Colonialism, slavery and 'The Great Experiment': carbon, nitrogen and oxygen isotope analysis of Le Morne and Bois Marchand cemeteries, Mauritius

Colonialism, Slavery and 'The Great Experiment': Carbon, Nitrogen and Oxygen Isotope Analysis of Le Morne and Bois Marchand Cemeteries, Mauritius

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Declarations of interest: none

Highlights

- Isotopic analyses of two 19th century cemeteries give insights into Mauritian diets
- A wide range of diets was consumed, particularly in terms of C_4 consumption
- People buried at Le Morne consumed more C_4 foods than those at Bois Marchand
- The individuals from Le Morne had different childhood diets but similar adult diets
- This is consistent with Le Morne's interpretation as a post-emancipation cemetery

Abstract

Slavery, colonialism and emancipation are important aspects of archaeological research in the Atlantic region, but the lifeways of colonial populations remain understudied in the Indian Ocean World. Here, we help to redress this imbalance by undertaking stable isotope analysis (C, N and O) on human remains from Mauritius, a location which played an important role in the movement of people across the Indian Ocean and beyond. The results indicate that a wide range of diets was consumed in Mauritius during the nineteenth century, varying with location and circumstances of birth such that while a range of resources would have been available on the island, the proportions of the different resources consumed was different for different people. Most people consumed some C_4 resources, likely maize, although the proportion of the diet that this represented varied widely. There is some evidence for the use of marine resources, with one individual consuming a very high proportion of marine foods. In general, the people buried at the post-emancipation cemetery Le Morne consumed a higher proportion of C_4 foodstuffs and a lower proportion of animal protein and/or marine resources than those individuals buried at the formal public cemetery Bois Marchand. The data from La Morne are consistent with a population that lived separately as children and then came to live, and eat, together during adulthood. This study has shown a much more nuanced picture of diet in Mauritius at this time than was previously known. The research complements and enriches the historic narrative, adding dimensions to small islands that would otherwise remain obscure in the absence of rigorous scientific assessment of archaeological finds.

Key words: Indian Ocean, indentured labour, palaeodiet, collagen, enamel carbonate

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1. Introduction

Archaeological aspects of slavery, colonialism and emancipation have been well-studied in the Atlantic region, but comparatively little research has been undertaken in the Indian Ocean area (Seetah, 2016). In particular, the lifeways of colonial populations, especially bondmen and women, freed slaves and indentured labourers remains under-studied. Mauritius formed an important node in the movement of people in the Indian Ocean and beyond, and was the home of the 'Great Experiment', when the British replaced slavery with 'free', indentured, labour. This research examines the diet of various groups residing in Mauritius in the years following emancipation. Using carbon, nitrogen and oxygen isotopic evidence from dentine collagen, enamel carbonate and bone collagen, we assess the diet and life histories of individuals buried in two cemetery sites in Mauritius (Fig. 1).

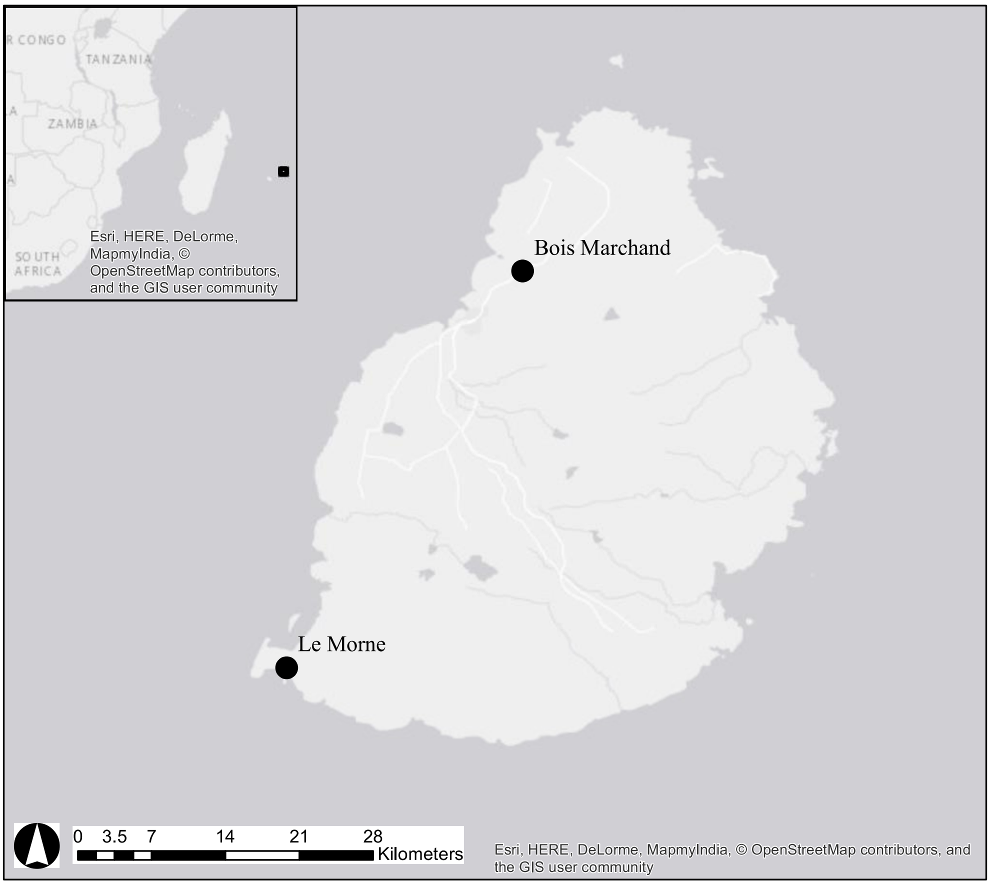

Figure 1: Map of Mauritius with analysed sites (generated with ArcGIS version 10.2.2).

Le Morne 'Old Cemetery' is thought to be a post-emancipation cemetery and is located within the buffer zone of a UNESCO World Heritage site that commemorates slave resistance. At the time of writing, it appears to be the only post-emancipation cemetery excavated from the Southwestern Indian Ocean (Seetah, 2015a). Bois Marchand is a formal cemetery dating from 1867 with extensive burial records indicating that a cross-section of society was buried there (Pike 1873; Seetah 2015a). By comparing the individuals buried at these two sites, this study ~~will acquire~~presents a better understanding of what life was like for nineteenth century Mauritians and how this varied with circumstances of birth and life history.

2. Background

2.1. Historical Background

Detailed accounts of the history of Mauritius are provided by Allen (1999, 2003, 2014a), Teelock (2009) and Vaughan (2005), and only a brief outline will be presented here. Mauritius was colonised by the French in AD 1721, although the Dutch had made two short-lived previous attempts, and runaway enslaved people most likely stayed on the island following the latter attempt. The island was under French jurisdiction until 1810 when the British seized it for its strategic significance, and it remained a British colony until 1968 when it ~~was granted~~gained independence.

Between the late seventeenth and mid-nineteenth centuries *c.* 280,000 to 322,000 enslaved people were brought to Mauritius and neighbouring Réunion (Allen, 2004). Although the British Empire banned the slave trade in 1807, the practice continued well into the 1820s. Most enslaved people were from Madagascar (45%) and Mozambique (40%), with smaller numbers from India (13%) and West Africa (2%; Allen, 1999, Filliot, 1974). Resistance was a significant problem for the French and British colonists (Peerthum, 2006); during the first half of the 1820s approximately 11% of the enslaved population absconded (Allen, 1999). In 1835, a Proclamation was issued that gave all slaves their freedom after a four to six-year apprenticeship (Nwulia, 1978).

The rapid expansion of the Mascarene sugar industries in the late 1820s, coupled with the decline and eventual demise of the slave trade, led to shortages of agricultural labour. Attempts were made in the 1820s to take free indentured labourers from China and India to Réunion, but there was heavy resistance from the ~~the scheme ultimately failed due to resistance of the~~ labourers to the poor conditions, and the scheme eventually failed. The indentured labour system began in earnest in 1835 and continued until 1910 (Allen, 2014b). By 1861 there were 193,000 South Asian people, mainly from Indian subcontinent, in Mauritius, representing 62% of the island's population at that time (Allen, 1999). The indentured labourers were subject to many of the same harsh treatments as slaves: recruitment through deception and tracking, diseased ship-board passage, travel restrictions within Mauritius and poor treatment, including corporal punishment and imprisonment on estates. They also resisted this oppression using many of the same tactics the enslaved people had, including absconding (Allen, 1999). Even so, the indentured labours were legally free and the small salary that they received set them apart from slaves; they were part of labour commodification in the post-slavery colonial empire system. Genetic analysis of the modern population of Mauritius has evidenced the multicultural nature of this region (Fregel et al., 2014). Today, most mtDNA lineages in Mauritius are of Indian origin (58.76%), with also significant contributions from Madagascar (16.60%), East/Southeast Asia (11.34%) and Sub-Saharan Africa (10.21%).

Historical evidence suggests that the diets of enslaved people were based upon maize and manioc. Baron Grant, a French planter who lived in Mauritius from 1740 to 1758, reports that enslaved people consumed ground maize boiled in water, or manioc loaves, and that owners were required to give enslaved people meat once a week, although this law was not observed (Grant, 1801). In 1825, Governor Sir Lowry Cole notes that daily slave food rations were no more than 1.25lb of maize or 3lb of manioc (Allen, 1999). There is evidence, however, that enslaved people owned pigs, goats and chickens and produced enough fruits, vegetables and other products to sell the surplus (Allen, 1999). After abolition, the vast majority of ~~ex-~~previously enslaved individuals~~s~~ left the plantations. They worked instead in a variety of occupations, including craft production, trade, agriculture and domestic service. Many previously en~~ex-~~slaved individuals~~s~~ became smallholders, acquiring plots of land which they used to grow bananas, maize, manioc, sweet potatoes and other fruits and vegetables, and to raise poultry or swine (Allen, 1999). According to their contracts, indentured labourers had to receive rations of rice, dal, oil, chilli, salt, salt fish, and so on which were often poor and inadequate. Through time, both in the camps and in newly acquired plots of land, labourers could supplement their modest diets by growing food (Sain, 1980).

Historical records also indicate that food shortages were a problem throughout the eighteenth century, which increased in the early nineteenth century when more land was given over to sugar production, and again with Indian immigration (Allen, 1999, Ly-Tio-Fane, 1968). Rice and cattle had to be imported to Mauritius from India and Madagascar in order to prevent famines (Allen, 1999).

2.2. Le Morne Cemetery

This study examines two sites, Le Morne and Bois Marchand cemeteries. Le Morne is located on a peninsular on the south-western tip of Mauritius. The area is isolated from the rest of the island by a 545m high inselberg with only a single, precarious access point. Oral history describes this region as a last resort for runaway slaves (Seetah, 2016). The cemetery itself lies at the foothill of the inselberg and is thought to be a post-emancipation cemetery. It has become a symbol of slave resistance, recognized by its inscription on the UNESCO World Heritage List in 2008 as Le Morne Cultural Landscape (http://whc.unesco.org/en/list/1259).

Archaeological investigations of the area, undertaken by the Mauritian Archaeology and Cultural Heritage (MACH) project and in close association with the Le Morne Heritage Trust Fund, commenced in 2009. The initial survey revealed 45 surface features thought to be burial structures, eight of which were excavated in 2010. The human remains found in these eight graves are included in this analysis (Seetah, 2010). The graves were delineated by basalt rocks, with the size of the graves proportional to the size of the interred. All graves contained evidence for well-constructed coffins but very few additional objects were found, although notable exceptions include a series of mother-of-pearl buttons, a small number of French coins dating from 1812 to 1828 (grave 7, Fig. 2) and seven clay tobacco pipes, manufactured in Britain in the first half of the nineteenth century (graves 23, 24 and 42). Radiocarbon dating has proved problematic; however, the evidence from coins and pipes suggests that the cemetery dates to the mid 1830s, around the period of emancipation (Seetah, 2015b, Seetah, 2015a). The burial traditions do not reflect Christian religious practices; the absence of any kind of religious building or any other sign of 'delimited sacred space', the orientation of the bodies to the west, the burial of neonatal and newborn individuals (i.e. individuals unlikely to have been baptized), and the inclusion of grave goods would suggest African traditions were being followed (Seetah, 2010). In particular, the tobacco pipes could be interpreted as 'slave material culture' as they are often found in slave cemetery graves in the Atlantic region but are not documented in cemeteries associated with people of European descent (Katz-Hyman and Rice, 2011). The burials themselves appear to reflect a population of some means, at least to the extent to which they could provision their deceased: the dead were buried in well-constructed coffins; the mother-of-pearl buttons suggests that they were dressed in relatively fine clothes; and they were placed in clearly delineated graves, which were maintained and cared for. This would seem to indicate that they were free people, but whether they had previously been enslaved remains unclear (Seetah, 2010).

Figure 2: Le Morne Cemetery: skeletal remains of an individual in the grave 7, with bronze coins in-situ; 2010 excavation (MACH archive).

Eleven skeletons were recovered from eight graves and were available for analysis. All were primary inhumations, with six juveniles (three perinatal and three under 5 years at death), four females or possible females and one male individual (Appleby et al., 2014, Appleby in Seetah, 2010). The presence and the position of a foetus between the legs of the female in grave 1 suggests that she may have died in childbirth. There were few osteological indications of dietary stress suggesting that nutrition was adequate, however the stature of the individuals was relatively small, fitting with the documentary evidence for slaves' heights recorded in the 1817 census (Allen pers. comm.). The presence of caries and abscesses in the mouth suggest that the diet was highly cariogenic and that dental hygiene was poor; 12% of teeth had caries and antemortem tooth loss is observed in 18% of alveoli (Santana pers. com.). Pathological conditions present include periosteal bone lesions which are frequent in individuals with compromised immunity and chronic illnesses, such as malnutrition and immune-deficiency diseases. Preliminary genetic analyses on the same ~~archaeological material~~individuals using mitochondrial DNA, suggests that nine of the individuals were most probably of East African (possibly Mozambican) descent while two were Madagascan (Seetah, 2015a), but it does not necessarily follow that these individuals had themselves been enslaved. Given the available evidence, Seetah (2015a) has tentatively concluded that the cemetery contains the remains of the first generation of freeborn Mauritians.

2.3. Bois Marchand Cemetery

Bois Marchand is a formal, public cemetery located in the northern part of the island, approximately 50 km from Le Morne. It was inscribed in 1867 in response to the tens of thousands of people who died from malaria (Pike, 1873). The cemetery was divided into large parcels, with different religious ascriptions including Christian, Hindu and Muslim, and occupational plots for police, firefighters, soldiers, criminals, and so on. Our research focuses on one such parcel (section "R") which was in use from 1867 to 1868. The parcel has 42 rows of graves, with *c.* 500 individuals buried here. We anticipated finding the remains of indentured laborers, however the public cemetery was open to all and the excavated individuals represent a cross-section of the Mauritian population, including many indentured workers. The extensive burial records indicate that the individuals buried here were from as far as England, Jamaica, 'Arabia' and 'America' (Bois Marchand Cemetery Archive, burial registers (BR) No. 2: June 6th to July 26th 1898; BR no number: August 23rd to October 1st 1903; BR No. 19: May 6th to July 9th 1901).

The archaeological research of the MACH project in Bois Marchand commenced in 2011. Here we are presenting the data from the seasons 2011 when we excavated six graves with eight individuals, and from 2015, when we excavated eight graves with fourteen individuals. The red ferralitic soil in the area causes all organic material to decompose extremely quickly, thus the human remains and other organic materials are very poorly preserved, preventing an in-depth osteological study of the skeletons (Fig. 3).

Figure 3: Bois Marchand cemetery: an individual buried in a corrugated iron coffin, grave 1, 2011 excavation (MACH archive).

All the graves in Bois Marchand cemetery follow an established protocol: NE-SW orientation; similar size (*c.* 1.80 x 0.90m) and depth (*c.* 1.60–1.70m); and *c.* 0.90m spacing between the graves. Out of 14 graves uncovered, nine were double and four single skeletal burials, with one grave empty; in total 22 interments with 17 adults, two adolescents and three infants. All 22 burials were interred in coffins made out of wood, corrugated iron or in corrugated iron lined wooden coffins, with two wooden coffins also lined with lead. Infants were buried wrapped in a shroud: the fabric decomposed, while silver pins that held the textile, remained as testimony. The burials contained various personal objects such as rings, toe-rings, earrings, and belt buckles. The double burials are intriguing, as they are not recorded in the cemetery's burial registers, except a few cases of mother dying with a new-born child. Seven individuals (three infants and four adults, representing four graves) were buried in atypical positions, mostly with the opposite orientation, that is SW-NE. The presence of these 'deviant' burials is highly unusual and calls for further research.

Due to the poor preservation of remains osteological analysis is limited and likely biased. However, the preserved remains showed evidence for osteoarthritis of the axial skeleton, hip and knee, and a high prevalence of dental caries and calculus. This poor preservation also has implications for collagen isotope analysis, as diagenesis could cause changes in the stable isotope ratios of bone and dentine collagen. Indeed, dentine samples were taken, in part, as a precaution against poor collagen preservation, because teeth tend to show better preservation than bone. Nevertheless, Dobberstein and colleagues (2009) have shown that the collagen triple helix and polypeptide chains remain intact until 99% of collagen is lost. Therefore, bone samples with collagen yields greater than 1% can reliably be used for stable isotope analysis. This and other collagen preservation criteria – a ratio of carbon to nitrogen atoms between 2.9–3.6 (De Niro, 1985), and final carbon and nitrogen yields of at least 13% and 4.8%, respectively (Ambrose, 1990) – are applied to our samples, below.

Ancient DNA analyses on the Bois Marchand individuals are ongoing. Preliminary results indicate a demographic shift compared with Le Morne, with some individuals having clear South Asian mtDNA lineages, which is congruent with archaeological findings and historical record. However, some individuals have an African/Malagasy origin, indicating that the population buried at Bois Marchand was admixed (Fregel et al., 2015).

2.4. Scientific Background

The individuals excavated from Le Morne and Bois Marchand were sampled for carbon, nitrogen and oxygen stable isotope analysis. Carbon and nitrogen stable isotope analysis is a quantitative method for studying palaeodiet. When foods vary in their isotopic composition individuals consuming these different diets can be identified via their body chemistry. Stable isotope ratios in adult bone protein (collagen) reflect diet over a period of years, the precise period varying between different skeletal elements (Hedges et al., 2007). Collagen extracted from tooth dentine reflects the diet at the time of tooth formation, that is from a number of years during childhood (Gage et al., 1989). As body protein is primarily constructed from the dietary protein intake, the stable isotope ratios of collagen reflect mainly the protein portion of the diet (Ambrose and Norr, 1993, Howland et al., 2003, Jim et al., 2006, Tieszen and Fagre, 1993). Stable carbon isotopic values in tooth enamel also reflect the diet at the time of tooth formation but reflect the whole diet (Ambrose and Norr, 1993, Tieszen and Fagre, 1993).

Carbon isotopic ratios can be used to distinguish between marine and terrestrial protein (Schoeninger and DeNiro, 1984) and between C_3 and C_4 plants (Vogel and van der Merwe, 1977). These two plant groups use different methods to take in carbon dioxide from the atmosphere during photosynthesis, resulting in different carbon isotopic ratios in the plant (Vogel and van der Merwe, 1977, Smith and S, 1971, O'Leary, 1988). Most staple plants are C_3, including wheat, barley and rice, while maize, sugar cane, millet and sorghum are C_4. Nitrogen isotope ratios provide an indication of trophic position, as there is an increase in $\delta^{15}N$ of between 3 to 5‰ per trophic level (Bocherens and Drucker, 2003, Hedges and Reynard, 2007). As marine and freshwater foodchains tend to be longer than terrestrial ones, nitrogen isotopes can be used to identify fish and aquatic predator consumption, and distinguish between C_4 and marine consumption (Schoeninger and DeNiro, 1984).

Oxygen isotopic analysis ~~is a~~ can be utilised as a method for the identification of non-local individuals. Oxygen isotope ratios in precipitation reflect the local climate and vary mainly with temperature and distance from the source of the water (Dansgaard, 1964, Rozanski et al., 1993, Rozanski et al., 1992). The oxygen isotope signal in tooth enamel carbonate is derived mainly from ingested water and thus reflects the local climate (Allen, 1999, Longinelli, 1984, Luz and Kolodny, 1985). As tooth enamel does not remodel during life, the isotopic ratios in the carbonate reflect the water drunk at the time of tooth formation. Individuals whose oxygen isotope ~~values~~ ratios are notably different from that of the local precipitation are identified as migrants. The identification of migrants using this method is not straightforward; the reader is referred to Lightfoot and O'Connell (2016), Pollard et al. (2011) and Pryor et al. (2014) for a full discussion.

Both nitrogen and oxygen isotope values are affected by breastfeeding. Infants tend to have higher $\delta^{15}N$ values than adults as breastfeeding effectively increases the tropic level of the infant (Mays et al., 2002, Fuller et al., 2006, Fogel et al., 1989). Oxygen isotope values are affected as the breastmilk is enriched in ^{18}O relative to local water due to the producer's higher body temperature (Wright and Schwarcz, 1989, Roberts et al., 1988, Lin et al., 2003). Food deprivation can also affect human isotope values, with $\delta^{15}N$ values increasing and $\delta^{13}C$ values decreasing ~~as~~ with body mass ~~decreases~~ in modern studies (Mekota et al., 2006, Neuberger et al., 2013). This has been seen archaeologically in incremental samples of human hair and dentine (Beaumont et al., 2013, Beaumont and Montgomery, 2016). With bulk collagen samples, which represent an average diet over many years, however, the influence of food deprivation is most likely seen through lower $\delta^{15}N$ values, related to low animal protein consumption, and potentially through the use of famine foods where these are isotopically distinct (Beaumont et al., 2013).

3. Methodology

3.1. Collagen Isotopic Analysis

Bone and dentine samples were taken from eight human skeletons from Le Morne. Bone samples only were also taken from the two peri-natal individuals in grave 6. From Bois Marchand, bone samples were taken from six individuals excavated in 2011, with dentine samples also taken from three of these individuals. No bone was available for sampling from the 2015 excavation; however, dentine samples were taken from 11 individuals. Ribs and molars were preferentially sampled, where possible; full sample details are given in Appendix 1.

The sample preparation was carried out in the Dorothy Garrod L~~l~~aboratory for Isotopic Analysis, University of Cambridge using the standard laboratory protocol based upon Richards and Hedges (1999). *c.* 0.5g of bone was sampled using a drill and cleaned via sand-blasting. Samples were demineralized in *c.* 10mL 0.5M aq. HCl at 4°C for up to two weeks and then gelatinized at 75°C for 48 hours in pH 3 water. The 'collagen' was then lyophilized before weighing for isotopic analysis.

Each sample was run in triplicate using a Costech elemental analyser coupled in continuous flow to a Finnigan isotope ratio mass spectrometer at the University of Cambridge. Stable carbon and nitrogen isotopic compositions were calibrated relative to the VPDB and AIR scales using international standards. Repeated measurements on international and in-house standards (L-alanine, IAEA-600, USGS-40, Protein 2 and EMC) showed that the analytical error was ±0.2% for both carbon and nitrogen (see Appendix 2).

Measured collagen is deemed to be of good quality if it fulfills the following criteria: an atomic C:N ratio of 2.9–3.6 (De Niro, 1985); a 'collagen' yield of 1% by mass; final carbon yields of 13%; and final nitrogen yields of 4.8% (Ambrose, 1990). All collagen data fulfilled these criteria, despite the poor bone preservation observed at Bois Marchand.

3.2. Tooth Enamel Carbonate Isotope Analysis

Enamel samples were taken from all individuals analysed for dentine, described above, plus two extra individuals from the 2011 Bois Marchand excavation (Appendix 1).

The teeth were cleaned with a tooth brush to remove adhering dirt and the surface abraded with a carbide drill bit. *c.* 6-8mg of t~~T~~ooth enamel powder was then taken using a diamond drill bit. The pretreatment method was based on Balasse et al. (2002). 0.1mL~~l~~ of 2–3% aqueous sodium hypochlorite was added per mg of sample and left for 24 hours at 4 ºC. They were then rinsed five times with distilled water. 0.1mg of acetic acid was added per mg of sample and left for four hours at room temperature. The samples were then rinsed with distilled water. The samples were freeze-dried to remove any remaining liquid and transferred to a vial with a screw cap holding a septa and PCTFE washer to make a vacuum seal. The samples were reacted with 100% orthophosphoric acid at 90 °C using a Micromass Multicarb Sample Preparation System and the carbon dioxide produced was dried and transferred cryogenically into a VG SIRA mass spectrometer for isotopic analysis. Carbon and oxygen isotopic ratios were measured on the delta scale, in comparison to the international standard VPDB calibrated using the NBS19 standard (Coplen, 1995, Craig, 1957). Repeated measurements on international and in-house standards show that the analytical error is better than ±0.08‰ for carbon and ±0.10‰ for oxygen.

3.3. Statistical Analyses

Statistical analyses were performed using SPSS version 23 for Mac. Samples were tested for normality using histograms, Kolmogorov-Smirnoff and Shapiro-Wilks tests and for equality of variance using Levene's tests. For parametric data independent samples t-tests were used, while Kolmogorov Smirnov Z tests were used for non-parametric data. Outliers are identified as samples that lie more than 1.5 times the interquartile range (IQR) below quartile 1 (Q1) or above quartile 3 (Q3) (following Lightfoot and O'Connell, 2016).

4. Results

The results are summarized in Table 1 and given in full in Appendix 1. The dentine results are shown in Figure 4, the enamel carbonate results in Figure 5 and the bone collagen data in Figure 6. The difference between the dentine and bone collagen results for individuals where both samples were analysed are shown in Figure 7.

			$\delta^{13}C$ (VPD) (‰)					$\delta^{15}N$ (AIR) (‰)					$\delta^{18}O$ (VPD) (‰)				
		n	**Mean**	**St Dev**	**Maximum**	**Minimum**	**Range**	**Mean**	**St Dev**	**Maximum**	**Minimum**	**Range**	**Mean**	**St Dev**	**Maximum**	**Minimum**	**Range**
Le Morne	**Bone collagen**	10	-13.9	1.2	-11.4	-14.8	3.4	11.0	0.6	11.8	10.1	1.7					
	Dentine Collagen	8	-14.0	2.4	-10.9	-17.7	6.8	11.0	2.0	13.1	6.4	6.8					
	Enamel Apatite	7	-8.1	2.7	-3.7	-10.9	7.2						-4.2	0.4	-3.7	-4.9	1.2
Bois Marchand	**Bone collagen**	6	-17.3	0.6	-16.6	-18.3	1.8	11.9	0.5	12.3	10.8	1.4					
	Dentine Collagen	14	-16.3	2.4	-9.1	-18.3	9.2	12.1	1.5	15.7	9.4	6.2					
	Enamel Apatite	16	-10.8	3.0	-0.7	-13.6	13.0						-4.3	0.7	-2.9	-5.1	2.2

Table 1: Summary of stable isotope results from Le Morne and Bois Marchand

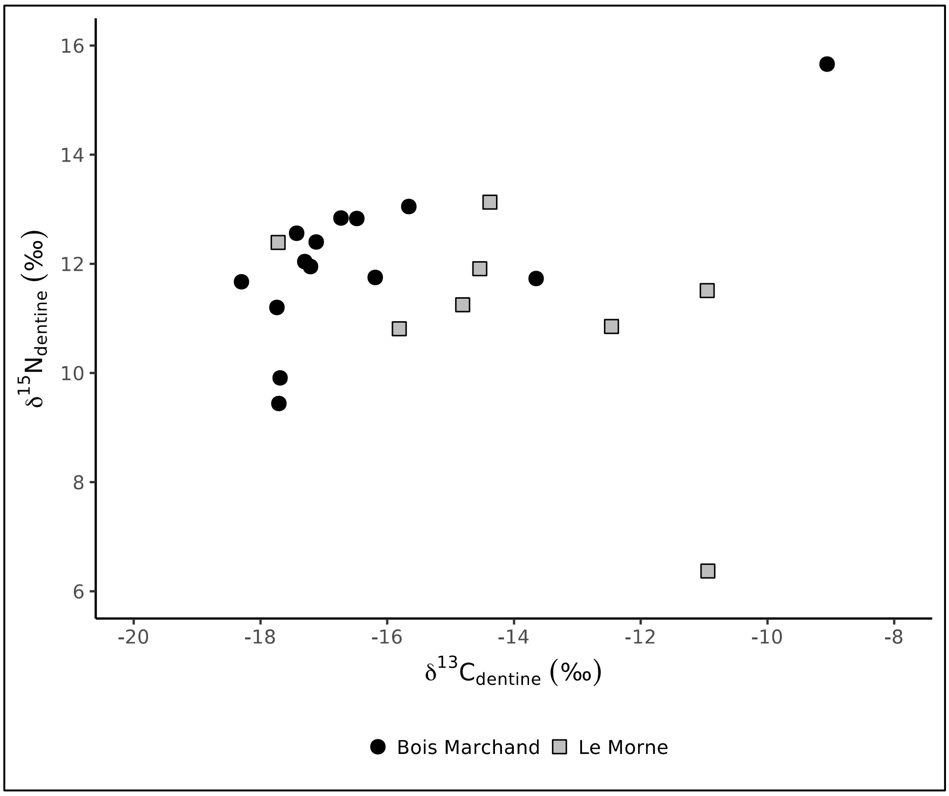

Figure 4: Scatter plot of human dentine collagen $\delta^{13}C$ and $\delta^{15}N$ values from Le Morne and Bois Marchand

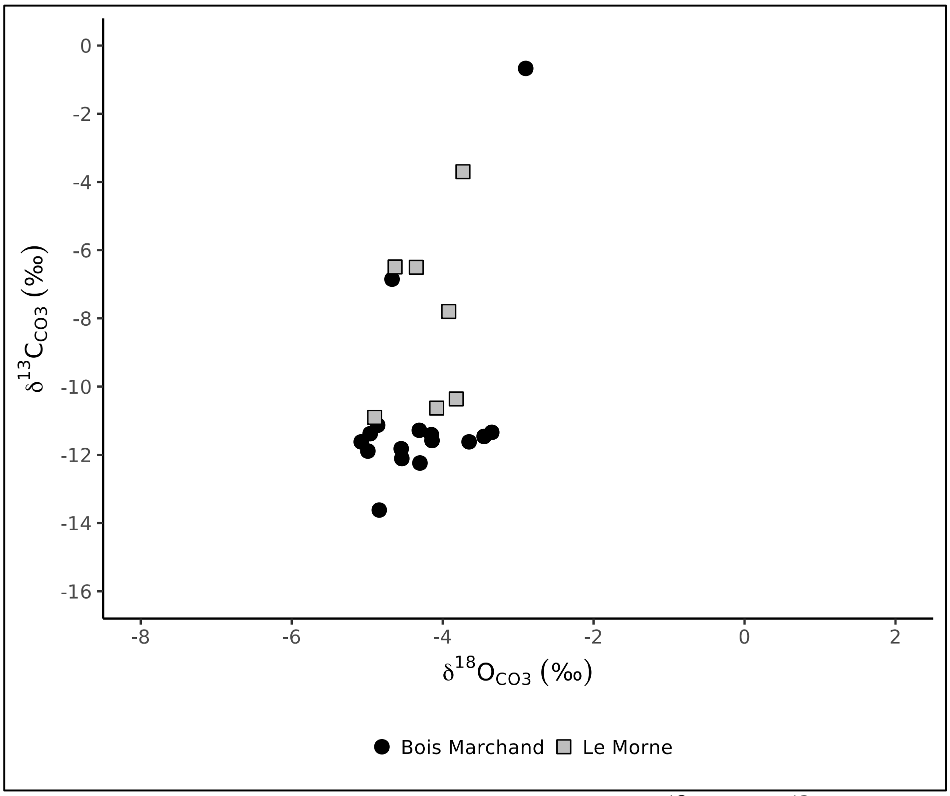

Figure 5: Scatter plot of human tooth enamel carbonate $\delta^{18}O$ and $\delta^{13}C$ values from Le Morne and Bois Marchand

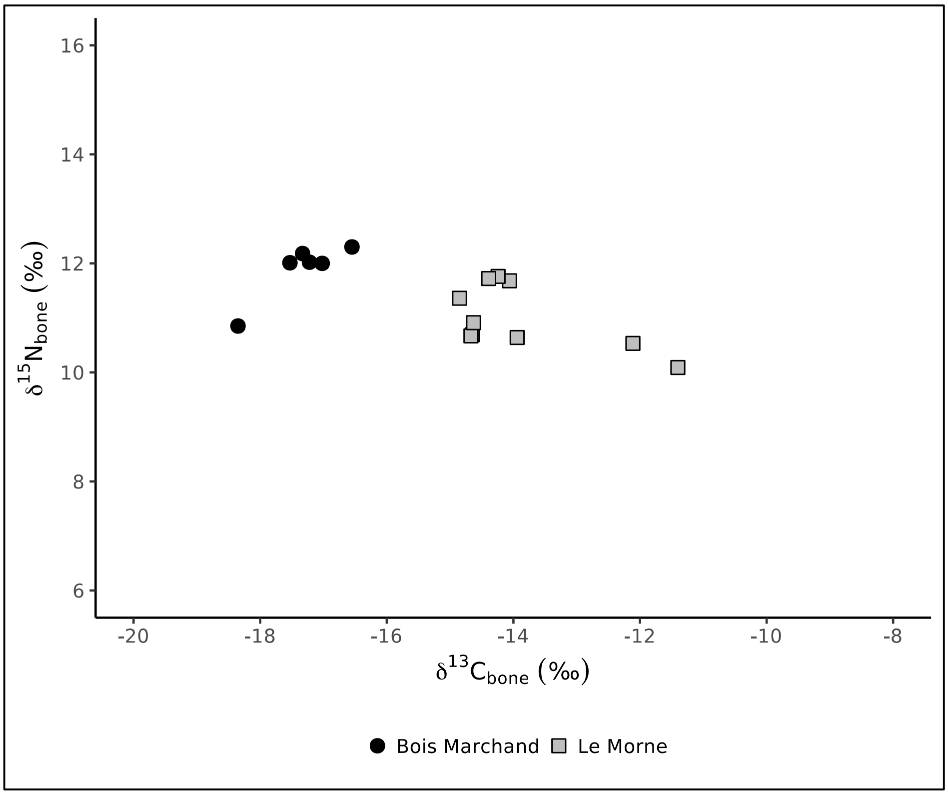

Figure 6: Scatter plot of human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from Le Morne and Bois Marchand

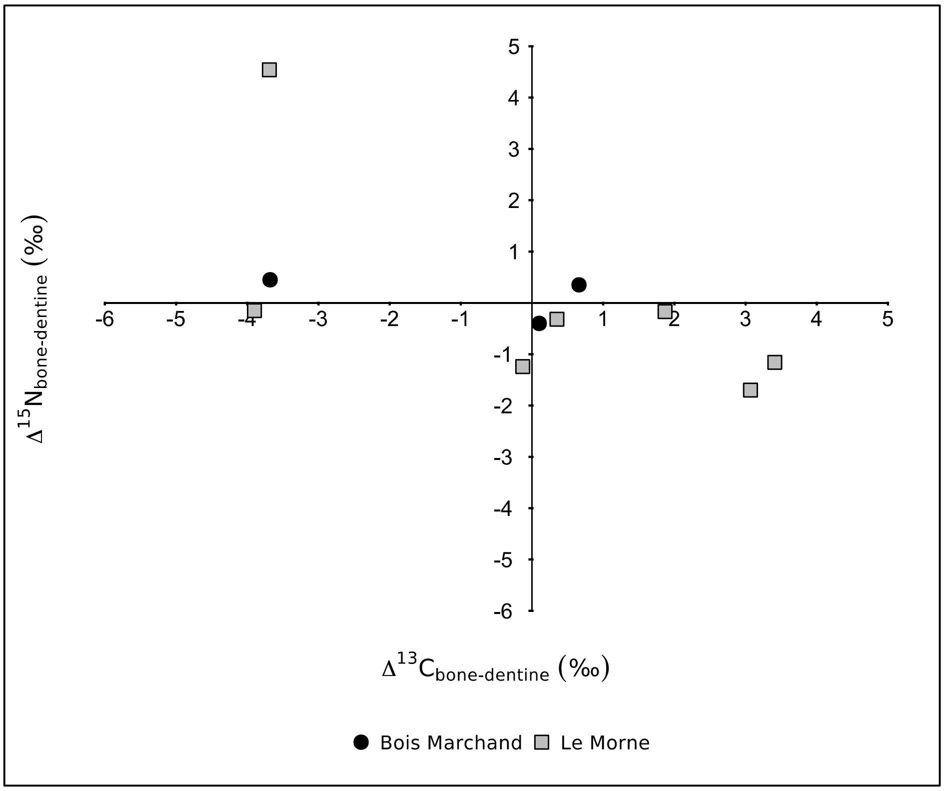

Figure 7: Scatter plot of the difference between human dentine and bone collagen isotope data from Le Morne and Bois Marchand

4.1. Le Morne

The dentine collagen $\delta^{13}C$ results from Le Morne range from -17.7 to -10.9‰, while the $\delta^{15}N$ results range from 6.4 to 13.1‰ (n = 8). One outlier can be identified (STR33/L) with a very low $\delta^{15}N_{dentine}$ value, despite this sample being taken from a canine and thus likely to have been affected by breastfeeding which should increase their $\delta^{15}N$ value. When this individual is excluded, the $\delta^{15}N_{dentine}$ results range from 10.8 to 13.1‰, with a mean of 11.7±0.9‰ (range = 2.3‰, n = 7). There is no correlation between $\delta^{13}C_{dentine}$ and $\delta^{15}N_{dentine}$ (r = -0.568, p = 0.142).

The enamel $\delta^{13}C_{CO3}$ results from Le Morne range from -10.9 to -3.7‰ (n = 7). No outliers were identified.

The bone collagen $\delta^{13}C$ results range from -14.8 to -11.4‰, while the $\delta^{15}N_{bone}$ results range from 10.1 to 11.8‰ (n = 10). Two outliers can be identified (STR33/U and STR25) who have high $\delta^{13}C_{bone}$ values. When these outliers are excluded, the $\delta^{13}C_{bone}$ results range from -14.8 to -13.9‰ with a mean of -14.4‰ (range=0.9‰, n=8). There is no correlation between $\delta^{13}C_{bone}$ and $\delta^{15}N_{bone}$ (r = -0.584, p = 0.076).

The difference between dentine and bone collagen results from individuals where both samples were analysed (n=8, including 3 children), range from -3.9 to 3.4‰ in $\delta^{13}C$ and -1.7 to 4.6‰ in $\delta^{15}N$. Seven individuals have a difference of at least 1‰ in carbon and/or nitrogen isotope values, with one individual (STR025, 3-5 years old) having differences of *c.* 0.3‰ in both $\delta^{13}C$ and $\delta^{15}N$.

The enamel $\delta^{18}O_{CO3}$ results from Le Morne range from -4.9 to -3.7‰ (n = 7). No outliers were identified.

4.2. Bois Marchand

The dentine collagen $\delta^{13}C$ results range from -18.3 to -9.1‰, while the $\delta^{15}N$ results range from 9.4 to 15.7‰ (n = 14). Four outliers have been identified. BM35/L is an outlier with high $\delta^{13}C_{dentine}$ and $\delta^{15}N_{dentine}$ values (from a premolar, and thus unlikely to have been affected by breastfeeding). BM04 is an outlier with a high $\delta^{13}C_{dentine}$ value. BM33/L and BM36/L are outliers with low $\delta^{15}N_{dentine}$ values. When the four outlying individuals are excluded the $\delta^{13}C_{dentine}$ results range from -18.3 to -15.7‰, with a mean of -17.0 ± 0.8‰ (range = 2.6‰, n = 10) while the $\delta^{15}N_{dentine}$ results range from 11.2 to 13.1‰, with a mean of 12.2 ± 0.6‰ (range = 1.9‰, n = 10). While there is a correlation between $\delta^{13}C_{dentine}$ and $\delta^{15}N_{dentine}$ (r = 0.731, p = 0.003), there is no correlation between $\delta^{13}C_{dentine}$ and $\delta^{15}N_{dentine}$ when the outlying individuals are excluded (r = 0.629, p = 0.051).

The enamel $\delta^{13}C_{CO3}$ results range from -13.6 to -0.7‰ (n = 16). There are two outliers (BM35/L and BM04) with high $\delta^{13}C_{CO3}$ values. BM38 is also an outlier, with a low $\delta^{13}C_{CO3}$ value. When these individuals are excluded the $\delta^{13}C_{CO3}$ results range from -13.6 to -11.1‰, with a mean of -11.8 ± 0.6‰ (range = 2.5‰, n = 14).

The bone collagen $\delta^{13}C$ results range from -18.4 to -16.6‰, while the $\delta^{15}N_{bone}$ results range from 10.9 to 12.3‰ (n = 6). There is one outlier with low values for both

$\delta^{13}C_{bone}$ and $\delta^{15}N_{bone}$. While there is a correlation between $\delta^{13}C_{bone}$ and $\delta^{15}N_{bone}$ (r = 0.893, p = 0.017), when the outlier is removed there is no correlation (r = 0.666, p = 0.220). This, combined with the small sample size, suggests that the correlation should be treated with caution.

The enamel $\delta^{18}O_{CO3}$ results from Bois Marchand range from -5.1 to -2.9‰ (n = 16). No outliers were identified.

4.3. Comparison between the sites

The dentine results show a wide variation at both sites, and they overlap substantially in $\delta^{15}N_{dentine}$ values (there is no statistical difference in $\delta^{15}N_{dentine}$: D (21) = 0.411, Z = 0.927, *n.s.*). In $\delta^{13}C_{dentine}$, there is notable overlap, but this mainly relates to an outlier from each site. In general, there is a tendency for the individuals buried at Le Morne to have higher $\delta^{13}C_{dentine}$ than those from Bois Marchand, with a statistically significant difference between the two sites (D(21) = 0.661, Z = 1.491, p = 0.023, outliers included).

With the exception of the two high $\delta^{13}C_{CO3}$ outliers from Bois Marchand, the results from the two sites show no overlap in enamel $\delta^{13}C_{CO3}$ values and the means of the two sites are statistically different (D(22) = 0.875, Z = 1.931, p = 0.001, outliers included).

The bone collagen results from the two sites are clearly and statistically different in both $\delta^{13}C_{bone}$ (D(15) = 1.00, Z = 1.936, p = 0.001) and $\delta^{15}N_{bone}$ (D(15) = 0.833, Z = 1.614, p = 0.011).

The enamel $\delta^{18}O_{CO3}$ data from the two sites are very similar and there is no statistical difference between them (*t*(21) = -0.337, *n.s.*). While there is a larger range in values at Bois Marchand than Le Morne (2.2‰ as compared to 1.2‰), this is likely related to the differences in sample size.

5. Discussion

5.1. Le Morne

The dentine and enamel $\delta^{13}C$ results indicate that during childhood the people buried at Le Morne ate a wide range of diets in terms of the proportion of C_3 and C_4 resources; some individuals (e.g. STR008) consumed a diet primarily based on C_3 resources, while others (e.g. STR033/L) consumed large proportions of C_4 or marine foodstuffs – although individuals that died as children are included in these analyses, we note that none of these individuals have either the highest or lowest values in terms of $\delta^{13}C_{dentine}$ or $\delta^{13}C_{CO3}$. Given that the $\delta^{13}C_{CO3}$ data suggests the consumption of C_4 carbohydrate, it is reasonable to conclude that these individuals were consuming C_4 plants, as opposed to consuming primarily animals fed upon C_4 plants or marine foods. Given the historical evidence it is likely that this reflects maize consumption (Grant, 1801; Allen 1999). It is also possible, however, that some or all of the C_4 consumption reflects sugar cane both directly consumed and animals fed on waste products from sugar production. Indeed the high prevalence of caries and abscesses, noted above, may support the human consumption of sugar cane, as high sugar use may be connected to poor dental health. The $\delta^{15}N_{dentine}$ data also shows a wide range of values; one individual's (STR33/L) $\delta^{15}N_{dentine}$ values were sufficiently low ($\delta^{15}N_{dentine} = 6.4‰$), and indeed, substantially lower than the other individuals (4.6‰ lower than the mean), that they must have consumed little or no animal protein during childhood (note that no animals were sampled or included in the batch during processing) (Bocherens and Drucker, 2003, Hedges and Reynard, 2007, O'Connell et al., 2012). While the remaining individuals certainly did consume animal protein during childhood, there is variation in the proportion they consumed, although some of this variation likely relates to the trophic effect of breastfeeding.

The bone collagen stable isotope data shows a different pattern, with a main group of individuals who consumed similar diets that included a significant proportion of C_4 resources and less variation in the proportion of animal protein in the adult diet. This group includes four out of the five children. Two outlying individuals (STR025, 3–5 years, and STR33/U, an adult) consumed diets that were predominantly based on C_4 resources.

These results, combined with the generally large differences between dentine and bone isotope results from the same individuals, are consistent with a population that lived separately as children and then came to live, and eat, together during life. When one considers the life histories of the adult individuals, we can see that there are some individuals who ate a higher proportion of C_4 foods during childhood than later in life (STR007, STR033/L), while others who consumed little C_4 during childhood but a higher proportion later in life (STR001, STR008). Individual STR33/U also shows an increase in the proportion of C_4 foods they consumed during life, and during adulthood their diet contained more C_4 than most of the other individuals. It is possible that this individual was a recent arrival to Le Morne who died before their bone had had enough time to remodel and reflect the new dietary conditions in this region.

Individual STR33/L (mid to old adult, female; biological sex confirmed by aDNA analysis: Fregel, unpublished results) stands out as having had the most pronounced change in diet during life; during childhood they ate a diet very low in animal protein but very high in C_4 plants (presumably maize), while during adulthood the proportion of animal protein in their diet increased, and their consumption of C_4 plants decreased. The aDNA results from this individual suggest that they are most probably of Mozambican ancestry (Fregel et al 2014; Seetah 2015b). It is tempting to speculate that this individual was enslaved during childhood, but came to live at Le Morne some years before death.

In general, the children's $\delta^{13}C$ results show consistency in the proportion of C_4 consumed between dentine and bone collagen, as would be expected. The individual with outlying $\delta^{13}C_{bone}$ data (STR025), also showed relatively high $\delta^{13}C$ enamel and dentine results. This suggests either that they were born and lived locally but consumed a diet different from that of the rest of the population, or that they were brought to Le Morne close to or after death. The latter scenario fits with the oral history tradition that Le Morne was a safe location for burial (Seetah 2016). There is some intra-individual variation in the children's $\delta^{15}N_{dentine}$ and $\delta^{15}N_{bone}$ values, likely related to the varying timing of tissue formation, different amounts of turnover and differences in breast-feeding practices. The peri-natal twins buried in STR006 show indistinguishable isotope results (bone only) that reflect the diet of their mother during her pregnancy, which was typical of the population buried at Le Morne.

The $\delta^{18}O_{CO3}$ results provide no evidence for migrants within this group, however we note that there is significant overlap in $\delta^{18}O$ values of rainfall in Mauritius and Madagascar (IAEA/WMO 2019). It is therefore not possible to distinguish between these individuals being enslaved people born in Madagascar, and these individuals being free-born Mauritians.

5.2. Bois Marchand

The dentine and enamel $\delta^{13}C$ results indicate that during childhood the people buried at Bois Marchand ate a fairly wide range of diets. The $\delta^{13}C_{CO3}$ results form a tighter main cluster of data than the $\delta^{13}C_{dentine}$ dataset. This suggests that while this main $\delta^{13}C_{CO3}$ group consumed relatively little C_4 carbohydrate, they also ate varying proportions of C_4 protein (i.e. animals fed on C_4 foods) or marine resources. This main group also shows a fairly large range in $\delta^{15}N_{dentine}$ results, with some individuals consuming more animal or marine protein than others (note that the teeth analysed here are unlikely to have a trophic effect from breastfeeding). It is therefore likely that a combination of C_4 protein and marine resources were consumed, with individuals consuming different proportions of these two resource types.

There are four individuals who consumed different diets to this main group. Individuals BM33/L and BM36/L have outlying $\delta^{15}N_{dentine}$ results, suggesting that~~n~~ they consumed a lower proportion of animal and marine protein than the other analysed individuals. Both of these individuals were the lower individuals in double burials and both buried in corrugated iron coffins. BM04 has high and statistically outlying $\delta^{13}C_{enamel}$ and $\delta^{13}C_{dentine}$ values but typical $\delta^{15}N_{dentine}$ values indicating that during childhood they consumed a higher proportion of C_4 resources than the other individuals analysed from Bois Marchand. Individual BM35/L has extremely high $\delta^{13}C_{CO3}$, $\delta^{13}C_{dentine}$ and $\delta^{15}N_{dentine}$ values (all of which are statistical outliers), suggesting that they consumed a diet largely based on marine resources combined with C_4 or marine carbohydrate, presumably maize. We note that high $\delta^{15}N$ values can also be caused by prolonged starvation (Mekota et al., 2006), however given that the enrichment is seen in both collagen carbon and nitrogen and therefore likely reflects the protein component of the diet, and that the magnitude of the enrichment is large, a marine diet is a more parsimonious explanation. This individual was buried in a manner inconsistent with the other excavated individuals. The body was orientated with the head towards the west, rather than the east; furthermore, the head was separated from the rest of the body and placed in the south-western corner of the grave, with the mandible and teeth scattered over the upper part of the skeleton. While it is difficult to form a conclusion about what this represents, it is clear that this individual was different in life and in death (cf. Parker Pearson, 1999, Reynolds, 2009, Gregoricka et al., 2017).

Very few bone samples were available for analysis due to the poor preservation conditions. In general, the analysed bone isotope results are consistent with the dentine data in that most individuals consumed a small proportion of C_4 protein, and one individual (BM03/L, adult, unknown sex, bone collagen data only) consumed a diet that had less C_4 than the other analysed individuals. It is likely that the differences in ranges between dentine and bone $\delta^{13}C$ and $\delta^{15}N$ relates to the difference in sample size.

As with Le Morne, the $\delta^{18}O_{CO3}$ results provide no evidence for migrants within this group. This is surprising given the historical evidence for the wide range of origins for the people buried in the cemetery. When one compares the modern precipitation oxygen isotope values from Mauritius to those from India and South Asia, these data indicate that, although there is overlap, the range of values found in South Asia is notably greater than would be expected for Mauritius (IAEA/WMO 2019). One would not therefore expect to be able to identify all migrants, but migrants from some areas of South Asia should in theory be identifiable, if present.

5.3. Comparison between Le Morne and Bois Marchand

The isotopic data from Le Morne and Bois Marchand show that a wide range of diets were consumed on Mauritius in the nineteenth century. Most people consumed some C_4 resources, although the proportion of the diet that this represented varied widely. There is some evidence for the use of marine resources at Bois Marchand, but there is only one individual (BM35/L) from either site who consumed significant quantities of marine resources, despite the historical evidence for fishing. The historical evidence discussed above indicates that the diet was likely quite poor and subject to shortages. The isotopic evidence for the consumption of a range of isotopically distinct diets on Mauritius, fits well with the idea that people had differential access to the limited available resources based upon, presumably, where and when they lived, their occupation and their social status.

The people buried at the two sites clearly consumed different diets during life – the sites are statistically different in $\delta^{13}C_{dentine}$, $\delta^{13}C_{CO3}$, $\delta^{13}C_{bone}$ and $\delta^{15}N_{bone}$. While there are exceptions, the people buried at Le Morne generally consumed a higher proportion of C_4 foods during childhood and adulthood than the people at Bois Marchand. The two sites also differ in the proportion of animal protein consumed, with the people buried at Bois Marchand tending to have a higher proportion of animal protein and/or marine resources in their diet than individuals buried at Le Morne. We note, however, that due to the lack of faunal samples it is not possible to exclude the possibility that isotopic baselines varied through time and space. Nevertheless, the isotopic difference is consistent with the osteological evidence noted above that the individuals buried at Le Morne had compromised immunity and chronic illnesses, and were relatively short in stature.

The Le Morne cemetery is approximately 30 years earlier in date than Bois Marchand, so it may be that the Mauritian diet changed through time with decreasing maize (or other C_4) consumption and increased access to animal protein and/or marine resources. It is likely that with the end of slavery the consumption of maize would have declined, as former enslaved people had more time and land available post-emancipation to grow a range of crops and raise animals, rather than being forced to rely on maize for sustenance. The isotopic data also fit with the historical evidence for increased use of animals for traction as sugar production expanded, as these animals would eventually have been consumed as meat (Joglekar et al., 2013).

Nevertheless, given the archaeological context of the sites, issues of time and identity cannot be clearly separated; it also seems likely that these dietary differences reflect the social circumstances of the buried individuals. Le Morne is a community cemetery representing people who lived at or near the site, although it remains possible that other former enslaved people or their descendants were buried here if it was seen as a haven for burial. The stable isotope results from Le Morne are consistent with a population including individuals who spent their childhoods in different groups, consuming different foods and who later came together and consumed similar diets (see above). Bois Marchand, on the other hand, was used as a burial ground for a much wider area of the island and for a cross-section of the population. Although hampered by the lack of bone samples available for analysis, this dataset is consistent with a burial population drawn from different social groups with access to the same suite of resources but utilizing them in different ways.

It is likely that a combination of both chronology and circumstances of birth explains the differences between the two sites. Further research is needed, particularly in terms of numbers of individuals available for analysis, before more firm conclusions can be drawn. Nevertheless, it is clear that the subsistence strategies undertaken by nineteenth century Mauritians varied through time, with location and with circumstances of birth, such that although a range of resources were, in theory, available to people on the island, the proportions of the different resources actually consumed was different for different people.

6. Conclusion

Isotopic analyses of people buried in two Mauritian cemeteries have revealed interesting insights into lifeways in nineteenth century Mauritius. Although sample size is small, it is clear that the people buried at Le Morne consumed different diets during childhood and adulthood to the people buried at Bois Marchand. It is likely that these differences relate both to the date of the cemeteries and to the circumstance of birth of the people buried in them. This study has shown a much more nuanced picture of diet in Mauritius at this time. The research complements and enriches the historic narrative, adding dimensions to small islands that would otherwise remain obscure in the absence of rigorous scientific assessment of archaeological finds.

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Appendix 2

Carbon and nitrogen isotopic and elemental compositions were determined using Costech elemental analyser coupled in continuous flow to a Finnigan isotope ratio mass spectrometer in the Godwin Laboratory (University of Cambridge). Stable carbon and nitrogen isotope compositions were calibrated relative to VPDB ($\delta^{13}C$) and AIR ($\delta^{15}N$) using the standards listed in Table S1.

Table S1. Standard reference materials.

Standard	Material	Mean $\delta^{13}C$ (‰, VPDB)	Mean $\delta^{15}N$ (‰, AIR)
L-alanine	Alanine	-26.9	-1.4
IAEA-600	Caffeine	-27.5	+1.05
USGS-40	Amino acid	-26.2	-4.5
Protein 2	Protein standard OAS	-26.95	6.0
EMC	Caffeine	-35.85	-2.5

Table S2 presents the means and standard deviations of the $\delta^{13}C$ and $\delta^{15}N$ values for standards as well as the number of standards included in each analytical session.

Table S2. Mean and standard deviation of all check and calibration standards for all analytical sessions containing data presented in this paper.

Session ID	Standard	n	$\delta^{13}C$ (‰, VPDB)	$\delta^{15}N$ (‰, AIR)
Session 1	Alanine	3	-26.90 ± 0.06	-1.50 ± 0.06
Session 2	Alanine	3	-26.89 ± 0.00	-1.48 ± 0.03
Session 3	Alanine	3	-26.96 ± 0.05	-1.43 ± 0.02
Session 4	Alanine	10	-26.91 ± 0.05	-1.47 ± 0.03
Session 5	Alanine	10	-26.93 ± 0.06	-1.46 ± 0.05
Session 6	Alanine	7	-26.89 ± 0.11	-1.44 ± 0.04
Session 7	Alanine	6	-26.89 ± 0.04	-1.47 ± 0.03
Session 8	Alanine	9	-26.90 ± 0.04	-1.44 ± 0.04
Session 9	Alanine	6	-26.88 ± 0.04	-1.42 ± 0.13
Session 1	Caffeine	3	-27.48 ± 0.05	1.11 ± 0.03
Session 2	Caffeine	3	-27.48 ± 0.05	1.13 ± 0.02

Session 3	Caffeine	3	-27.48 ± 0.03	1.19 ± 0.01
Session 4	Caffeine	6	-27.62 ± 0.07	1.13 ± 0.07
Session 5	Caffeine	6	-27.59 ± 0.07	1.12 ± 0.07
Session 6	Caffeine	6	-27.55 ± 0.05	1.08 ± 0.08
Session 7	Caffeine	6	-27.54 ± 0.05	1.06 ± 0.07
Session 8	Caffeine	6	-27.53 ± 0.04	1.06 ± 0.03
Session 9	Caffeine	3	-27.55 ± 0.08	1.02 ± 0.18
Session 1	USGS-40	3	-26.12 ± 0.04	-4.56 ± 0.01
Session 2	USGS-40	1	-26.13	-4.49
Session 3	USGS-40	3	-26.14 ± 0.03	-4.43 ± 0.06
Session 4	USGS-40	6	-26.17 ± 0.07	-4.43 ± 0.08
Session 5	USGS-40	5	-26.10 ± 0.07	-4.43 ± 0.13
Session 6	USGS-40	6	-26.12 ± 0.03	-4.51 ± 0.05
Session 7	EMC	3	-35.87 ± 0.04	-2.54 ± 0.01
Session 8	EMC	3	-35.87 ± 0.03	-2.58 ± 0.05
Session 9	EMC	3	-35.94 ± 0.05	-2.57 ± 0.14
Session 7	Protein 2	7	-26.98 ± 0.04	6.05 ± 0.04
Session 8	Protein 2	7	-26.98 ± 0.03	6.08 ± 0.06
Session 9	Protein 2	4	-26.94 ± 0.06	6.08 ± 0.28

All of the samples were analyzed in triplicate, the results of which are presented in Table S3.

Table S3. Triplicate stable carbon and nitrogen isotopic compositions for all samples.

Sample	**$\delta^{13}C_a$**	**$\delta^{13}C_b$**	**$\delta^{13}C_c$**	**$\delta^{15}N_a$**	**$\delta^{15}N_b$**	**$\delta^{15}N_c$**
BM05	-17.01	-16.94	-17.10	12.00	11.95	12.04
BM04	-17.35	-17.33	-17.31	12.14	12.16	12.23
BM03L	-18.32	-18.34	-18.38	10.84	10.83	10.87
BM03U	-17.12	-17.22	-17.33	12.03	12.00	12.02
BM02U	-16.52	-16.44	-16.70	12.25	12.33	12.31

BM01	-17.58	-17.43	-17.57	11.96	12.01	12.08
BMD02	-17.28	-17.14	-17.21	11.92	12.06	11.89
BMD04	-13.71	-13.61	-13.62	11.66	11.79	11.74
BMD05	-17.13	-17.15	-17.09	12.39	12.42	12.40
BMD33	-17.77	-17.74	-17.73	11.20	11.29	11.11
BMD33L	-17.73	-17.64	-17.71	9.94	9.98	9.81
BMD34L	-16.22	-16.15	-16.21	11.79	11.80	11.66
BMD35	-17.52	-17.50	-17.28	12.57	12.58	12.52
BMD35L	-9.05	-9.01	-9.12	15.70	15.76	15.53
BMD36	-16.52	-16.43	-16.49	12.96	12.98	12.57
BMD36L	-17.73	-17.68	-17.72	9.46	9.53	9.34
BMD37	-17.37	-17.20	-17.32	12.07	12.05	11.98
BMD37L	-15.72	-15.65	-15.62	13.04	13.13	12.99
BMD38	-18.30	-18.29	-18.32	11.67	11.74	11.59
BMD39	-16.78	-16.71	-16.70	12.84	12.94	12.74
STR001	-13.94	-13.90	-13.99	10.68	10.57	10.66
STR006_7	-14.05	-14.02	-14.10	11.60	11.71	11.73
STR006_8	-14.38	-14.13	-14.21	11.70	11.75	11.82
STR007	-14.89	-14.82	-14.83	11.33	11.32	11.43
STR008	-14.66	-14.64	-14.65	10.68	10.60	10.79
STR025	-12.10	-12.12	-12.10	10.47	10.56	10.58
STR029	-14.41	-14.40	-14.35	11.71	11.71	11.73
STR030	-14.69	-14.66	-14.66	10.62	10.69	10.71
STR033_U	-11.43	-11.39	-11.40	10.13	10.00	10.13
STR033_L	-14.65	-14.66	-14.57	10.89	10.93	10.92
STRD01	-15.90	-15.78	-15.76	10.72	10.79	10.90
STRD07	-11.02	-10.91	-10.91	11.40	11.48	11.66
STRD08	-17.70	-17.75	-17.70	12.37	12.52	12.28
STRD25	-12.51	-12.51	-12.36	10.83	10.91	10.79
STRD29	-14.44	-14.34	-14.35	13.11	13.16	13.12
STRD30	-14.53	-14.53	-14.57	11.98	11.90	11.84
STRD33_U	-14.92	-14.77	-14.75	11.31	11.25	11.19
STRD33_L	-10.99	-10.96	-10.88	6.60	6.57	5.93

Figure 1

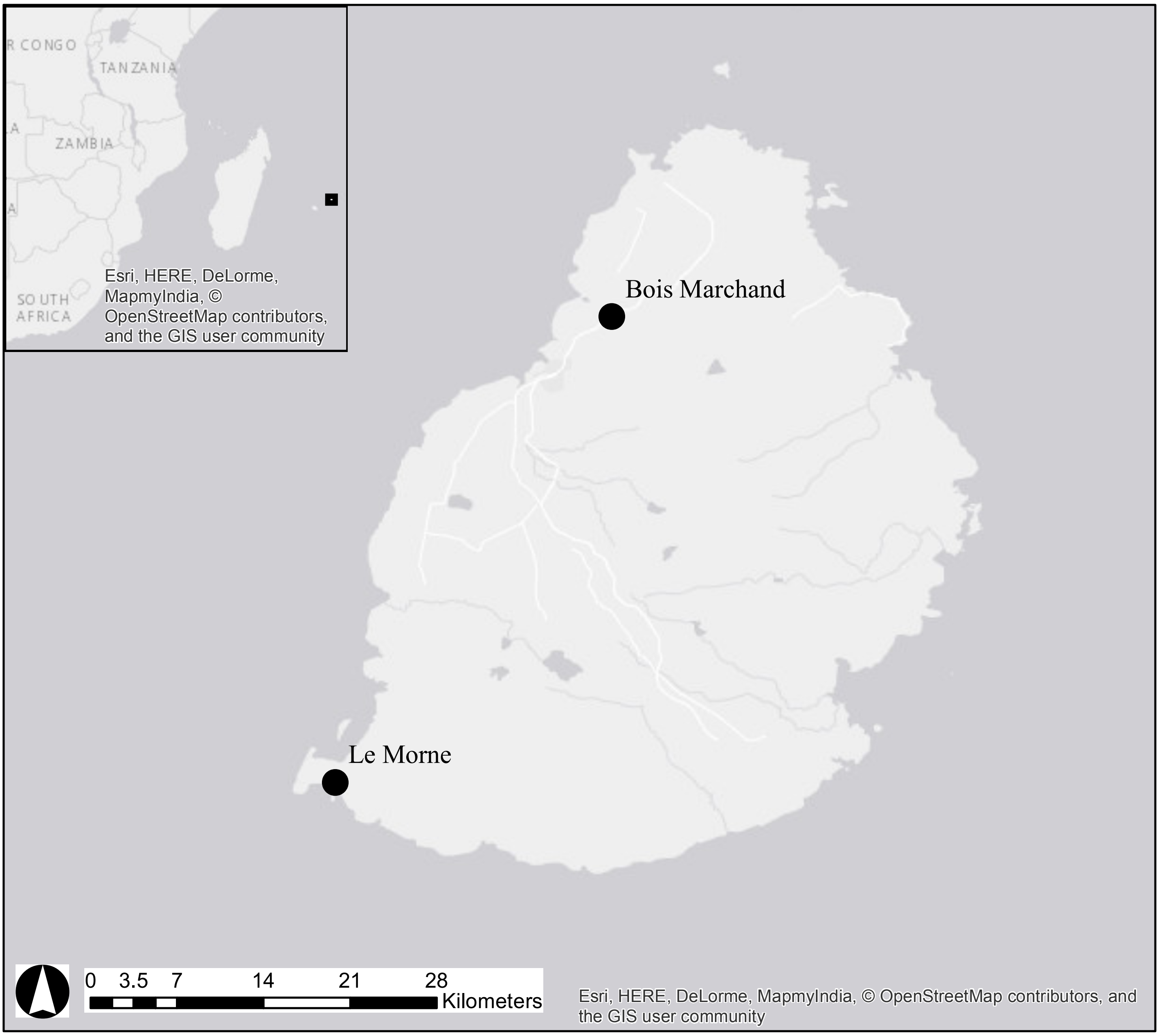

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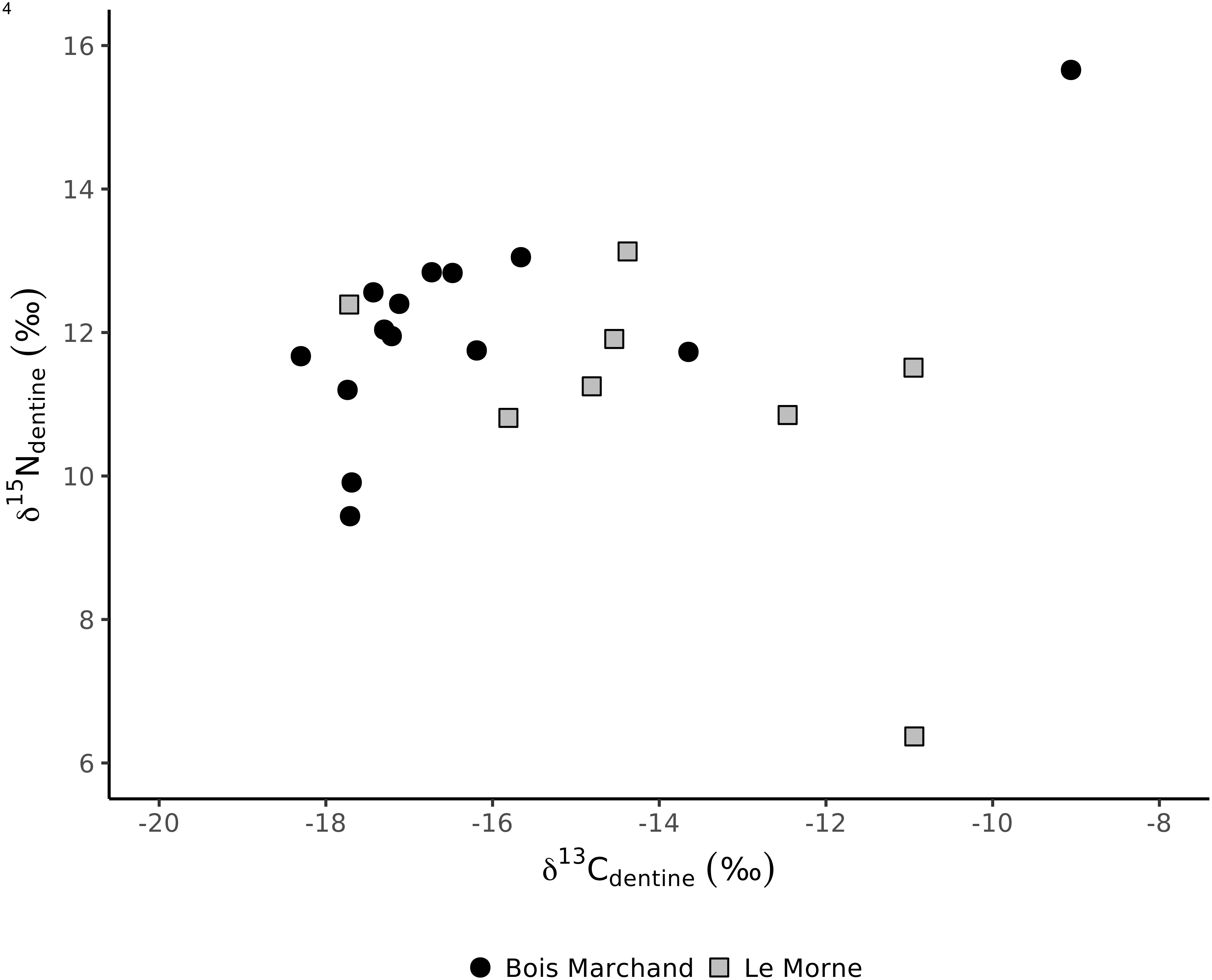
Figure 3

Figure 4



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$\delta^{15}N_{dentine}$ (‰)
$\delta^{13}C_{dentine}$ (‰)
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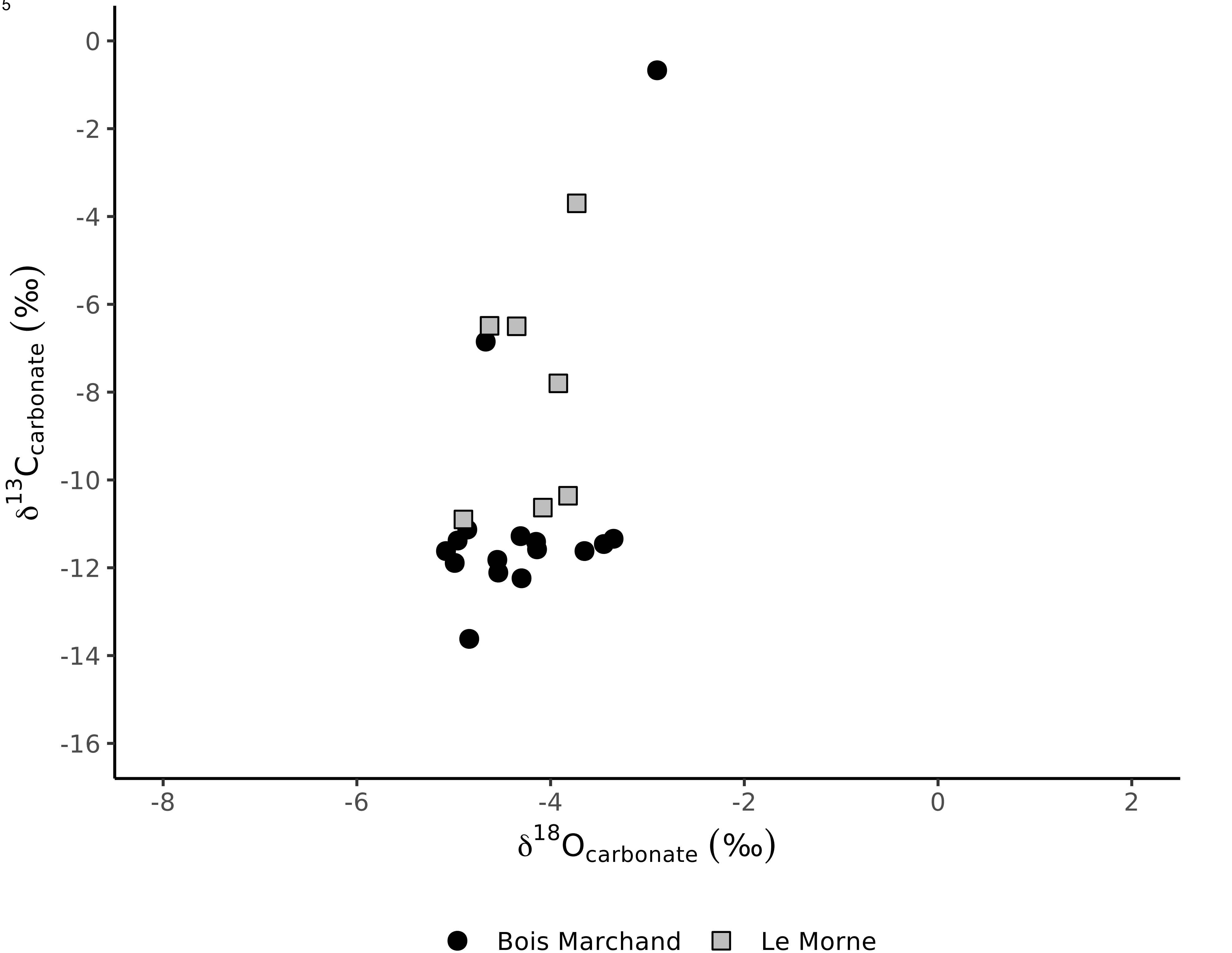
Figure 5



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δ13Ccarbonate (‰)
δ18Ocarbonate (‰)
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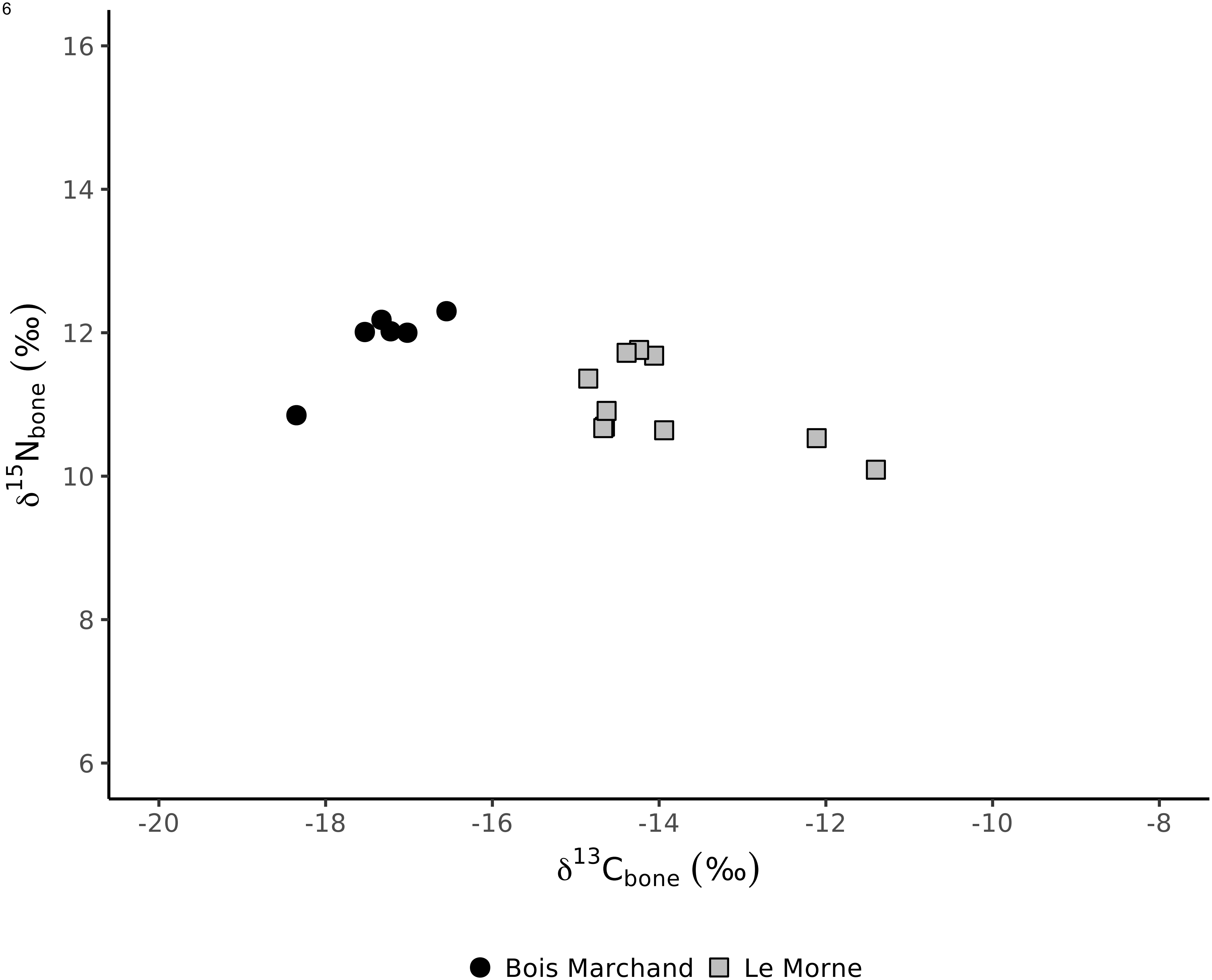
Figure 6



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δ15Nbone (‰)
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δ13Cbone (‰)
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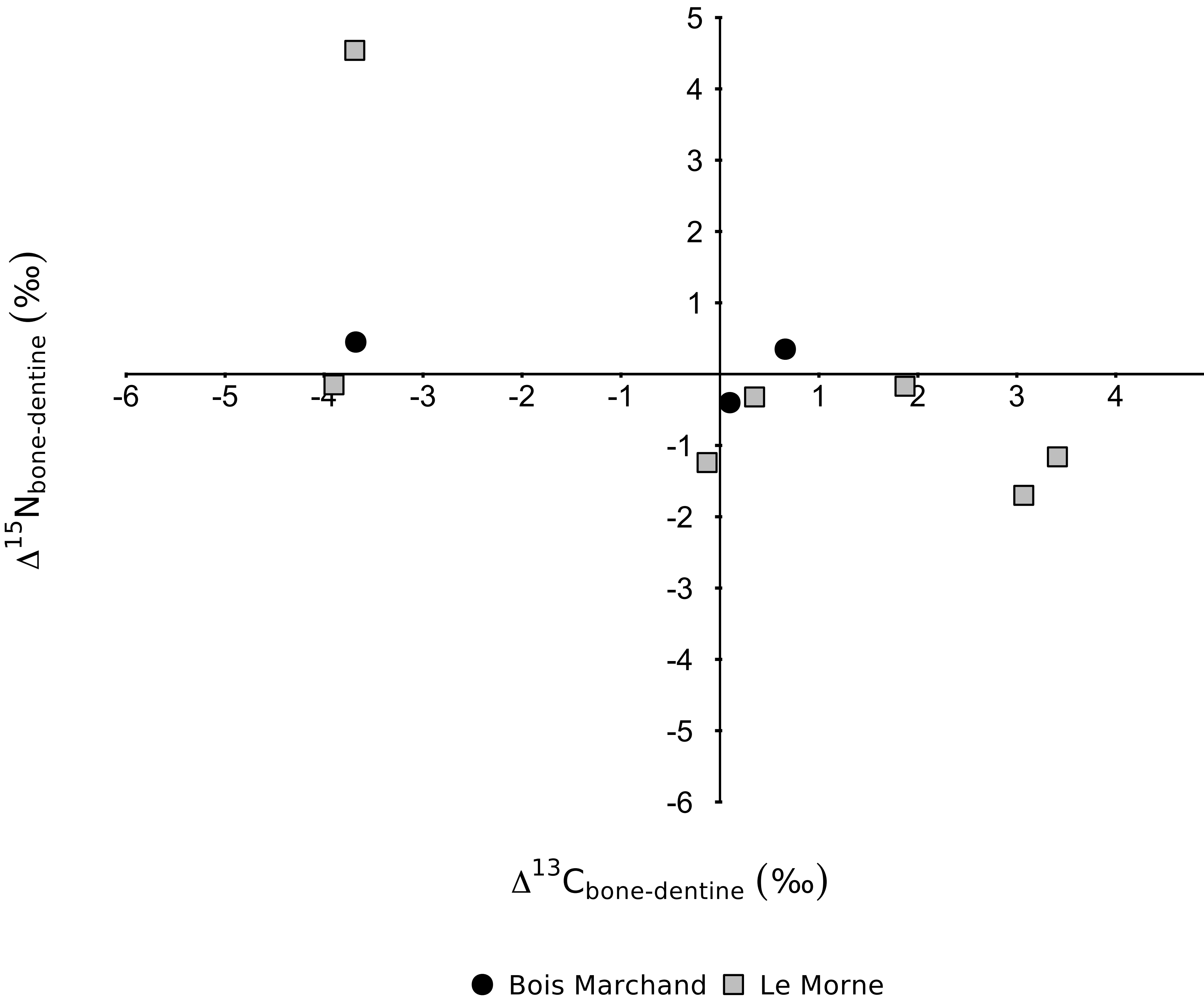
Figure 7



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5
Δ15Nbone-dentine (‰)
Δ13Cbone-dentine (‰)
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Table
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Appendix 1

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: