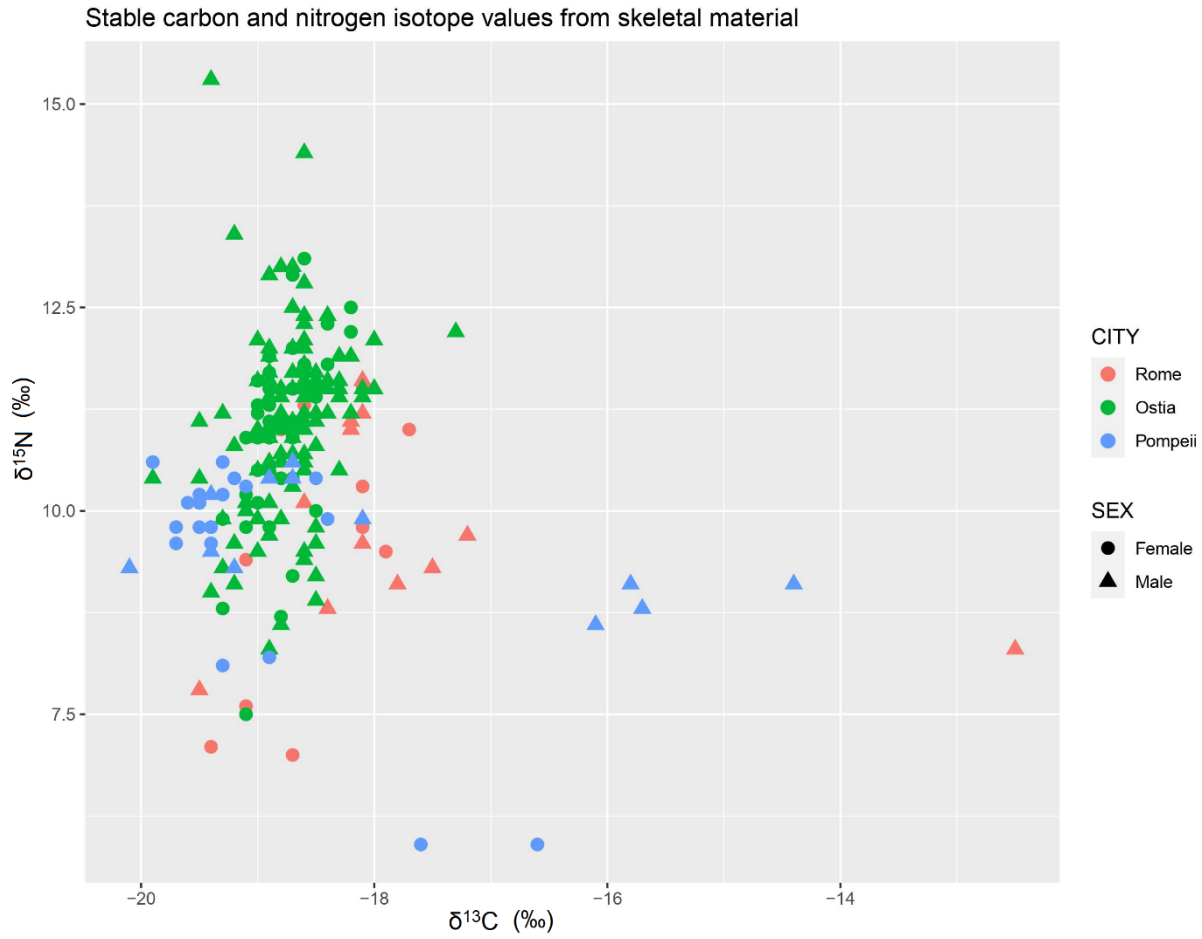

Figure 8: Scatter plot with the $\delta^{13}C$ values on the X-axis and the $\delta^{15}N$ values on the Y-axis. Every point represents one individual and is coloured by city and shaped by sex.

4.4.1 Stable carbon isotopes: general comparison

An independent samples Kruskal-Wallis H test was performed to determine if the three groups differed in $\delta^{13}C$ values. The test showed a statistically significant difference in $\delta^{13}C$ values between the three cities (H(2) = 20.600, p = <0.001, n = 211). Pairwise comparisons show that this significant difference lies between all three cities, as the p-values are lower than the threshold of 0.05 (table 4). The boxplot in figure 9 below shows that Rome has the highest median $\delta^{13}C$ value, while Pompeii has the lowest, but with many high outliers. These outliers cause Pompeii's mean to be higher than those of Rome and Ostia.

Table 4: Pairwise statistical comparison of the $\delta^{13}C$ values between the cities of males and females combined.

GEN.	City	H(2)	p	n
$\delta^{13}C$	Rome – Ostia	47.389	**<0.001**	180
	Ostia – Pompeii	27.090	**<0.001**	187
	Rome - Pompeii	74.479	**0.024**	55

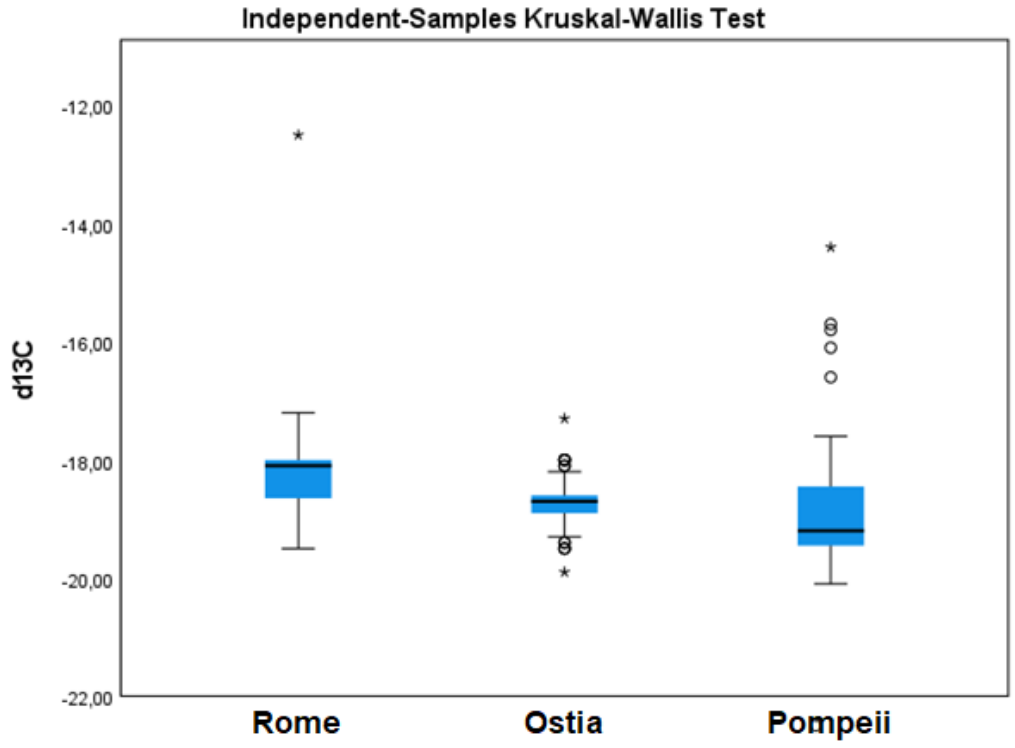

Figure 9: Boxplot of the $\delta^{13}C$ values per city of males and females combined.

4.4.2 Stable nitrogen isotopes: general comparison

An independent samples Kruskal-Wallis H test was performed to determine if the three groups differed in stable nitrogen isotope values. The test showed a statistically significant difference in $\delta^{15}N$ values between the three cities (H(2) = 51.731, p = <0.001, n = 211). Pairwise comparisons show that this significant difference lies between Ostia and Pompeii and between Ostia and Rome, as these p-values are lower than the threshold of 0.05 (table 5). Between Rome and Pompeii, no significant difference was found for $\delta^{15}N$. The boxplot in figure 10 shows that Ostia has the highest median $\delta^{15}N$ value, while Rome and Pompeii have similar median values.

Table 5: Pairwise statistical comparison of the $\delta^{15}N$ values between the cities of males and females combined.

GEN.	City	H(2)	p	n
$\delta^{15}N$	Rome – Ostia	-56.603	**<0.001**	180
	Ostia – Pompeii	76.557	**<0.001**	187
	Rome - Pompeii	19.954	0.687	55

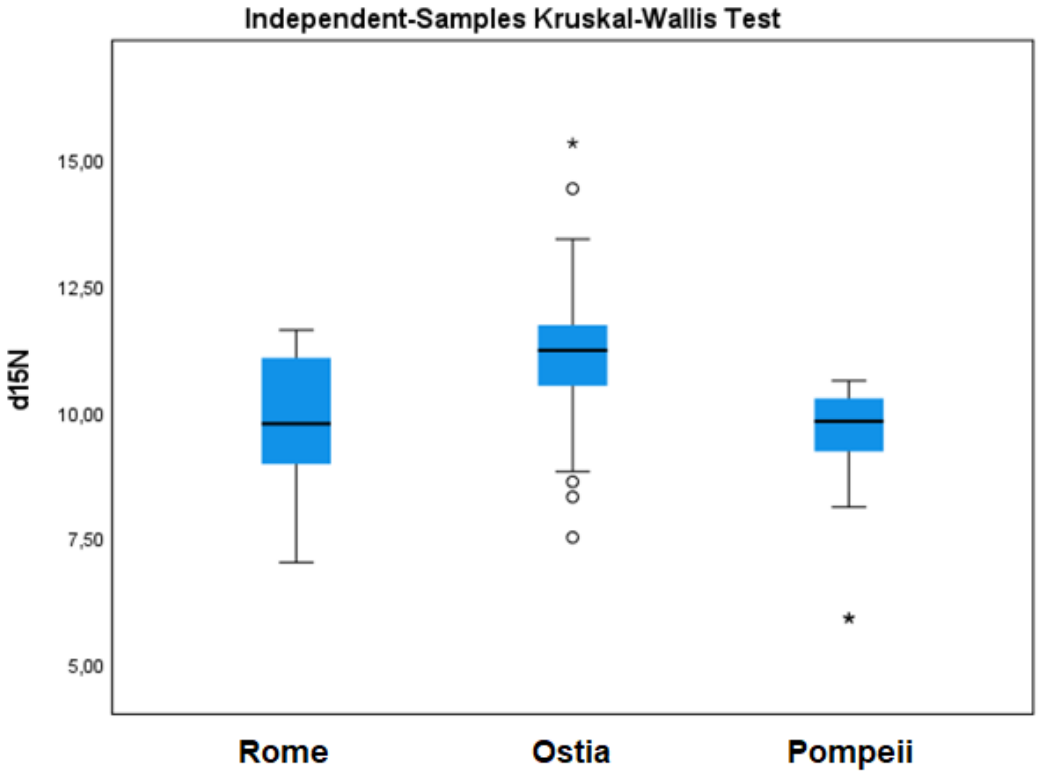

Figure 10: Boxplot of the $\delta^{15}N$ values per city of males and females combined.

4.5 City comparisons: males

For the analysis of sex dependency of stable carbon and nitrogen isotope values, a total of 134 male individuals were analysed. First the $\delta^{13}C$ values, then the $\delta^{15}N$ values were compared for every city.

4.5.1 Stable carbon isotopes: comparison males

An independent samples Kruskal-Wallis H test was performed to determine if the three groups of males differed in $\delta^{13}C$ values. The test showed a statistically significant difference in $\delta^{13}C$ values between the three cities (H(2) = 15.745, p = <0.001, n = 134). Pairwise comparisons show that this significant difference lies between Rome and Ostia and between Rome and Pompeii, as these p-values are lower than the threshold of 0.05 (table 6). The boxplot in figure 11 below shows that Rome has the highest median $\delta^{13}C$ value, while Ostia and Pompeii have similar median values.

Table 6: Pairwise statistical comparison of the $\delta^{13}C$ values of males between the cities.

MALE	City	H(2)	p	n
$\delta^{13}C$	Rome – Ostia	44.970	**<0.001**	122
	Ostia – Pompeii	-6.348	0.589	121
	Rome - Pompeii	15.470	**0.013**	25

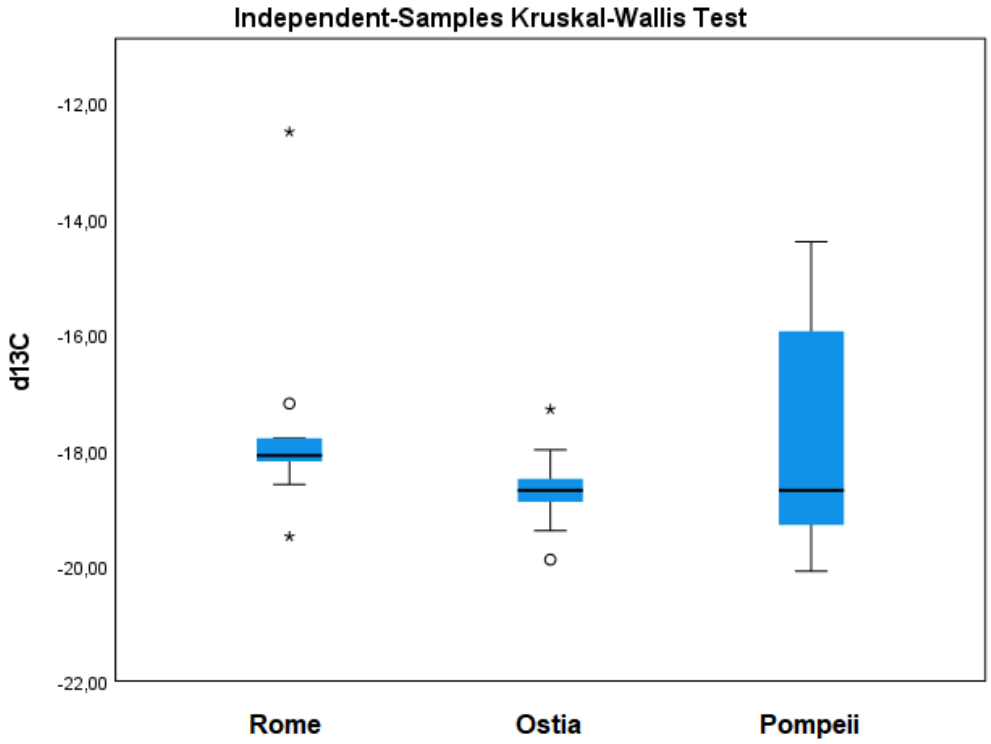

Figure 11: Boxplot of the $\delta^{13}C$ values of males per city.

4.5.2 Stable nitrogen isotopes: comparison males

An independent samples Kruskal-Wallis H test was performed to determine if the three groups of males differed in $\delta^{15}N$ values. The test showed a statistically significant difference in $\delta^{15}N$ values between the three cities (H(2) = 25.779, p = <0.001, n = 134). Pairwise comparisons show that this significant difference lies between Rome and Ostia and between Ostia and Pompeii, as these p-values are lower than the threshold of 0.05 (table 7). The boxplot in figure 12 below shows that Ostia has the highest median $\delta^{15}N$ value, while Rome and Pompeii have similar median values.

Table 7: Pairwise statistical comparison of the $\delta^{15}N$ values of males between the cities.

MALE	City	H(2)	p	n
$\delta^{15}N$	Rome – Ostia	-34.296	**0.003**	122
	Ostia – Pompeii	51.616	**<0.001**	121
	Rome - Pompeii	17.321	0.265	25

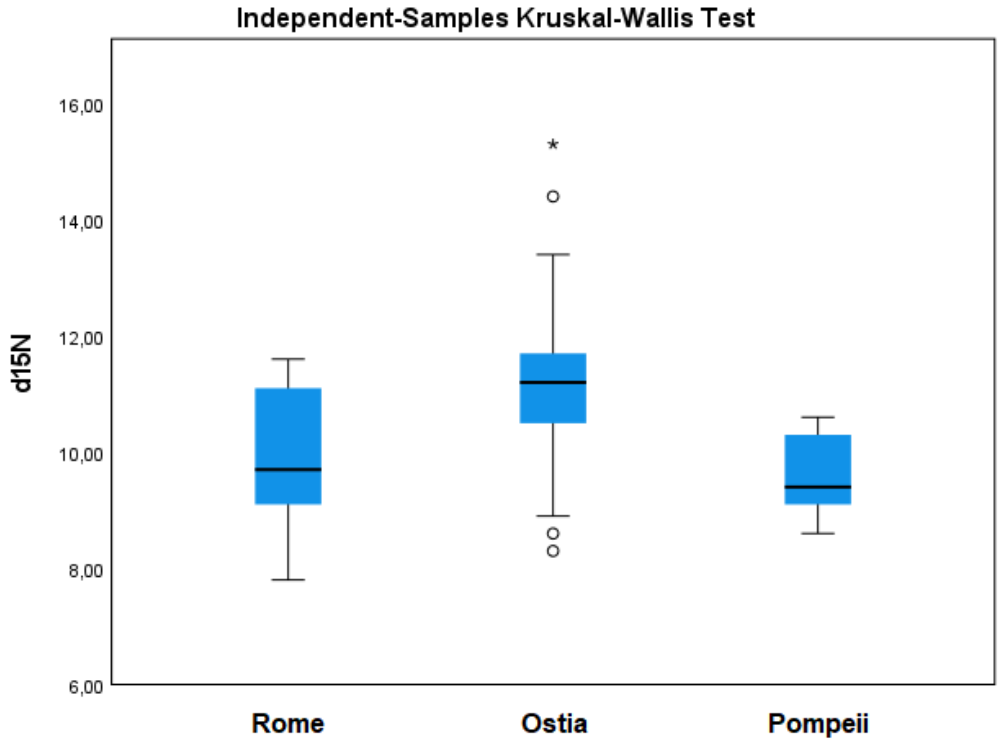

Figure 12: Boxplot of the $\delta^{15}N$ values of males per city.

4.6 City comparisons: females

For the analysis of the sex dependency of stable carbon and nitrogen isotope values, a total of 77 female individuals were analysed. First, the $\delta^{13}C$ values were compared for every city, followed by the $\delta^{15}N$ values.

4.6.1 Stable carbon isotopes: comparison females

An independent samples Kruskal-Wallis H test was performed to determine if the three groups of females differed in $\delta^{13}C$ values. The test showed a statistically significant difference in $\delta^{13}C$ values between the three cities (H(2) = 13.618, p = 0.001, n = 77). Pairwise comparisons show that this significant difference lies between Ostia and Pompeii and between Rome and Pompeii, as these p-values are lower than the threshold of 0.05 (table 8). The boxplot in figure 13 below shows that Pompeii has the lowest median $\delta^{13}C$ value, while Rome and Ostia have a similar median value.

Table 8: Pairwise statistical comparison of the $\delta^{13}C$ values of females between the cities.

FEM	City	H(2)	p	n
$\delta^{13}C$	Rome – Ostia	9.058	0.225	58
	Ostia – Pompeii	18.825	**0.002**	66
	Rome - Pompeii	27.883	**0.001**	30

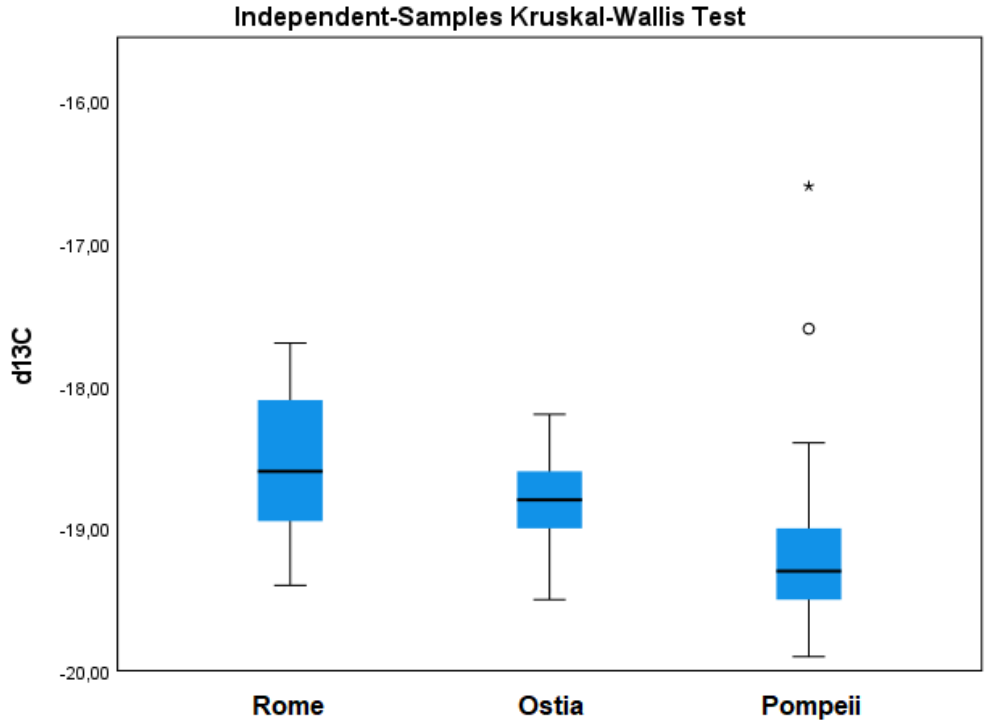

Figure 13: Boxplot of the $\delta^{13}C$ values of females per city.

4.6.2 Stable nitrogen isotopes: comparison females

An independent samples Kruskal-Wallis H test was performed to determine if the three groups of females differed in $\delta^{15}N$ values. The test showed a statistically significant difference in $\delta^{15}N$ values between the three cities (H(2) = 22.285, p = <0.001, n = 77). Pairwise comparisons show that this significant difference lies between Rome and Ostia and between Ostia and Pompeii, as these p-values are lower that the threshold of 0.05 (table 9). The boxplot in figure 14 below shows that Ostia has the highest median $\delta^{15}N$ value, while Rome and Pompeii have similar median values.

Table 9: Pairwise statistical comparison of the $\delta^{15}N$ values of females between the cities.

FEM	City	H(2)	p	n
$\delta^{15}N$	Rome – Ostia	-21.305	**0.004**	58
	Ostia – Pompeii	26.295	**<0.001**	66
	Rome - Pompeii	4.990	0.589	30

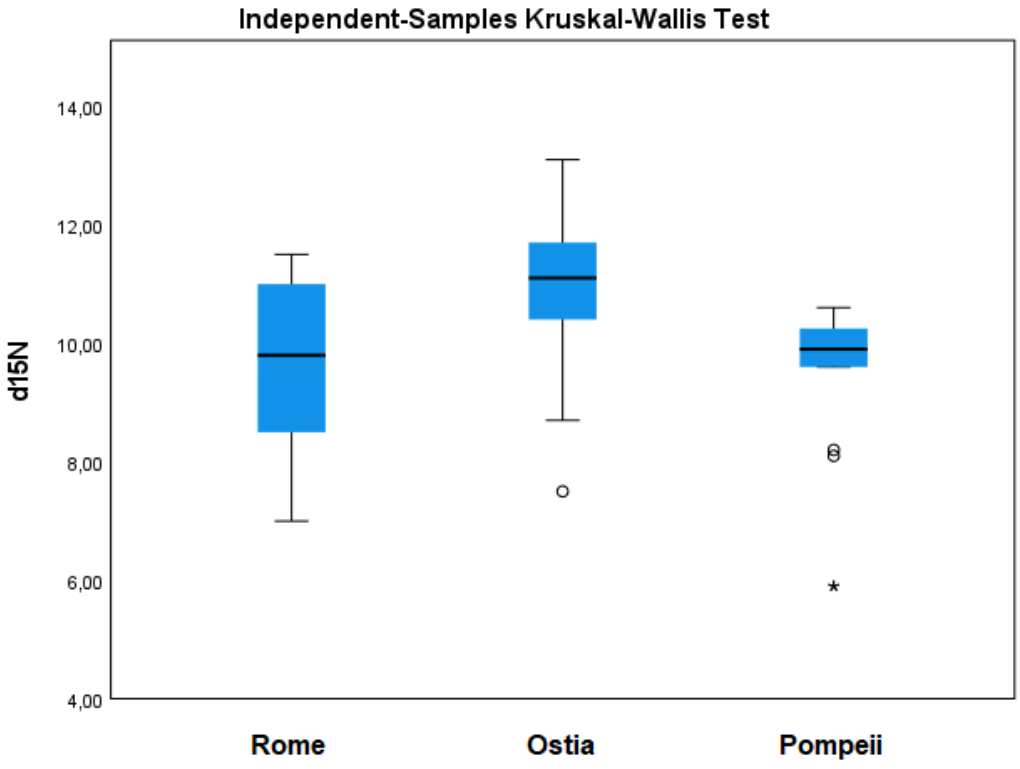

Figure 14: Boxplot of the $\delta^{15}N$ values of females per city.

4.7 Summary of the obtained results

The isotopic data from the three cities has been analysed in several ways. First, the data from within the cities was studied. The key focus there was on sex-dependent differences in stable carbon and

nitrogen isotope values within the cities. The analysis showed that only the stable carbon isotope values for Pompeii significantly differed between the sexes. The male individuals had significantly higher $\delta^{13}C$ values than the female individuals. The $\delta^{15}N$ values in Pompeii and the $\delta^{13}C$ and $\delta^{15}N$ values from the other two cities showed no significant differences between the sexes.

Next, the three cities were compared to each other as a whole, followed by comparisons of only the males and only the females from the three cities. The stable isotope values from the three cities differed from each other at several occasions. First, the general comparison between the cities showed that all three groups were significantly different from each other regarding $\delta^{13}C$ values. Rome had the highest median values, and Pompeii the lowest. Looking at the $\delta^{15}N$ values, Ostia significantly differed from Pompeii and Rome because it had higher values. Secondly, the comparison between the males from each city showed that the Rome group had significantly higher $\delta^{13}C$ values than Ostia and Pompeii. On the other hand, the $\delta^{15}N$ values in males from Ostia were significantly higher than those of Rome and Pompeii. Then finally, the comparison between the females from the three cities showed that females from Pompeii had significantly lower $\delta^{13}C$ values than those from Rome and Ostia. For the $\delta^{15}N$ values in females, again, Ostia had significantly higher values than Rome and Pompeii.

Chapter 5. Discussion

This chapter discusses the results that were presented in the previous chapter. They will be interpreted and the similarities and differences between the cities will be put into context. First, the city-internal analyses will be discussed, in which a close look will be taken at every city to discover their variety of diets. Similarities and differences between the sexes will also be discussed for each city. Next, the comparisons between the cities will be discussed. First, the city comparisons between the whole groups will be discussed, followed by a discussion of the male and female comparisons per city.

5.1 City-internal analysis

The stable isotope data from the three different cities can show us what the diet was of the individuals from the three Imperial Roman cities. The cities were individually analysed and the sexes were compared to each other to look for differences. Below, the results of these analyses will be discussed and interpreted by proposing possible factors that could have caused variation in the sample or differences between the sexes.

5.1.1 Rome

Based on the obtained results for the Rome sample, an interpretation of the average diet of the studied individuals can be made. The sample consisted of 24 individuals, of which 13 were male and 11 were female. The group had a mean $\delta^{13}C$ value of -18.635‰ and the values ranged between -19.5‰ and -17.2‰, with one outlier of -12.5‰. As was explained in section 2.3.1, a pure C_3 plant diet will give a $\delta^{13}C$ value around -21.5‰ and a pure C_4 plant diet will give a value around -7.5‰. This means that the studied individuals from Rome likely had a tendency towards the consumption of C_3 plants. These would probably include wheat, barley, oats and maybe also rice, because these were the main C_3 plants that were consumed in the Roman world (see section 2.2.1). The fact that the $\delta^{13}C$ values are higher than -21.5‰, however, shows us that the diet did not only contain C_3 plants. A small portion of the diet could have included C_4 plants like millet and sorghum, which is especially likely for the individuals with a higher $\delta^{13}C$ value. Marine resources could also be present in the diet due to these higher values. An even better way to show the proportion of marine resources in diet is by looking at the $\delta^{15}N$ values. The mean $\delta^{15}N$ value of the Rome sample was 9.997‰, and the values ranged from 7.0‰ to 11.6‰. As explained in section 2.3.2, a plant based diet will give a $\delta^{15}N$ value of around 6‰, while a carnivorous diet will give a value of around 9‰. A diet based on marine products will give an even higher value.

Because it is likely from the background literature that the diet of the Rome individuals consisted for a substantial amount of plants like cereals, the height of the 9.997‰ value is probably not caused by terrestrial animal resources alone. Small amounts of marine products were likely part of the diet of these individuals as well. This is supported by the original study by Killgrove (2010, p. 160) from which the stable isotope data was used: the $\delta^{15}N$ values in the human remains were more enriched than expected in comparison to the $\delta^{15}N$ values of local faunal remains. This implies that some marine intake must have been present. The diets within the Rome group do seem to have varied somewhat, as the individual with the lowest $\delta^{15}N$ value (7.0‰) probably ate mostly plants, while the individual with the highest $\delta^{15}N$ value (11.6‰) ate quite some marine products.

This reflection of diet from the stable isotope data can be compared to the most commonly eaten foods in the Roman Empire that were discussed in section 2.2. An ordinary Roman citizen would eat a substantial amount of bread and other cereal products, some simple types of animal products like sausage, eggs and cheese, and some preserved fish and other marine products. The stable isotope data from Rome is in line with this information: the stable carbon isotopes showed that C_3 plants, such as oats, wheat and barley, were one of the main components in the diet. The stable nitrogen isotopes suggested an intake of quite some animal and marine products. The context of the burials at the studied sites in Rome agree with the impression that these individuals were ordinary Roman citizens. The necropoles at Castellaccio Europarco and Casal Bertone both contained mainly pit burials and *cappuccina* burials that are associated with the lower classes. The buildings that were found in the vicinity of both sites were associated with labour like the processing of leather and food, which also suggests that the buried individuals were labourers. The mausoleum that was found at Casal Bertone, however, could have been for wealthier individuals. Yet, the diets of these individuals did not differ from the other Rome individuals. Either the sample from the mausoleum was too small to see significant differences in diet, or the diet did in fact not differ that much between the mausoleum and necropolis individuals. As mentioned in section 3.1.1, it is also possible that the individuals in this mausoleum did not differ in social class from the necropolis individuals.

The obtained results included one outlier with a very high $\delta^{13}C$ value that should be considered. The outlier in question is easily recognizable in figure 8: it is the datapoint to the far right of the graph. It has a $\delta^{13}C$ value of -12.5‰, which is much lower than the mean of the Rome individuals. The $\delta^{15}N$ value of 8.3‰ on the other hand, lies within the range of the Rome sample. The original study by Killgrove (2010, pp. 302–303) discussed this individual and concluded that they must have had a much more C_4 plant based diet than other individuals in the sample. This could include a large amount of millet, sorghum and/or beans, which would have led to such a high $\delta^{13}C$ value. The study also found, based on $\delta^{18}O$ values, that this person had immigrated into Rome from an area north of the city (Killgrove,

2010, p. 281). Perhaps their diet did not change after immigration, sticking to the diet of their homeland. Another possible reason that they mentioned was that this person ate an individualized diet, possibly due to a lack of resources or specific dietary preferences (Killgrove, 2010, pp. 302–303). Even though the Rome sample showed a fairly homogenous distribution of stable isotope values, this outlier does tell us that not everyone ate in a similar way.

When comparing the sexes within the Rome sample, there were no significant differences found in either the $\delta^{13}C$ or the $\delta^{15}N$ values. This means that there were no apparent differences in diet between males and females in Imperial Rome at the studied sites. It must be noted however, that three smaller groups were considered as one. Moreover, these groups and the group as a whole do not add up to a very large sample size. Because the resolution of these groups is quite low, there is a higher chance that a larger sample would yield different results. It can therefore not be ruled out that differences existed between the different sites and between the sexes. However, small sample size is a common problem in archaeology, and cannot be avoided. The obtained results will therefore, with some caution, be regarded as a true representation of the population at the studied site.

5.1.2 Ostia

For Ostia, the remains of 156 individuals, of which 109 males and 47 females, from the Isola Sacra site were studied. The group had a mean $\delta^{13}C$ value of -18.733‰ and the values ranged between -19.9‰ and -17.3‰. These values suggest that the studied individuals from Isola Sacra had a diet that was mostly centred around C_3 plants, as the values come close to the average of -21.5‰ of a pure C_3 plant diet. Some influence of C_4 plants and marine products is expected to have brought the values up a bit. The mean $\delta^{15}N$ value of the Ostia sample was 11.099‰ and the values ranged between 7.5‰ and 15.3‰. These values show that in addition to terrestrial animal products, the consumption of marine products must have made a contribution to the average diet in the Ostia sample: the values are higher than the average of 9‰ of a carnivorous diet. The original study by Prowse (2001, pp. 204–205) from which the data in this thesis is retrieved, also states that this level of nitrogen enrichment must have been caused by a significant marine intake. They state that the $\delta^{15}N$ values in the human samples are significantly higher than those of local fauna, which points at marine products as a considerable component of the diet. The range of $\delta^{15}N$ values in the Ostia sample is remarkably large, since the highest value is more than twice the lowest value. Looking at figure 8, it can be seen that the values are quite evenly distributed throughout the $\delta^{15}N$ range, with a few high and low extremes. This means that the intake of animal and marine products varied widely within the group. From almost only plant-based diets to diets with an increasing amount of animal products, to more marine dominated diets.

This last group can be compared to the individuals from the Russian Cherepakha 13 site, as discussed in section 2.4. These individuals were considered to have a diet based on mainly marine and terrestrial animal intake because of their mean $\delta^{15}N$ value of 12.4‰ (Kuzmin et al., 2018, p. 1617). The Ostia individuals with a similar value are therefore also expected to have a large marine and terrestrial animal intake.

This reflection of the diet in Ostia shows us, among other things, the importance of bread and cereal products made from C_3 and a small amount of C_4 plants. Moreover, it especially shows that marine products were an important aspect of the diet of most studied individuals. It is likely that the Isola Sacra sample included people from different socioeconomic classes, because many different types of burials were found. Tombs or mausolea were probably for the wealthier people, while cappuccina and pit burials were for the lower classes. This variety of represented social classes proves the assumption made in section 2.2.2 that fish and marine products, mainly the preserved types, were consumed by people of all classes. It could be expected that the variety of social classes also accounts for the large variety in $\delta^{15}N$ values. It would be likely that people buried in cappuccina and pit graves had a lower $\delta^{15}N$ values than people buried in tombs, due to lower marine intake. However, Prowse (2001, p. 117) examined if there was a relation between the stable carbon and nitrogen isotope values and the type of burial the remains were found in, but no significant differences were found.

The 109 male and 47 female individuals in this sample were compared to each other regarding their $\delta^{13}C$ and $\delta^{15}N$ values. This comparison showed no significant differences between the two groups. This suggests that there were no structural differences in diet between males and females that lived in Ostia during the Imperial period. The resolution of this sample is high because of the large sample size, which adds to the credibility of the outcome. However, the amount of females in the sample is less than half the amount of male individuals. The underrepresentation of females is a common archaeological problem that can have several reasons that were discussed in section 3.1: females could have undergone different burial practices, or the lower density of their bones could have caused their remains to decay more quickly. In the case of the Isola Sacra site, there were many more skeletons than the 156 studied individuals, but the latter were the only available skeletons with stable isotope data. It is possible that male skeletons were more intact than female skeletons due to larger density and were therefore more often suitable for stable isotope analysis. In the end, because the group size is filtered out as the mean is used for analyses, it does not have such a big influence. It should however be kept in mind that the resolution of the male group is twice as big as the female group.

5.1.3 Pompeii

For Pompeii, the remains of individuals were studied that were found spread throughout the city under the cover of volcanic ashes. The sample contained 31 individuals, of which 12 were male and 19 were female. The mean $\delta^{13}C$ value of the group as a whole was -18.610‰ and the values ranged between -20.1‰ and -14.4‰. The majority of the individuals therefore had a mainly C_3 plant based diet, with little influence of C_4 plants and marine products. The range, however, reveals that there were also individuals with a $\delta^{13}C$ value quite a bit higher than the mean. These individuals must have had a more substantial influence of C_4 plants or marine products. The mean $\delta^{15}N$ value of the Pompeii individuals was 9.507‰ and the values ranged between 5.9‰ and 10.6‰ This suggests that the overall diet contained a considerable amount of animal products, due to the mean value that is over 9‰. Some marine intake is also expected: the $\delta^{15}N$ value of dog remains from the site was 8.5‰, which is lower than the mean for the humans. Because dogs are carnivorous, the higher human $\delta^{15}N$ value is likely caused by an additional intake of marine products. The amount of terrestrial animal and marine intake however varies within the group. Individuals with the lowest values are expected to have consumed almost only plants, while those with the highest values ate quite some marine products. Two outliers are present with a value of 5.9‰, that are visible at the bottom of the graph in figure 8. These female individuals differ with more than 2‰ from the individual with the next lowest value of 8.2‰. The values of these two individuals show us that they likely had a fully plant based diet, as opposed to the more omnivorous diet the rest of the Pompeii group had. Their slightly higher $\delta^{13}C$ values suggest that they might also have eaten more C_4 plants, like millet, than the rest.

This reflection of the diet in Pompeii is in line with the expectations of ordinary Roman citizens. C_3 plants like oats, barley and wheat likely made up a large part of the diet, while animal and marine products were not out of the ordinary for most individuals. As discussed in section 3.3, Pompeii housed quite some wealthy inhabitants, but also a middle and lower class. It is however not clear what class the studied individuals belonged to: their bodies were retrieved from streets and houses because they died from the Vesuvius eruption. They were not buried in graves and therefore no burial context is present that could give us a clue as to what social class these people belonged to. We can only assume that these individuals were a mix of middle and lower class citizens, as was the main makeup of Pompeii's inhabitants. Moreover, it is not unlikely that the wealthier citizens had a better means of fleeing the natural disaster that caused the city to be buried, such as a boat or a second house in the area. The poorer citizens might have stayed behind and got killed by the eruption. This is supported by the fact that the stable isotope values reflect a diet of ordinary Roman citizens.

One thing that is important to note about the Pompeii sample, is that it's individuals did not die under 'normal' circumstances. They did not die of a natural cause, which means they probably did not suffer from severe health issues before their death. As was explained in section 2.3.3, bone reflects approximately the last 10 years of an individual's life. For individuals that died of a natural cause, this means that the chance is higher that health issues are reflected in their bones. This means that the Pompeii sample might give an even better reflection of diet in a living population, as most of them would have been healthy. It is important to keep that in mind when interpreting the results and when comparing the sample to other cities.

The Pompeii sample was previously studied by Pate et al. (2016) to look for differences between the sexes in stable isotope ratios. Repeating their analysis has confirmed the results of their study: a significant difference in the $\delta^{13}C$ values between males and females was present, but no difference in $\delta^{15}N$ values. The males had a significantly higher $\delta^{13}C$ value than females. They ascribed this to a difference in marine product intake: the males would have structurally consumed more marine products than females (Pate et al., 2016, p. 130). As was explained in section 2.3.1, marine plants have a signature $\delta^{13}C$ value around -20‰. When corrected with the +5‰ as it will be reflected in bone collagen, the value of a marine based diet will be around -15‰. The Pompeii males had a mean $\delta^{13}C$ value of -17.875‰, which indeed lies closer to the -15‰ than the female mean of -19.074‰. Moreover, the values of the males varied more than those of the females. In figure 8 it is clearly visible that four individuals have values between -16‰ and -14‰, which is distinctly higher than the mean of all Pompeii individuals. Pate et al. (2016, pp. 128, 130) suggest that the marine intake of these individuals was likely based on lower trophic level foods, because the $\delta^{15}N$ values do not show enrichment above -9‰ which would be expected for considerable marine intake. They also found that a marine product from a lower trophic level is *garum*, a fermented fish sauce that was a popular food in the Roman empire. Pate et al. (2016, pp. 129–130) confirmed that the $\delta^{15}N$ value of *garum* is 4.9‰, which means it was probably made of smaller fish at the beginning of a food chain. These results show that at least for the studied sample, it is likely that Pompeiian males more often ate substantial amounts of *garum* than females.

Recently, another stable isotope analysis study was done at the nearby city Herculaneum, that was also covered by the ashes of the Vesuvius eruption in 79 AD. This study showed a similar tendency for males to consume more marine products than females. They ascribed this difference to males being more involved in fishery and having higher social status that would allow them more access to marine products (Soncin et al., 2021, p. 3). It is possible that Pompeii males more often consumed marine products for the same reasons. Therefore, there might have been specific gender roles relating to marine consumption in both Pompeii and Herculaneum. It might even be that these gender roles are

reflections of an indigenous 'non-Roman' or pre-Roman culture. Further studies into gender roles in the Bay of Naples and the Roman world in general would be helpful to confirm this view.

5.2 City comparisons

Following the city-internal analysis, the samples from the three cities were compared to each other. First, a general comparison was done, followed by a comparison of the males and females between the cities. Below, the results of these comparisons will be discussed and interpreted by proposing possible factors that could have caused differences between the cities.

5.2.1 General comparison

Looking at the previous sections, it seems that the diets in Rome, Ostia and Pompeii mostly contain the same components. The three groups all show a tendency towards the consumption of C_3 plants based on their $\delta^{13}C$ values. This means that for most individuals, wheat, barley and/or oats were their main source of cereal consumption. Based on the $\delta^{15}N$ values in the different cities, it has become clear that animal products were consumed by most, which would probably include the most affordable kinds like sausage, eggs and cheese. Most individuals in each group also consumed some amount of marine products, which could include preserved salted fish and the popular Roman fish sauce *garum*.

However, the cities were not entirely similar regarding their diets. Several differences are present between the $\delta^{13}C$ and the $\delta^{15}N$ values of the groups. First, the statistical analyses pointed out that all three cities significantly differ from each other regarding their $\delta^{13}C$ values. From the mean values this is not directly evident, but the median values depicted in figure 9 represent the differences better. Mean values are easily influenced by outliers, so for a skewed distribution, the median is best used (Witte & Witte, 2006, p. 64). These are depicted with the bold black lines in figure 9, and show that Rome had the highest median $\delta^{13}C$ value and Pompeii the lowest. Due to this, the Rome sample seems to have had a slightly larger intake of either C_4 plants or marine foods. Because Rome was not located near the coast, it would not be likely for its inhabitants to have more marine consumption than those from Pompeii and Ostia. More likely would be a slightly larger C_4 plant consumption. Millet is a C_4 plant that was available to Romans, but often associated with food shortages and poorer consumers (Killgrove & Tykot, 2013, p. 36). A study of $\delta^{13}C$ values from bone apatite instead of collagen was done on the same Rome sample that this thesis has used. The study showed that in the more suburban Castellaccio Europarco the $\delta^{13}C_{ap}$ values were higher than in Casal Bertone, which pointed at a higher intake of millet (Killgrove & Tykot, 2013, p. 36). This might mean that in more suburban areas, wheat,

barley and oats were more often substituted with millet than in the urban contexts of Ostia and Pompeii. The inhabitants of Pompeii, on the other hand, might have had better access to wheat, barley and oats, causing their $\delta^{13}C$ values to be the highest of all cities. The four Pompeii individuals with $\delta^{13}C$ values between -16‰ and -14‰ might have also had similar access to wheat, barley and oats, but their $\delta^{13}C$ values rose anyway because of higher marine intake.

A more distinct difference can be found when looking at the $\delta^{15}N$ values. The statistical analysis showed that the Ostia sample differed significantly from the Rome and Pompeii samples. The latter two did not have significant differences. Ostia's $\delta^{15}N$ values were significantly higher, which suggests that these individuals ate considerably more marine products than those from Rome and Pompeii. To find a cause for this occurrence, we can look in different directions. First, the location of the city might have influenced marine consumption. Ostia is a coastal city, which is a logical reason for its inhabitants to eat more marine products. Marine foods, probably fresh as well, must have been easily accessible. For a city like Rome, the marine products would first have to be transported over a longer distance which would have made them less accessible. However, location cannot be the only factor at play: Pompeii is also a coastal city, but does not show the same level of $\delta^{15}N$ enrichment as Ostia.

Another reason we could look at is a difference in social class. If Ostia's inhabitants were more wealthy, they might have been able to afford more marine products. However, there are no indications that the social classes of the samples from the three cities differed significantly. All three samples are thought to include mainly middle and lower class citizens, including labourers and traders. No specific evidence is present that elite class citizens are part of the samples from the three cities. The fact that none of the burials from Ostia and Rome contained a large amount of grave goods supports this.

More likely to be of influence is the size of the harbours of Ostia and Pompeii. Ostia, together with Portus Romae, functioned as the main harbour connected to Rome during the Imperial period. The harbour is thought to have been more than large enough to provide space for all ships destined for Rome. Its connected basins had a total size of around 233 ha (Steinby, 2020, p. 37). Pompeii's harbour, on the other hand, is yet to be found. There is thus no clear indication of its size, but it is unlikely to have been as large as the harbour of Ostia and Portus Romae. Pompeii probably provided for some of the towns in its hinterland, but Pompeii itself only had around 10.000 inhabitants (Flohr & Wilson, 2017, pp. 13–14). Its harbour is unlikely to have provided for more people than Rome's inhabitants, which is thought to have reached 1 million in the Imperial period. Ostia's access to such a large amount of maritime trade products might have made marine consumption easier than for Pompeii's inhabitants. Moreover, Ostia is characterized as a city of traders, as mentioned in section 3.2. This

could mean that a larger proportion of the city's inhabitants was involved with marine trade than in Pompeii, and therefore have even more often have access to marine foods.

Overall, there might be several factors at play that could have caused Ostia to have a higher marine intake than Rome and Pompeii. A combination of its location at the coast and the large harbour with a lot of maritime trade activity is a plausible explanation, but more factors could have had an influence. Future research could shine a light on what possible other explanations there could be.

5.2.2 Comparison of males

For the comparison between the males of the three cities, 13 males from Rome were studied, 109 from Ostia and 12 from Pompeii. The statistical analysis showed that the Rome males had significantly higher $\delta^{13}C$ values than those from Ostia and Pompeii. This is in line with the results of the general comparison. It seems that the Rome males ate slightly more C_4 plants like millet, that caused their $\delta^{13}C$ values to rise. The Ostia and Pompeii samples did not differ significantly, while they did differ in the general comparison. This could have been caused by the large influence the four male outliers in the Pompeii sample had on the mean and median values of the sample. While in the general comparison this influence was not so big due to the females with lower values that were present in the sample, it increased when they were excluded. The mean and median $\delta^{13}C$ values therefore increased in the male Pompeii sample, causing the sample to be more similar to the male Ostia sample.

The $\delta^{15}N$ values were also compared between the males of each city, which showed a similar pattern to the general comparison: Ostia had significantly higher $\delta^{15}N$ values than Rome and Pompeii. The Ostia males therefore likely had a higher marine intake than the males of Rome and Pompeii. This pattern is likely also caused by a combination of factors that were discussed above. Ostia's location at the coast must have given the males there quite good access to marine foods. Adding up to that, the harbour at Ostia was very large, creating more opportunity for marine products to be available to Ostia's males.

5.2.3 Comparison of females

For the comparison between the females of the three cities, 11 females from Rome were studied, 47 from Ostia and 19 from Pompeii. The statistical analysis showed that the Pompeii females had significantly lower $\delta^{13}C$ values than those from Rome and Ostia. These lower values could be ascribed to a slightly higher consumption of C_3 plants like wheat, barley and oats than the individuals from the

Rome and Ostia samples. It is also possible that these lower $\delta^{13}C$ values in Pompeii females are caused by a lower consumption of marine foods. We have seen in section 5.1.3 that Pompeii males had a higher marine consumption than females due to higher $\delta^{13}C$ values. It is possible that the gender roles that might have caused this difference were not present in Rome and Ostia. Therefore, lower consumption of marine products by females might have been a local phenomenon in Pompeii, causing the $\delta^{13}C$ values of females from Rome and Ostia to be higher.

The analysis of $\delta^{15}N$ values between the females of the three cities showed that just like in the general comparison, Ostia's females had significantly higher values than those from Rome and Pompeii. This means that females from Ostia likely had a considerably higher marine intake than females from the other cities. Here too, the most probable cause is a combination of factors. Ostia's coastal location and its large marine trading harbour together could have provided for considerable access to marine foods.

Chapter 6. Conclusion

This thesis has aimed to discover if dietary differences were present within and between three Imperial Roman cities. The main focus was to study stable isotope data from skeletal remains found in these cities and compare the data to each other. Differences in stable isotope data are indicators of dietary differences and can be ascribed to a variety of factors. Understanding these differences and their possible causes can give a deeper knowledge of day to day life in Imperial Roman cities. It could also tell us how diverse the different cities in Roman Italy were. Therefore, the research question that this thesis has tried to answer is: "To what extent do local and regional factors influence the human diet in Roman Italy between 0 and 300 CE, as seen through stable isotopes?". To conclude this thesis, an answer to this question can now be formulated.

6.1 Answering the research questions

The main research question can be answered by considering the answers to the three sub-questions that were posed. The first sub-question was: "What differences are observed in $\delta^{13}C$ ratios within and between the archaeological sites in Rome, Ostia and Pompeii?". Within the three cities, the diets were varied, but did form a coherent group. In some cases there were outliers that were different from the rest of the group. For example, in the Rome sample, one individual had a much higher $\delta^{13}C$ value than the rest of the group. This could have been caused by a high millet consumption. Also, there were four outliers in the Pompeii sample that had higher $\delta^{13}C$ values than the rest, which was likely caused by the consumption of low trophic level marine products. Between the cities, there were also significant differences between the $\delta^{13}C$ values. Rome had the highest value, which could be caused by a larger intake of C_4 plants like millet. The suburban location of the Rome sites are more often associated with food shortages that are linked to millet consumption. The individuals from the urban Pompeii had the lowest $\delta^{13}C$ values, so they might have had better access to C_3 plants that caused their $\delta^{13}C$ values to be lower.

Next, the second sub-question was: "What differences are observed in $\delta^{15}N$ ratios within and between the archaeological sites in Rome, Ostia and Pompeii?". Within the cities, there was quite a lot of variation. Some extremes were present, but these did not differ as much from the rest as the outliers in the $\delta^{13}C$ distribution. For Ostia, there were some extremes with high $\delta^{15}N$ values caused by high marine consumption. For Pompeii, there were two female individuals with a considerably lower $\delta^{15}N$ value than the rest, which could be attributed to a plant based diet. Between the cities, there was a significant difference between the Ostia group and the Rome and Pompeii groups, which did not differ

from each other. The Ostia group had significantly higher $\delta^{15}N$ values, which is likely caused by high marine consumption. The reason for this difference can be ascribed to Ostia's location at the coast and its large trading harbour that could have provided for plenty of marine products.

Finally, the third sub-question was: "What differences are observed between the sexes within and between the archaeological sites in Rome, Ostia and Pompeii?". Within the three cities, the only difference that was observed was a difference between the males and females from Pompeii. Ostia and Rome did not show any sex-related differences. Pompeii's males had a significantly higher $\delta^{13}C$ value, which could be ascribed to a larger intake of low trophic level marine products, such as garum. The comparison between the males of each city and the females of each city showed similar differences as the comparison of the group as a whole. For the males, the $\delta^{13}C$ values were significantly higher in Rome than in the other cities, which could again be ascribed to higher millet consumption. The $\delta^{13}C$ values of the Pompeii females were significantly lower than the females from Rome and Ostia. This could be caused by a higher C_3 plant consumption due to better access in the urban area. It could possibly also be caused by lower marine consumption due to the difference in gender roles that seems to be present in Pompeii. For both the male and the female comparisons between the cities, the $\delta^{15}N$ values were significantly higher in the Ostia samples than in the Rome and Pompeii samples. In both cases, this is likely caused by higher marine consumption due to Ostia's coastal location and plenty of access to marine products from the large harbour.

Combining these answers tells us how to answer the main research question. We have seen that many factors contribute to the diet in these three Imperial Roman cities. The diet was influenced by social, economic, and locational factors that were different for every city. In Pompeii, we saw that gender roles likely influenced the consumption of marine products, while in Rome and Ostia there was no difference between the sexes. In Ostia, we saw that both the location at the coast, and the large trading harbour likely caused a higher consumption of marine foods. In Rome, we saw that the suburban location where the sample was retrieved might have caused a higher consumption of millet, due to the higher famine risk there. It can therefore be concluded that the several significant differences that were found between the cities show us that a uniform diet was not present in these Imperial Roman cities. Instead, several factors influence the diets that cause them to be diverse throughout the Italian peninsula.

This brings us back to the beginning of this thesis, where it was questioned if a uniform Roman culture existed. With the new insights that were collected in this thesis, we should consider that cultural aspects like diet can be influenced by many different factors. Just like the diets in Rome, Ostia and Pompeii, many other cultural aspects can differ due to a variety of local influences. A purely 'uniform

culture' would therefore not be able to exist over a large area, because of the many different local factors. To see if this is really the case, it would be best to expand the research to a larger area, including more cities and possibly also rural areas. In the next section, these possibilities for future research will be discussed.

6.2 Suggestions for future research

This thesis has shown that the diet in Imperial Roman Italy was diverse, and differences were present within and between cities. However, improvements can be made to understand these differences even better, and on a larger scale. Future research could address the limitations of the current research and improve and expand on it. As a first point of improvement to this thesis, it would be beneficial to increase the sample sizes of Rome and Pompeii to a similar size as Ostia. This increases the resolution of the samples and can give a more accurate representation of the diet in these cities. Unfortunately, there is no abundance of stable isotope data available from Imperial Roman sites in Italy. The IsoArch database did not include more suitable data on sites in Rome, Ostia or Pompeii than was used for this thesis. Of course, any stable isotope studies that will be done in the near future could be used, but as of now, that is not an option yet.

Instead, to get a broader view of the diet in Imperial Roman Italy, additional stable isotope data from other cities could be used. This would create a valuable insight into the diversity of Roman diet over a larger area, allowing implications to be made on the diversity of Roman culture in general. Additional stable isotope data is present in the IsoArch database on Imperial Roman sites in Italy. These include samples of considerable size from Herculaneum, Velia and Vagnari. Using this data for a broader dietary analysis in Imperial Roman Italy is a good starting point for a future study.

In addition to that, similar studies could be done that are focused on different time periods in the same area, such as the Republican era. Comparing dietary data from the Republican era to the data from this thesis could show changes in diet over time. It is possible that the diet became more uniform in the Imperial period, which can be proven by comparing the data to the previous period. Overall, there are a lot of possibilities for future research, as there is still a lot to uncover. Connecting existing studies on stable isotope analysis can help us understand ancient diet in a broader context.

Abstract

Roman Italy was the core of the Roman Empire during the Imperial period. Many Roman Italian cities were politically and socioeconomically influenced by the Roman rule that radiated from its capitol. The outdated concept of 'Romanization' caused historians to believe the Roman rule came with a pure Roman culture that was imposed on conquered territories. However, more recently it has been suggested that this 'Roman culture' was not as uniform, but was an ongoing interaction between the cultures of indigenous peoples and Roman influences. One important aspect of culture is diet: the foods that people ate on a day to day basis. The diets of individual Roman Italian cities have been researched in the past. It is however unclear whether the diets in these cities were uniform, or more dependent on regional factors. This thesis aims to study the diet in three Imperial Roman Italian cities and compare them to each other. The inhabitants' diets can be studied by looking at the ratios of stable carbon and nitrogen isotopes extracted from bone from human burials. Stable carbon isotopes can give insight in the types of plants that were eaten, while stable nitrogen isotopes can show the amount of animal products and seafood that was consumed. The isotopic data from the three cities was retrieved from the IsoArch database. Statistical analyses were performed to see if any differences within and between the cities were present. These analyses showed that in the Pompeii sample, there was a significant difference in marine food consumption between the sexes, possibly caused by a difference in gender roles. Between the cities, there were differences in the types of plants that were consumed, showing that perhaps Roman suburban citizens more often dealt with food shortages. In addition to that, the Ostia sample showed a significantly higher seafood consumption than the other two cities, which can be attributed to its location at the coast and the large trading harbour nearby. These results make us believe that the diet in Roman Italian cities was not as uniform, and not necessarily ruled by influences from the Roman rule.

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Appendix A: Isotopic dataset

	CITY	SITE NAME	REF NR ISOARCH	SEX	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
1	Rome	Casal Bertone Mausoleum	2547	Female	-19.4	7.1
2	Rome	Casal Bertone Mausoleum	2550	Female	-18.1	10.3
3	Rome	Casal Bertone Mausoleum	2557	Female	-18.7	7.0
4	Rome	Casal Bertone Mausoleum	2562	Female	-17.7	11.0
5	Rome	Casal Bertone Mausoleum	2545	Male	-18.6	10.1
6	Rome	Casal Bertone Mausoleum	2549	Male	-17.5	9.3
7	Rome	Casal Bertone Mausoleum	2560	Male	-18.1	11.2
8	Rome	Casal Bertone Necropolis	2580	Female	-18.6	11.3
9	Rome	Casal Bertone Necropolis	2593	Female	-18.1	9.8
10	Rome	Casal Bertone Necropolis	2617	Female	-19.1	7.6
11	Rome	Casal Bertone Necropolis	2563	Male	-18.2	11.0
12	Rome	Casal Bertone Necropolis	2569	Male	-18.2	11.1
13	Rome	Casal Bertone Necropolis	2577	Male	-18.1	11.6
14	Rome	Casal Bertone Necropolis	2578	Male	-18.1	9.6
15	Rome	Casal Bertone Necropolis	2585	Male	-17.2	9.7
16	Rome	Casal Bertone Necropolis	2586	Male	-18.1	11.6
17	Rome	Castellaccio Europarco	2622	Female	-18.8	11.0
18	Rome	Castellaccio Europarco	2638	Female	-17.9	9.5
19	Rome	Castellaccio Europarco	2641	Female	-18.1	11.5
20	Rome	Castellaccio Europarco	2643	Female	-19.1	9.4
21	Rome	Castellaccio Europarco	2623	Male	-12.5	8.3
22	Rome	Castellaccio Europarco	2630	Male	-18.4	8.8
23	Rome	Castellaccio Europarco	2642	Male	-19.5	7.8
24	Rome	Castellaccio Europarco	2644	Male	-17.8	9.1
25	Ostia	Isola Sacra	2806	Female	-19.0	11.2
26	Ostia	Isola Sacra	2815	Female	-18.5	10.0
27	Ostia	Isola Sacra	2817	Female	-19.3	9.9
28	Ostia	Isola Sacra	2820	Female	-19.1	7.5
29	Ostia	Isola Sacra	2824	Female	-19.0	11.6
30	Ostia	Isola Sacra	2825	Female	-19.0	11.3
31	Ostia	Isola Sacra	2843	Female	-18.6	13.1
32	Ostia	Isola Sacra	2844	Female	-18.7	11.1
33	Ostia	Isola Sacra	2844	Female	-18.9	10.9
34	Ostia	Isola Sacra	2845	Female	-18.9	9.8
35	Ostia	Isola Sacra	2849	Female	-18.6	11.5
36	Ostia	Isola Sacra	2852	Female	-18.8	11.1
37	Ostia	Isola Sacra	2854	Female	-18.7	9.2
38	Ostia	Isola Sacra	2854	Female	-18.7	10.4
39	Ostia	Isola Sacra	2864	Female	-18.7	11.0
40	Ostia	Isola Sacra	2871	Female	-18.2	12.5
41	Ostia	Isola Sacra	2877	Female	-18.5	11.4
42	Ostia	Isola Sacra	2878	Female	-18.6	11.8
43	Ostia	Isola Sacra	2882	Female	-18.9	11.5
44	Ostia	Isola Sacra	2885	Female	-18.4	12.3
45	Ostia	Isola Sacra	2908	Female	-18.9	11.0

	CITY	SITE NAME	REF NR ISOARCH	SEX	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
46	Ostia	Isola Sacra	2911	Female	-18.9	11.1
47	Ostia	Isola Sacra	2920	Female	-18.7	12.9
48	Ostia	Isola Sacra	2920	Female	-18.4	12.3
49	Ostia	Isola Sacra	2924	Female	-18.9	10.5
50	Ostia	Isola Sacra	2929	Female	-19.1	9.8
51	Ostia	Isola Sacra	2935	Female	-19.0	10.9
52	Ostia	Isola Sacra	2946	Female	-18.5	11.5
53	Ostia	Isola Sacra	2954	Female	-18.8	10.4
54	Ostia	Isola Sacra	2960	Female	-18.2	12.2
55	Ostia	Isola Sacra	2964	Female	-18.6	11.5
56	Ostia	Isola Sacra	2975	Female	-19.5	10.1
57	Ostia	Isola Sacra	2977	Female	-18.7	10.9
58	Ostia	Isola Sacra	2979	Female	-19.0	10.5
59	Ostia	Isola Sacra	2980	Female	-19.1	10.9
60	Ostia	Isola Sacra	2981	Female	-18.8	8.7
61	Ostia	Isola Sacra	2986	Female	-19.3	8.8
62	Ostia	Isola Sacra	2998	Female	-19.0	10.1
63	Ostia	Isola Sacra	2999	Female	-18.4	11.8
64	Ostia	Isola Sacra	3000	Female	-18.7	12.0
65	Ostia	Isola Sacra	3001	Female	-18.9	11.7
66	Ostia	Isola Sacra	3004	Female	-18.6	11.7
67	Ostia	Isola Sacra	3006	Female	-18.9	11.9
68	Ostia	Isola Sacra	3017	Female	-18.9	11.3
69	Ostia	Isola Sacra	3018	Female	-18.7	11.5
70	Ostia	Isola Sacra	3038	Female	-18.6	11.7
71	Ostia	Isola Sacra	3078	Female	-19.1	10.2
72	Ostia	Isola Sacra	2804	Male	-19.0	10.9
73	Ostia	Isola Sacra	2805	Male	-18.9	10.5
74	Ostia	Isola Sacra	2807	Male	-18.8	9.9
75	Ostia	Isola Sacra	2808	Male	-18.6	11.5
76	Ostia	Isola Sacra	2809	Male	-18.6	9.5
77	Ostia	Isola Sacra	2810	Male	-19.1	10.1
78	Ostia	Isola Sacra	2811	Male	-19.2	13.4
79	Ostia	Isola Sacra	2813	Male	-18.8	10.6
80	Ostia	Isola Sacra	2814	Male	-18.7	12.0
81	Ostia	Isola Sacra	2816	Male	-18.4	12.4
82	Ostia	Isola Sacra	2818	Male	-19.2	10.8
83	Ostia	Isola Sacra	2819	Male	-18.7	10.9
84	Ostia	Isola Sacra	2823	Male	-18.8	11.0
85	Ostia	Isola Sacra	2826	Male	-18.5	9.6
86	Ostia	Isola Sacra	2827	Male	-18.6	11.2
87	Ostia	Isola Sacra	2828	Male	-18.9	11.7
88	Ostia	Isola Sacra	2829	Male	-18.6	12.3
89	Ostia	Isola Sacra	2832	Male	-18.6	12.0
90	Ostia	Isola Sacra	2833	Male	-19.9	10.4
91	Ostia	Isola Sacra	2855	Male	-18.8	8.6
92	Ostia	Isola Sacra	2856	Male	-18.3	10.5
93	Ostia	Isola Sacra	2857	Male	-18.6	12.8

	CITY	SITE NAME	REF NR ISOARCH	SEX	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
94	Ostia	Isola Sacra	2859	Male	-19.4	15.3
95	Ostia	Isola Sacra	2873	Male	-18.9	11.4
96	Ostia	Isola Sacra	2874	Male	-18.6	12.4
97	Ostia	Isola Sacra	2875	Male	-19.0	12.1
98	Ostia	Isola Sacra	2876	Male	-18.1	11.4
99	Ostia	Isola Sacra	2879	Male	-18.5	11.7
100	Ostia	Isola Sacra	2880	Male	-18.8	11.1
101	Ostia	Isola Sacra	2881	Male	-18.7	11.1
102	Ostia	Isola Sacra	2883	Male	-18.5	9.2
103	Ostia	Isola Sacra	2892	Male	-19.5	10.4
104	Ostia	Isola Sacra	2894	Male	-18.0	11.5
105	Ostia	Isola Sacra	2896	Male	-18.5	11.6
106	Ostia	Isola Sacra	2896	Male	-18.6	11.8
107	Ostia	Isola Sacra	2901	Male	-18.7	11.1
108	Ostia	Isola Sacra	2902	Male	-18.3	11.9
109	Ostia	Isola Sacra	2903	Male	-18.5	8.9
110	Ostia	Isola Sacra	2909	Male	-19.0	10.5
111	Ostia	Isola Sacra	2918	Male	-18.7	11.1
112	Ostia	Isola Sacra	2919	Male	-19.2	9.1
113	Ostia	Isola Sacra	2921	Male	-18.7	11.1
114	Ostia	Isola Sacra	2922	Male	-18.2	11.2
115	Ostia	Isola Sacra	2923	Male	-18.5	9.8
116	Ostia	Isola Sacra	2925	Male	-18.4	11.6
117	Ostia	Isola Sacra	2927	Male	-18.6	11.1
118	Ostia	Isola Sacra	2928	Male	-18.6	11.2
119	Ostia	Isola Sacra	2934	Male	-19.5	11.1
120	Ostia	Isola Sacra	2936	Male	-18.6	10.5
121	Ostia	Isola Sacra	2937	Male	-18.5	10.8
122	Ostia	Isola Sacra	2938	Male	-18.4	11.2
123	Ostia	Isola Sacra	2940	Male	-18.8	11.5
124	Ostia	Isola Sacra	2942	Male	-18.6	12.0
125	Ostia	Isola Sacra	2945	Male	-17.3	12.2
126	Ostia	Isola Sacra	2955	Male	-18.8	13.0
127	Ostia	Isola Sacra	2958	Male	-18.6	14.4
128	Ostia	Isola Sacra	2959	Male	-18.3	11.6
129	Ostia	Isola Sacra	2963	Male	-18.9	11.6
130	Ostia	Isola Sacra	2965	Male	-18.6	11.7
131	Ostia	Isola Sacra	2968	Male	-18.7	12.5
132	Ostia	Isola Sacra	2973	Male	-18.0	11.5
133	Ostia	Isola Sacra	2978	Male	-19.0	9.5
134	Ostia	Isola Sacra	2982	Male	-18.6	9.4
135	Ostia	Isola Sacra	2987	Male	-18.9	11.9
136	Ostia	Isola Sacra	2988	Male	-18.5	11.1
137	Ostia	Isola Sacra	2988	Male	-18.6	10.7
138	Ostia	Isola Sacra	2990	Male	-18.7	11.5
139	Ostia	Isola Sacra	3003	Male	-18.3	11.5
140	Ostia	Isola Sacra	3007	Male	-18.6	12.1
141	Ostia	Isola Sacra	3010	Male	-18.7	10.3

	CITY	SITE NAME	REF NR ISOARCH	SEX	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
142	Ostia	Isola Sacra	3012	Male	-18.5	11.5
143	Ostia	Isola Sacra	3013	Male	-18.1	11.5
144	Ostia	Isola Sacra	3023	Male	-18.0	12.1
145	Ostia	Isola Sacra	3024	Male	-18.9	12.9
146	Ostia	Isola Sacra	3031	Male	-18.5	11.6
147	Ostia	Isola Sacra	3043	Male	-19.4	9.0
148	Ostia	Isola Sacra	3046	Male	-18.7	12.0
149	Ostia	Isola Sacra	3048	Male	-19.0	11.0
150	Ostia	Isola Sacra	3049	Male	-18.6	11.0
151	Ostia	Isola Sacra	3051	Male	-18.9	8.3
152	Ostia	Isola Sacra	3052	Male	-18.9	10.6
153	Ostia	Isola Sacra	3053	Male	-19.3	9.3
154	Ostia	Isola Sacra	3054	Male	-19.3	11.2
155	Ostia	Isola Sacra	3056	Male	-18.6	11.6
156	Ostia	Isola Sacra	3059	Male	-19.2	9.6
157	Ostia	Isola Sacra	3060	Male	-18.7	13.0
158	Ostia	Isola Sacra	3061	Male	-18.6	11.6
159	Ostia	Isola Sacra	3063	Male	-18.6	10.6
160	Ostia	Isola Sacra	3067	Male	-18.3	11.4
161	Ostia	Isola Sacra	3069	Male	-19.1	10.0
162	Ostia	Isola Sacra	3070	Male	-18.9	11.0
163	Ostia	Isola Sacra	3071	Male	-18.7	10.7
164	Ostia	Isola Sacra	3074	Male	-18.2	11.9
165	Ostia	Isola Sacra	3077	Male	-18.8	10.7
166	Ostia	Isola Sacra	3079	Male	-18.9	10.5
167	Ostia	Isola Sacra	3081	Male	-19.0	11.6
168	Ostia	Isola Sacra	3082	Male	-19.0	9.9
169	Ostia	Isola Sacra	3083	Male	-18.9	12.0
170	Ostia	Isola Sacra	3084	Male	-18.9	9.7
171	Ostia	Isola Sacra	3085	Male	-18.9	10.1
172	Ostia	Isola Sacra	3087	Male	-18.8	11.2
173	Ostia	Isola Sacra	3088	Male	-18.8	11.4
174	Ostia	Isola Sacra	3089	Male	-18.9	10.9
175	Ostia	Isola Sacra	3090	Male	-19.3	9.9
176	Ostia	Isola Sacra	3091	Male	-18.7	11.7
177	Ostia	Isola Sacra	3092	Male	-18.0	11.5
178	Ostia	Isola Sacra	3093	Male	-18.5	11.2
179	Ostia	Isola Sacra	3094	Male	-18.6	11.4
180	Ostia	Isola Sacra	3095	Male	-18.4	11.5
181	Pompeii	Pompeii	10416	Female	-19.9	10.6
182	Pompeii	Pompeii	10417	Female	-19.7	9.8
183	Pompeii	Pompeii	10418	Female	-19.7	9.6
184	Pompeii	Pompeii	10419	Female	-19.6	10.1
185	Pompeii	Pompeii	10420	Female	-19.5	10.2
186	Pompeii	Pompeii	10421	Female	-19.5	10.1
187	Pompeii	Pompeii	10422	Female	-19.5	9.8
188	Pompeii	Pompeii	10423	Female	-19.4	9.8
189	Pompeii	Pompeii	10424	Female	-19.4	9.6

	CITY	SITE NAME	REF NR ISOARCH	SEX	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
190	Pompeii	Pompeii	10425	Female	-19.3	10.6
191	Pompeii	Pompeii	10426	Female	-19.3	10.2
192	Pompeii	Pompeii	10427	Female	-19.3	8.1
193	Pompeii	Pompeii	10428	Female	-19.2	10.4
194	Pompeii	Pompeii	10429	Female	-19.1	10.3
195	Pompeii	Pompeii	10430	Female	-18.9	8.2
196	Pompeii	Pompeii	10431	Female	-18.5	10.4
197	Pompeii	Pompeii	10432	Female	-18.4	9.9
198	Pompeii	Pompeii	10433	Female	-17.6	5.9
199	Pompeii	Pompeii	10434	Female	-16.6	5.9
200	Pompeii	Pompeii	10406	Male	-20.1	9.3
201	Pompeii	Pompeii	10407	Male	-19.4	10.2
202	Pompeii	Pompeii	10408	Male	-19.4	9.5
203	Pompeii	Pompeii	10409	Male	-19.2	9.3
204	Pompeii	Pompeii	10410	Male	-18.9	10.4
205	Pompeii	Pompeii	10411	Male	-18.7	10.6
206	Pompeii	Pompeii	10412	Male	-18.7	10.4
207	Pompeii	Pompeii	10413	Male	-18.1	9.9
208	Pompeii	Pompeii	10414	Male	-16.1	8.6
209	Pompeii	Pompeii	10415	Male	-15.8	9.1
210	Pompeii	Pompeii	10435	Male	-15.7	8.8
211	Pompeii	Pompeii	10436	Male	-14.4	9.1

Appendix B: Laboratory analysis methods per study

Killgrove, 2010, pp. 158–159 (Rome):

"The procedures followed in his lab for extracting collagen from bone are based on those of Ambrose (1990) and can be summarized as follows (see also Tykot, 2004 and similar). Bone is first placed in 2% HCl to demineralize, after which contaminants are removed from the mixture with 0.1 M NaOH and with a 2:1:0.8 mixture of CH_3OH, $CHCl_3$, and water. The freeze-dried samples are then analyzed with a Finnigan MAT stable isotope mass spectrometer for $\delta^{13}C$ and $\delta^{15}N$. The reliability of the samples is confirmed through measurement of collagen yields and C:N ratios.

The methods used for extracting carbon information from bone apatite are modified from Koch and colleagues (1997). Bones are first cleaned, and about 10 mg of powder is drilled from each sample. The bone sample is dissolved in 2% NaOCl, and non-biogenic carbonates are removed from the sample with 1.0 M buffered acetic acid. Samples are processed by a Finnigan MAT mass spectrometer with a Kiel III individual acid bath carbonate system. The reliability of samples is confirmed through assessment of apatite yields during the pre-treatment process. Analytical precision of the $\delta^{13}C$ values is ± 0.1‰, and all values are reported with respect to the VPDB standard. For δ15N, the precision is ± 0.2‰, reported with respect to AIR.

Additional $\delta^{13}C_{ap}$ data were supplied by Dr. Janet Montgomery at the University of Bradford, who processed 60 teeth for oxygen isotope analysis (chapter 9), all of which were from individuals subjected to strontium, carbon, and nitrogen isotope analysis. It is standard practice when measuring δ18O values to measure carbon isotopes as well, and the methods of processing the enamel for analysis can be found in chapter 9. Analytical precision of the $\delta^{13}C_{ap}$ measurements from dental enamel is ± 0.06?. The 37 individuals for whom there is available dietary information from bone apatite thus also provided enamel apatite ($\delta^{13}C_{ap}$) information from their first molars. Measurement of one individual's diet at two different times - from birth to about 3 years old and during the last several years or decades of life - can provide a significant amount of information about intraindividual dietary changes through time in the Roman population. The enamel data are presented below in comparison with the $\delta^{13}C_{ap}$ measurements from bone."

Prowse, 2001, pp. 94–96 (Ostia):

"The procedure used for the extraction of bone collagen is the method originally described by Longin (1971), and later modified by Chisholm and coworkers (1982). Samples were washed with tap water to remove dirt and broken into smaller pieces using a mortar and pestle. Remaining trabecular bone on

internal surfaces was filed down with a metal file and visible dirt was removed. Bone fragments were placed in beakers with distilled water and washed in three ultrasonic baths, or until the water remained clear. The water was poured off and the beakers were placed in a drying oven (at 600°C) overnight.

Approximately 3 grams of clean. dry bone was weighed out for each sample, and the fragments were placed into labeled 50 ml plastic centrifuge tubes. These samples were covered with 0.25 M HCl (hydrochloric acid), and left to sit for approximately 20 minutes until the pH was greater than 1. The acid was poured off and the procedure repeated until the bone mineral was dissolved. As the dissolution advanced, it was necessary to centrifuge the tubes for approximately 5 minutes before changing the acid to ensure that all organic material was conserved. Once dissolution was complete (ea. 6-20 acid washes), the material in the tubes was rinsed 3 times with distilled water and 20 ml of 0.1 M NaOH (sodium hydroxide) was added to remove any remaining humic and fulvic acids. The samples were soaked in NaOH for approximately 20 minutes, after which time the tubes were centrifuged and rinsed 4 times with distilled water. If the NaOH solution remained dark after the initial wash, the procedure was repeated a second time. The samples were then placed in an acid wash of 0.25 M HCl for 2 minutes, centrifuged again, and the liquid was poured off. The remaining material was washed from the centrifuge tubes into 50 ml glass vials using distilled water. These vials were topped up with distilled water, covered with plastic wrap, sealed with tape, and put into beakers. The beakers, each containing 4 vials, were placed in an oven (90°C) for a minimum of 6 hours (usually overnight) to convert the solid collagen into a liquid form. Next, the tubes were removed, centrifuged, and the liquid containing the soluble collagen was decanted into labeled teflon beakers. More distilled water was added to the remaining material in the glass centrifuge tubes, the tubes were covered, and placed in the oven again overnight. The teflon beakers were placed in a drying oven to evaporate the water, leaving a light to dark brown material (the dried collagen). After a second overnight heating, the liquid collagen in the glass tubes was recovered and added to the teflon beakers.

After drying, a small amount of distilled water (<5 ml) was added to the beakers and the dissolved collagen was transferred to pre-weighed plastic vials. The vials were placed in the drying oven until the collagen had completely dried, usually taking a few days. After drying, the vials were weighed again to calculate the dry weight of the collagen and to calculate the collagen yield. Collagen yield is determined with the following equation:

$$\text{Equation 4.1 - } \%\ Collagen\ Yield = \frac{(weight\ of\ extracted\ collagen)\ x\ 100}{(weight\ of\ cleaned\ bone)}$$

Approximately 2-3 mg (for Carbon) and 9-13 mg (for Nitrogen) of the dried collagen from each sample was loaded with CuO (cupric oxide) into separate 6 mm heat- treated pyrex tubes. The tubes were placed on a vacuum line for 4 hours to remove any air and water and then sealed with a torch. The

sealed tubes were placed in an oven at 550 °C for 2.5 hours, causing a reaction to produce CO_2. Heating also causes the nitrogen in the collagen to break down into N2. The samples were then analyzed using a VG SIRA 10 Series II mass spectrometer."

Crowe et al., 2010, pp. 358–359 (Ostia):

"Collagen was extracted from all sampled individuals using a modified Longin method. For those individuals measured by Prowse et al. (2004) and Craig et al. (2009), details of the full methodologies and mass spectrometry are given in the relevant papers. For the additional 91 individuals from Isola Sacra, the collagen was extracted and analyzed at the Research Laboratory for Archaeology, University of Oxford, according to Privat et al. (2002) and Kirsanow (2003). In brief, cleaned bone samples of 1–2 g were crushed, demineralized in 0.5 M aq. HCl at 48°C, then gelatinized in pH 3 water at 75°C for 48 h, then the solubilized collagen was filtered off and freeze-dried. All collagen extracts were analyzed in triplicate by continuous flow isotope ratio mass spectrometry using a Carlo Erba elemental analyzer coupled to a PDZ Europa Geo 20-20 isotope ratio monitoring mass spectrometer. Carbon and nitrogen isotopic values for all measurements are expressed on the delta scale, in comparison to international standards, VPDB for carbon and AIR for nitrogen, in units of ''permil" (Hoefs, 1997). Repeated measurements of international and in-house standards showed that the analytical error was <0.2% for both carbon and nitrogen. Percentage elemental yields were used to calculate the atomic C/N ratio to assess the quality of each collagen sample (DeNiro, 1985)."

Pate et al., 2016, pp. 128–129 (Pompeii):

"In relation to human and faunal bone analyses, a 1 - 2 g cortical bone specimen was taken from each individual. Sample preparation involved ultrasonic cleaning of whole bone specimens, demineralization, and sodium hydroxide treatment. Whole bone chunks were demineralized in dilute HCl according to the methods of Sealy (1986). Humic acids and other base-soluble contaminants were removed using a 0.125 M NaOH solution. Extracts were soaked and washed thoroughly following acid and base treatments in order to remove dissolved contaminants and the remaining organic component was oven dried at 35 C. Plant and food materials were oven dried at 40 C. All oven dried specimens were ground to fine powders using a Retsch mixer mill. Carbon and nitrogen concentrations of the ground powders were measured using an elemental analyzer, and stable carbon and nitrogen isotope values were determined by mass spectrometry using a Europa Scientific ANCA-SL system at at the CSIRO Land and Water laboratories in Adelaide, South Australia."

Appendix C: Normality test

Before the application of statistical tests to compare the means of the different groups, the data needs to be tested for normality. The type of test that is used is dependent on the degree of normal distribution within the groups. If the individual scores within a group are normally distributed, parametric tests can be applied. If not, only non-parametric tests can be applied. Testing the groups for normality with the Kolmogorov-Smirnov test shows that not all groups are normally distributed. Both for $\delta^{13}C$ and for δ15N, the significance is higher than p = 0.05 for several groups. See the table below. All groups should be normally distributed to be able to use parametric tests. Therefore, only non-parametric tests will be used for statistically analysing the data.

	Site name	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig.
$\delta^{13}C$	Isola Sacra	0.112	156	0.000
	Pompeii	0.235	31	0.000
	CB Maus.	0.192	7	0.200
	CB Necr.	0.318	9	0.009
	Cast. Europ.	0.382	8	0.001
$\delta^{15}N$	Isola Sacra	0.102	156	0.000
	Pompeii	0.179	31	0.013
	CB Maus.	0.222	7	0.200
	CB Necr.	0.240	9	0.142
	Cast. Europ.	0.226	8	0.200