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UNIVERSITY OF WALES
Trinity Saint David

“Ab ovo usque ad mala”

A multi-factor diachronic study of Romano-British dietary behaviours using stable isotope analysis data

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30th September 2026

University of Wales, Trinity Saint David

MA Apprenticeship Archaeological Practice - Distance

Master's Degrees by Examination and Dissertation

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1. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Abstract

Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analysis is an established biomolecular technique providing direct evidence of consumption from skeletal remains, and has been used to reconstruct Romano-British diets for almost 30 years. However, few studies have collated $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from multiple sites to draw conclusions about dietary behaviour during the Romano-British period on a national scale, and less have considered how diet changed over time. This research sought to expand upon previous compilatory studies by constructing an up-to-date dataset of published Romano-British dietary isotope data, which was used to investigate general dietary behaviour and how this differed in relation to a range of variables: sample type, biological sex, geographical region, and chronological period. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data for 630 individuals from 58 sites was analysed, revealing differing levels of variation between dentine and bone samples, males and females, northern and southern regions, and throughout the Romano-British period. Diachronic analysis of these variables was also conducted to examine whether identified patterns change over time, with both dietary and non-dietary causes inferred for observed differences. The study represents the first to not only investigate diet in relation to multiple factors but also assess diachronic change, and the findings are significant to understanding Romano-British diets as they support earlier interpretations and also provide new insights.

Word count: 16,496

Acknowledgements

Endless thanks to my Mam and Dad, Brandon, Beth and Jo for their support.

1. Introduction

1.1 Research Context

“Ab ovo usque ad mala”, the Latin phrase coined by the poet Horace (1862) in his *Satires* 1.3.6, perfectly portrays the importance of food to Roman culture. As its literal translation is “from the egg to the apples”, intimating the typical succession of lavish elite feasts from an egg-based starting course through to a fruit-focused final dish (Brown, 1993), the phrase illustrates the diversity of culinary choices present in Roman society. With varied consumption practices and dietary behaviours already in existence across the Roman Empire, the extent to which these were incorporated within Britain during its time under Roman rule has long been debated in archaeological research (Van der Veen *et al.*, 2008; Witcher, 2013). Established biomolecular techniques, such as stable isotope analysis, provide the opportunity to contribute to this discussion using evidence directly obtained from remains of those who lived and ate in Roman Britain. This method grants the ability to reconstruct diets of past peoples by examining carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope values measured in collagen preserved within skeletal tissues, and has been widely applied to remains recovered from Romano-British sites since the 1990s (Richards *et al.*, 1998). Despite this, much of the isotope data produced from these sites has only been analysed within a narrow framework, typically being interpreted on a site-level scale or where contextualised with comparative data, this tends to be constricted to data from local or regional sites (e.g. Redfern *et al.*, 2010; 2012; Cheung *et al.*, 2012). For isotope analysis to contribute effectively to our understanding of Romano-British diet, it is vital not only for all available data to be considered together to develop interpretations on a national scale, but for there to be a practical and interoperable way for the data to be accessed collectively.

Having access to a wide range of relevant comparative data and associated contextual information is essential to research projects utilising isotope analysis, to situate sampled individuals within their wider chronological and geographical context and apply meaning to the raw numerical data produced through analysis. This has encouraged development of large-scale online databases aimed at making isotope data as readily obtainable for users as possible. These resources compile isotope data for multiple periods and places, with the Biosphere Isotope Domains dataset for Great Britain (Evans *et al.*, 2022; 2023; UKRI, 2026) being most applicable for the geographical area under investigation here, but sadly only includes strontium, oxygen, sulphur, and lead isotope data. In fact, no compilatory resources

exist for dietary $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data on a similar scale, except for IsoArch (Salesse *et al.*, 2018; 2020) which is still developing and not yet well-established, revealing a large gap in the research field hindering data acquisition. Whilst a database of this nature is outside the scope of this dissertation, this research hopes to put foundational steps in place to develop a comprehensive dataset of published Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data that can be used by others and enhanced in future. By focusing on data from Roman Britain, the author aspires to demonstrate the potential of compiling available dietary isotope data to facilitate interpretations on a greater scale than previously attempted, thereby highlighting the possibility for the dataset to be expanded over time to cover other periods.

Previous large-scale studies of Romano-British isotope data include compilations of multi-site $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data investigating diet, mobility, and mortality (Müldner, 2013; Redfern *et al.*, 2019), which have shown the value of comprehensive data analysis to forming holistic interpretations. By consolidating $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data available at the time, Müldner (2013) was able to draw conclusions about Romano-British diets that supported interpretations made from other lines of evidence, including: increased consumption of freshwater and marine foods compared to the Iron Age; links between marine resource consumption and higher social status; some differences in dietary behaviours between males and females; and the presence of migrants from outside Britain with distinct diets, especially in urban areas. Taking inspiration from these works and the significant breadth and depth of their findings, creation of the Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ dataset also hopes to provide the opportunity to examine and reassess how dietary behaviours changed in relation to a range of factors including time and geography, and between different demographic groups.

1.2 Current Understanding of Romano-British Diet

To investigate what isotope analysis can contribute to the study of Romano-British dietary behaviour, it is first necessary to establish what is already known about food availability and consumption practices from other archaeological evidence. The Roman period has been described as a turning point in British food history, bringing in a whole host of new foods, intensifying and enhancing food production, and expanding culinary practices to new levels (Witcher, 2013). The zooarchaeological record attests to the importance of cattle, sheep and pigs as the primary domestic mammals used to supply meat, as well as use of birds including ducks, geese and domestic fowl, and occasionally non-domesticated game like deer, hare, and

wild boar as sources of protein (Cool, 2006; Maltby, 2014). Although evidence of their presence is more scarce, alternative products from these animals such as dairy items and eggs have been shown to have contributed to Romano-British diets in some capacity through residue analysis, identification of specialised vessel forms for cheese production, preserved eggshells, and documented purchase requests from writing tablets (Green, 1987; Bowman and Thomas, 1994; Cool, 2006). In terms of non-terrestrial food sources, despite issues with recovery, fish remains have been found within Romano-British contexts in larger numbers and with greater variation than at Iron Age sites, with evidence for exploitation of both freshwater and marine species (Locker, 2007; Maltby, 2014). Eel is particularly well-documented, alongside carp, cod and other diadromous species like salmon, although observed distribution patterns are believed to represent consumption of locally available species (Locker, 2007; Maltby and Hamilton-Dyer, 2012; Maltby 2014). The fish-based sauce *garum* has been popularised within the public sphere of knowledge as being a Roman introduction to Britain commonly used across recipes, and whilst evidence of local production is limited, amphorae and writing tablets document its import into the province mainly from the Iberian Peninsula (Curtis, 1991; Bowman and Thomas, 1994; Cool, 2006; Locker, 2007). However, it's now well-known, despite the weight previously given to Roman influence on the British diet post-conquest, that many commonplace foodstuffs, delicacies and exotic edibles were already present in Britain before colonisation. Instead, evidence suggests that items like *garum*, wine, and olive oil were available to the Iron Age population in the century or so before occupation, arriving as imports through trade with the Roman Empire on the Continent (Cool, 2006).

Similarly, many plants exploited for consumption during the Romano-British period would have also been utilised by the Iron Age population, with debate surrounding just how many new resources were introduced by the incoming population and their dietary culture (Witcher, 2013). Nevertheless, it is generally accepted that the Romano-British people had access to a more diverse range of flora (including new resources and different species of native plants already present), and incorporated a variety of fruit, vegetables, pulses, herbs, spices and nuts into their diet (Witcher, 2013; Cool, 2006). Examples of the considerable number of plant foods shown to have been available at the time include: cucumber, pepper and coriander, apple and peach, figs, pine nuts and almonds, as well as grapes used in winemaking (Van der Veen *et al.*, 2008; Witcher, 2013). Cultivation of these plants for the wider population rather than personal use is evidenced by the development of orchards and market gardens in urban

areas, signifying agricultural intensification was needed to meet demand for these foods (Van der Veen *et al.*, 2008). Staple cereal crops still retained their importance within the British diet and economy however, as spelt wheat, emmer wheat, and bread wheat, as well as barley, rye and oats are found in varying but considerable quantities across sites within environmental assemblages, with emmer wheat and barley believed to be the principal crops (Cool, 2006; Van der Veen, 2014). In comparison, although millet is attested to in the Romano-British archaeobotanical record, this non-native C₄ cereal crop is not thought to have been cultivated within Britain and was instead imported (Van der Veen, 2014). Its occurrence exists as a limited number of grains primarily found at Early Romano-British military sites, and has always been found with other imported foodstuffs, suggesting it was not an established or widespread food source (Van der Veen *et al.*, 2008; Van der Veen 2014). Where identified isotopically as having a significant contribution to individuals' diets as indicated by high $\delta^{13}\text{C}$ values, millet consumption has been used to suggest the presence of migrants with origins outside Britain elsewhere in the Empire where millet was a commonplace dietary component (Müldner *et al.*, 2011; 2013; Van der Veen, 2014).

Differences in consumption practices have also been inferred on a geographical scale from environmental and material culture evidence between urban and rural, and civilian and military sites. As seen in other civilisations, a relationship between variation in diet and social stratification has been suggested from this, with Romano-British people able to access a more or less diverse range of foods depending on wealth, status, occupation, location, and cultural influences (Cool, 2006; Van der Veen *et al.*, 2008; Van der Veen, 2014). Additionally, diachronic dietary change has been demonstrated through the material culture record, with evidence for trade of items like garum declining throughout the Romano-British period, potentially representing changing import or production sources, economic decline, or a decrease in the food's popularity amongst Romano-British people (Cool, 2006). Variation on a biological scale is harder to identify, and little evidence has been found to suggest males and females consumed significantly different diets within palaeopathological studies (Bonsall, 2014). With the diversity of available foods firmly established by environmental and material sources, isotope analysis has the potential to further interpretations of dietary variation over time, space, and between demographic groups by providing direct evidence for consumption. The method's contributions to developing a holistic, multidisciplinary understanding of Romano-British dietary behaviours will be explored through this study's goals.

1.3 Aims and Objectives

To explore contributions of isotope analysis to our understanding of Romano-British diet, two aims were developed for this research alongside carefully chosen objectives with which to achieve them:

Aim 1: To investigate trends in Romano-British diet using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data collected from published sources.

- Collate $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from publications using online search engines and data repositories.
- Gather relevant contextual information and comparative faunal isotope data to construct a faunal baseline.
- Compile all collected data into a new dataset for analysis and synthesis to identify general dietary trends and outliers.
- Create data visualisation products (scatter graphs and box and violin plots) to visually demonstrate identified patterns and outliers.

Aim 2: To analyse variation in Romano-British dietary behaviour by investigating the impact of multiple variables (sample type, biological sex, geographical region, and chronological period) on $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data, with a focus on identifying diachronic change.

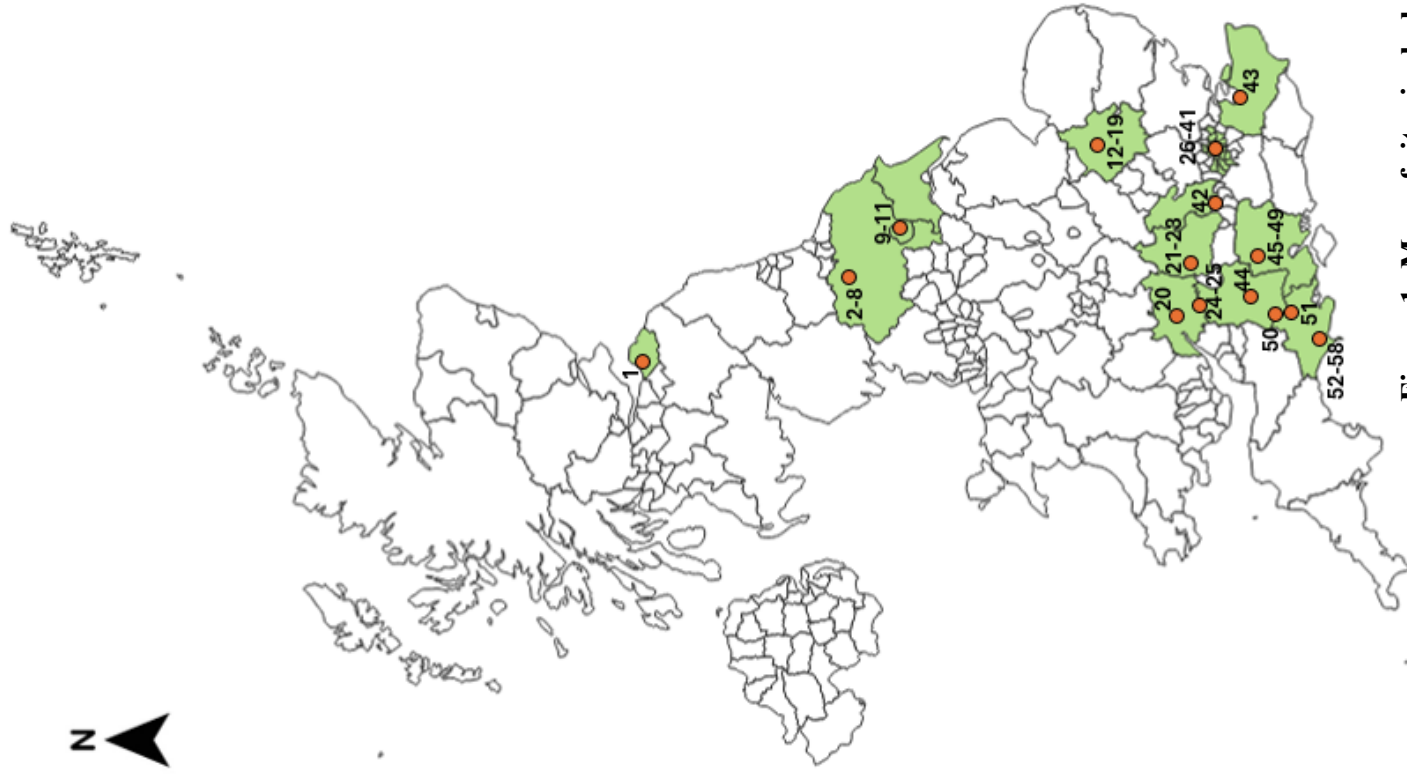
- Examine $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ variation between dentine, long bone, and rib samples to infer if diet differed between life stages.
- Determine if dietary differences are isotopically visible between males and females using available biological sex estimation data.
- Compare dietary isotope data from northern and southern, and eastern and western Romano-British sites to explore potential geographical differences in diet.
- Assess whether chronological change in diet can be identified isotopically using available dating information.
- Integrate the variables into diachronic analysis to assess if inferred patterns and trends change over time.

Müldner's (2013) acknowledgment that the availability of larger datasets allows isotope analysis to become more integrated into academic discourse surrounding Romano-British diet justifies this research, especially as more data has become available since their earlier compilatory study. As the importance of accessible comparative data to isotope studies cannot

be overstated, the dataset and dissertation are hoped to be made available via the UWTSD research repository, an archaeological database like the Archaeology Data Service (ADS, 2025), or developed into a publication alongside Durham University's Archaeological Isotope and Peptide Research Laboratory (AIPRL) in future to ensure wide dissemination and long-term availability for researchers.

1.4 Chronological and Geographical Scope

This study encompasses the Roman period in Britain, following the well-established date range from invasion in AD 43 through to removal of Roman rule in AD 410 (Historic England, 2026). Geographically, this work covers only Britain, using its modern boundaries to aid interpretations of dietary variation between regions and align with geographical terminology used throughout the literature. Locations and names of sites included within the Romano-British human dataset are shown in Figure 1.



Key:

1. Musselburgh (East Lothian)

2-8. Hollow Banks, Scorton (North Yorkshire), Dere Street, Catterick (North Yorkshire), Honeypot Road, Catterick (North Yorkshire), Catterick Bridge, Catterick (North Yorkshire), Racecourse, Catterick (North Yorkshire), Bainesse, Catterick (North Yorkshire), Bainesse Farm, Catterick (North Yorkshire)

9-11. Blossom Street (North Yorkshire), Driffeld Terrace (North Yorkshire), Trentholme Drive (North Yorkshire)

12-19: A14-10 Brampton West (Cambridgeshire), A14-11 Brampton West (Cambridgeshire), A14-38 Bar Hill (Cambridgeshire), A14-20 River Great Ouse (Cambridgeshire), A14-28 Fenstanton Gravels (Cambridgeshire), A14-19 River Great Ouse (Cambridgeshire), A14-27 Fenstanton Gravels (Cambridgeshire), A14-7A Brampton West (Cambridgeshire)

20. London Road (Gloucestershire)

21-23. Yarnton (Oxfordshire), Tubney Wood Quarry (Oxfordshire), Queenford Farm, Dorchester-on-Thames (Oxfordshire)

24-25. Horcott Quarry (Gloucestershire), Cotswold Community (Gloucestershire)

26-41. Eastern Cemetery (London), Southern Cemetery (London), Western Cemetery (London), 1-4 Giltspur Street (London), St. Bartholomew's Hospital (London), Lant Street (London), Great Dover Street (London), Spitalfields Market (London), Courage Brewery (London), Northgate House (London), Atlantic House (London), Mansell Street (London), Trinity Street (London), Red Cross Way (London), Basinghall Street (London), Haydon Street (London)

42. Eton College Rowing Course (Buckinghamshire)

43. Gravesend (Kent)

44. Boscombe Down (Wiltshire)

45-49. Andover Road, Winchester (Hampshire), Lankhills, Winchester (Hampshire), Hyde Street, Winchester (Hampshire), Hyde Close, Winchester (Hampshire), Chester Road, Winchester (Hampshire)

50. Rotherley Down flat grave, Berwick St. John (Wiltshire)

51. Gussage All Saints (Dorset)

52-58. Tolpuddle Ball (Dorset), Old Vicarage (Dorset), Albert Road (Dorset), Poundbury Camp (Dorset), Alington Avenue (Dorset), Maiden Castle Road (Dorset), Portesham G14, Friar Waddon (Dorset)

Figure 1: Map of sites included in the Romano-British dataset (QGIS 3.34.12, 2026).

2. Stable Isotope Analysis

2.1 Foundational Principles

An element is comprised of atoms, each containing protons and neutrons within their nucleus. The atomic number of an element, which influences its overall chemical properties, is determined by the number of protons and is the same for every atom of a specific element. The two elements under consideration here, carbon and nitrogen, have an atomic number of 6 and 7 respectively, but it is the variable number of neutrons present within the atoms of these elements that instructs their utility within stable isotope analysis. Unlike with protons, the number of neutrons between atoms of an element can differ and the atoms consequently have different atomic mass numbers (number of protons and neutrons). These different forms of a single element are known as isotopes and have slightly different physical properties due to their different masses, but predominantly share the same chemical properties (Hoefs, 1987). Stable isotopes are those that do not undergo radioactive decay over time, with two stable forms of naturally occurring carbon (^{12}C and ^{13}C) and nitrogen (^{14}N and ^{15}N) isotopes used within archaeology to investigate diets of past populations (Figure 2). In nature, the lighter isotope is typically more abundant than the heavier form, as illustrated by the isotopic abundance of ^{12}C (98.89%) and ^{14}N (99.63%) compared to that of ^{13}C (1.11%) and ^{15}N (0.37%) (Sharp, 2017).

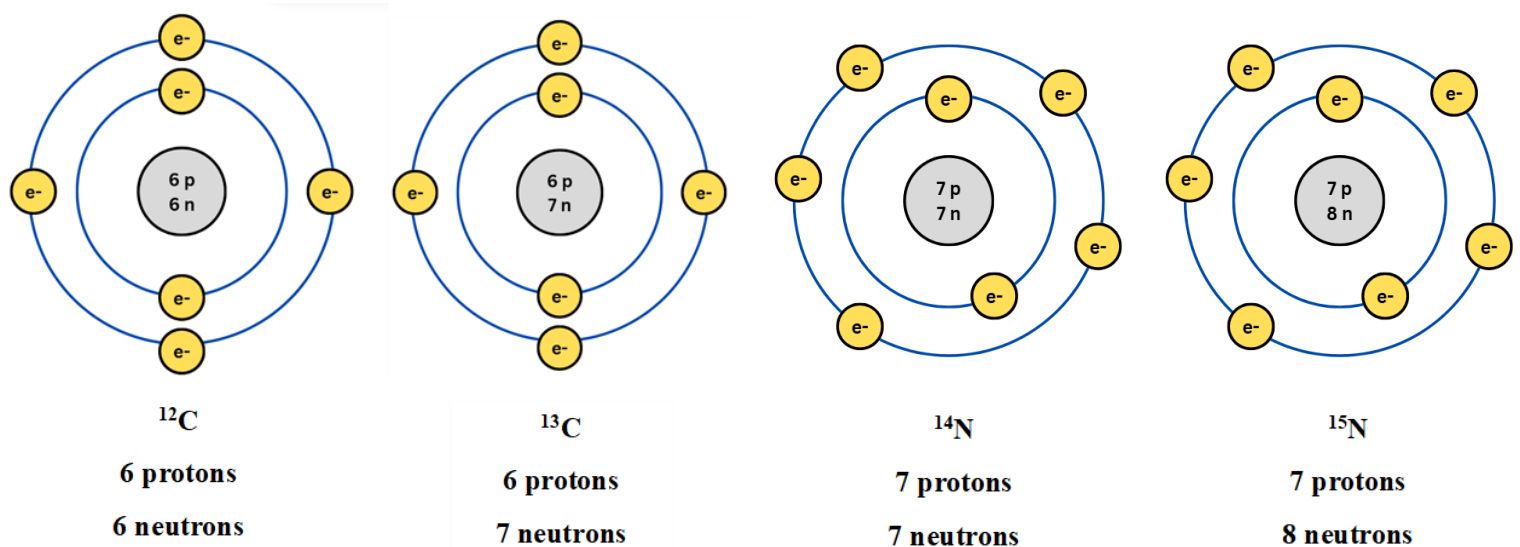


Figure 2: Atomic structure of carbon and nitrogen isotopes (author's image).

Fractionation occurs during physical and chemical reactions due to the differences in atomic mass between isotopes of the same element, separating the lighter and heavier isotopes. Within biochemical reactions, either the lighter or heavier isotope is preferentially used, thereby influencing the abundance of the isotopes and the ratio of the two isotope forms to each other as a result (Sharp, 2017). By measuring the isotope ratios of ^{13}C to ^{12}C and ^{15}N to ^{14}N in preserved biological tissues of plants and collagen from animals and humans using mass spectrometry, archaeologists are able to infer information about dietary behaviour in the past. Delta (δ) values are used to express the measured isotope ratios for carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$), and are given relative to established reference standards: Pee Dee Belemnite (PDB) or Vienna Pee Dee Belemnite (VPDB – the modern international standard established to replace the exhausted original source for PDB) for $\delta^{13}\text{C}$ values, and atmospheric nitrogen (ambient inhalable reservoir - AIR) for $\delta^{15}\text{N}$ values (Schoeninger and Moore, 1992; Pate, 1994; Coplen, 1994). If a sample's measured isotope ratio is lower than that of the standard it is expressed as a negative value, as commonly seen for collagen $\delta^{13}\text{C}$ values which predominantly have less ^{13}C in relation to ^{12}C than PDB (lower quantity of the heavier isotope). Alternatively, as seen in most collagen $\delta^{15}\text{N}$ values, positive values indicate samples with higher isotope ratios compared to the standard, which therefore have a higher quantity of the heavier isotope (Schoeninger and Moore, 1992; Pate, 1994). As the measured difference between the isotope ratios is very small, the notation parts per thousand (‰), commonly recorded as “per mil”, is used to represent these values (Pate, 1994; Coplen, 2011). To calculate the carbon and nitrogen isotope delta values, the following equations are used (Schoeninger and Moore, 1992):

$$\delta^{13}\text{C} = \left[\frac{^{13}\text{C} / ^{12}\text{C}_{\text{sample}}}{^{13}\text{C} / ^{12}\text{C}_{\text{standard}}} - 1 \right] \times 1000\text{‰}$$

$$\delta^{15}\text{N} = \left[\frac{^{15}\text{N} / ^{14}\text{N}_{\text{sample}}}{^{15}\text{N} / ^{14}\text{N}_{\text{standard}}} - 1 \right] \times 1000\text{‰}$$

2.2 Applications in Archaeology

Carbon and nitrogen isotope analysis of human teeth and bones has become a well-established technique within bioarchaeological palaeodietary studies, developing from earlier research applying the method to animals (DeNiro and Epstein, 1978; Schoeninger *et al.*, 1983; Kohn, 1999). Collagen is the main protein component of bones and teeth. It is an abundant source of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ within these tissues, providing averaged values reflecting the animal products and plants a person has consumed during tissue development, due to the body reusing dietary proteins obtained from food sources to produce collagen (Lee-Thorp, 2008). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values measured in collagen can therefore be used to infer the food sources exploited by individuals and populations, with carbon and nitrogen isotope analysis increasingly being recognised for the contributions it can also make to our understanding of the cultural, social, and economic factors that influence diet, consumption practices, and food choices in the past (Beaumont *et al.*, 2013b; Rose *et al.*, 2026).

Carbon isotopes enter the bottom of the food chain as plants incorporate carbon from environmental sources during photosynthesis. Most terrestrial plants in human and animal diets use either the C_3 or C_4 photosynthetic pathways, which fractionate carbon isotopes in distinct ways thereby causing variation in $\delta^{13}\text{C}$ values. C_3 plants, common in temperate regions like Britain, include rice, wheat, barley, and potato and have lower (more negative) $\delta^{13}\text{C}$ values. C_4 plants include maize, millet, and sorghum, are typically found in warmer, tropical regions, and have higher (less negative) $\delta^{13}\text{C}$ values (Schoeninger and Moore, 1992; Pate, 1994). Some plants use the CAM (crassulacean acid metabolism) pathway, in which either the C_3 or C_4 pathway can be employed for photosynthesis, but as this is restricted to arid environment species such as succulents it will not be detailed here (O’Leary, 1988). As discussed above, ultimately the $\delta^{13}\text{C}$ values of consumed plants are incorporated into collagen within teeth and bone, becoming enriched through metabolic fractionation. Thus, variation in human collagen $\delta^{13}\text{C}$ values can be used to infer the relative contribution of C_3 and C_4 resources (i.e. plants and products from animals consuming these plants) to the diet of past peoples (Van der Merwe, 1982). Seminal work in the field exploited this knowledge to compare $\delta^{13}\text{C}$ values between North American sites, two pre-dating maize cultivation introduction and two post-dating this C_4 crop’s arrival. The research demonstrated clear isotopic differences between the two groups (pre-maize C_3 -consumers mean $\delta^{13}\text{C} = -19.7\text{‰}$ vs. post-maize mixed C_3/C_4 -consumers mean $\delta^{13}\text{C} = -14.4\text{‰}$) directly correlating with their dietary practices (Vogel and Van der Merwe, 1977; Van der Merwe and Vogel, 1978), and has

since acted as a cornerstone from which the use of stable isotope analysis to reconstruct diets has developed.

$\delta^{13}\text{C}$ values can also be interrogated to infer exploitation of food resources from different ecosystems. Producers in the marine food chain typically have higher $\delta^{13}\text{C}$ values than terrestrial C_3 plants, as dissolved bicarbonate (their primary carbon source) has higher $\delta^{13}\text{C}$ values than atmospheric CO_2 used by C_3 species for photosynthesis (Lee-Thorp, 2008). $\delta^{15}\text{N}$ values have been found to be particularly useful when interpreted alongside $\delta^{13}\text{C}$ values to understand reliance on terrestrial or marine resources in past diets. Nitrogen is made available to producers at the base of terrestrial and marine food chains through three primary pathways: atmospheric nitrogen fixation, organic matter decomposition by bacteria, and bacterial denitrification. This creates variation in $\delta^{15}\text{N}$ values between producers, as nitrogen-fixing plants display values similar to the atmosphere, whereas nitrates produced through decay have higher (more positive) $\delta^{15}\text{N}$ values, as does available nitrogen produced through denitrification (Schoeninger and Moore, 1992). As denitrification is the main nitrogen source in marine ecosystems, marine producers generally have higher $\delta^{15}\text{N}$ values than terrestrial plants, which is consequently reflected in the tissues of marine animals and humans who consume them (Schoeninger and DeNiro, 1984). Similarly, $\delta^{15}\text{N}$ variation correlates with the position (trophic level) of organisms within their food chain, with an enrichment of +2-6‰ expected from one level to the next, meaning $\delta^{15}\text{N}$ values increase from plants to herbivores to carnivores (Schoeninger and DeNiro, 1984). As marine food chains are longer and more complex than in terrestrial ecosystems (with more trophic levels), individuals consuming considerable quantities of marine resources are expected to have high $\delta^{15}\text{N}$ values compared to those exploiting predominantly terrestrial foods (Minigawa and Wada, 1984; Schoeninger and DeNiro, 1984). In this way, $\delta^{15}\text{N}$ values are particularly important to distinguish between C_4 and marine resource contributions to past diets, as both would produce higher $\delta^{13}\text{C}$ values than terrestrial C_3 foods, but where marine resource consumers should have high $\delta^{15}\text{N}$ values, C_4 resource consumers would not (Richards, 2020). Fittingly for this study's aims, the combination of these two isotopes has previously helped enhance understanding of diachronic dietary change between the Mesolithic and Neolithic periods in Europe, which predominantly saw a decrease in riverine and marine resources in favour of terrestrial C_3 foods (Lubell *et al.*, 1994; Bonsall *et al.*, 1997). Diverse information about the diets of individuals and populations can therefore be inferred by analysing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in collagen, including the trophic level of consumed food and the relative contribution of

terrestrial vs. marine, and C₃ vs. C₄ protein to the diet. These values provide direct evidence of the foods consumed by people in the past, making isotope analysis vital to our understanding of palaeodietary behaviour, complimenting more subjective lines of investigation prone to preservation biases (Lee-Thorp, 2008). However, as $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values vary naturally between and within ecosystems across time and space, the isotopic composition of foods that would have been available to the humans under investigation must be established to facilitate reliable interpretations of diet (Schoeninger and Moore, 1992).

2.3 Establishing Baselines

Variation influencing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values at any point within a food chain will eventually impact the isotopic make-up of the collagen of humans as consumers. Many factors can affect these values between ecosystems over time and space including latitude, climate, temperature, rainfall and other environmental conditions (Ambrose, 1991; Pate, 1994; Drucker *et al.*, 2003; Richards and Hedges, 2003). Even within ecosystems anthropogenic agency can introduce variation through resource management practices such as crop manuring and foddering of domestic species (Bogaard *et al.*, 2007; Britton *et al.*, 2008; Fraser *et al.*, 2011; Schulting *et al.*, 2017). Therefore, to understand the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of available dietary resources which contributed to the isotopic composition of human collagen, baselines must be established. This is especially important for comparative studies such as this, where isotopic differences observed between groups or sites may be interpreted as reflecting different consumption practices, but could instead be caused by natural baseline variation (Casey and Post, 2011; Bownes *et al.*, 2018). The ideal approach to baseline creation is to sample preserved plant and animal collagen from a site or its surrounding area, assuming food was sourced locally, however due to preservation issues this is not often possible for plant remains. Instead, faunal $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, particularly of herbivores, are commonly used to establish baselines for sites, regions, and contemporaneous populations, though caution must be taken when using these to interpret human diet as it is unlikely that all sources of dietary protein and isotopic variation will be represented (Richards, 2020; Leggett, 2020). Despite this, by comparing human values to their respective faunal baseline (Figure 3), it's possible to infer individuals' trophic position within the food chain. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values closer to those of herbivores indicate greater reliance on plant-

based foods, and values similar to omnivores and carnivores indicate higher proportions of animal products such as meat and dairy items within the diet (Richards, 2020).

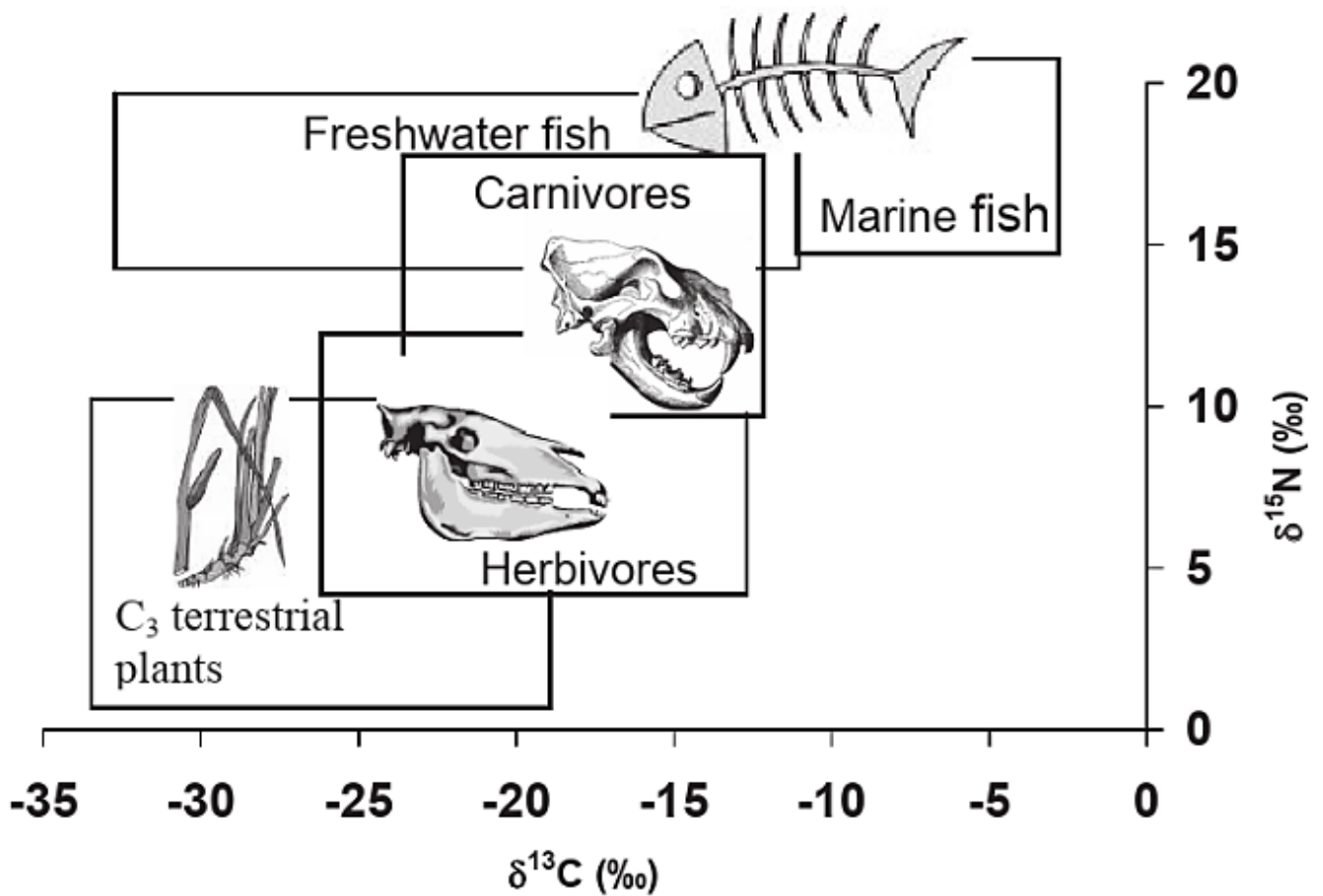


Figure 3: Example faunal baseline showing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data ranges for various resource types (Jay and Richards, 2019, pp. 304).

2.4 Collagen in Bones and Teeth

The fibrous protein collagen is the main organic material within bones and teeth, making up approximately 90% of the organic component of these tissues. Each collagen molecule is comprised of three polypeptide chains forming a triple helical structure, and molecules are arranged together as fibrils to form collagen fibres. This provides elasticity to bones and teeth, and the inorganic hydroxyapatite crystals embedded in the collagen matrix provide structural strength (White *et al.*, 2011). Collagen is synthesised using amino acids made available through the breakdown of dietary proteins during digestion, meaning that the chemical composition (and therefore $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values) of collagen is directly related to that of ingested foods (Pate, 1994). However, it has been demonstrated that collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values differ between tooth dentine, cortical, and trabecular bone sampled from the same individual, with the isotopic make-up of these tissues interpreted as reflecting food consumption at different points within an individual's life (Sealy *et al.*, 1995).

In bone collagen, measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values represent a long-term average of consumed dietary protein due to continuous bone turnover (remodelling), where old bone is resorbed by osteoclasts and new bone deposited by osteoblasts (Pate, 1994). Turnover rates vary across an individual's lifetime and between bones. In adults, long bones with higher proportions of denser cortical bone exhibit slower turnover rates, reflecting averaged dietary input over a minimum of 10 years and likely including isotopic signals of food consumed during adolescence as well as adulthood (Sealy *et al.*, 1995; Hedges *et al.*, 2007). In comparison, quicker turnover rates are documented for bones with greater proportions of more porous trabecular bone like ribs, which record later life diet in the years prior to death (Sealy *et al.*, 1995).

Unlike with bone, collagen in tooth dentine does not remodel after formation in childhood, so $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values yielded reflect the diet consumed during the developmental period of the analysed tooth (Hillson, 2023). As development timings vary between tooth types, researchers must understand the full dietary timespan represented by $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, with established reference materials created by AlQahtani (2008; AlQahtani *et al.*, 2010) and Beaumont and Montgomery (2015) used for deciduous and permanent dentition. Dentine collagen can also be sampled incrementally to create a profile of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values throughout a tooth's development, allowing diet and other physiological events to be

explored at high resolution (Beaumont *et al.*, 2013a; 2014), although this method hasn't been widely applied to Romano-British sites.

Ultimately, analysing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in different skeletal elements provides information about diet at various stages of life, from childhood (dentine), adolescence/adulthood (long bone), through to later life (rib). To ensure reliable interpretations can be made from $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, collagen samples should be assessed for good preservation against recognised quality control parameters. A sample's %C (total organic carbon content) and %N (total organic nitrogen content) should fall between 31-43% and 9-15%, respectively, and an acceptable C:N atomic ratio lies between 3.1-3.5 (or 2.9-3.6 more leniently), indicating that the extent of diagenesis has not contaminated or significantly modified the collagen (DeNiro, 1985; Ambrose, 1990; Van Klinken, 1999).

3. Methodology

To achieve the research aims, the Romano-British dataset (Appendix 1) has been created to collect, store, analyse and interpret $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data sourced from publications. As data can be presented in vastly different ways depending on researchers' objectives and priorities, it is necessary to explain and justify choices made in this dataset's creation. This chapter outlines data acquisition methods, the dataset's structure and format, and decisions influencing data standardisation and categorisation, as well as how data visualisation products have been created. These aspects of the dataset's design will be detailed for the Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data, associated contextual information, and comparative faunal isotope data compiled during this research.

3.1 Data Collation

The initial aspiration of this research was to gather Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data from all available published sources, as stated in Aim 1. However, during data collection it was decided not to include data from resources outside traditional academic peer-reviewed publication (i.e. grey literature) to control the study's scope and ambition, ensuring the planned research was achievable in the restricted timeframe. This decision was also made in acknowledgement of the issues that arise from using grey literature to source data, including problems with findability of relevant quality-assured data, usability of search engines and databases, and standardisation of data presentation (as discussed in Appendix 2).

Formal publications are not immune to issues with data quality and standardised reporting. However, the greater level of controls for quality assurance and data reproducibility afforded by peer review processes with specialist reviewers, in tandem with the more sophisticated nature of academic research databases, ultimately informed the decision to narrow the dataset's scope. Rather than incorporating grey literature sources, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data has been collected from formally published peer-reviewed academic literature, including journal articles and books accepted as being suitable for public dissemination within established multi-disciplinary research outputs distributed by well-respected publishing bodies. Widely used academic search engines including Scopus (Elsevier, 2026) and Google Scholar (Google, 2026c) were consulted for data collection, as well as online library databases and research repositories of Durham University (2026a; 2026b) and University of Wales Trinity

St David (2026). Great thanks and acknowledgement must also be given to Dr Mandy Jay, who's compiled dataset of published and undistributed isotope data and associated contextual information, kindly shared by the AIPRL team (Jay, 2021; Moore, 2023), was used as a foundation from which the preliminary structure of the Romano-British dataset was developed and initial data references were gathered. Faunal isotope data was also sourced from formal publications using the same methodology. No new isotope data was generated as part of this research.

It is important to acknowledge that purposeful omission of grey literature does limit the dataset. By excluding potential data sources, the dataset's sample size is reduced considerably in comparison to its full potential scale, suggesting that interpretations made from data analysis conducted in this work may not be wholly representative of dietary behaviour across all aspects of Romano-British society. Despite this, it is the authors' intention that the data compiled using this methodology represents not a 'complete' collection of all existing data, but a relatively large and comprehensive analytical dataset that will act as an indicator of both the amount and type of Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data currently available, and its research potential to answer diverse questions about dietary behaviour. It is hoped that grey literature data will be incorporated in future as part of the dataset's expansion.

3.2 Dataset Structure

This dataset's structure and format justification has been influenced by the author's previous lead isotope dataset created as part of module HPAR7004's assignment portfolio (Parker, 2024). All collected data is compiled within a file titled "Roman_Britain_CN_Isotope_Dataset". Generated using Microsoft Excel, the dataset contains two spreadsheets: "Roman_Human_CN_Isotope_Data" and "Faunal_CN_Isotope_Data". In Appendix 1, the dataset is provided as both a comma-separated values (.csv) plain text file and an Excel file (.xlsx) to safeguard its accessibility and use in future. As the dataset is intended to be used and manipulated by future researchers to support isotope research and commercial projects, providing the file in a plain text format ensures it can be accessed using different software packages than Excel, whilst also preserving the dataset's content and structure during data migration. Both .xlsx and .csv formats are recommended for digitally archiving the dataset (ADS and Digital Antiquity, 2013; ADS, 2026).

Excel was chosen to gather, store and analyse data as the software's spreadsheets and inbuilt features are well-suited for tabulating different types of data cohesively, and are particularly useful for handling numerical data like $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. The use of Excel also aligns well with this study's aims and objectives due to the ability to easily generate charts and tables within the software from inputted data, in order to create visualisation products and facilitate analysis (Niven, 2012). Moreover, it is hoped this Romano-British dataset will eventually be able to be used by researchers as a complementary tool alongside existing publicly available isotope datasets such as the Biosphere Isotope Domains dataset for Great Britain (Evans *et al.*, 2022; 2023; UKRI, 2026), the Global Lead Isotope Database (Westner *et al.*, 2021, GlobaLID Core Team, 2025), the Oxford Archaeological Lead Isotope Database (Stos-Gale and Gale, 2009), and IsoArch (Salesse *et al.*, 2018; 2020). As these datasets store data and export query results using Excel file formats, the software's use was deemed suitable within this research for continuity, and to facilitate data consolidation and comparison in future.

The structure of the main spreadsheet ("Roman_Human_CN_Isotope_Data") is comprised of 31 columns, grouped into five broad categories: locational and site-specific information, chronological information, osteological information, isotope data, and references. The first three categories (representing 13 columns) record essential contextual information for each individual the isotope data derives from. This data provides the background information required during analysis to separate the individuals into groups to investigate effects different variables have on dietary behaviour, and thus achieve Aim 2's objectives. There are 6 columns for locational and site-specific information ("Site_Name", "Site_Map_ID", "Country", "County/Region", "Settlement_Type", and "Rural/Urban"); 3 for chronological information ("Dating_Information", "Summary_Date" and "Final_Date"); and 4 columns for osteological information ("Context/Skeleton_ID", "Age-at-Death_Estimation", "Age_Category", and "Biological_Sex_Estimation"). Various other contextual data could have been included as additional columns, such as grave goods, burial orientation, stature estimation, and pathology. However, as this information wasn't available for many individuals within the dataset and is not wholly relevant to the demographic, geographical, and chronological variables under investigation, its inclusion was deemed to be more appropriate as an objective for future work.

Isotope data required a more complex recording structure to acknowledge where multiple samples from the same individual have been analysed, yielding $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for

different sample types. Three separate columns for “Dentine”, “Long_Bone” and “Rib” have been included to represent tissue types sampled across the literature. They are listed here as they are ordered in the dataset, which reflects their formation order from earliest to latest. As stated, dentine collagen forms during tooth development in childhood and does not remodel (Hillson, 2023), whilst collagen from long bones is assumed to have a slower turnover rate than that of ribs (Sealy *et al.*, 1995; Hedges *et al.*, 2007). Each of these overarching columns contains 5 sub-columns with the isotope data (“ $\delta^{13}\text{C}$ ” and “ $\delta^{15}\text{N}$ ”) alongside the C:N atomic ratio (“C:N”), total organic carbon content (“%C”), and total organic nitrogen content (“%N”). “Dentine” and “Long_Bone” columns also have an additional sub-column (“Tooth_Sampled” and “Bone_Sampled”, respectively), recording the type of tooth and bone analysed, which is essential to approximate the dietary timeframe represented by the isotope values. “Tooth_Sampled” data is standardised using the notation style popular across the literature (White and Folkens, 1991), which utilises initials and numbers to represent different tooth types. Separate columns for dentine, long bone and rib means all data available for one individual is stored within a single row. This prevents issues encountered when using similar multi-sample datasets, where separate spreadsheets were created for tooth and bone isotope data, and contextual information was duplicated across them (Leggett, 2020). This makes cross-referencing the dataset more difficult for users, individuals with data for multiple sample types harder to find, and introduces the risk that the isotope data is interpreted as being from two different individuals. It’s therefore hoped the structure adopted here reduces the chance of data misinterpretation and makes the dataset more user-friendly.

The final column records reference details for the data’s source publications. Citations are documented using an amended format of Harvard’s in-text referencing style, avoiding use of stylistic text formatting (italicisation) that doesn’t transfer properly during data migration. Commas after authors’ names are also omitted to preserve the dataset’s structure in future, as commas indicate the start of new columns and data fields within .csv files. Full references are instead available in Appendix 3. In line with this, formatting across the dataset was purposefully kept minimal to facilitate data continuity. Where possible, special characters have been avoided, with only delta symbols used as part of the typical notation style for reporting the measured ratio of carbon and nitrogen isotopes relative to their appropriate standard. Even superscript numbers in the “ $\delta^{13}\text{C}$ ” and “ $\delta^{15}\text{N}$ ” columns haven’t been included to limit the chance of data loss or misinterpretation by future users. Overall, all aspects of the dataset’s structure, from software and file format choices to the chosen title,

columns and non-stylistic design, aim to ensure the dataset adheres to FAIR guiding principles (Wilkinson *et al.*, 2016), and is not only created to be fair, accessible, interoperable and reusable but to retain these features over its use long-term.

The “Faunal_CN_Isotope_Data” spreadsheet has been kept brief. As the purpose of this data is only for creation of the faunal baseline, detailed recording falls outside this work’s scope. The spreadsheet contains 8 columns: “Site_Name”, “Country”, “County/Region”, “Summary_Date”, “Species”, “ $\delta^{13}\text{C}$ ”, “ $\delta^{15}\text{N}$ ” and “Reference”. Sex, age, and sampled element information as well as %C, %N, and C:N data were rarely available in the literature so were not included. Figure 4 demonstrates the structure and column order for both spreadsheets.

“Roman_Human_CN_Isotope_Data” Spreadsheet:

Site Name	Site Map ID	Country	County/Region	Settlement Type	Rural/Urban	Dating Information	Summary Date	Final Date	Context/Skeleton ID	Age-at-Death Estimation	Age Category	Biological Sex Estimation	Dentine				Long Bone				Rib				Reference		
													δ13C	δ15N	C:N	%C	%N	Bone Sampled	δ13C	δ15N	C:N	%C	%N				
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC329	50 Middle Adult	M							-17.8	11.5								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC348	25 Young Adult	M							-17.9	10.8								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC388	25 Young Adult	M							-18.5	10.4								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC236	40 Middle Adult	M							-18.3	9.8								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC234	50 Middle Adult	M							-18.4	10.1								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC235	25 Young Adult	F							-18.2	7.3								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC173	25 Young Adult	F							-17.6	10.4								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC529	40 Middle Adult	F							-18.7	10.1								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC513	30 Young Adult	M							-18.1	10.7								Richards et al 1998
Poundbury Camp		England	Dorset		Urban	4th C AD	Late Roman	Late Romano-British	PC530	30 Young Adult	M							-18.6	9.7								Richards et al 1998

“Faunal_CN_Isotope_Data” Spreadsheet:

Site_Name	Country	County/Region	Summary_Date	Species	δ13C	δ15N	Reference
Tanner Row, York	England	Yorkshire	Roman	Cattle	-21.8	7.1	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Cattle	-22.1	6.7	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Cattle	-21.9	6.6	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Cattle	-21.0	8.6	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Cattle	-21.9	7.0	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Cattle	-21.5	5.4	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Sheep/Goat	-21.5	5.1	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Sheep/Goat	-22.3	6.6	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Sheep/Goat	-21.3	7.9	Müldner and Richards 2007
Tanner Row, York	England	Yorkshire	Roman	Sheep/Goat	-21.6	6.0	Müldner and Richards 2007

Figure 4: Structure of “Roman_Human_CN_Isotope_Data” and “Faunal_CN_Isotope_Data” spreadsheets

3.3 Data Categorisation and Standardisation

To conform with FAIR guiding principles (Wilkinson *et al.*, 2016) and good practice standards outlined by ADS and Digital Antiquity (2013), vocabulary controlling data entry into the dataset's columns is presented in Appendix 3. Similar to a metadata statement, this documents how data held within the dataset has been recorded, so that it can be understood by future users and to ensure any further data added will follow the categorisation and standardisation methods outlined below. If deposition with ADS (2026) is explored later, a full metadata file and supporting statement will be created using their template file for spreadsheet submission.

3.3.1 Locational and site-specific information

Site names are recorded as they appear in the literature. Each site has been assigned a number in the “Site_Map_ID” column, corresponding to the key in Figure 1. Sites are numbered from north to south to ensure the key is easier to understand and use. This decision was made to combat issues observed in publications that order sites alphabetically (e.g. Evans *et al.*, 2012), which makes it difficult to quickly pick out sites of interest using the key without having to continually refer to the map to find the correct locations and numbers. Mapped site locations were determined using information available within publications, and where this was unavailable, Google Earth Pro and Google Maps (Google, 2026a; 2026b) were used to find approximate locations. Co-ordinate data was not available for most sites. As this study's geographical scope only concerns Britain, data entry in the “Country” and “County/Region” columns is restricted to England, Scotland, Wales and their recognised counties and regions. In all cases, modern names and current political boundaries for countries, counties and regions have been used to simplify recording, analysis, and figure creation, and to align with information provided in publications.

The “Settlement_Type” column records information about the context of sites relating to their civilian or military associations. If a site or individuals analysed have been interpreted in the source publication as being associated with military activity this should be documented, as military regulations and status are another variable that could impact diet and therefore the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. However, as Romano-British settlement types are complex and diverse, especially as some larger civilian settlements and towns grew from settlements with existing military associations (Historic England, 2018), data was only entered into this column when a military, civilian or mixed settlement link is explicitly mentioned in the literature. Similarly,

sites' rural or urban contexts have been recorded to aid interpretations of geographic variation in dietary behaviour, with the data entered from information available in publications.

3.3.2 Chronological information

Across both spreadsheets, the “Summary_Date” column logs the broad chronological period each individual/animal is associated with, as described in publications. Where chronological prefixes such as “Early” or “Late” have been used, these have been retained to preserve information from original sources. Numerical date ranges from the literature are reported in the “Dating_Information” column, encompassing information derived from both scientific and relative dating methods. Where relative dating was used, date ranges use the “AD/BC” reporting standard to align with the majority of the publications, but this is interchangeable with the more inclusive “BCE/CE” system. Where radiocarbon dating was employed, date ranges are reported using both “cal AD/BC” and “BP”, where available. Both scientific dating unit formats were used to ensure cohesion with original source data and to avoid introducing inaccuracies through conversion, and are recorded as presented in the literature. All recorded date ranges are standardised using the following presentation style: “date range” followed by the corresponding unit, with analytical uncertainties (denoted using “±”) and laboratory codes included for radiocarbon dates where available to conform to reporting conventions (Millard, 2014).

3.3.3 Osteological information

Context numbers and/or skeleton ID's given to individuals in publications have been copied directly into the dataset to allow easy reference back to original data sources. For all osteological information, data is also recorded as described in the literature, as reassessment of remains is not possible and beyond the research scope.

As investigating dietary differences between males and females forms part of this study's aims, accurate and standardised data is essential to facilitate reliable interpretations. Established terminology is used to standardise biological sex estimation data, following Buikstra and Ubelaker (1994), which employs five categories: male, probable male, probable female, female, and undetermined (shortened in the dataset to the more widely used abbreviations: M, M?, F?, F, and U).

As recommended in guidelines for recording human remains (O'Connell, 2004) and widely used across the literature, Buikstra and Ubelaker's (1994) four broad age categories have

been employed for adults and adolescents to standardise the “Age_Category” column. Accepted vocabulary and established age ranges of these categories are: Adolescent (12-20 years), Young Adult (20-35 years), Middle Adult (35-50 years), and Old Adult (50+ years). Whilst included in the dataset to demonstrate their presence in the literature and highlight potential avenues of future research, data for non-adult individuals younger than 12-years-old will not be used in analysis. This is because $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of non-adults (particularly infants) are often influenced by various factors aside from diet such as breastfeeding, stress, and illness (Beaumont *et al.*, 2015; 2018), so would introduce additional uncontrollable variables that must be accounted for when interpreting their isotope data. As such, these individuals are grouped together in the dataset as “Non-Adults”. Where provided, age-at-death estimations are preserved from publications as numerical age ranges in the “Age-at-Death_Estimation” column for transparency and to store useful data for future users.

3.3.4 Isotope data

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are documented as reported in the literature, and are measured in parts per thousand (per mil: ‰) relative to the PDB/VPDB and AIR standards, respectively. This data is standardised to one decimal place in the “ $\delta^{13}\text{C}$ ” and “ $\delta^{15}\text{N}$ ” columns as is generally considered standard practice to avoid being overly precise, due to the analytical error commonly associated with $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values being ± 0.2 ‰ (Leggett, 2020). Data in columns “C:N”, “%C” and “%N” is also copied from publications and standardised to one decimal place, with C:N atomic ratio being a unitless measurement, and both total organic carbon content and total organic nitrogen content measured as percentages (%).

3.3.5 Faunal data

Data within columns shared between the Romano-British human data spreadsheet and the faunal data spreadsheet have been recorded and standardised in the same way as described above. Species have been reported using their common names, as is typically practiced within the literature. Across the entire dataset, all attempts have been made to keep data as true to source publications as possible during categorisation and standardisation. By doing so, the data retains its original meaning, and no additional connotations are prescribed to it. Terminology used for standardised columns is explained in Appendix 3.

3.4 Analytical Variables

For analysis, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data has been categorised into variable groups to meet Aim 2's objectives. Appendix 1 includes an "active" version of the dataset, showing the working process of how variables are sorted, analysed, and combined with chronological data for diachronic analysis.

Isotope data is separated into dentine, long bone, and rib groups to investigate variation between sample types. Male and probable male, and female and probable female data are combined to assess $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ variation between the sexes. Data from individuals with undetermined or no sex estimation information have not been included in this analysis due to these groups likely including both male and female individuals. Sites have been sorted into the following wider geographical region groups based on their county (Appendix 3): South-East Scotland, North England, East England, South-East England, and South-West England. To investigate broader geographical variation, these groups are combined into northern (South-East Scotland and North England) and southern regions (East, South-East and South-West England). $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data is also separated into chronological categories for the Early (1st–2nd centuries AD), Mid (2nd–4th centuries AD), Late (4th–5th centuries AD), and Late/Sub-Romano-British periods (5th–6th centuries AD), using compiled dating information and periods assigned in the literature. Where date ranges span two categories, prefixes are combined (e.g. Early-Mid) to avoid mis-assigning individuals to the wrong period, and to avoid using overly broad categories that may miss nuanced change over time. Individuals with no specific dating information available are grouped together as "Romano-British (undefined date)". These categorised dates are shown in the "Final_Date" column.

3.5 Data Visualisation Products

To achieve Aim 1's fourth objective, scatter graphs, box, and violin plots were created to visually represent data and observed trends. Scatter graphs were created in Excel. Within them, all data is given at 2σ (standard deviations) range, and analytical error ($1\sigma = 0.2\%$) is also shown to 2σ . Box and violin plots were generated using Numiqo statistical software (2026). Further statistical analysis using comparative tests fell outside this study's scope, but is an aim for future research.

4. Results

This chapter summarises results of data collection and analysis, providing summary descriptive statistic tables and visualisation figures for the Romano-British human isotope data and faunal data used to create the faunal baseline. Data analysis results for the variables under investigation are also described, alongside results of the integrated diachronic analysis. Where significant differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ indicate dietary change, this is described and will be interpreted in Chapter 5.

4.1 Compiled Data

4.1.1 *Romano-British Dataset*

The “Roman_Human_CN_Isotope_Data” spreadsheet contains data for 772 individuals from 58 sites. Of these individuals, 140 are non-adults and were thus omitted from data analysis as previously explained, leaving only adults and adolescents. A further 2 individuals (FB2189 – Fordington Bottom, Dorset, and Sk208 – Lant Street, London) were excluded as their C:N ratios fall outside the range of acceptable collagen preservation quality (DeNiro, 1985; Ambrose, 1990; van Klinken, 1999), at 2.1 and 4.4, respectively. With these exclusions, 630 individuals were included in data analysis. In Table A3.5 (Appendix 3), site names are listed alongside the number of individuals they have contributed to the dataset.

4.1.2 *Faunal Dataset*

The “Faunal_CN_Isotope_Data” spreadsheet includes data for 296 faunal samples, representing 23 sites from 12 publications (Table A3.6: Appendix 3). This data was primarily obtained from the same literature as the human data to ensure the produced faunal baseline is directly related to the human isotope data it is being used to help interpret, and to avoid introducing additional isotopic variation from other sites with potentially different environments and animal husbandry practices.

For the faunal baseline, the data has been separated into 7 diet and environment-based categories:

- Terrestrial herbivores: 4 species (cattle, sheep/goat, horse, and wood pigeon)

- Terrestrial omnivores: 5 species (pig, wild boar, dog, domestic fowl, chicken)
- Semi-aquatic birds: 3 species (duck, goose, and swan)
- Freshwater fish: 2 species (cyprinid, pike)
- Marine fish: 8 species (cod, herring, flatfish, gadidae, haddock, ling, ray, whiting)
- Catadromous fish: 1 species (eel)
- Anadromous fish: 1 species (salmon)

Semi-aquatic birds are categorised separately as they occupy a unique ecological niche with access to terrestrial and aquatic resources. Whilst many species are primarily herbivorous, their diet can be supplemented by insects, small fish and other meat-based protein, consequently raising their $\delta^{15}\text{N}$ values (Müldner and Richards, 2007). Similarly, as catadromous and anadromous fish are diadromous (migrating from marine to freshwater and freshwater to marine environments, respectively, during their lifecycle) they've been separated from the purely marine and freshwater species their isotope values are expected to fall between (Müldner and Richards, 2007). Most of the faunal data is Romano-British, however as limited data was available for contemporaneous freshwater, marine and diadromous species, data for these groups has also been collated from Iron Age-Late Medieval contexts (like in earlier publications – Redfern *et al.*, 2010) to facilitate interpretations of their contributions to human diet.

4.2 Isotope Data

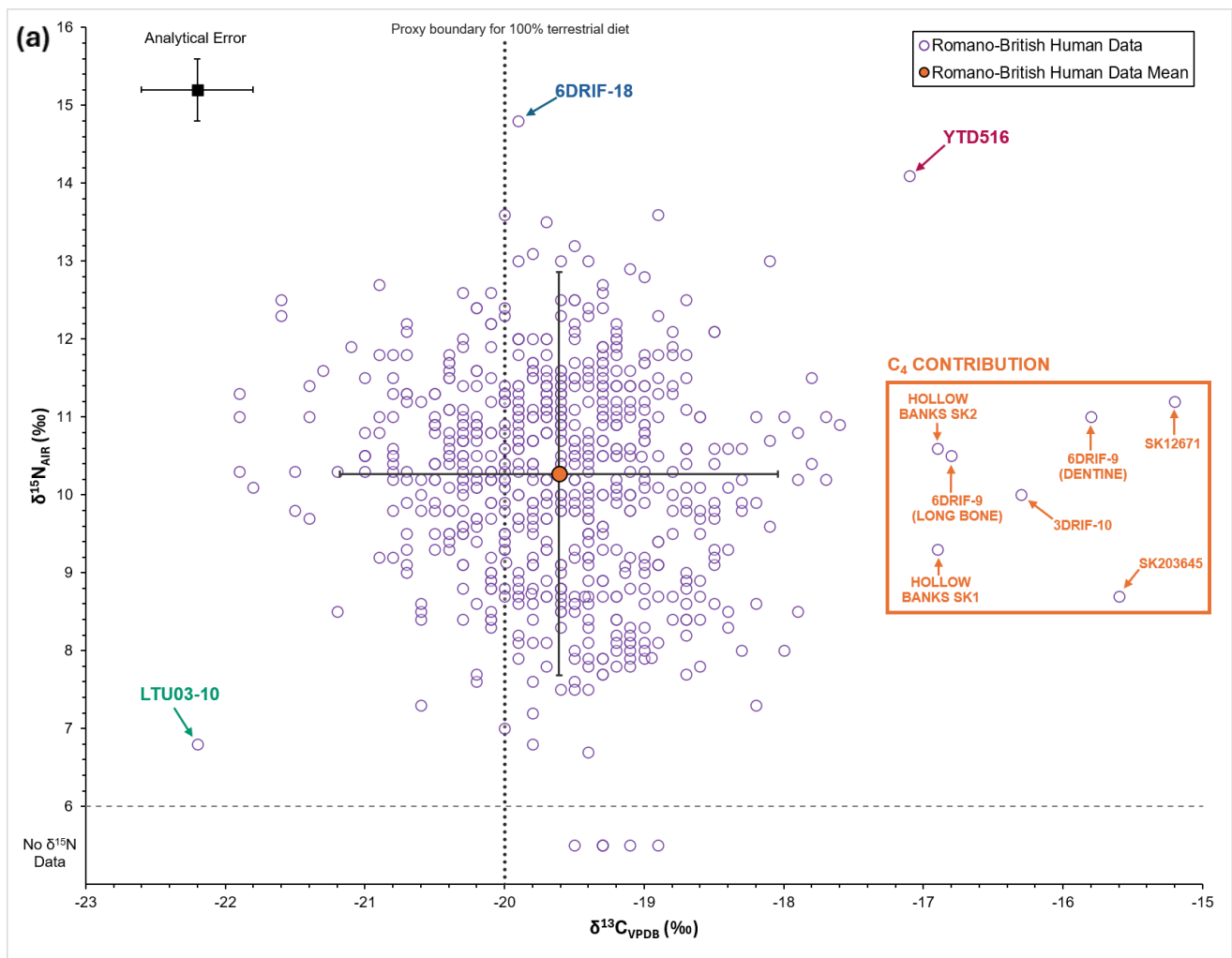
4.2.1 Romano-British Dataset

The analysed Romano-British human isotope data comprises 1,384 values ($\delta^{13}\text{C} = 695$; $\delta^{15}\text{N} = 689 - 6$ individuals' long bone $\delta^{13}\text{C}$ values did not have accompanying $\delta^{15}\text{N}$ values). All samples have C:N ratios (range = 2.9 – 3.6) in the accepted range for good collagen preservation (DeNiro, 1985; Ambrose, 1990; van Klinken, 1999). In Table 1 the data is summarised, and is presented together within scatter plots and alongside the faunal baseline in Figure 5.

Table 1: Summary descriptive statistics for Romano-British human isotope data.

Isotope Data	n	Min (‰)	Max (‰)	Range (‰)	Median (‰)	Mean (‰)	SD (‰)	2 SD (‰)
$\delta^{13}\text{C}_{\text{VPDB}}$								
All Romano-British Data	695	-22.2	-15.2	7	-19.6	-19.6	0.8	1.6
$\delta^{15}\text{N}_{\text{AIR}}$								
All Romano-British Data	689	6.7	14.8	8.1	10.4	10.3	1.3	2.6

In Figure 5a, the Romano-British data is scattered in a wide group around the mean, with no clear linear relationship between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Three clear individual outliers have been identified (6DRIF-18 – Driffield Terrace, North Yorkshire; YTD516 – Trentholme Drive, North Yorkshire; and LTU03-10 – Lant Street, London), as well as a cluster of 6 individuals (Sk12671 – Gravesend, Kent; Sk203645 – A14-20 River Great Ouse, Cambridgeshire; 6DRIF-9 – Driffield Terrace, North Yorkshire; 3DRIF-10 – Driffield Terrace, North Yorkshire; Sk1 – Hollow Banks, North Yorkshire; and Sk2 – Hollow Banks, North Yorkshire), with both dentine and long bone values from 6DRIF-9 represented in this outlier group. These are highlighted in Figure 5a and will be explored in Chapter 5.



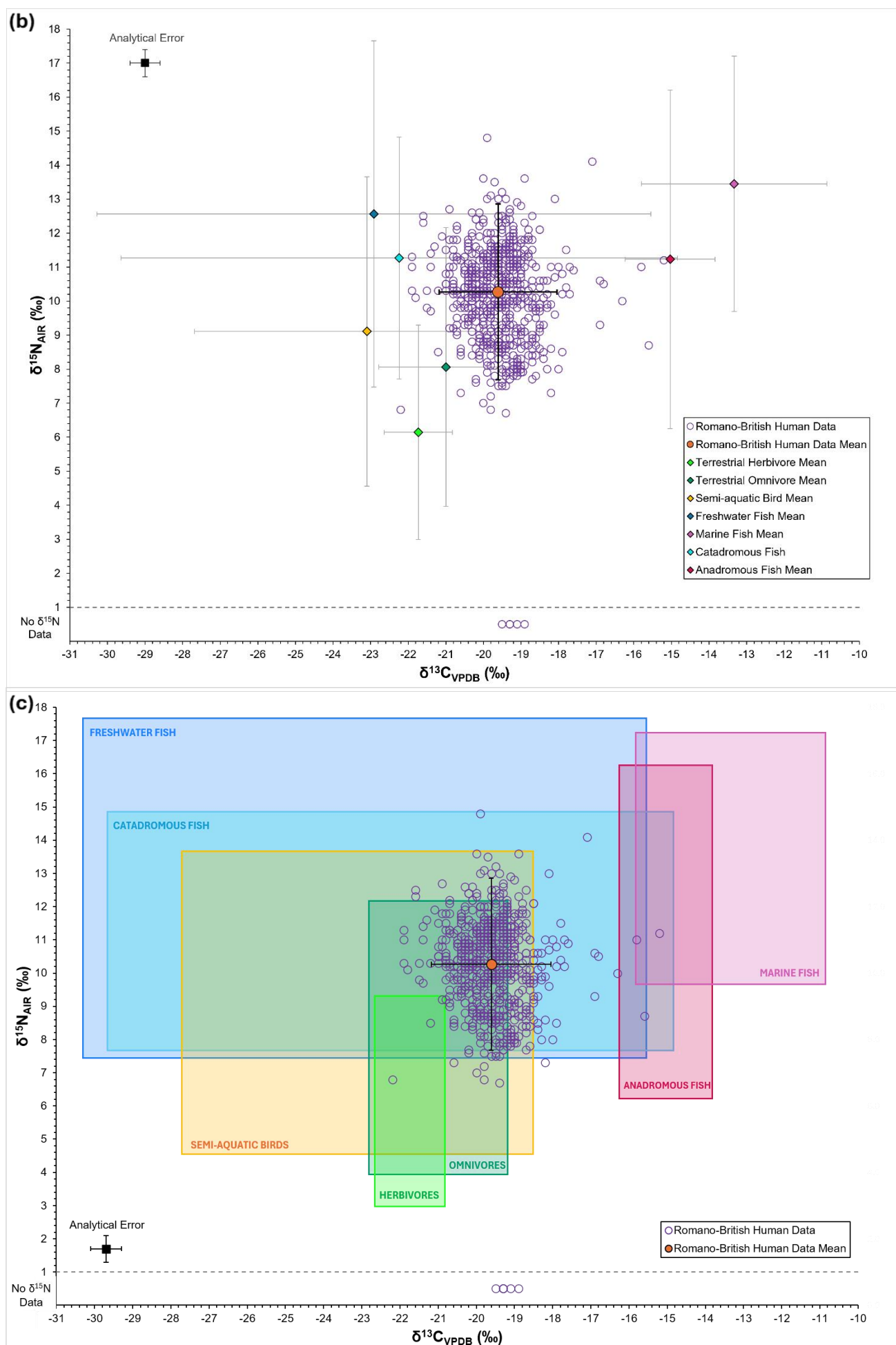


Figure 5: Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data distribution and mean, alongside outliers and the proxy boundary for 100% terrestrial diet (Bonsall et al., 2009) (a). Romano-British human data plotted against mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of faunal categories (b), and their data spread (c).

4.2.2 Faunal Baseline

592 isotope values ($\delta^{13}\text{C} = 296$; $\delta^{15}\text{N} = 296$) constitute the 7 faunal categories used to construct the faunal baseline. Table 2 summarises this data. The isotope values are shown in Figure 6, and Figure 5b and c show the categories' means and data spreads.

Table 2: Summary descriptive statistics for faunal isotope data categories.

<i>Faunal Group</i>	<i>n</i>	<i>Min</i> (‰)	<i>Max</i> (‰)	<i>Range</i> (‰)	<i>Median</i> (‰)	<i>Mean</i> (‰)	<i>SD</i> (‰)	<i>2 SD</i> (‰)
$\delta^{13}\text{C}_{\text{VPDB}}$								
Terrestrial Herbivores	149	-22.8	-20.3	2.5	-21.7	-21.7	0.5	0.9
Terrestrial Omnivores	85	-22.8	-17.6	5.2	-21.0	-21.0	0.9	1.8
Aquatic Birds	8	-26.2	-19.7	6.5	-22.2	-23.1	2.3	4.6
Freshwater Fish	14	-27.0	-14.2	12.8	-23.4	-22.9	3.7	7.4
Marine Fish	22	-16.1	-11.8	4.3	-13.0	-13.3	1.2	2.5
Catadromous Fish	12	-25.2	-12.8	12.4	-23.2	-22.2	3.7	7.4
Anadromous Fish	6	-15.6	-14.0	1.6	-15.2	-15.0	0.6	1.2
$\delta^{15}\text{N}_{\text{AIR}}$								
Terrestrial Herbivores	149	2.2	10.4	8.2	6.0	6.1	1.6	3.2
Terrestrial Omnivores	85	2.7	12.9	10.2	8.1	8.1	2.0	4.1
Aquatic Birds	8	4.9	11.8	6.9	9.7	9.1	2.3	4.5
Freshwater Fish	14	8.0	16.7	8.7	12.4	12.6	2.5	5.1
Marine Fish	22	10.1	17.2	7.1	14.0	13.5	1.9	3.8
Catadromous Fish	12	8.8	14.7	5.9	11.6	11.3	1.8	3.6
Anadromous Fish	6	8.6	13.9	5.3	11.3	11.2	2.5	5.0

As seen in Figure 6, terrestrial herbivore data clusters nicely and is less enriched in $\delta^{15}\text{N}$ than the higher-trophic-level terrestrial omnivores. Marine and anadromous fish group together in the plot's far-right corner, having high $\delta^{15}\text{N}$ values and being more enriched in $\delta^{13}\text{C}$ than other faunal groups. Semi-aquatic birds have quite a wide range of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, but ultimately plot between terrestrial and freshwater groups as expected. Similarly, freshwater and catadromous fish have wide data spreads and include one outlier each which falls within the range of marine and anadromous fish. These outliers have been retained due to the

groups' small sample sizes and their use in previous studies' analyses (Redfern *et al.*, 2010; 2018). However, these two groups generally plot where expected, having lower $\delta^{13}\text{C}$ than marine and anadromous fish, and being more enriched in $\delta^{15}\text{N}$ than terrestrial omnivores and herbivores.

When combined with the faunal baseline (Figure 5b), the Romano-British human mean has higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ than that of terrestrial herbivores, omnivores and aquatic birds, is less enriched in $\delta^{13}\text{C}$ than marine and anadromous fish but more enriched in $\delta^{13}\text{C}$ than freshwater and catadromous fish, and has lower $\delta^{15}\text{N}$ than the means of these four aquatic groups. The implications of this for the general nature of Romano-British diets is discussed in Chapter 5.

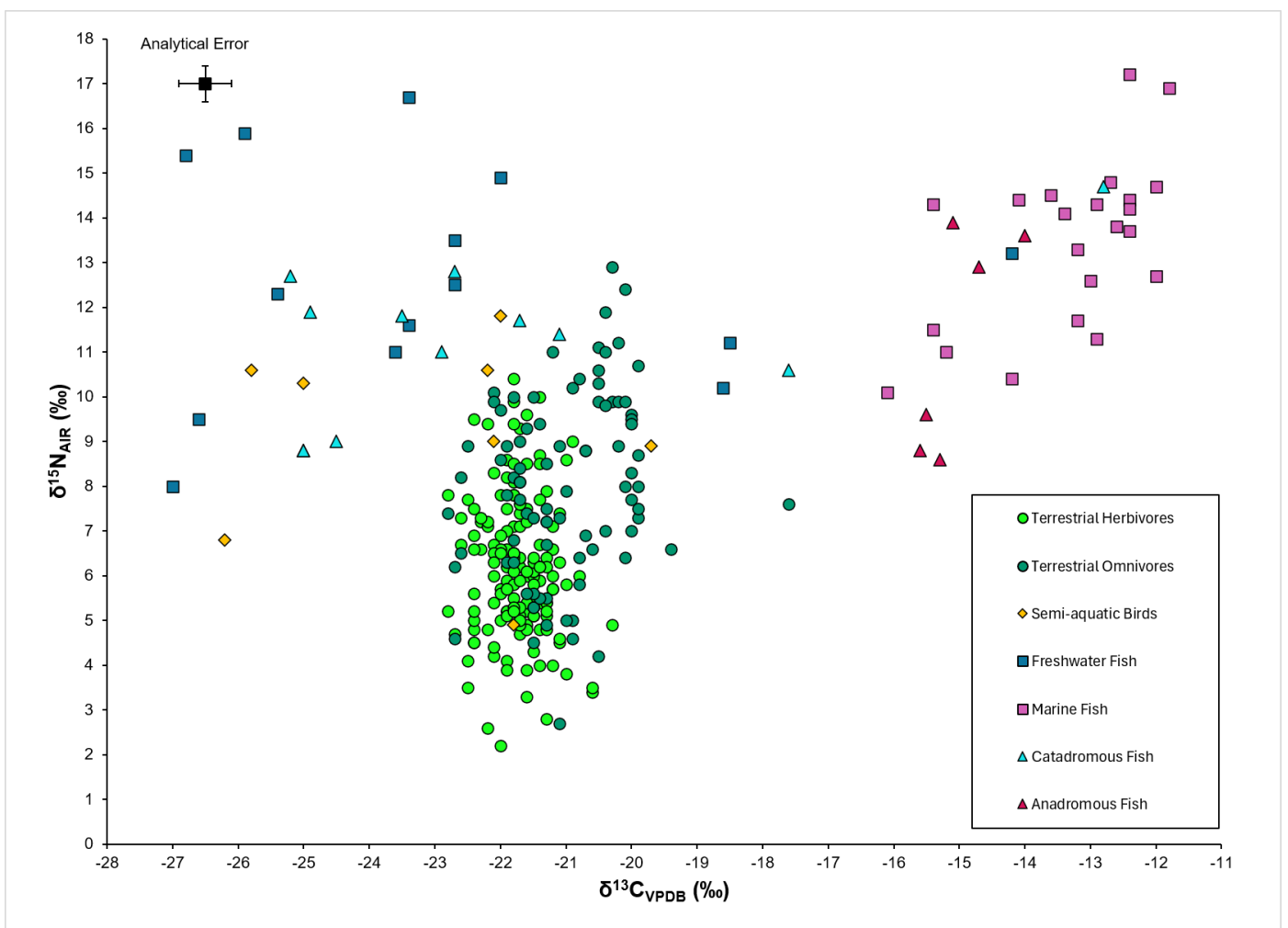


Figure 6: $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data distribution for faunal categories.

4.3 Analytical Variables

Summary descriptive statistics for all variables are presented in Appendix 4.

4.3.1 Sample Type

101 dentine, 194 long bone, and 400 rib $\delta^{13}\text{C}$ values were analysed alongside 101 dentine, 188 long bone, and 400 rib $\delta^{15}\text{N}$ values. Tooth types represented by dentine data include permanent canines (C), first and second pre-molars (PM1/PM2), and first, second and third molars (M1/M2/M3). Long bone data derives from femora, tibiae, fibulae, radii, humeri, and non-specified long bones. This category also includes data from one scapula, one skull and non-distinct bone samples. Although not long bones, their inclusion in the dataset is important to represent available data. Incorporation of these samples in analysis has minimal effect as all bone data will later be combined. The rib category contains only data obtained from rib samples.

Mean $\delta^{13}\text{C}$ values of dentine, rib, and long bone data are -19.7‰ (range = -21.4‰ – -15.6‰), -19.7‰ (range = -21.5‰ – -15.2‰), and -19.5‰ (range = -22.2‰ – -16.3‰), respectively. These means (Figure 7) show little variation in $\delta^{13}\text{C}$ between sample types, with dentine and long bone having the same mean and the rib mean within analytical error at 1 σ range. This lack of variation is highlighted in the range of $\delta^{13}\text{C}$ between the groups (Figure 8), but is contrasted by $\delta^{15}\text{N}$ data.

Mean long bone (10.0‰: range = 6.7‰ – 13.1‰) and rib (10.1‰: range = 6.8‰ – 14.1‰) $\delta^{15}\text{N}$ (Figure 7) show little variation and are within analytical error at 1 σ range. However, dentine's $\delta^{15}\text{N}$ mean (11.2‰: range = 8.7‰ – 14.8‰) sits well outside of analytical error at over 1‰ higher than the other sample types, implying this observed difference is statistically significant, as supported by Figure 8 showing how the dentine $\delta^{15}\text{N}$ range varies in comparison to the bone sample groups.

These observations imply there is no significant difference between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of long bone and rib samples, suggesting a similar diet was consumed by Romano-British individuals during adolescence/adulthood and the years before death. As such, these groups have been combined into one category representing all bone samples for further analysis and interpretation. Dentine isotope values remain a distinct group. Potential reasons for this variation between childhood and adolescent/adult/late life data is explored in Chapter 5.

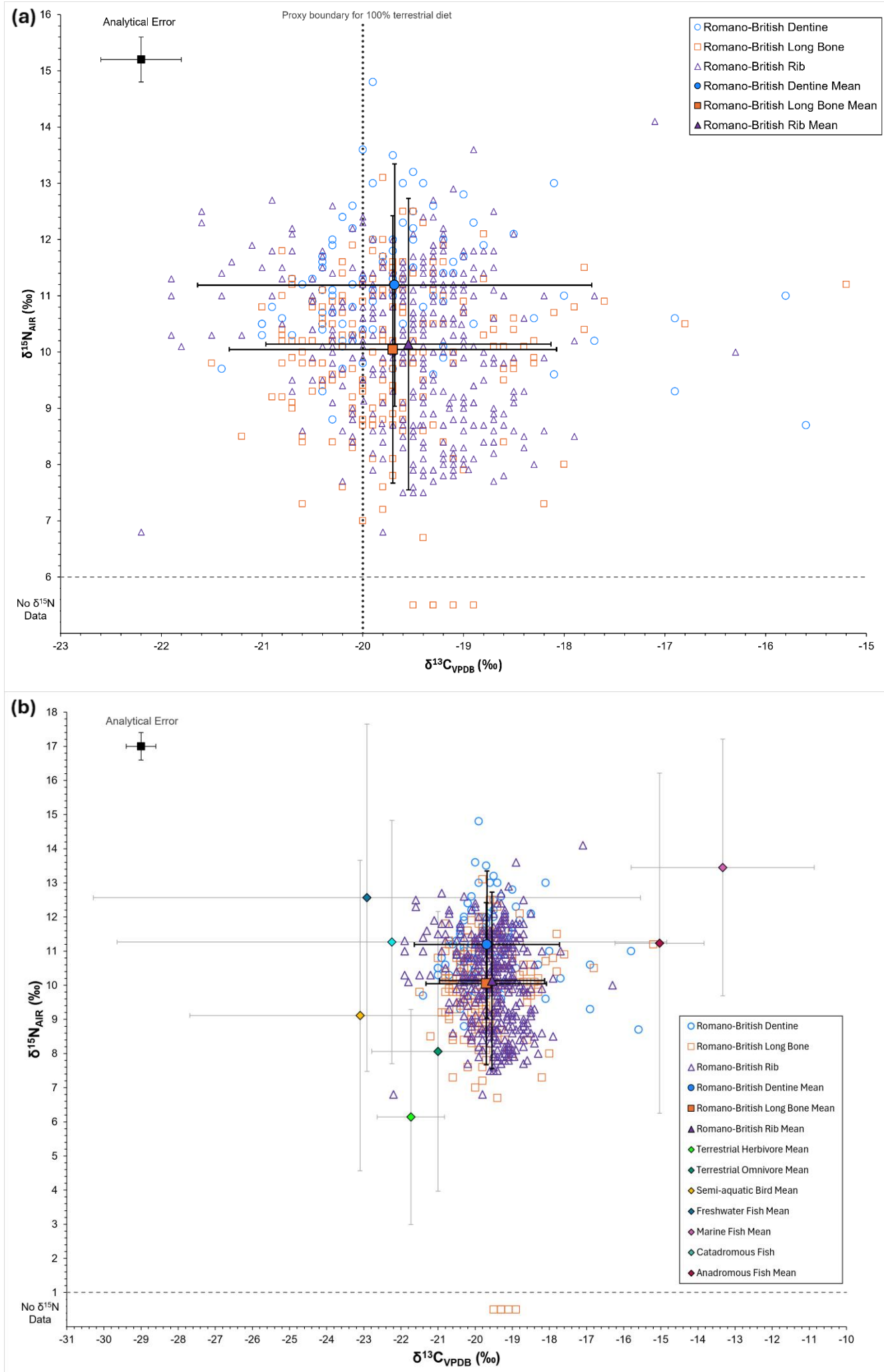


Figure 7: Dentine, long bone, and rib $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data and means (a). Sample type data compared against the faunal baseline (b) – note dentine’s higher $\delta^{15}\text{N}$ mean.

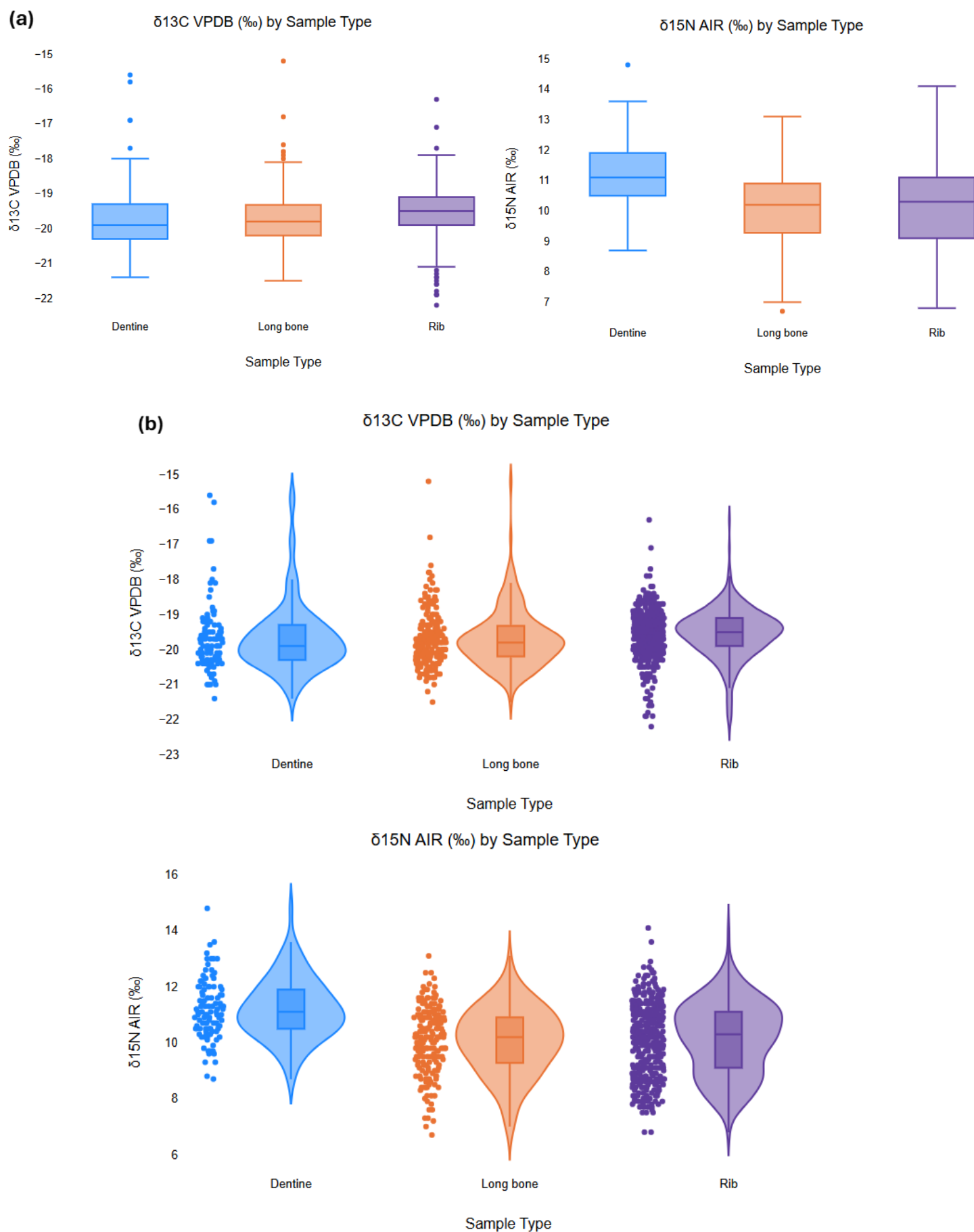


Figure 8: Box (a) and violin plots (b) comparing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ranges for dentine, long bone, and rib – note greater $\delta^{15}\text{N}$ variation in dentine than bone.

4.3.2 Biological Sex

Male (M + M?) isotope data is represented by 388 $\delta^{13}\text{C}$ values and 384 $\delta^{15}\text{N}$ values, whilst female (F + F?) isotope data consists of 197 $\delta^{13}\text{C}$ and 195 $\delta^{15}\text{N}$ values.

$\delta^{13}\text{C}$ means are -19.5‰ (range = -22.2‰ – -15.2‰) for males, and -19.7‰ (-21.6‰ – -17.6‰) for females (Figure 9). This 0.2‰ difference means both groups are within analytical error at 1 σ range, however Figure 10 highlights the 3‰ difference between male and female $\delta^{13}\text{C}$ ranges.

Male mean $\delta^{15}\text{N}$ (10.4‰: range = 6.8‰ – 14.8‰) is 0.4‰ higher than for females (10.0‰: range = 6.7‰ – 13.6‰) (Figure 9), which is just within analytical error at 2 σ range. This difference may not be statistically significant, however as the male $\delta^{15}\text{N}$ range is 1.1‰ higher than the females' (Figure 10), and 8 out of 9 of the identified outliers are male, variation in dietary behaviour between males and females and the resources they could access will be investigated. Therefore, males and females remain as separate groups for further analysis.

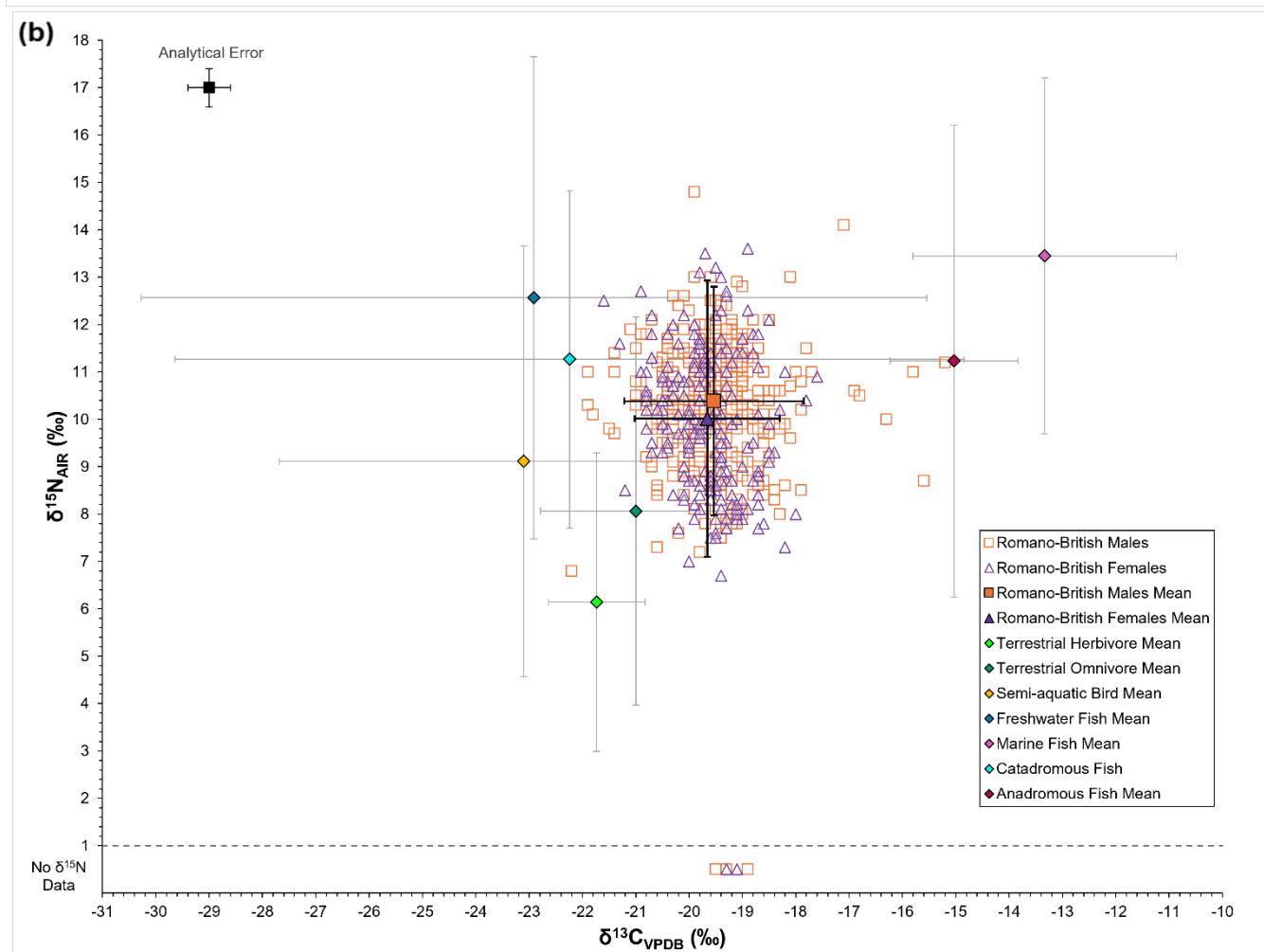
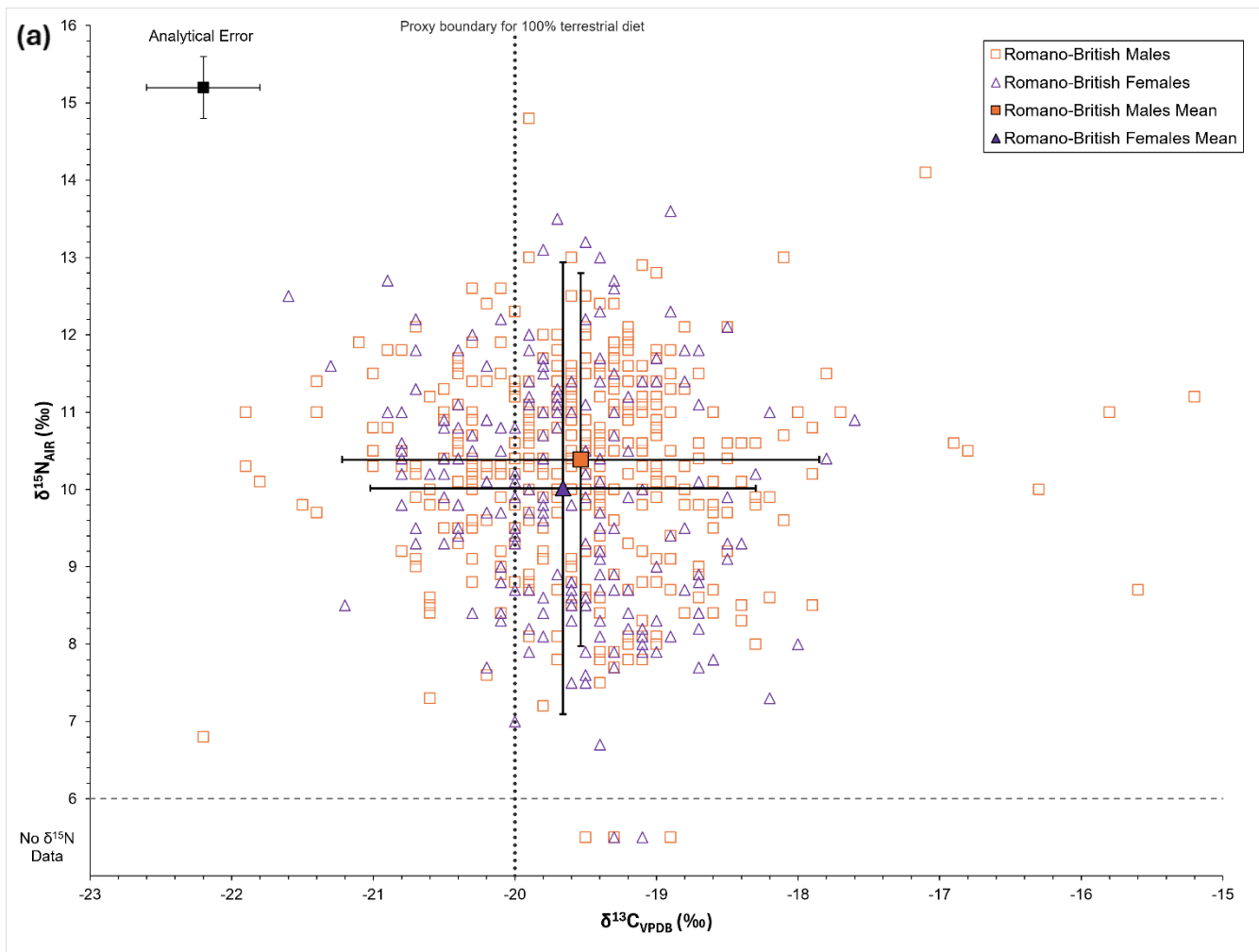


Figure 9: Male and female $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data and means (a). Biological sex data compared against the faunal baseline (b).

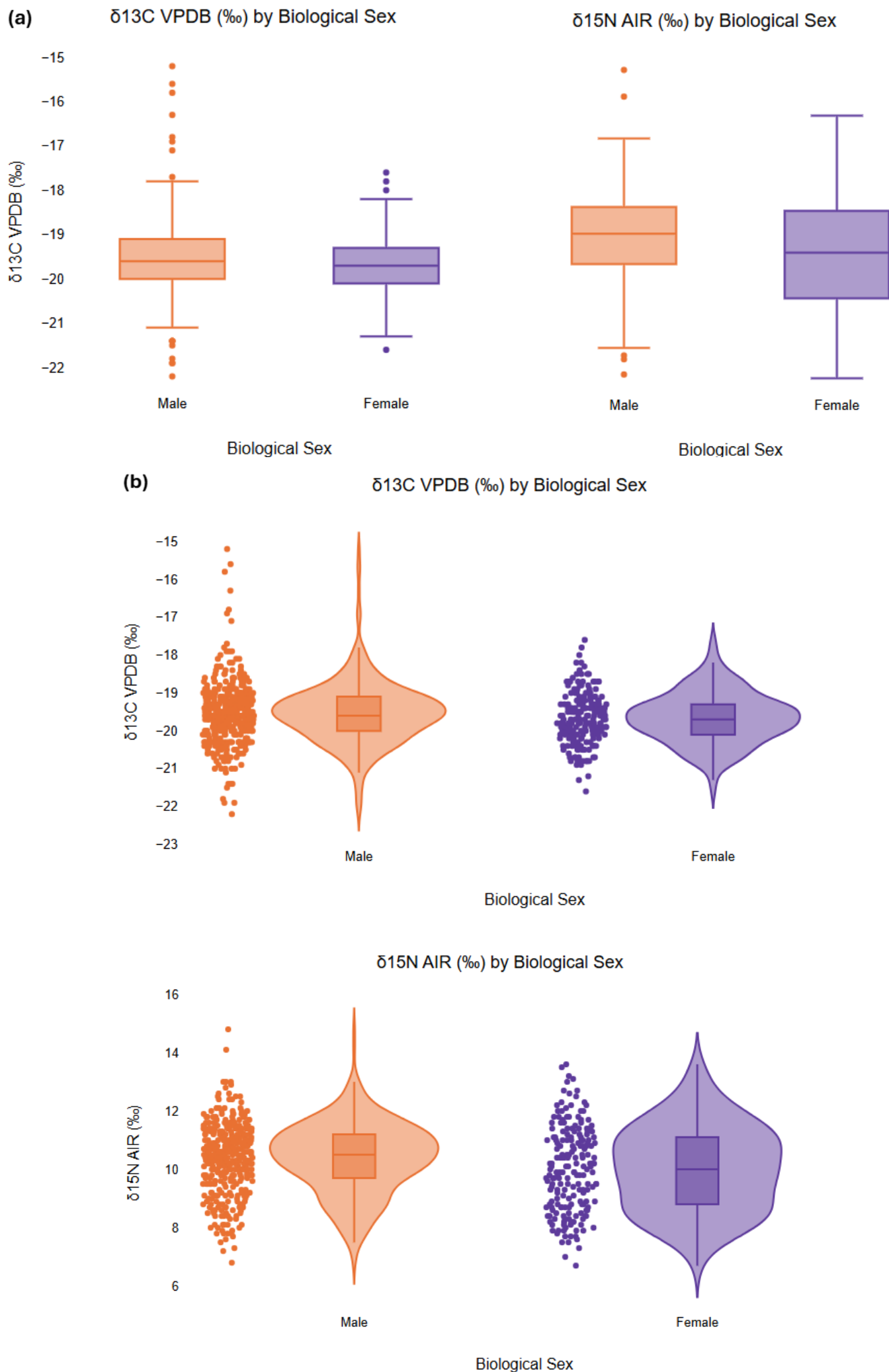


Figure 10: Box (a) and violin plots (b) comparing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data for males and females – note higher male $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ranges.

4.3.3 Geographical Region

The 5 geographical categories include data for South-East Scotland ($\delta^{13}\text{C} = 10$; $\delta^{15}\text{N} = 10$), North England ($\delta^{13}\text{C} = 213$; $\delta^{15}\text{N} = 213$), East England ($\delta^{13}\text{C} = 45$; $\delta^{15}\text{N} = 45$), South-East England ($\delta^{13}\text{C} = 247$; $\delta^{15}\text{N} = 242$), and South-West England ($\delta^{13}\text{C} = 182$; $\delta^{15}\text{N} = 179$).

$\delta^{13}\text{C}$ means for North (-19.6‰: range = -21.0‰ – -15.8‰), South-East (-19.4‰: range = -22.2‰ – -15.2‰), and South-West England (-19.7‰: range = -21.5‰ – -17.7‰) are within analytical error at 2σ range. But whilst mean $\delta^{13}\text{C}$ for South-East Scotland (-20.4‰: range = -21.4‰ – -19.2‰) and East England (-20.3‰: range = -21.9‰ – -15.6‰) are within analytical error at 1σ range, they fall outside analytical error of the other three groups at 2σ range and are significantly lower (Figure 11). This is mirrored in the $\delta^{13}\text{C}$ ranges (Figure 12), with South-East Scotland and East England plotting slightly below other groups.

$\delta^{15}\text{N}$ means for South-East (9.6‰: range = 6.8‰ – 13.6‰) and South-West England (9.9‰: range = 6.7‰ – 12.6‰) are within analytical error at 2σ range, whilst those of South-East Scotland (10.9‰: range = 9.5‰ – 11.9‰) and North England (11.0‰: range = 8.4‰ – 14.8‰) are higher and within analytical error at 1σ range. East England's mean $\delta^{15}\text{N}$ (11.6‰: range = 8.7‰ – 13.6‰) is significantly higher than other groups (Figure 11), as supported by the $\delta^{15}\text{N}$ ranges (Figure 12). This variation in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ may imply exploited dietary resources differed between regions in Roman Britain.

Combining regional groups masks this observed variation due to sample size differences between merged groups, but simultaneously reduces the impact of possible outliers. $\delta^{13}\text{C}$ means for South-East Scotland/North England (-19.6‰: range = -21.4‰ – -15.8‰), East/South-East England (-19.6‰: range = -22.2‰ – -15.2‰), and South-West England (above) are all within analytical error at 1σ range and show little difference between $\delta^{13}\text{C}$ ranges (Figure 13 and 14). Yet, despite mean $\delta^{15}\text{N}$ being the same for East/South-East England (9.9‰: range = 6.8‰ – 13.8‰) and South-West England (above), South-East Scotland/North England's mean $\delta^{15}\text{N}$ (11.0‰: range = 8.4‰ – 14.8‰) is 1.1‰ higher and plots above other groups when comparing $\delta^{15}\text{N}$ ranges (Figure 13 and 14).

These results do not indicate dietary differences between western and eastern Romano-British sites in England, as supported by $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means and ranges not changing when the large South-West group is combined with East/South-East England. However, a north-south dietary divide can be inferred from the significant variation in $\delta^{15}\text{N}$ and will be explored, implying location influenced Romano-British dietary behaviours.

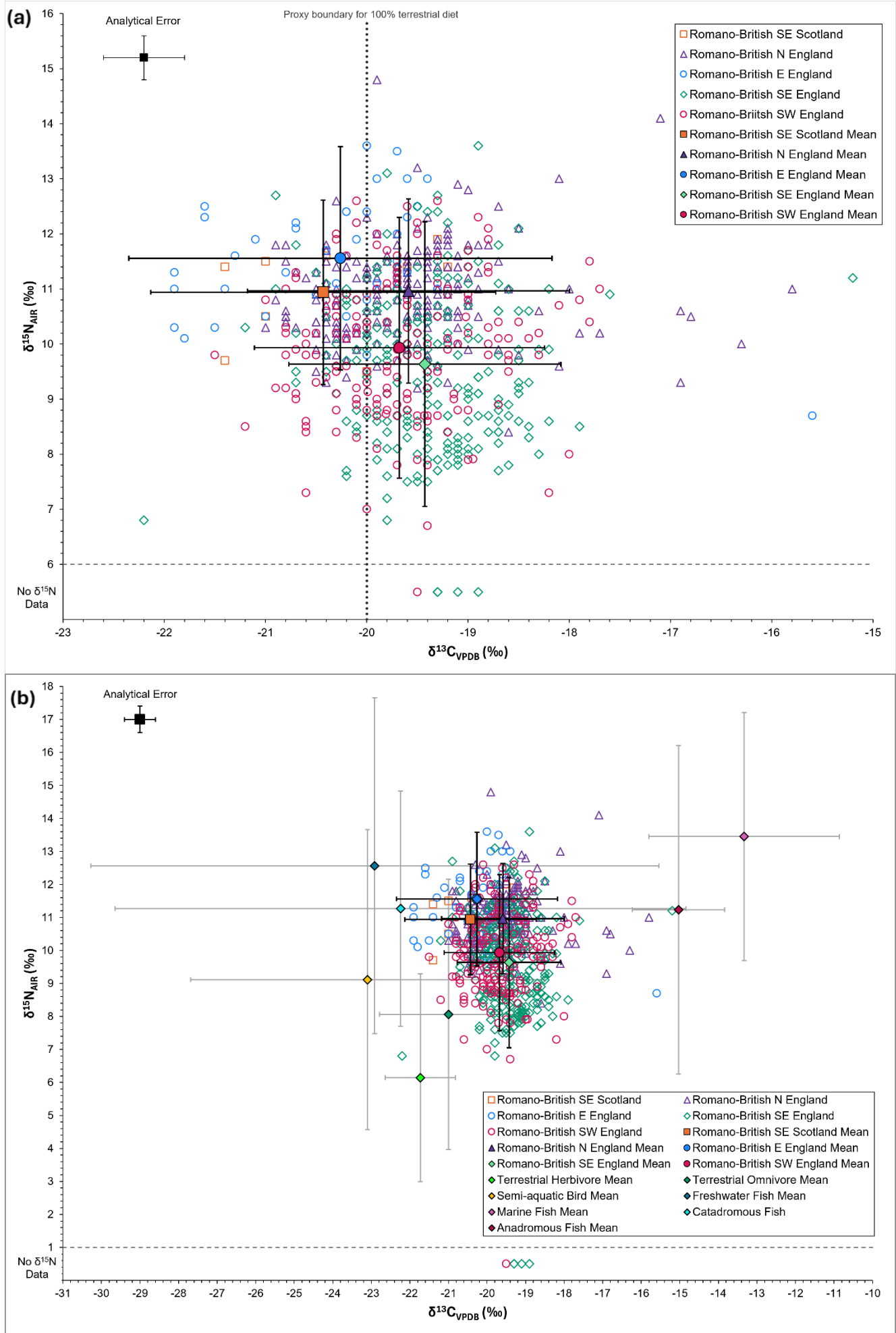


Figure 11: Geographical region $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data and means (a). Geographical data compared against the faunal baseline (b).

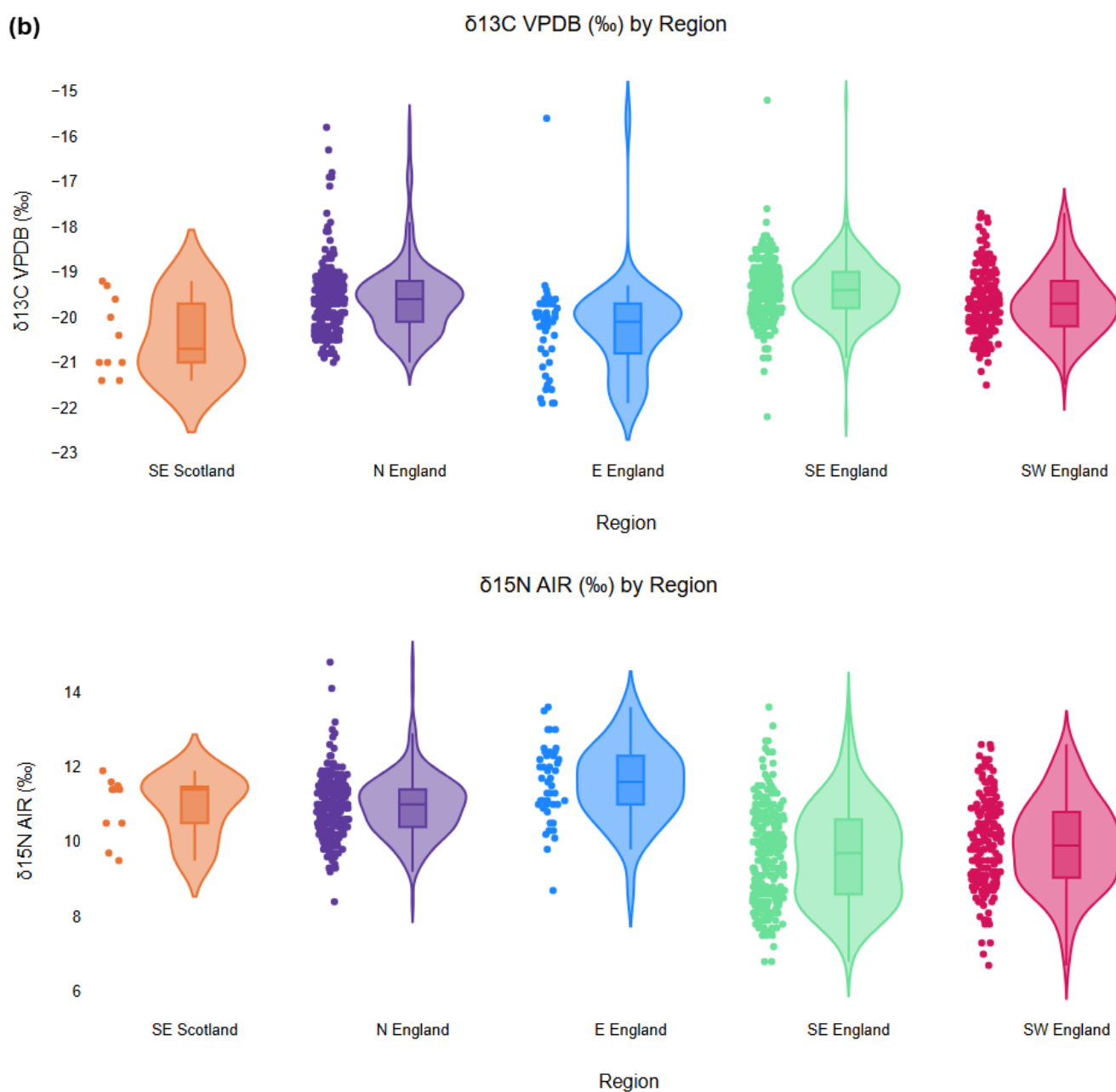
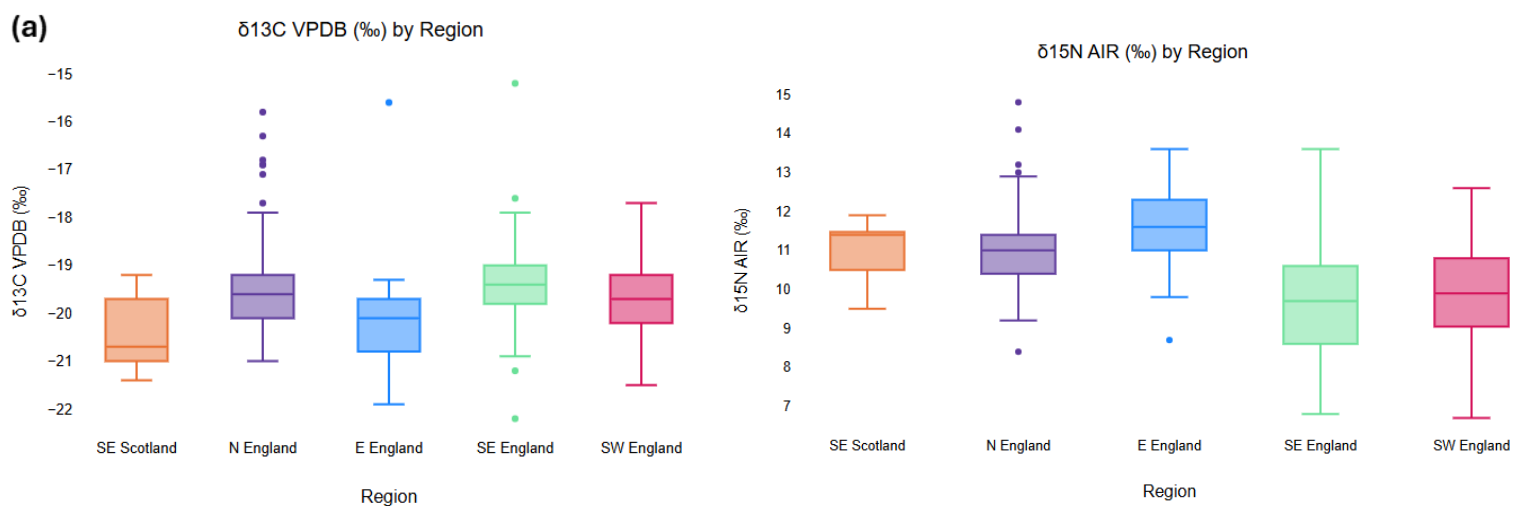


Figure 12: Box (a) and violin plots (b) comparing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ranges for geographical data – note variation in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$.

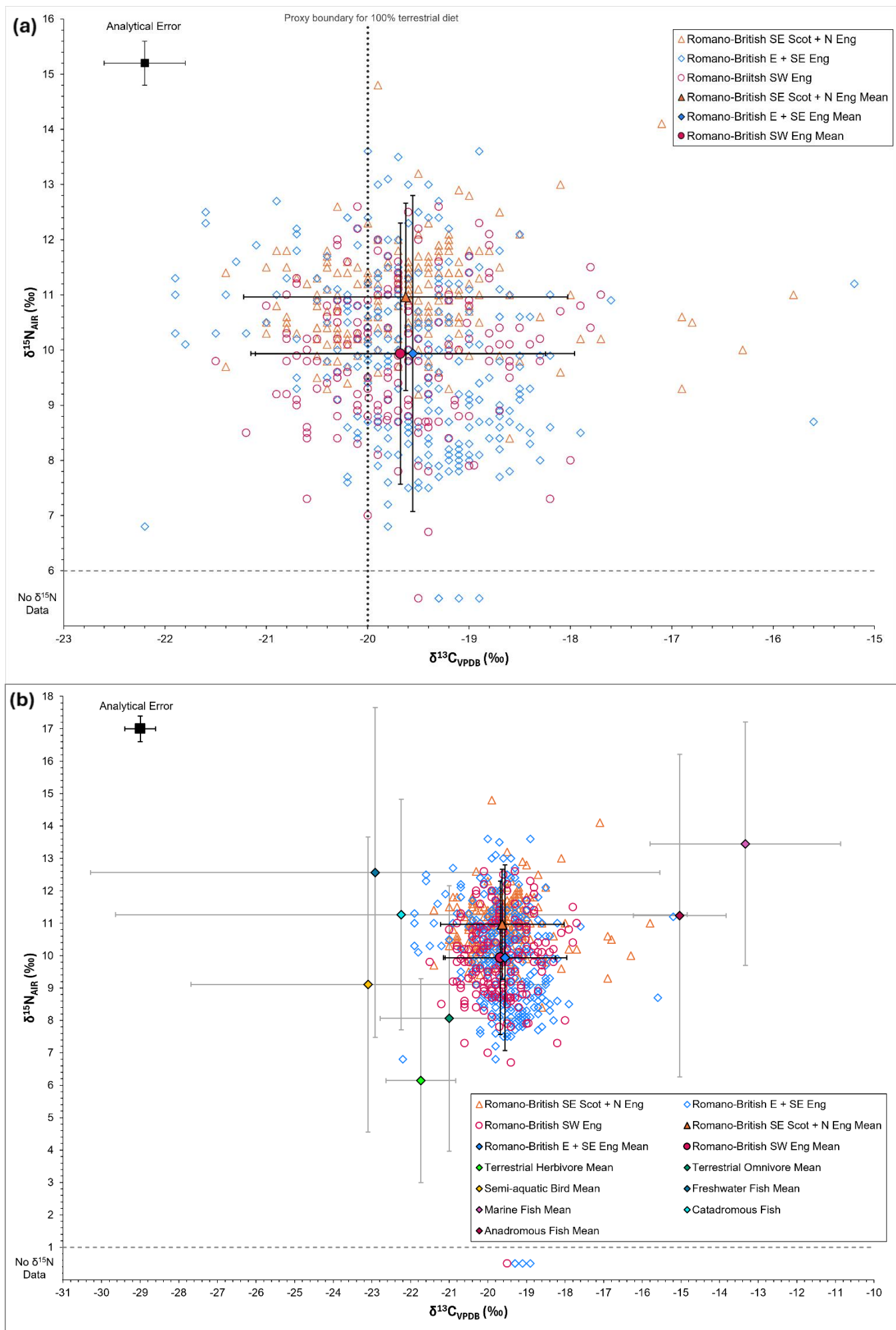


Figure 13: Combined geographical region $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data and means (a). Combined geographical data compared against the faunal baseline (b) – note northern regions' higher mean $\delta^{15}\text{N}$.

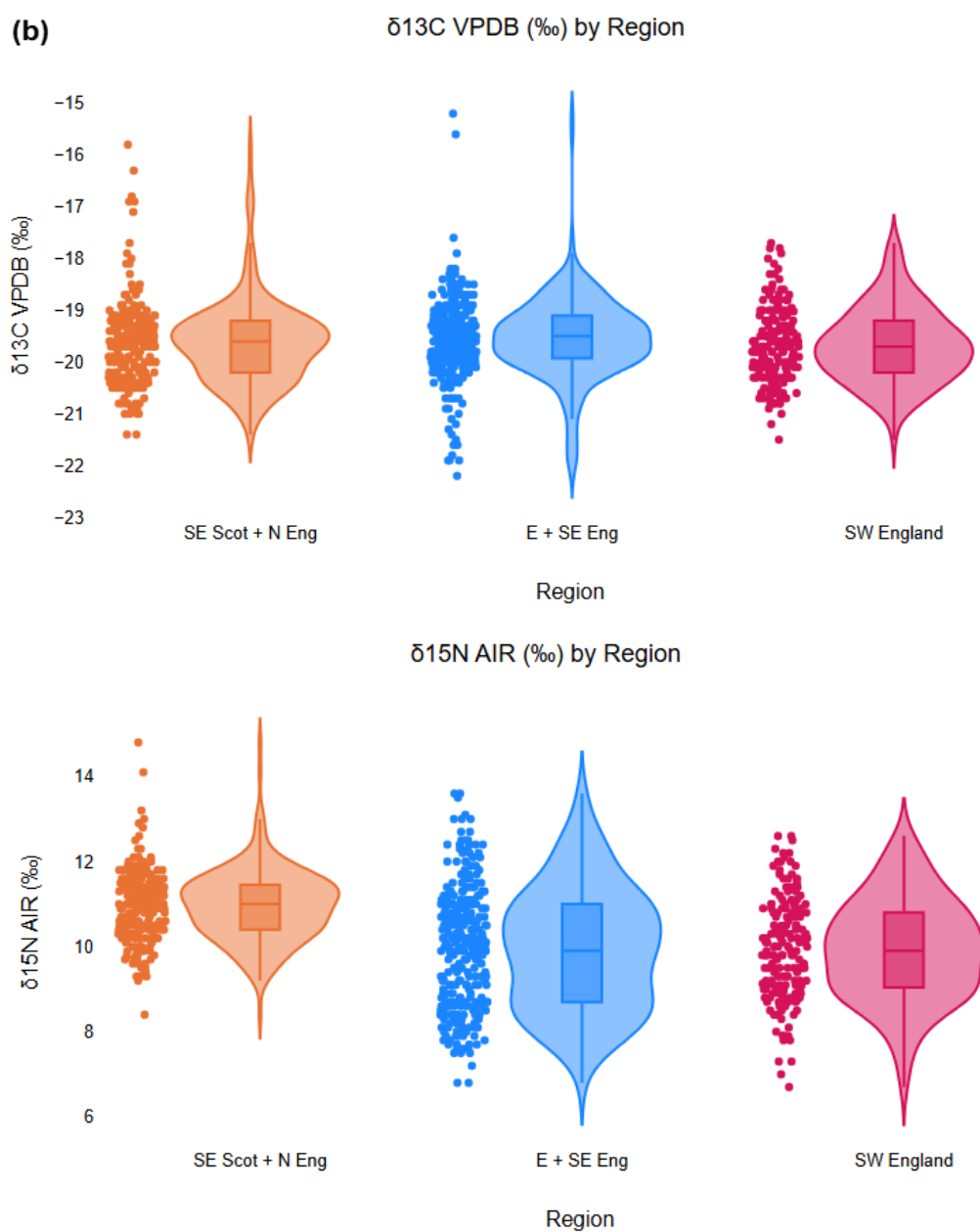
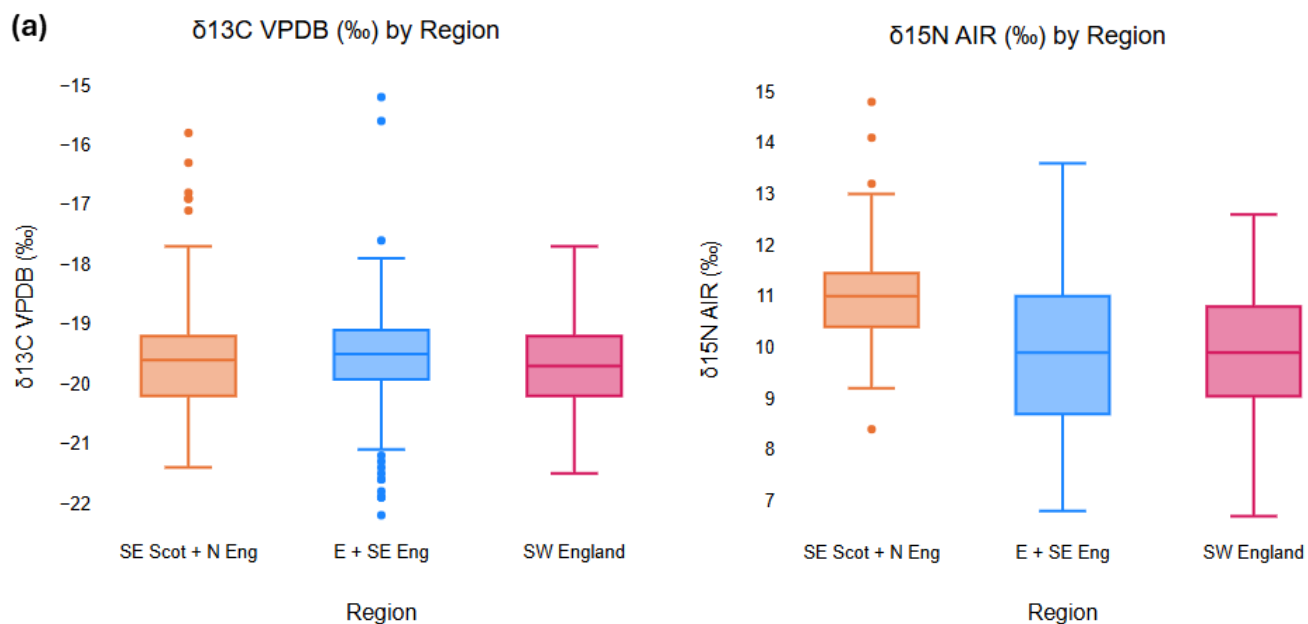


Figure 14: Box (a) and violin plots (b) comparing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ranges for combined geographical data – note similarity between East/South-East and South-West England.

4.3.4 Chronological Period

Isotope data was analysed for 6 chronological period groups: Early-Mid ($\delta^{13}\text{C} = 42$; $\delta^{15}\text{N} = 41$), Mid ($\delta^{13}\text{C} = 52$; $\delta^{15}\text{N} = 52$), Mid-Late ($\delta^{13}\text{C} = 186$; $\delta^{15}\text{N} = 181$), Late ($\delta^{13}\text{C} = 209$; $\delta^{15}\text{N} = 209$), Late/Sub-Romano-British ($\delta^{13}\text{C} = 41$; $\delta^{15}\text{N} = 41$), and Romano-British (undefined date) ($\delta^{13}\text{C} = 165$; $\delta^{15}\text{N} = 165$).

$\delta^{13}\text{C}$ means for Early-Mid (-19.8‰: range = -21.4‰ – -18.5‰), Mid (-19.9‰: range = -20.9‰ – -15.6‰), Mid-Late (-19.9‰: range = -21.9‰ – -15.2‰), Late/Sub-Romano-British (-19.7‰: range = -20.4‰ – -18.9‰), and Romano-British (undefined date) (-19.6‰: range = -21.0‰ – -15.8‰) groups fall within analytical error at 2σ range. The Late Romano-British group (-19.3‰: range = -22.2‰ – -16.9‰) has the highest $\delta^{13}\text{C}$ mean (Figure 15). This is within analytical error of the Late/Sub-Romano-British and Romano-British (undefined date) groups at 2σ range, but is significantly different than the three earlier groups. $\delta^{13}\text{C}$ ranges also exhibit this slight variation between groups, with Figure 16 showing the Late Romano-British group plotting just above the others.

Conversely, the Late Romano-British group (9.6‰: range = 6.7‰ – 13.6‰) has the lowest $\delta^{15}\text{N}$ mean, whilst the Early-Mid Romano-British group (11.1‰: range = 9.0‰ – 13.0‰) has the highest, with both sitting outside analytical error of all other groups. $\delta^{15}\text{N}$ means of the Mid (10.6‰: range = 8.7‰ – 12.6‰), Mid-Late (10.5‰: range = 7.2‰ – 14.1‰), and Romano-British (undefined date) (10.6‰: range = 7.8‰ – 14.8‰), groups are within analytical error at 1σ range, whilst the Late/Sub-Romano-British mean (10.1‰: range = 8.2‰ – 11.4‰) only falls within analytical error of the Mid-Late Romano-British group at 2σ range and is significantly different than the other groups (Figure 15). Greater variation in $\delta^{15}\text{N}$ than $\delta^{13}\text{C}$ between the groups is highlighted in Figure 16, with $\delta^{15}\text{N}$ seeming to decline from the Early-Mid to Late Romano-British periods before increasing slightly in the Late/Sub-Romano-British period. It can therefore be suggested that change in diet is isotopically visible across the Romano-British period, and will be examined.

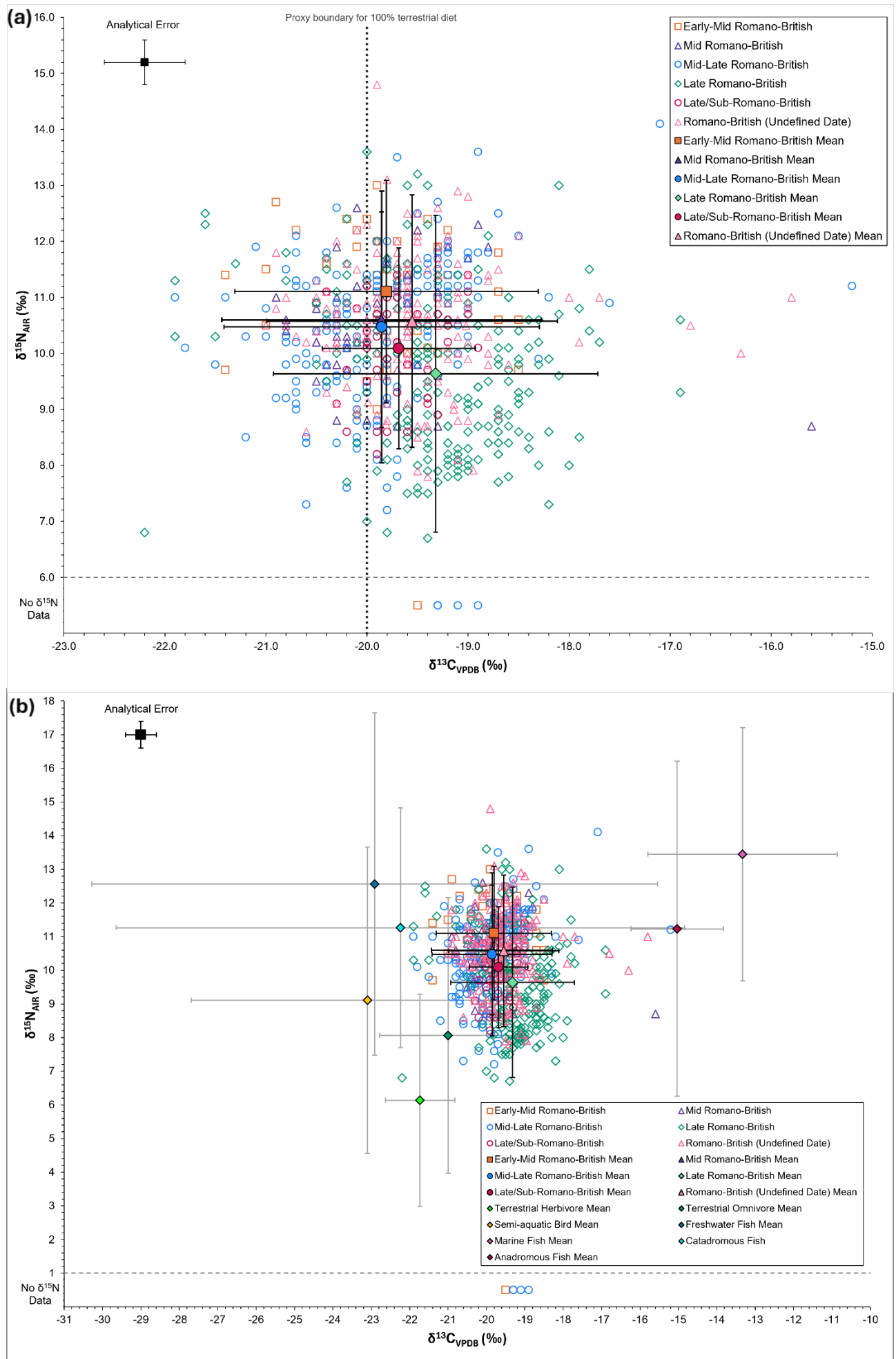


Figure 15: Chronological period $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data and means (a). Chronological data compared against the faunal baseline (b) – note Late period's low $\delta^{15}\text{N}$ and high $\delta^{13}\text{C}$.

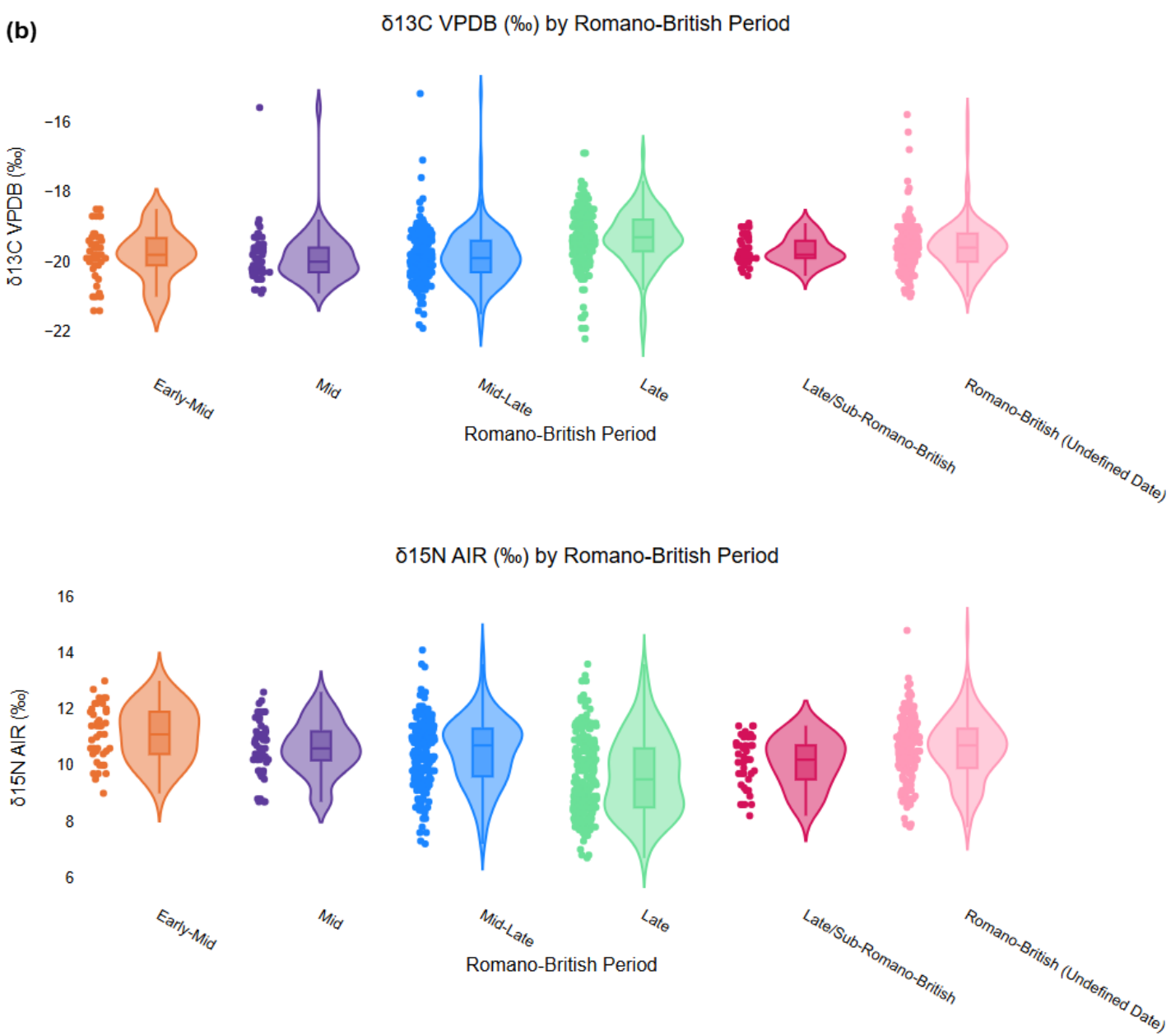
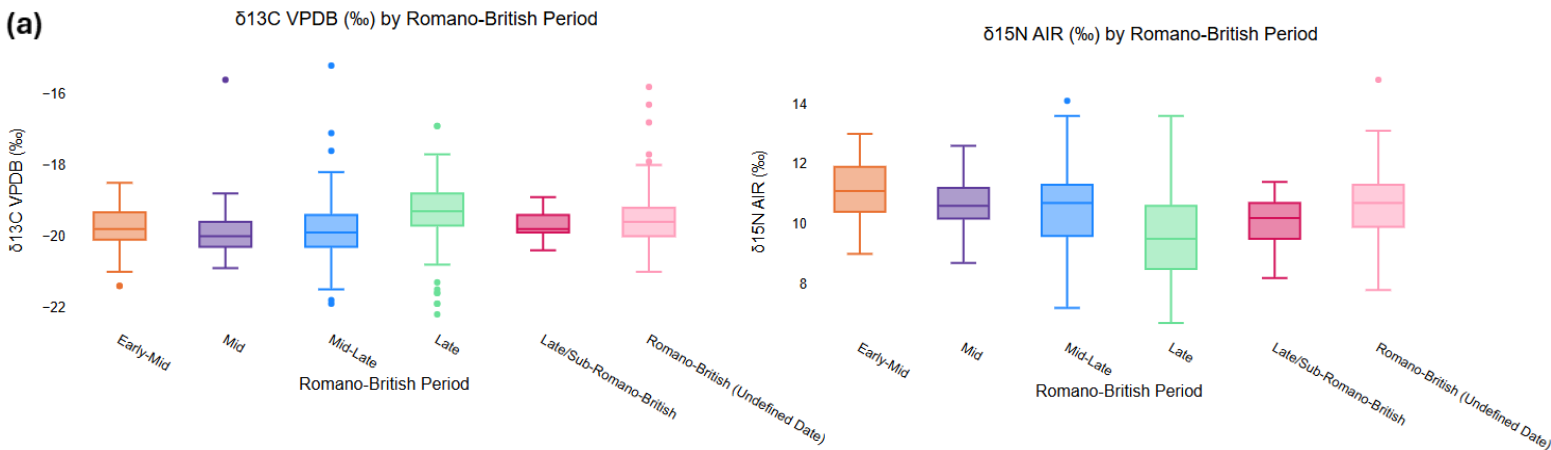


Figure 16: Box (a) and violin plots (b) comparing $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ranges for chronological period data – note decreasing $\delta^{15}\text{N}$ between Early-Mid and Late periods.

4.4 Diachronic Analysis

Sample type (Figures 17 and 18), biological sex (Figures 19 and 20), and geographical region (Figures 21 and 22) data was further categorised by chronological period (Tables A4.5-A4.7: Appendix 4) to investigate if variables exhibit diachronic change. Table 3 summarises $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means from diachronic analysis.

4.4.1 Sample Type

Comparing dentine and bone $\delta^{13}\text{C}$ for each chronological period shows means for both sample types are within analytical error at either 1σ or 2σ range for all periods, except the Early-Mid Romano-British period (bone's mean is 0.5‰ higher than dentine's mean). No dentine data is available for the Late/Sub-Romano-British period. Differences in dentine and bone $\delta^{15}\text{N}$ means follow the observed trend of dentine values being significantly higher than bone, with all periods' means outside analytical error at 2σ range, except for the Early-Mid and Mid Romano-British periods. This demonstrates $\delta^{15}\text{N}$ variation between childhood and adolescent/adult/late life data is maintained across much of the Romano-British period, but as explained later this may not be indicative of dietary differences.

Dentine $\delta^{13}\text{C}$ shows some diachronic change across the Romano-British period. The Early-Mid Romano-British mean is 0.5‰ lower than the Mid Romano-British mean, and the Mid-Late Romano-British mean is 0.8‰ lower than the Late Romano-British mean – both differences putting the means outside analytical error at 2σ range. The Mid and Mid-Late Romano-British periods are the only consecutive groups within analytical error at 2σ range. Dentine $\delta^{15}\text{N}$ shows similar variation, although between different periods. The Mid Romano-British mean is significantly lower than the Early-Mid (by 0.6‰) and Mid-Late Romano-British (by 0.5‰) means, whilst the insignificant 0.1‰ difference between the Mid-Late and Late Romano-British periods puts these groups within analytical error at 1σ range. This suggests childhood diet may have varied slightly throughout the Romano-British period.

Bone $\delta^{13}\text{C}$ shows less variation throughout the Romano-British period, with means within analytical error at 1σ or 2σ range between all consecutive groups apart from the Mid-Late and Late Romano-British periods (0.5‰ difference). Interestingly, bone $\delta^{15}\text{N}$ shows considerable variation between periods, as only the Mid and Mid-Late Romano-British means are within analytical error (1σ range). The Mid Romano-British mean is 0.6‰ lower than the Early-Mid Romano-British mean, the Late Romano-British mean is 1.0‰ lower than the Mid-Late

Romano-British mean, and the Late/Sub-Romano-British mean is 0.7‰ higher than the Late Romano-British mean, indicating dietary protein sources potentially shifted across these periods for adolescents and adults.

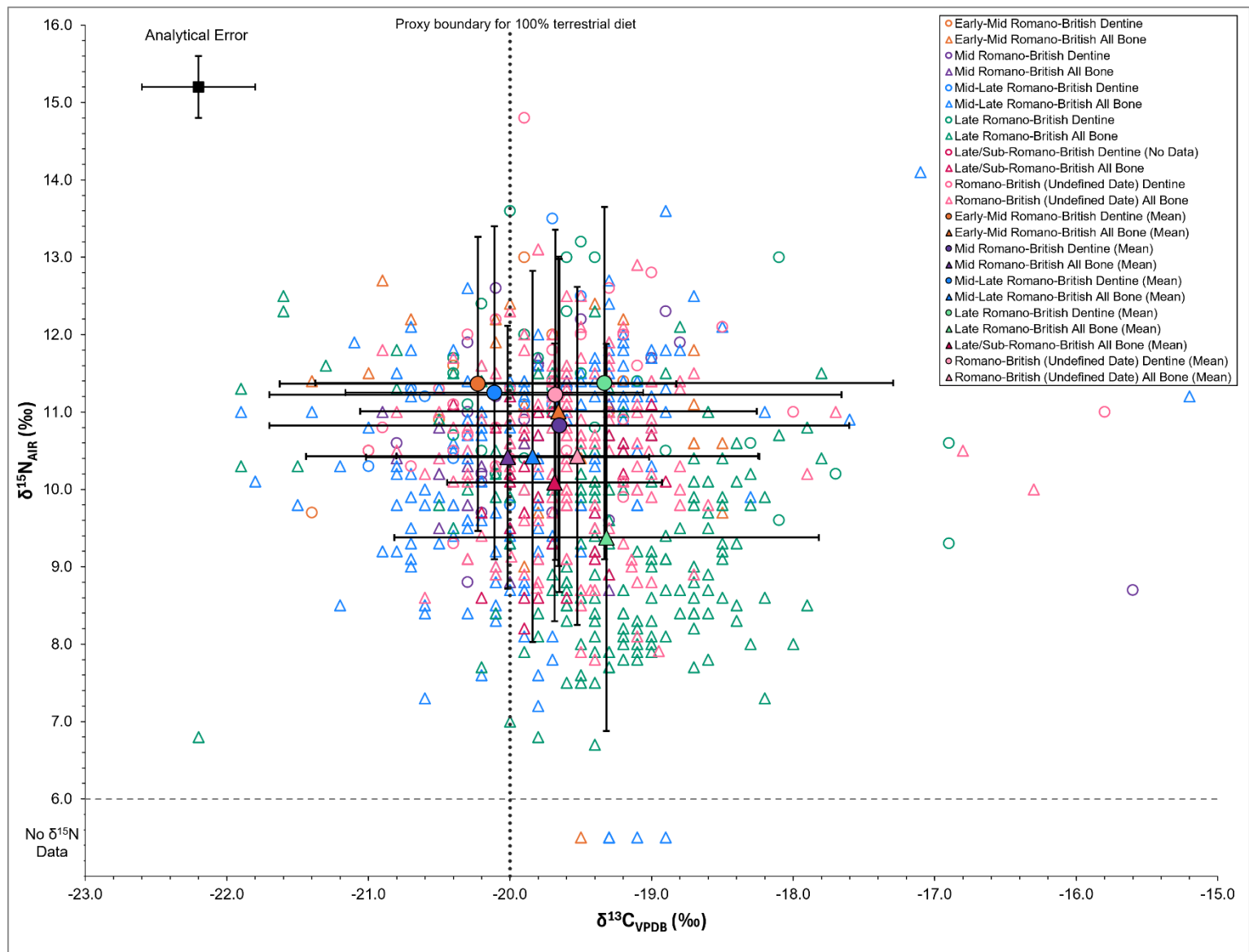


Figure 17: Sample type $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data categorised by chronological period.

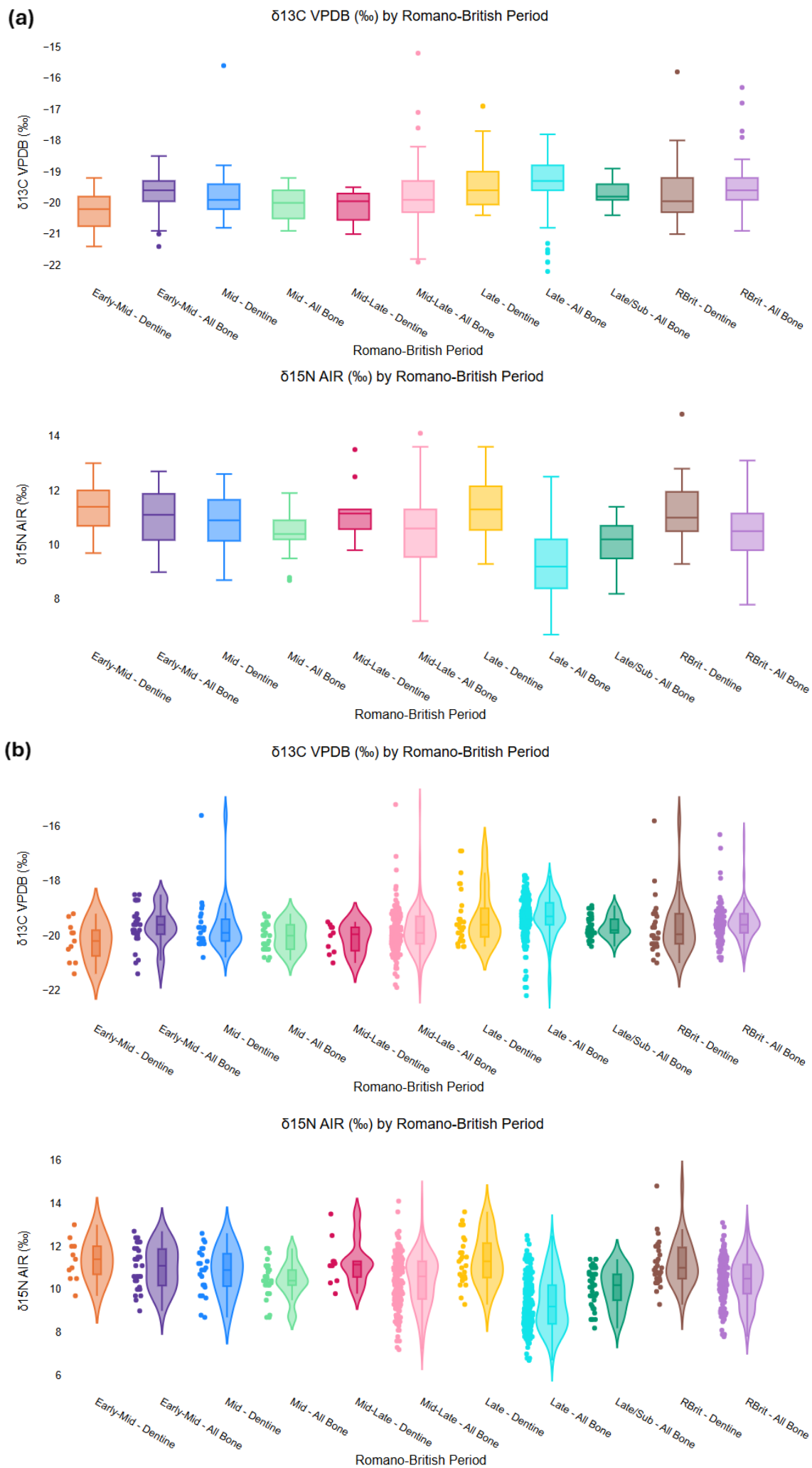


Figure 18: Box (a) and violin plots (b) comparing sample type $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data across periods.

4.4.2 Biological Sex

When separated by chronological period, all male and female $\delta^{13}\text{C}$ means remain within analytical error at 1σ or 2σ range. $\delta^{15}\text{N}$ means show greater variation between males and females, as identified previously. The Early-Mid, Late, and Late/Sub-Romano-British male and female $\delta^{15}\text{N}$ means are outside analytical error at 2σ range, whilst the Mid, Mid-Late, and Romano-British (undefined date) means are within analytical error at 1σ range for both sexes. This suggests male and female diets may have been very similar at some points throughout the Romano-British period, and differed slightly at others.

Male $\delta^{13}\text{C}$ means exhibit limited diachronic change. The means of all consecutive periods lie within analytical error at 1σ or 2σ range, save for the Late Romano-British mean which is 0.6‰ higher than the Mid-Late Romano-British mean. The $\delta^{15}\text{N}$ mean for Late Romano-British males is instead 0.7‰ lower than the Mid-Late Romano-British mean and 0.8‰ lower than the Late/Sub-Romano-British mean. Earlier consecutive period's means are within analytical error at 1σ or 2σ range. The slight, but significant, variation in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ indicates a change within male data during the Late Romano-British period that necessitates further examination.

Similar trends are present for females throughout the Romano-British period. As with males, female $\delta^{13}\text{C}$ means show no significant difference between all consecutive periods, except for the 0.6‰ increase between the Mid-Late and Late Romano-British means. The female Late Romano-British $\delta^{15}\text{N}$ mean is 1.4‰ lower than the Mid-Late Romano-British mean, showing a larger decrease between these two periods than for males. The $\delta^{15}\text{N}$ mean then rises by 0.8‰ between the Late and Late/Sub-Romano-British periods, like with the males. But unlike males, the earlier consecutive periods' means fall outside analytical error at 2σ range. This highlights that the Late Romano-British period is an outlier within male both and female data.

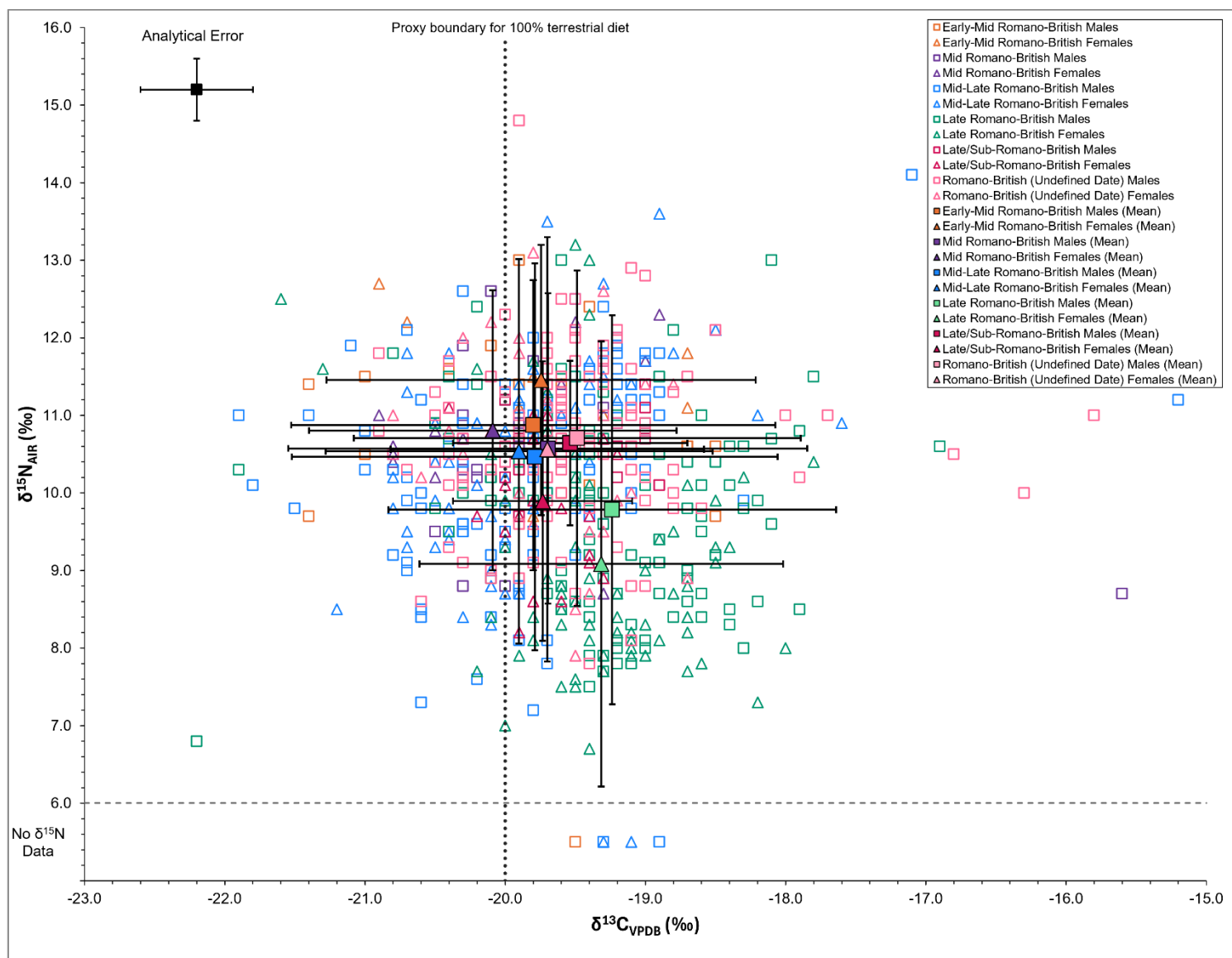


Figure 19: Biological sex $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data categorised by chronological period.

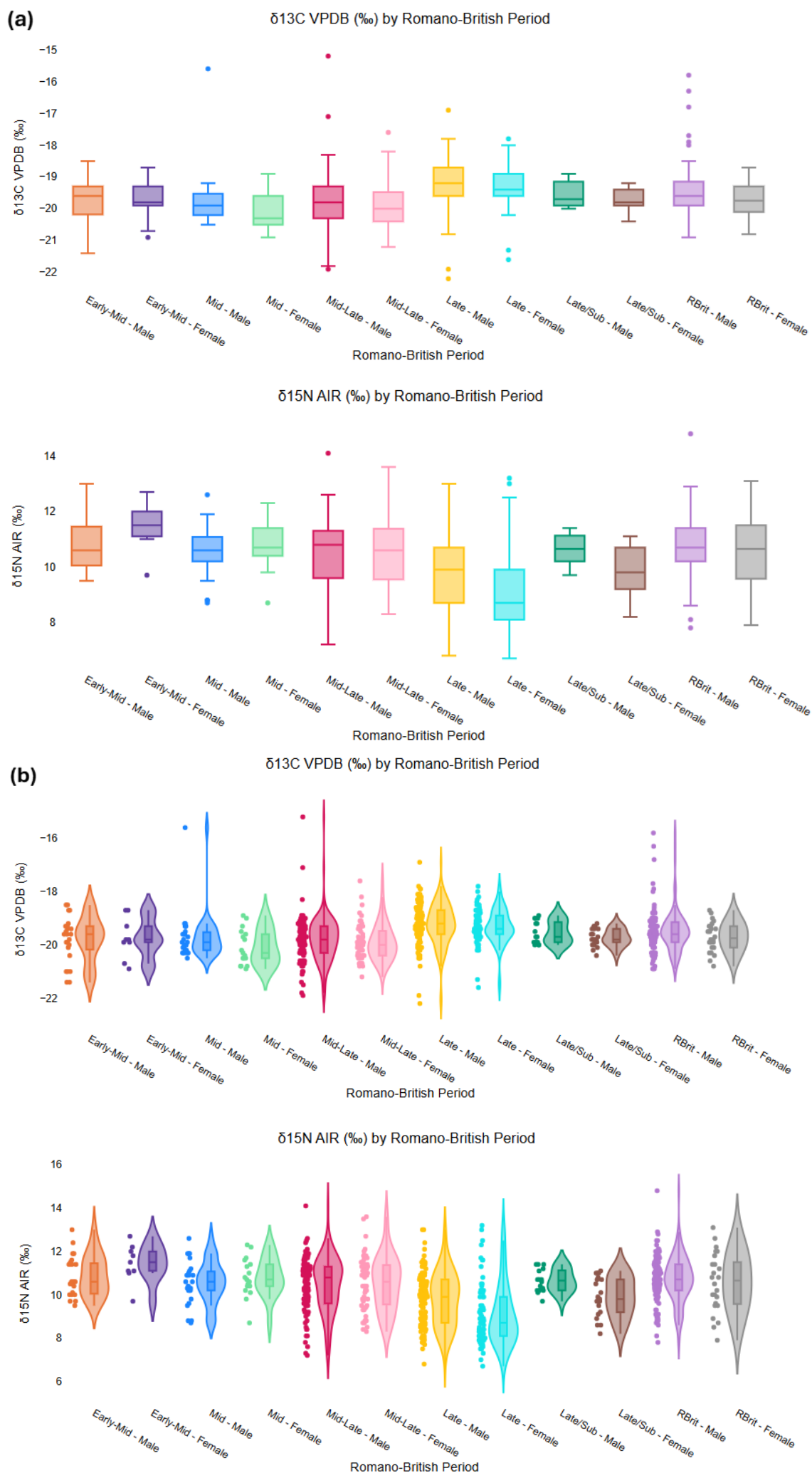


Figure 20: Box (a) and violin plots (b) comparing biological sex $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data across periods.

4.4.3 Geographical Region

Categorising combined geographical data for northern (South-East Scotland/North England) and southern regions (East/South-East/South-West England) by chronological period reveals interesting trends and variation. $\delta^{13}\text{C}$ means of the two groups are within analytical error at 1σ or 2σ range for all periods, excluding the Early-Mid Romano-British period (southern mean is 0.8‰ higher than the northern mean). $\delta^{15}\text{N}$ means show greater variation. Whilst the Early-Mid and Mid Romano-British means for both regional groups are not significantly different, northern $\delta^{15}\text{N}$ means are much higher than southern means for the Mid-Late (by 1.1‰), Late (by 1.6‰), and Romano-British (undefined date) (by 0.8‰) periods. No northern data is available for the Late/Sub-Romano-British period. By identifying diachronic change, these results support previously inferred dietary differences between northern and southern regions in Roman Britain.

Diet in northern regions appears to remain mostly stable throughout the Romano-British period. $\delta^{13}\text{C}$ means are within analytical error at 2σ range for all consecutive periods, but there is an overall 1.1‰ decrease between the Early-Mid and Late periods, indicating protein sources may have varied slightly over time. Only $\delta^{15}\text{N}$ means of the Mid and Mid-Late Romano-British periods show a significant difference (0.6‰) just outside analytical error at 2σ range. This implies minimal diachronic dietary change for this region overall.

The same cannot be said for southern regions. Although the Mid-Late and Late Romano-British periods are the only consecutive periods to have $\delta^{13}\text{C}$ means outside analytical error at 2σ range, southern $\delta^{15}\text{N}$ means between all consecutive periods are significantly different. $\delta^{15}\text{N}$ means decline by 0.6‰ between the Early-Mid and Mid Romano-British periods, 0.5‰ between the Mid and Mid-Late periods, and 0.8‰ between the Mid-Late and Late periods, before increasing by 0.8‰ between the Late and Late/Sub-Romano-British periods. This diachronic variation suggests levels of protein consumption may have changed over time within southern regions.

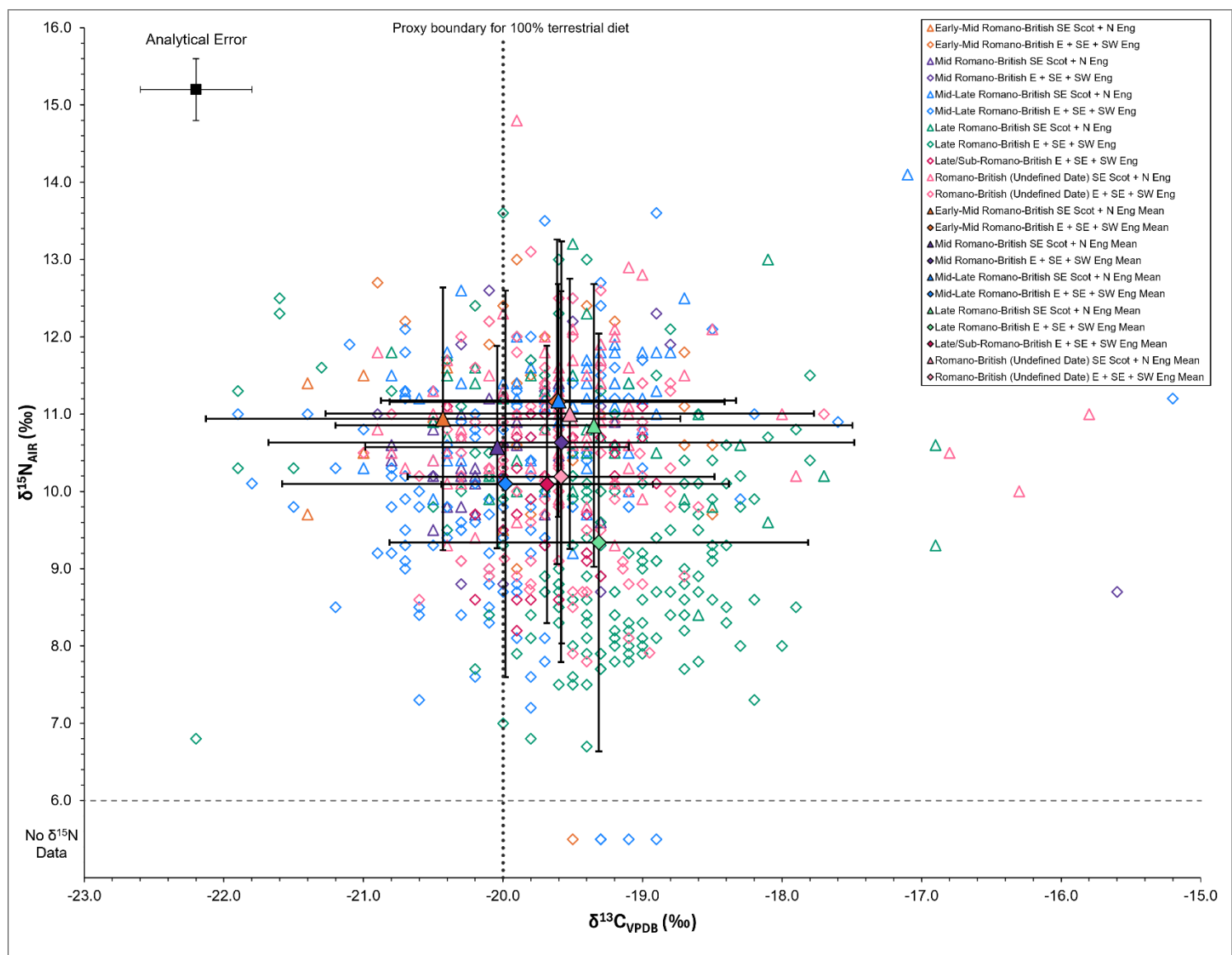


Figure 21: Geographical region $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data categorised by chronological period.

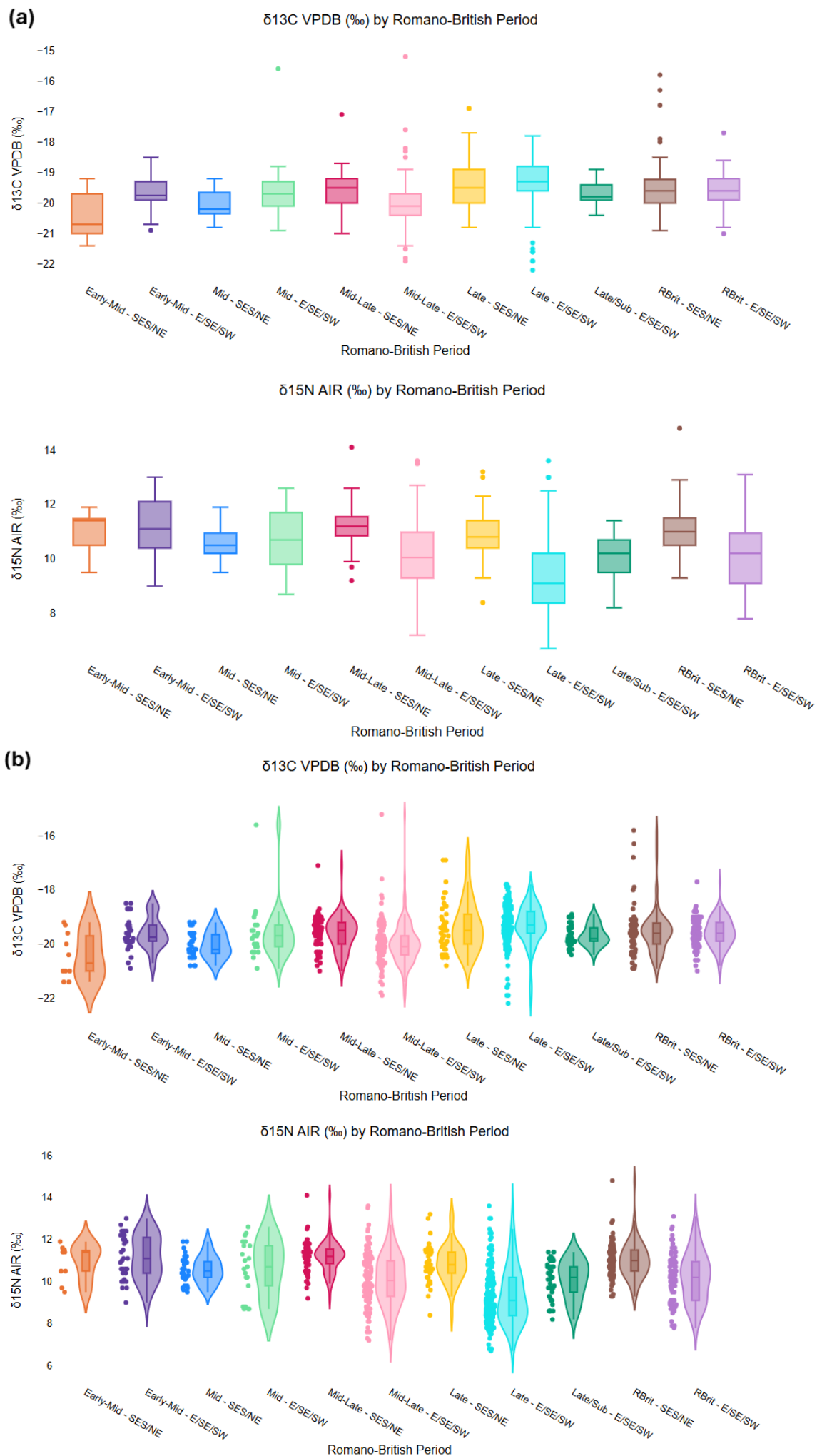


Figure 22: Box (a) and violin plots (b) comparing northern and southern $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data across periods.

Table 3: $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means for sample type, biological sex, and geographical region variables, categorised by chronological period.

Chronological Period	Sample Type				Biological Sex				Geographical Region			
	Dentine mean $\delta^{13}\text{C}$ (‰)	Bone mean $\delta^{13}\text{C}$ (‰)	Dentine mean $\delta^{15}\text{N}$ (‰)	Bone mean $\delta^{15}\text{N}$ (‰)	Male mean $\delta^{13}\text{C}$ (‰)	Female mean $\delta^{13}\text{C}$ (‰)	Male mean $\delta^{15}\text{N}$ (‰)	Female mean $\delta^{15}\text{N}$ (‰)	North mean $\delta^{13}\text{C}$ (‰)	South mean $\delta^{13}\text{C}$ (‰)	North mean $\delta^{15}\text{N}$ (‰)	South mean $\delta^{15}\text{N}$ (‰)
Early-Mid Romano-British	-20.2	-19.7	11.4	11.0	-19.8	-19.7	10.9	11.5	-20.4	-19.6	10.9	11.2
Mid Romano-British	-19.7	-20.0	10.8	10.4	-19.7	-20.1	10.6	10.8	-20.0	-19.6	10.6	10.6
Mid-Late Romano-British	-20.1	-19.8	11.3	10.4	-19.8	-19.9	10.5	10.5	-19.6	-20.0	11.2	10.1
Late Romano-British	-19.3	-19.3	11.4	9.4	-19.2	-19.3	9.8	9.1	-19.3	-19.3	10.9	9.3
Late/Sub-Romano-British	-	-19.7	-	10.1	-19.5	-19.7	10.6	9.9	-	-19.7	-	10.1
Romano-British (Undefined Date)	-19.7	-19.5	11.2	10.4	-19.5	-19.7	10.7	10.6	-19.5	-19.6	11.0	10.2

5. Discussion

Aim 1's objectives are achieved through creation of the dataset, faunal baseline, and data visualisation figures presented in Chapter 4, and this Chapter's investigation of identified patterns. General dietary trends inferred from the dataset are examined and outliers explained, before discussing possible explanations for observed variation within variable groups and their diachronic analysis to meet Aim 2's objectives.

5.1 Romano-British Diet

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data suggest a varied diet across the Romano-British population, primarily based on C_3 resources. The 2.1‰ and 4‰ increase in mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ between the herbivore baseline and Romano-British human bone (Figure 5b) signifies a single level trophic shift from herbivores to humans. This aligns with the expected 1-2‰ and 3-5‰ trophic level increase in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively, between dietary protein and an individual's bone collagen values (DeNiro and Epstein, 1981; Van der Merwe, 1989; Bocherens and Drucker, 2003; Robbins *et al.*, 2005), indicating terrestrial animal protein (meat and other animal products) was an important component of Romano-British diets alongside C_3 plants. However, within the wide data spread in Figure 5a, the general trend shows that a significant proportion of the individuals' $\delta^{13}\text{C}$ values (including the mean) lie above -20‰, a proxy value used to represent the upper limit of a purely terrestrial C_3 diet (Bonsall *et al.*, 2009). This therefore implies additional resources aside from C_3 plants and C_3 -plant-fed animals were incorporated into their diet. As C_4 resources were an uncommon import and unlikely dietary staple as established (Van der Veen *et al.*, 2008; Van der Veen 2014), it is more likely that many Romano-British individuals regularly consumed small, but significant, amounts of marine or anadromous protein as part of a mixed diet alongside terrestrial C_3 protein, thereby elevating their $\delta^{13}\text{C}$. Importantly, this supports Müldner's (2013) identification of marine contributions to diet in Roman Britain using a larger dataset, and corroborates increased exploitation of marine resources inferred from the more frequent appearance of these foods in the zooarchaeological record between Iron Age and Roman contexts (Locker, 2007; Maltby, 2014).

Conversely, regular consumption of freshwater and catadromous fish is difficult to interpret as their lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and standard deviations overlap with herbivores and

omnivores (Figures 5b, 5c, and 6), meaning their dietary contribution may be obscured by the population's greater reliance on terrestrial protein (Redfern *et al.*, 2010). However, although the Romano-British human mean $\delta^{13}\text{C}$ is too high to suggest regular consumption of these aquatic foods for most individuals, those with “terrestrial” $\delta^{13}\text{C}$ values (below -20‰) but high $\delta^{15}\text{N}$ values (individuals towards the upper left of the data spread: Figure 23) could be interpreted as having occasional access to these resources. These findings are significant towards highlighting variation within Romano-British diets, with the whole dataset ultimately providing direct biological evidence for consumption of a diverse range of foodstuffs, as previously deduced from indirect archaeological evidence (Cool, 2006; Witcher, 2013).

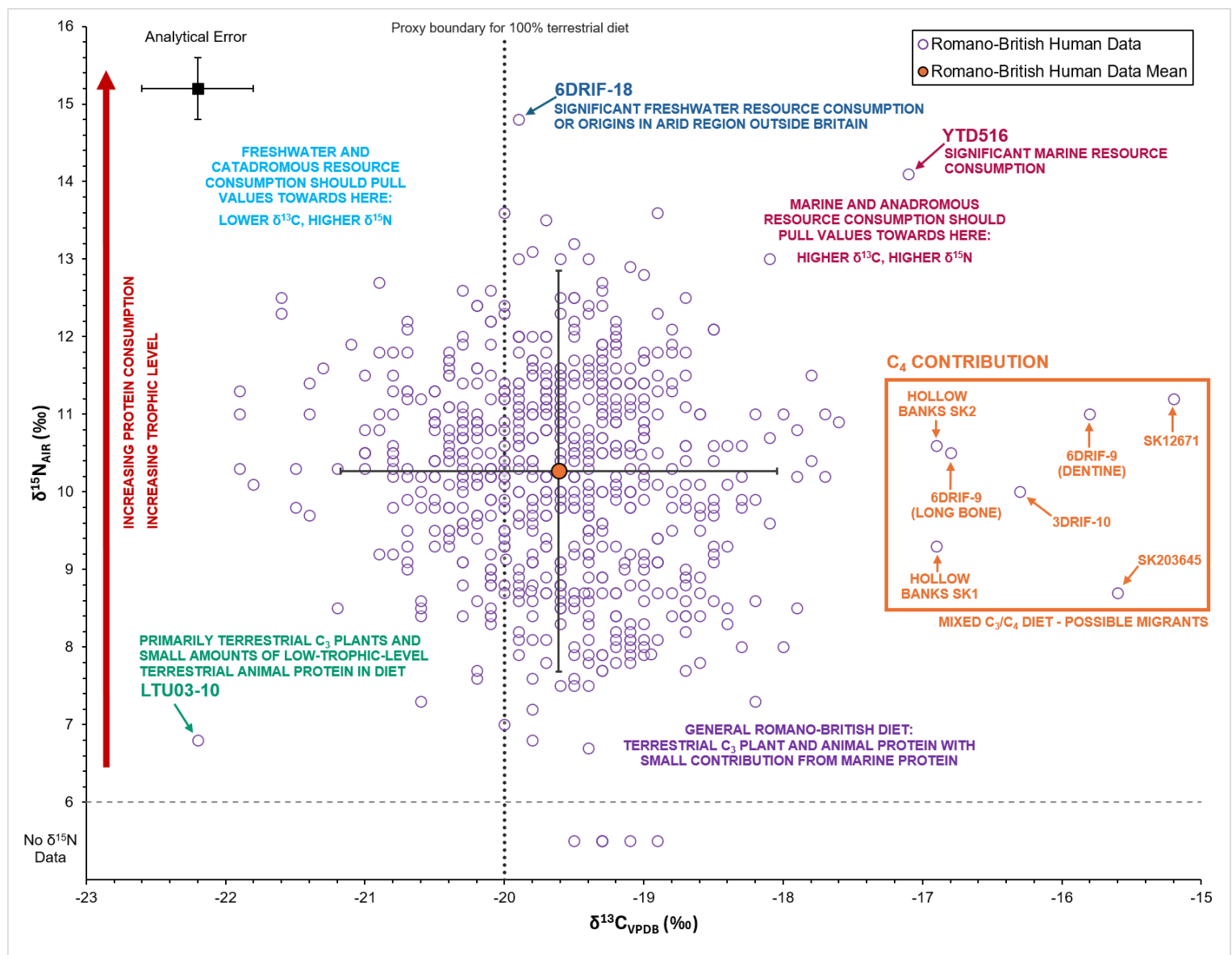


Figure 23: Annotated version of Figure 5a, providing outliers' dietary interpretations and showing how consumption of different resources should influence plot positions of individuals' data.

5.1.1 Outliers

Dietary interpretations from source publications and contextual information for identified outliers are presented in Appendix 5. When interpreted within the Romano-British dataset (Figure 23), original dietary interpretations are maintained for all but one individual – LTU03-10, previously not identified as unusual (Redfern *et al.*, 2018). With the lowest $\delta^{13}\text{C}$ and second lowest $\delta^{15}\text{N}$ values, LTU03-10, is a clear outlier and likely relied on terrestrial C_3 plant resources and minimal herbivore protein, with little to no contribution from higher-trophic-level resources. The others' isotope values are consistent with 6DRIF-18 originating from a more arid region than Britain or consuming substantial freshwater resources (high $\delta^{15}\text{N}$, “terrestrial” $\delta^{13}\text{C}$); YTD516 having a very significant marine dietary input (high $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$); and Sk12671, Sk203645, 6DRIF-9, 3DRIF-10, and Hollow Banks Sk1 and Sk2 being possible migrants with mixed C_3/C_4 diets (high $\delta^{13}\text{C}$, “lower-trophic-level” $\delta^{15}\text{N}$) (Müldner and Richards, 2007; Müldner *et al.*, 2011; Pollard *et al.*, 2011; Eckardt *et al.*, 2015; Moore *et al.*, 2024). Notably, most of these outliers are potential non-local males from urban sites with military associations, highlighting how more diverse, cosmopolitan places cultivated greater diversity in Romano-British diet. Overall, demonstrating that outliers remain identifiable and their dietary interpretations retain their validity emphasises the importance compilatory datasets play in assessing the reproducibility of previous inferences against larger bodies of data, thereby highlighting the value of the dataset to our holistic understanding of Romano-British diet.

5.2 Sample Type Comparisons

As established, despite lack of variation in $\delta^{13}\text{C}$ between sample types, dentine displays significantly higher $\delta^{15}\text{N}$ than bone. Whilst this could infer a diet including larger amounts of high-trophic-level protein during childhood than adolescence/adulthood/later life, this seems unlikely. Instead, this stark over 1‰ increase visible in the dentine $\delta^{15}\text{N}$ mean is typical of a breastfeeding signature. When $\delta^{15}\text{N}$ from breastmilk is incorporated into dentine collagen of a child's developing tooth, the child is effectively consuming the mother's body tissue and consequently will have higher $\delta^{15}\text{N}$ and appear to be a trophic level above the mother, with $\delta^{15}\text{N}$ values decreasing as supplementary foods are introduced during weaning (Jay, 2009). This signature is retained in teeth as they don't remodel, but is not expected to be present in teeth developing past weaning age. Development ages of tooth types within the dataset are:

7.5 months–14.5 years (C); 2.5–13.5 years (PM1); 3.5–14.5 years (PM2); 4.5 months–9.5 years (M1); 2.5–15.5 years (M2); and 8.5–21/23 years (M3) (AlQahtani, 2008; Beaumont and Montgomery, 2015). As previous studies show weaning typically started around 6 months and finished around 4 years old in Roman Britain (Nehlich *et al.*, 2011; Redfern *et al.*, 2012; 2018), $\delta^{15}\text{N}$ values of canines and first molars will be particularly impacted by breastfeeding signatures, those of premolars and second molars should be less affected, and third molars should not be impacted.

This is supported by high $\delta^{15}\text{N}$ means of canines (12.7‰) and first molars (11.6‰), and the lower second molar mean (10.7‰). However, $\delta^{15}\text{N}$ means of premolars (PM1 = 11.4‰; PM2 = 11.3‰) and third molars (11.3‰) are still high and significantly different from bone, although similar values are common within bone $\delta^{15}\text{N}$ ranges and align with consumption of terrestrial animal protein. Other studies have inferred consumption of freshwater fish in childhood, before a transition to marine foods throughout adolescence (Redfern *et al.*, 2018), which could explain these higher $\delta^{15}\text{N}$ values and perhaps infer that as childhood was recognised as a distinct life stage and social group in Roman Britain, different foods were provided at this time than those available later in life (Harlow and Laurence, 2002; Gowland, 2014). Ultimately, whilst further research is needed to ascertain whether significant dietary differences existed between childhood and later life diets, data analysis demonstrates isotopic variation exists between Romano-British dentine and bone samples and possible explanations for this have been explored, therefore achieving Aim 2's first objective.

5.3 Sex-based Differences

Whilst $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ means don't imply dietary differences between Romano-British males and females, the large differences in isotopic ranges between the sexes necessitate further inspection. Males have higher ranges for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, explained by this group including the highest and lowest $\delta^{13}\text{C}$ values in the dataset, and the highest and second lowest $\delta^{15}\text{N}$ values. The $\delta^{13}\text{C}$ values at the upper end of the male range are attributable to the identified outliers with significant marine contributions and inclusion of C_4 resources within their diets. Likewise, the upper and lower $\delta^{15}\text{N}$ values belong to the two outliers with opposing diets: consumption of high-trophic-level protein (6DRIF-18) and reliance on low-trophic-level protein (LTU03-10). The fact that these outliers are all male and contribute to the wide dietary diversity interpreted within the Romano-British population, may suggest

males could access a wider range of foods than females. For instance, males not only held a higher status in Roman society (D'Ambra, 2007; Gallio, 2018), which likely permitted access to higher-trophic-level and larger amounts of protein, but also had greater social mobility especially regarding employment. They could join occupations such as trading and notably military service that allowed them to travel, which may explain how the C₄ outliers came to be in Britain (Müldner *et al.*, 2011). Female dietary diversity therefore may have been restricted by their lower societal position and consequential lack of opportunities. Where investigated in the literature, sex-based differences aren't found for most sites, and sites where they are present have mostly been identified previously by Müldner (2013), who also notes males' higher mobility could influence observed differences. Therefore, despite variation between females and some outlying males, generally both sexes' diets did not differ and there is no evidence of sex-based dietary practices. Mean values ($\delta^{13}\text{C} = -19.8\text{‰}$; $\delta^{15}\text{N} = 10.3\text{‰}$) of individuals with undetermined or no sex data (which will include both males and females), support this as they closely resemble the male and female means. With this finding, Aim 2's second objective is met.

5.4 Geographical Variation

Variation observed between the five regions is likely to reflect consumption of locally available foods rather than regional dietary practices, as availability of marine and other higher-trophic-level resources is known to have varied across Roman Britain, with differing access to riverine and coastal environments and imported foodstuffs (Locker, 2007; Maltby, 2014). However, interpretations of differences between individual regions are potentially unreliable due to variation in sample sizes between groups and the number of sites they include. For example, South-East Scotland and East England are represented by only one site each, with the former group including just 10 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values compared to the largest group's 247 $\delta^{13}\text{C}$ and 242 $\delta^{15}\text{N}$ values (South-East England). Thus, it would be inaccurate to claim single sites provide representative data to interpret dietary behaviour for an entire region, and comparisons between individual regions should therefore be reserved until more data becomes available.

Instead, focusing on combined regional groups, the significant difference between $\delta^{15}\text{N}$ means implies a north-south divide, with northern regions potentially having access to more varied protein sources, likely including higher-trophic-level terrestrial animals and some

marine and freshwater foods. Variation in bioavailable $\delta^{15}\text{N}$ within regional food chains could also cause these higher $\delta^{15}\text{N}$ values, as within ecosystems $\delta^{15}\text{N}$ values are understood to differ geographically and can also be increased by manuring and other anthropogenic actions (Pate, 1994; Bogaard *et al.*, 2007; Schulting *et al.*, 2017). However, baseline $\delta^{15}\text{N}$ means don't differ significantly between herbivores from northern (6.0‰) and southern (6.2‰) sites, suggesting the 5‰ uplift between northern herbivores and humans compared to the 3.7‰ uplift for southern sites supports consumption of higher proportions of animal protein in northern Roman Britain. Northern data derives solely from urban and suburban sites (most with military associations), is dominated by males, and contains six of the nine outliers. These factors may influence the presence of more varied diets in northern populations, especially as many individuals were found around York: an important Roman *colonia*, originally founded as a military fortress and later named provincial capital of *Britannia Inferior*, known as a trading hub and attracting a diverse range of people from Britain and beyond who likely had access to different foods (Ottaway, 1993; Leach *et al.*, 2009). Identification of this dietary north-south divide is significant, and to the author's knowledge has not been interpreted isotopically in previous studies. To further assess this divide, future research should prioritise expanding geographical coverage of Romano-British isotope data for under-represented regions and those where no data is currently available (see gaps in Figure 1) by consulting grey literature and funding isotope analysis. Nevertheless, despite the poor geographical coverage of current data, regional dietary variation is still visible, therefore fulfilling Aim 2's third objective.

5.5 Chronological Change

As variation in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ identifies Late Romano-British data as an outlier within the chronological period groups, potential reasons for this must be explored. With the highest mean $\delta^{13}\text{C}$ value, Late Romano-British diets could be interpreted as including greater quantities of anadromous or marine resources than earlier periods. However, consumption of these should typically produce a rise in $\delta^{15}\text{N}$ (Minigawa and Wada, 1984; Schoeninger and DeNiro, 1984), but the Late period has the lowest $\delta^{15}\text{N}$ mean. Consumption of anadromous fish with $\delta^{15}\text{N}$ values at the lowest end of the faunal group's range may yield the minimum 3‰ trophic level increase to suggest minor contributions of these aquatic resources to Late period diets. Though this seems unlikely and cannot be concluded, especially as most of the

anadromous data is non-contemporaneous to the humans (Müldner and Richards, 2007; Redfern *et al.*, 2010). High $\delta^{13}\text{C}$ and low $\delta^{15}\text{N}$ instead indicate minor consumption of C_4 protein alongside terrestrial C_3 plant and animal protein. Yet, this too seems improbable as C_4 crops like millet weren't grown in Britain and mainly occur in early Romano-British contexts, and any import of them would be expected to follow the decline in trade of other "exotic" foodstuffs in the Late period (Cool 2006; Van der Veen *et al.*, 2008; Van der Veen, 2014). However, this chronological group includes outliers Hollow Banks Sk1 and Sk2 (identified C_4 -consumers and possible migrants), with smaller C_4 contributions to childhood diets also suggested for other Hollow Banks individuals (Eckardt *et al.*, 2015). High $\delta^{13}\text{C}$ values may therefore be influenced by the presence of these potential incomers, rather than indicating a dietary change within the general population in Late Roman Britain, though migrants are also present in other groups. The inability to confidently identify migrants is a major limitation of this dataset, as interpretations of dietary change within Roman Britain may be skewed by the inclusion of individuals with "non-British" diets, leading to artificial differences. Incorporating mobility isotopes into the dataset would combat this and should be an aim for future research, as combining dietary and mobility isotopes has been invaluable towards developing holistic interpretations of dietary influences in large-scale studies of other periods (Parker Pearson *et al.*, 2019; Leggett, 2020). Ultimately, further research is needed to ascertain whether higher $\delta^{13}\text{C}$ signifies dietary change in Late Roman Britain.

The 1.5‰ decrease between Early-Mid and Late Romano-British $\delta^{15}\text{N}$ means is somewhat unsurprising, as the decrease in animal protein consumption it infers fits the wider context of decline in Late Roman Britain. Marine and other high-trophic-level resources were likely more expensive and harder to obtain during times of economic and trade instability, leading to greater reliance on lower-trophic-level terrestrial protein (Redfern *et al.*, 2018). The 0.6‰ decline in $\delta^{15}\text{N}$ between the Early-Mid and Mid periods is unexpected however, as consumption of marine and higher-trophic-level resources is believed to have increased as part of the rise in dietary diversity, previously suggested by isotopic and zooarchaeological studies, between the Iron Age and Romano-British periods (Locker, 2007; Müldner, 2013; Maltby, 2014). It would be easy to assume that as Roman influence spread across Britain, people would adopt more diverse diets over time, but $\delta^{15}\text{N}$ values suggest the opposite occurred. Could the higher Early-Mid mean instead be influenced by incomers from the continental Roman Empire with different dietary habits to Britain's resident population? If so, the subsequent decrease in $\delta^{15}\text{N}$ could represent mixing between an incoming diverse diet

including high-trophic-level protein and the existing population's terrestrial-based diet. Comparison of how low $\delta^{15}\text{N}$ values were in the Iron Age pre-conquest should be prioritised in future to explore this possibility. Overall, chronological change in Romano-British diet seems to have affected supplementary resources, with limited $\delta^{13}\text{C}$ variation suggesting the terrestrial C_3 base diet remained stable throughout the period. As chronological change is rarely investigated in earlier studies, these findings are significant to current understanding, and achieve Aim 2's fourth objective.

5.6 Diachronic Assessment

Diachronic analysis of sample type data reveals $\delta^{15}\text{N}$ remains higher in dentine than bone throughout the Romano-British period. Whether this relates to breastfeeding signatures or consumption of higher-trophic-level terrestrial or aquatic protein remains unclear (Jay, 2009; Redfern *et al.*, 2018). But minimal $\delta^{13}\text{C}$ variation between dentine and bone across periods at least infers primary components of childhood and adolescent/adult/late life diets didn't differ significantly, with their shared terrestrial C_3 base diet remaining stable. $\delta^{13}\text{C}$ means vary more over time in dentine than bone, however both groups' highest value occurs in the Late period. Influence of C_4 -consumers (potential migrants) can again be proposed as a possible cause for this, as bone's mean $\delta^{15}\text{N}$ value is also lowest in this period (Müldner *et al.*, 2011). However, dentine's Late $\delta^{15}\text{N}$ mean remains high, with the potential breastfeeding signature obscuring interpretation of C_4 input to diet, preventing further conclusions about the cause of high $\delta^{13}\text{C}$ means. Higher marine input within Late period childhood diets is also an unlikely explanation for dentine's high $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, especially as diachronic change previously identified between adult and non-adult diets suggests freshwater fish was chosen over other supplementary foods for younger individuals in Late Roman Britain (Redfern *et al.*, 2018). Similarly, decline in $\delta^{15}\text{N}$ across the chronological groups is mirrored within bone data between the Early-Mid and Late periods, potentially indicating varying protein consumption over time, but it's unclear why dentine doesn't follow this trend. Future work could incorporate collated non-adult data to further investigate childhood diet, but as with dentine data, non-dietary factors potentially influencing isotopic variation must be considered (Beaumont *et al.*, 2015; 2018; Crowder *et al.*, 2019). Ultimately, this diachronic analysis highlights issues with interpreting diet from dentine data, but does identify unusual variation

in the Late period for both sample types which is also seen for other variables, suggesting underlying influencing factors within Late Romano-British data.

The Late period is also a visible outlier within diachronic analysis of biological sex data, again displaying higher $\delta^{13}\text{C}$ and lower $\delta^{15}\text{N}$ means for both sexes. As this pattern of rising $\delta^{13}\text{C}$ and falling $\delta^{15}\text{N}$ is visible within Late period, bone, and both male and female data, the dataset was probed to try and identify links between these variables and underlying biases. As a Late Romano-British mixed-sex cemetery providing only rib data, Lankhills, Winchester (Cummings and Hedges, 2010) could be influencing this variation, especially as it contributes the most individuals (106) to the dataset, exhibiting high $\delta^{13}\text{C}$ (-19.1‰) and low $\delta^{15}\text{N}$ (8.8‰) means. Whilst C_4 consumption was not proposed for Lankhills' population and local faunal baseline values may explain the humans' low $\delta^{15}\text{N}$, shared burial rites and mobility isotope analyses imply high numbers of European-origin migrants at this site (Evans *et al.*, 2006; Eckardt *et al.*, 2009). The influence of migrants' "non-British" signatures can once more be suggested as an explanation for diachronic $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ variation in bone and biological sex data, rather than dietary change. Geographical isotopic variation known across Europe due to climatic and environmental differences supports this, with high $\delta^{13}\text{C}$ and low $\delta^{15}\text{N}$ baselines (capable of yielding Lankhills migrants' data) expected in more southernly or easterly regions (Van Klinken *et al.*, 2002; Goude and Fontugne, 2016; Neil *et al.*, 2023). Frustratingly, sample number inconsistencies prevent alignment of dietary and mobility isotope data to identify specific migrants, but omitting Lankhills data highlights the site's bias in the dataset, as Late period $\delta^{13}\text{C}$ means fall and $\delta^{15}\text{N}$ means rise for bone ($\delta^{13}\text{C} = -19.6\text{‰}$; $\delta^{15}\text{N} = 10.2\text{‰}$), males ($\delta^{13}\text{C} = -19.4\text{‰}$; $\delta^{15}\text{N} = 10.5\text{‰}$), and females ($\delta^{13}\text{C} = -19.5\text{‰}$; $\delta^{15}\text{N} = 9.9\text{‰}$) to be within analytical error of other periods. Collectively, diachronic assessment highlights the importance of considering potential non-dietary causes of isotopic variation, suggesting both sexes' diets instead varied minimally over time, and stressing the influence one site's data can have on observed patterns.

Lankhills' influence on variation patterns identified in Chapter 4.4 is supported by diachronic analysis of geographical data, as its exclusion also lowers $\delta^{13}\text{C}$ (-19.6‰) and raises $\delta^{15}\text{N}$ (10.2‰) for Late Romano-British southern data. This brings southern $\delta^{13}\text{C}$ means of all periods within analytical error, and restricts significant variation in $\delta^{15}\text{N}$ to only the Early-Mid and Mid periods, therefore implying a relatively stable terrestrial- C_3 -based diet with higher-trophic-level protein consumption possibly decreasing over time. This doesn't mean Lankhills should be removed from the full dataset, as migrants still lived, ate, and were

buried in Britain and consequently form part of Romano-British dietary behaviour, despite their continental origins. Instead, the influence of Lankhills' large sample size must be acknowledged, especially when data is sub-divided into smaller groups for analysis. With or without Lankhills' inclusion, variation is still present between northern and southern regions. Northern base diets were similarly stable, but with $\delta^{15}\text{N}$ remaining high and $\delta^{13}\text{C}$ becoming "less terrestrial" (increasing) between the Early-Mid and Late periods, this supports the previous interpretation that northern diets included more varied supplementary foods. Marine signatures gradually overtake input from freshwater and high-trophic-level terrestrial resources over time, aligning with marine resources' higher prevalence (especially salmon) in northern sites' zooarchaeological assemblages (Locker, 2007; Maltby, 2014). Only southern data therefore supports the earlier inference from chronological analysis that higher-level-trophic protein consumption declines in Roman Britain over time, again highlighting the weight large sample sizes have within interpretations, as northern data (223) includes half as many values as southern data (472). Diachronic assessment ultimately facilitates recognition of limitations and biases influencing interpretations of Romano-British dietary behaviour. This is critical to identify potential artificial or non-dietary variation, and achieves Aim 2's final objective by supporting inferences of dietary differences between northern and southern populations, similarities between the sexes, and underlying factors affecting sample type variation through integrated examination of the independent variables. Multi-factor diachronic analysis of this scale has not previously been undertaken for Romano-British populations, and resulting interpretations therefore hold great value for furthering knowledge of dietary behaviour within this period.

6. Conclusions

This study's principal aim was to develop an up-to-date dataset of Romano-British $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data to investigate dietary trends, and has been achieved through collation and analysis of 630 individuals' data from 58 sites. Analysis reveals diet within Roman Britain relied on terrestrial C_3 plants and animals and was regularly supplemented by small quantities of marine resources, supporting earlier studies. Identification of outliers exhibiting different dietary behaviours emphasises diversity within Romano-British diets and the variety of foods available, with evidence for significant consumption of marine and freshwater resources, reliance on low-trophic-level terrestrial protein, and mixed C_3/C_4 diets of possible migrants.

Categorising data by sample type revealed variation between childhood (dentine) and later life (bone) values, likely influenced by breastfeeding signatures, but possibly corroborating inclusion of freshwater resources within childhood diets. No significant dietary differences were found between the sexes, although the male-dominated outliers imply male diets could be more varied than females', possibly linked to their higher status and mobility.

Geographical location was shown to influence diet through identification of more varied diets with higher animal protein consumption in northern than southern regions, which hasn't been detected previously. Chronological analysis not only indicated declining higher-trophic-level resource consumption over time, but suggested variation in Late Romano-British data could be influenced by migrants' presence rather than dietary change. Incorporating variables within diachronic analysis supported these inferences by identifying dietary continuity and change over time, but primarily served to emphasise limitations and inherent biases within the dataset influencing interpretations, and how non-dietary causes of variation must also be recognised. These findings achieved Aim 2's objectives by contributing new and supporting knowledge to current understanding of Romano-British diets, emphasising the complexity of dietary behaviours and the many factors influencing them.

Though limited by geographical coverage, sample size discrepancies, difficulty of distinguishing non-British migrants, and the omission of grey literature data, interpretations made using this substantial dataset are credible and valuable, and potential contributions to future research are vast. If proposed recommendations of targeted data collection, isotopic sampling, and incorporation of mobility isotope data are followed, the dataset will be particularly significant to future academic and commercial research as a comparative resource, and provides opportunities to investigate dietary transitions between the Romano-

British period and the Late Iron Age and early Medieval periods. Next steps for this research involve publishing the dataset for wider use, allowing further examination of interpretations and potential dietary differences between urban, rural, and sites with military associations touched upon here but not explored in detail. Through multi-factor diachronic analysis, this research ultimately exemplifies the phrase “Ab ovo usque ad mala” by improving our understanding of diets “from beginning to end” of the Romano-British period.

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