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ABSTRACT

The complex relationships between humans and dogs (*Canis lupus familiaris*) have a very deep and unique history. Dogs have accompanied humans as they colonised much of the world, and were introduced via human agency into the insular Caribbean where they became widespread throughout the Ceramic Age. It is likely that the dynamic interactions between humans, dogs, and their environments in the Caribbean were spatially, chronologically, and socially variable. However, almost no research has specifically addressed the nature, or potential variability, of human/dog interactions in this region. This study presents isotopic (strontium and carbon) evidence bearing on human and dog paleomobility and paleodietary patterns in the pre-colonial Caribbean. The isotope results illustrate a generally high degree of correspondence between human and dog dietary practices at all analysed sites but also slight differences in the relative importance of different dietary inputs. Striking parallels are also observed between the human and dog mobility patterns and shed light on broader networks of social interaction and exchange. Lastly, the paper addresses the possible utility and relevance of canine isotope data as proxies for inferring past human behaviours.

Introduction

Dogs (*Canis lupus familiaris*) represent the first of only two domesticated animal species, with guinea pigs (*Cavia porcellus*) being the other, that were introduced to the Antilles by indigenous peoples in pre-colonial times (Newsom and Wing 2004; Wing 2001). The timing and routes of the first introductions(s) of dogs from the mainland to the islands are not well known, but there is strong evidence that dogs were brought by Early Ceramic Age (ca. 500 BC to 500 AD) colonists (Wing 2008), as early as ca. 2500–2000 BP (Grouard, Perdikaris, and Karyne 2013; Newsom and Wing 2004; Pestle 2010). The Early Ceramic Age of the Caribbean is characterised by high rates of human mobility (Booden et al. 2008; Laffoon 2012; Laffoon et al. 2012), the long-distance exchange of materials and goods, and dynamic networks of social interaction operating at multiples scales from intra-island, inter-island, inter-archipelagic, and island-mainland (e.g. Fitzpatrick 2015; Hofman and Hoogland 2011; Hofman et al. 2007, 2010; 2011, 2014; Keegan and Hofman 2017; Laffoon et al. 2014; Rodríguez Ramos 2010). The widespread presence of canid faunal remains in Ceramic Age archaeological assemblages (Wing 2001, 2012) indicates that dogs were eventually dispersed to most, if not all, of the insular Caribbean over the subsequent centuries.

In this region, dog skeletal remains have been recovered from a diverse array of archaeological contexts such as intentional burials of dogs (with and without grave offerings) or composite burials containing both humans and dogs; in domestic refuse deposits, middens, and caves; and as modified objects of personal adornment or social valuables (e.g. Grouard 2001; Grouard, Perdikaris, and Karyne 2013; Hoogland and Hofman 2013; Lawrence 1977; Newsom and Wing 2004; Rodríguez Ramos 2010; Roe 1995). These diverse contexts and the widespread and varied representations of dog imagery on various other material culture media (wood, stone, ceramic) suggest important but highly variable roles of dogs in pre-colonial Amerindian societies of the Caribbean (Boomert 1987; Grouard, Perdikaris, and Karyne 2013; Laffoon et al. 2015; Newsom and Wing 2004; Roe 1995).

Grouard and colleagues (2013) have reviewed the chronology, distribution, and context of dog burials for much of the Antilles, and provide compelling evidence that the custom of dog burial is primarily an Early Ceramic Age phenomenon in this region and that dogs in general become less common over time (in the Lesser Antilles) based on decreasing absolute and relative abundances of dog remains in many archaeological assemblages. These trends imply that the roles of dogs in pre-colonial societies of the

Caribbean varied not only spatially and socially, but also temporally. Nonetheless, relatively little is known about many issues concerning pre-colonial dogs in the Caribbean and their dynamic relationships with humans including their origins, the timing and mechanisms of their dispersal across the region, the mechanisms of natural and human-mediated movement within and between islands, their diets, and their adaptions to and alterations of local and regional food webs.

Numerous isotopic studies in the Caribbean region have revealed substantial insights on indigenous human paleodiet (Buhay et al. 2013; Chinique de Armas et al. 2015; Keegan and DeNiro 1988; Krigbaum, Fitzpatrick, and Bankaitis 2013; Laffoon and de Vos 2011; Laffoon, Hoogland et al. 2016; Norr 2002; Pestle 2010, 2013; Stokes 1998) and human paleomobility (e.g. Booden et al. 2008; Laffoon 2012, 2013; Laffoon and Hoogland 2012; Laffoon et al. 2012; Valcárcel Rojas et al. 2011) practices. More recently, a broader range of biomolecular methods and approaches have been applied to the Caribbean faunal record to investigate various topics pertaining to patterns of animal paleomobility. These latter include genetic (Kimura et al. 2016) and isotopic studies of the anthropogenic introduction of wild or commensal species (Giovas et al. 2016; see also Giovas, 2017) and domesticated species (Laffoon et al. 2015), and the transport/exchange of animal skeletal resources and artefacts (Laffoon et al. 2014, Laffoon, Sonnemann et al. 2016). However, to our knowledge, no studies to date have explicitly explored correspondences and contrasts between humans and animals in this region by combining strontium and carbon isotopes analyses.

Stable isotope analyses of dog remains to infer human dietary patterns has a long history in archaeological research (e.g. Burleigh and Brothwell 1978; Cannon, Schwarcz, and Knyf 1999; Noe-Nygaard 1988; West and France 2015). Recently, Guiry (2012; see also Guiry 2013; Guiry and Grimes 2013) has extensively reviewed and explicitly developed a systematic and cohesive approach for inferring human dietary patterns based on stable isotope data derived from dog skeletal remains. This 'canine surrogacy approach' (CSA)

> analyzes archaeological domesticated dog (*Canis familiaris*) remains in order to offer some indication of their human keepers' dietary practices (e.g. Cannon, Schwarcz, and Knyf 1999), the premise being that dogs were likely provisioned with scraps from human meals and feces and thus could have shared an isotopically similar diet with contemporaneous humans. (Guiry 2012: 352)

Based on a study of published collagen stable isotope data from co-occurring human and dog remains from various cultural contexts worldwide, it has been demonstrated that dogs and humans generally possess broadly similar carbon and nitrogen isotope values, indicating the general utility of this approach (see Guiry 2012, 2013; Guiry and Grimes 2013, and references therein). Exceptions to this general pattern do, however, exist and Guiry (2012, 2013) details a number of interpretive complications which may arise using the CSA approach. Furthermore, nearly all CSA approaches to date have been made on the basis of collagen stable isotope data and have focused exclusively on paleodiet, and have not addressed questions pertaining to paleomobility.

This study, rather than representing a CSA per se, rather explores the utility and suitability of the CSA for paleodietary and paleomobility reconstructions in the Caribbean as it offers great promise for elucidating human dietary patterns in cases 'where human remains are scarce, poorly preserved, or otherwise unavailable' (Guiry 2012: 351). Before CSA can be effectively applied to this region it is necessary to demonstrate first that human and dog remains from the same contexts possess similar isotope values and patterns (in this study based on enamel isotope signals, as opposed to collagen), and to consider various complicating factors in the use of dogs as analogues for human behavioural reconstruction including biological or behavioural differences between dogs and humans, and cultural and environmental variables (Guiry 2012: 362). We also explicitly aim to test the degree of correspondence between human and dog $^{87}Sr/^{86}Sr$ data and examine the possibly usefulness of dog isotope data for inferring human mobility patterns (Guiry 2013).

This study aims to explore the nature of human–dog interactions and with their local environments in the pre-colonial Caribbean. Dual isotope data derived from the dental enamel of humans and dogs from the same sites are compared and contrasted to assess several distinct but related issues concerning human-canine dynamics. Specific hypotheses are tested concerning various aspects of human and canine paleodietary and paleomobility patterns at multiple scales. These hypotheses are: (1) Human–Dog Diets (H_1): humans and dogs from the same sites will possess similar bioapatite carbon isotope values owing to shared foodways; (2) Regional Patterning in Dietary Ecology (H_1): the geographic structure of human carbon isotope data, reflecting regional differences in foodways, is also evident in dog carbon isotope results; (3) Human–Dog Mobility (H_1): humans and dogs from the same sites will possess similar strontium isotope values owing to shared histories of residential mobility; (4) Human–Dog Linkages between diet and mobility (H_1): local and nonlocal individuals (humans and/or dogs) from the same sites possess dissimilar carbon isotope values owing to differences in dietary patterns between location of origin and location of recovery.

Materials and Methods

Study Sites and Samples

Teeth samples analysed for this study derive from four pre-colonial archaeological sites in the Antilles: Morel and Anse à la Gourde, Guadeloupe; and El Flaco and El Cabo de San Rafael, Dominican Republic (Figure 1), that were excavated from the 1990s to 2016 by Leiden University in collaboration with local partners. Both Morel and Anse à la Gourde are located along the eastern coast of Grande-Terre, Guadeloupe (Delpuech, Hofman, and Hoogland 2001, 2008; Hofman, Hoogland, and Delpuech 1999). El Flaco is located in the foothills of the southern flank of the Cordillera Septentrional about 20 km from the north-central coast of Hispaniola, and El Cabo is located directly on the eastern coast of Hispaniola (Hofman and Hoogland 2015; Samson 2010).

Morel is a multi-component site with both Saladoid and Huecoid cultural remains dating primarily to the Early Ceramic Age (ca. 500 BC to AD 600) (Delpuech, Hofman, and Hoogland 2008; Grouard, Perdikaris, and Karyne 2013; Hoogland and Hofman 2013) but most of the dated skeletal remains derive from a narrower time range (ca. AD 50–650). The other three sites are roughly contemporaneous and date primarily to the latter half of the Late Ceramic Age (ca. AD 600 to 1500), thereby permitting comparative assessment of possible changes in human–dog mobility and dietary patterns over time. Although Anse à la Gourde contains a minor earlier component, the most significant occupation, and most of the skeletal remains, are Troumassoid and date to roughly AD 1100–1400 (Hoogland and Hofman 2013). El Flaco possesses Ostionoid, Meillacoid and Chicoid deposits and the primary occupation dates to around AD 1200–1500 (Hofman and Hoogland 2015). El Cabo contains both Ostionoid and Chicoid cultural materials and the materials analysed herein derive from the later occupation dating to approximately AD 1200–1500 (Hofman et al. 2008; Samson 2010).

All of the human samples clearly derive from different individuals, and we assume that the dog teeth from different midden/burial contexts are from different individuals as well. The analysed dog samples from Morel were recovered from burial contexts during the earlier excavations of the site in the 1960s (Clerc 1968) of either individual dog burials or of dog remains associated with human burials, while the human samples from Morel were obtained during excavations conducted in the 1990s (Hofman, Hoogland, and Delpuech 1999; see also Grouard 2001; Grouard, Perdikaris, and Karyne 2013; Hoogland and Hofman 2013). At El Flaco, human burials derive from mounds along with associated dog remains. The dog teeth from the Anse à la Gourde and El Cabo were recovered from domestic or refuse contexts (Hofman and Hoogland 2015; Samson 2010). New multi-isotope evidence (both strontium and carbon) is presented from both the human and dog samples from El Cabo (humans $n = 3$; dogs $n = 2$) and El Flaco (humans $n = 5$; dogs $n = 2$), and from the human samples from Morel ($n = 7$), as well as the enamel carbon isotope results for the Morel ($n = 3$) and Anse à la Gourde ($n = 3$) dog samples. These data are compared to, and interpreted in conjunction with, previously published strontium isotope results from the human population at Anse à la Gourde (Booden et al. 2008; Hoogland, Hofman, and Panhuysen 2010; Laffoon and Hoogland 2012; Laffoon et al. 2012) and the dog collections from both Anse à la Gourde and Morel (Laffoon et al. 2015) and build upon a limited data set of enamel carbon isotopes from Anse à la Gourde (Laffoon, Valcárcel Rojas, and Hofman 2013) and the wider Caribbean (Table 1).

Isotope Principles

For this study we employ a dual isotope approach combining strontium ($^{87}Sr/^{86}Sr$), and carbon ($\delta^{13}C$) isotope analyses of human and canid dental enamel. Strontium isotopes are the most widely used and well established isotopic proxy for human and animal mobility and provenance studies in archaeology (Bentley 2006; Ericson 1985; Makarewicz 2016). The principle of the strontium isotope method (reviewed in Bentley 2006) is that biogenic tissues are in isotopic equilibrium with the local biogeochemical environment, reflecting a combination of different inputs from the geological and hydrological cycles. The physical and chemical weathering of minerals in bedrock is generally considered to be the predominant source of strontium to most terrestrial ecosystems. As strontium does not undergo significant isotopic fractionation as it passes from the soil into and through the food web (Price, Burton, and Bentley 2002), $^{87}Sr/^{86}Sr$ ratios do not vary significantly between different trophic levels. Dental enamel is the preferred tissue type for strontium isotope applications in archaeology as it is both highly resistant to diagenesis (Budd et al. 2000; Hoppe, Koch, and Furutani 2003) and does not undergo remodelling. Hence enamel preserves the isotopic signal of the biogeochemical environment in the location where it was formed.

Carbon isotope analysis of skeletal tissues is one of the most commonly utilised methods for paleodietary research in archaeology (Katzenberg 2008; Vogel and

Table 1. Site names, locations, distance from coast, and approximate chronological range of sampled skeletal materials.

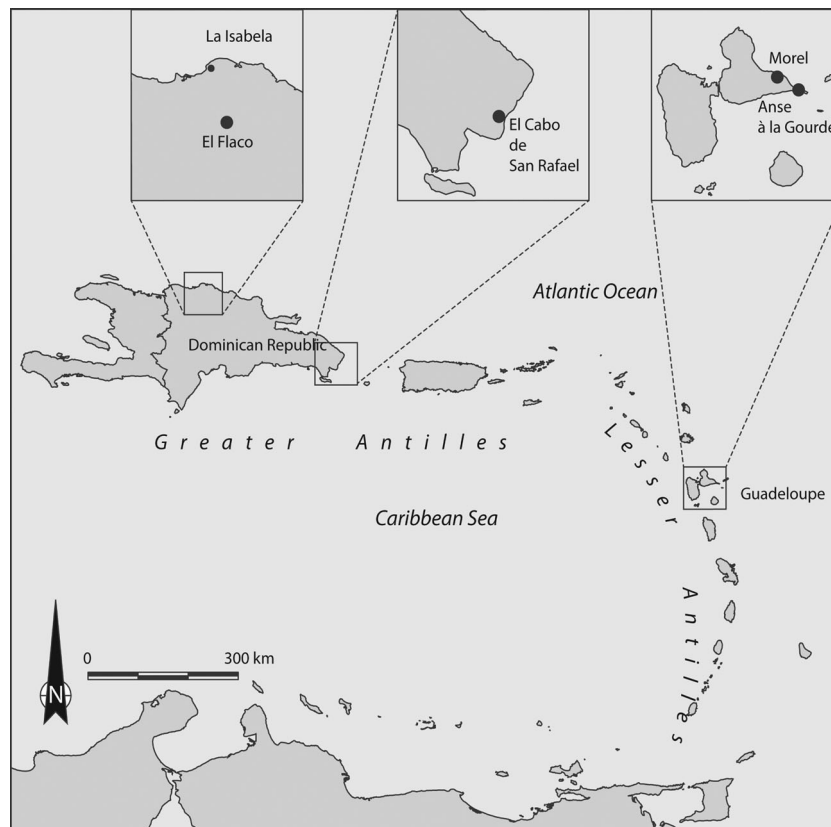| Site	Island	Distance from coast	~Date range*
Morel	Guadeloupe	<1 km	AD 50–650
Anse à la Gourde	Guadeloupe	<1 km	AD 1100–1400
El Cabo	Hispaniola	<1 km	AD 1200–1500
El Flaco	Hispaniola	~20 km	AD 1200–1500

Figure 1. Map of the Caribbean indicating the location of sites mentioned in the text.

van der Merwe 1977). Although bone collagen is the most frequently analysed biogenic tissue for such studies, carbon isotope analysis of the apatite fraction of bone and dental enamel is also frequently conducted (Katzenberg 2008). Multiple controlled feeding studies (Ambrose and Norr 1993) have clearly established that carbon isotopes in collagen ($\delta^{13}C_{collagen}$) and (bio-) apatite ($\delta^{13}C_{apatite}$) reflect different aspects of diet. Owing to dietary routing of macro-nutrients, collagen $\delta^{13}C$ is heavily biased by the protein component of diet (Fernandes, Nadeau, and Grootes 2012; Froehle, Kellner, and Schoeninger 2010), whereas bioapatite $\delta^{13}C$ (both bone and enamel) generally reflects an average of the whole diet including proteins, fats/lipids, and carbohydrates (Ambrose and Norr 1993; Lee-Thorp, Sealy, and Van der Merwe 1989).

In contrast to bone apatite which represents a long-term average of dietary intake, carbon isotopes of dental enamel ($\delta^{13}C_{enamel}$) reflect consumption patterns occurring during the mineralisation of the dental crown, which varies amongst humans from *in utero* for deciduous teeth to adolescence for third molars (M3) with most permanent teeth forming in early childhood (Hillson 1996). The sampling of the human dental elements focused on premolars but other permanent teeth were also analysed when an intact premolar was unavailable. The sampling strategy for the dog dental remains was more opportunistic and analysed various dental elements. For humans, the formation times of the sampled dental elements overlap significantly and each tooth crown will represent a few years of an individual's early life and range from ca. birth to 8–14 years of age (AlQahtani et al. 2010) based on the various dental elements sampled for this study. For dogs, whose developmental stages and life spans are vastly reduced compared to humans, the sampled elements likely reflect roughly several months of mineral formation spanning from *in utero* to ca. 1 year of age (Hillson 1996).

Isotopic Patterns in the Pre-Colonial Antilles

Stable isotope analyses ($\delta^{13}C$ and $\delta^{15}N$) have a long history of applications to paleodietary research in the Caribbean (e.g. Keegan and DeNiro 1988; Norr 2002; Schoeninger, DeNiro, and Tauber 1983; Stokes 1998; van Klinken 1991). The extant stable isotope datasets of archaeological skeletal materials for the Caribbean region currently include several hundred human and faunal samples representing a wide range of taxa, ecological settings, and geographical and temporal coverage. Previous research (e.g. Chinique de Armas et al. 2015, 2016; Krigbaum, Fitzpatrick, and Bankaitis 2013; Laffoon 2016; Laffoon, Hoogland et al. 2016; Pestle 2010; Stokes 1998) has documented that collagen stable isotope data in particular display clear spatial patterning with populations from smaller islands generally possessing both enriched $\delta^{13}C_{co}$ and $\delta^{15}N$ values. These patterns have been interpreted as reflecting biogeographical parameters with a generally greater

reliance on marine protein sources amongst the smaller islands of the Lesser Antilles (Stokes 1998).

Regional spatial patterning is also evident in $\delta^{13}C$ values recorded in the bioapatite fraction of human bone (Krigbaum, Fitzpatrick, and Bankaitis 2013; Norr 2002; Pestle 2010; Stokes 1998) and enamel (Laffoon, Valcárcel Rojas, and Hofman 2013) samples in the Antilles. Although bioapatite $\delta^{13}C$ values display greater overlap between populations and less distinctive clustering relative to biogeographical parameters such as island size. These observed differences in the spatial patterns of the different isotopic proxies likely reflects the fact that while collagen which is heavily influenced by protein intake, bioapatite isotope composition is highly correlated with that of the whole diet (Ambrose and Norr 1993). As such, bioapatite $\delta^{13}C$ values are reliable indicators of whole diets, and despite substantial overlap between pre-colonial populations of the Antilles, regional human data display a high degree of variation: (range = 10‰; −14 to −4‰) (Krigbaum, Fitzpatrick, and Bankaitis 2013; Laffoon, Valcárcel Rojas, and Hofman 2013; Norr 2002; Pestle 2010; Stokes 1998). Dental enamel $\delta^{13}C$ data are highly complementary to traditional isotopic approaches using bone collagen and bone bioapatite sampling, and are ideal proxies for childhood dietary practices as enamel is both highly resistant to diagenesis and does not undergo remodelling after initial mineralisation of the dental crown (Hillson 1996). For example, recent research (Mickleburgh and Laffoon 2017) has demonstrated that 'Archaic' individuals from Aruba, where multiple lines of archaeological and bioarchaeological evidence have previously suggested distinct hunter-gatherer subsistence practices and highly marine-reliant diets, also possessed extremely enriched enamel $\delta^{13}C$ values (−5.3 to −3.9‰).

In recent years, strontium isotope ($^{87}Sr/^{86}Sr$) approaches have also been widely applied to studies of human and animal paleomobility, and artefact provenance studies in the Caribbean (Booden et al. 2008; Giovas et al. 2016; Hofman et al. 2012; Hoogland, Hofman, and Panhuysen 2010; Laffoon 2012, 2013, 2016; Laffoon et al. 2012, 2014, 2015, 2017; Laffoon, Sonnemann et al. 2016; Valcárcel Rojas et al. 2011). The Caribbean region is particularly well suited to the application of the strontium isotope method owing to the geological diversity (Donovan and Jackson 1994) and hence high degree of variability and spatial patterning of bedrock and bioavailable $^{87}Sr/^{86}Sr$. For this region, both large-scale empirical datasets and spatially explicit predictive models of regional isotope landscapes (isoscapes), of bioavailable $^{87}Sr/^{86}Sr$ have been developed (Bataille, Laffoon, and Bowen 2012; Laffoon et al. 2012). Previous strontium isotope analyses of human and mammalian teeth from archaeological assemblages in the Caribbean have revealed valuable insights into paleomobility patterns including high

rates of immigration, chronological changes in the migration rates, linkages between nonlocal origins and exotic grave goods and burial practices, and correlations between nonlocal origins (based on Sr data) and nonlocal dietary preferences (based on $\delta^{13}C$ and $\delta^{15}N$ data) for some individuals (Laffoon 2012; Laffoon and Hoogland 2012; Laffoon et al. 2012, 2014; Mickleburgh and Laffoon 2017). Furthermore, applications of isotope analyses in archaeological research are increasingly utilising multiple isotope proxies which increase the interpretive power of these analytical tools and provide for more nuanced reconstructions of past human behaviours. For example, in regions where skeletal stable isotope data also display clear spatial patterns, they can also be potentially informative of individual origins and may provide additional evidence concerning geographic origins (e.g. Cook and Schurr 2009; Dupras and Schwarcz 2001; Fischer et al. 2007). Given the documented spatial structure of stable isotope data in the Caribbean (Stokes 1998), we propose that these datasets should be more explicitly explored for their utility to paleomobility and provenance studies (Laffoon 2016), in addition to their demonstrated utility for paleodietary research.

Analytical Procedures and Protocols

Details of the applied methods are presented elsewhere (Booden et al. 2008; Laffoon, Valcárcel Rojas, and Hofman 2013) and all aspects of sample preparation and isotope analyses were conducted in designated facilities. Teeth were sonicated in ultra-pure water (Milli-Q H_2O) and mechanically cleaned with a dental drill. The outer surface of the crown was removed and ca. 2–5 mg of inner enamel was extracted for isotope analyses. Powdered enamel samples were chemically pretreated to remove potential organics and secondary carbonates following the protocol outlined in Bocherens et al. (2011). Samples were soaked in 2.5% bleach (NaOCl) for 24 h, rinsed thoroughly, leached in Ca-acetate buffered (pH 4.75) 1.0 M acetic acid (CH_3COOH) for 4 h, and then rinsed to neutral pH. Owing to the general resistance of enamel to diagenic alteration, the selection of well-preserved teeth based on macroscopic inspection, the thorough pre-treatment protocol, and previous trace element analysis of a subset of the human teeth presented herein (Laffoon 2012) which provided no indication of post-mortem contamination, we assume that the enamel isotope results are reliable and reflective of the original biogenic signal.

For analysis of strontium isotope compositions ($^{87}Sr/^{86}Sr$), ca. 2 mg of enamel was dissolved in 0.5 ml of 3 N nitric acid (HNO_3). The strontium fraction was separated with ion-exchange column chromatography using Sr-spec resin. Strontium isotopes were analysed on a ThermoFinnigan MAT262 TIMS

and measured $^{87}Sr/^{86}Sr$ ratios were corrected for mass fractionation using an exponential law and an $^{86}Sr/^{88}Sr$ ratio of 0.1194. The international standard NBS987 was analysed to monitor system performance with a long-term average $^{87}Sr/^{86}Sr$ ratio of 0.71024 ± 0.00004 (2σ) and the $^{87}Sr/^{86}Sr$ ratios of samples were normalised relative to the accepted value of the NBS987 standard of 0.71024.

For analysis of carbon isotopes, ca. 0.7 mg of enamel was weighed into pre-cleaned sampling tubes that were flushed with carrier gas, and samples were then dissolved in 100% orthophosphoric acid (H_3PO_4) in a hot-block at 45°C for 24 h. Carbon isotope compositions were analysed using a DeltaPlus IRMS coupled to a GasBench II sampler. Stable isotope values are reported as delta (δ) values in units of per mil (‰) normalised to the PDB scale using an internal carbonate reference material (VICS) calibrated against certified reference materials (NBS19 and LSVEC). Long-term reproducibility of the international (NBS19) reference materials for $\delta^{13}C$ is <0.1‰.

Results and Discussion

Individual isotope results are listed in Table 2 and basic descriptive statistics in Table 3, and the data are displayed in Figures 2 and 3. For the Morel samples, human $^{87}Sr/^{86}Sr$ ratios ($n = 7$) vary between ca. 0.7071 and 0.7091, and dog $^{87}Sr/^{86}Sr$ ($n = 7$) varies between 0.7080 and 0.7091. For the Anse à la Gourde samples, human $^{87}Sr/^{86}Sr$ ratios ($n = 72$) vary between 0.7075 and 0.7094, and dog $^{87}Sr/^{86}Sr$ ($n = 3$) varies between 0.7076 and 0.7091. Previous research has demonstrated that the range of bioavailable $^{87}Sr/^{86}Sr$ variation for Grande-Terre (the eastern portion of Guadeloupe) is ca. 0.7090–0.7093 (Booden et al. 2008; Laffoon et al. 2012). This very restricted range reflects the fact that both geological and marine inputs of strontium to the local terrestrial ecosystem are nearly identical as the underlying bedrock is predominantly composed of geologically young marine carbonates.

For this study, nonlocal individuals are identified as those whose $^{87}Sr/^{86}Sr$ ratios fall outside of the absolute range of local $^{87}Sr/^{86}Sr$ for the locale defined on the basis of independent measurements of local faunal and floral samples (Price, Burton, and Bentley 2002). Previous research has revealed that a substantial proportion (>25%) of the human population at Anse à la Gourde are nonlocals (Booden et al. 2008; Hoogland, Hofman, and Panhuysen 2010; Laffoon et al. 2012), as well as one of the three dogs from this site and two out of seven dogs at Morel (Laffoon et al. 2015). The new human $^{87}Sr/^{86}Sr$ data from Morel indicates an even higher proportion of nonlocals amongst this population (∼57%) with four of seven individuals falling outside of the 'local' range of $^{87}Sr/^{86}Sr$ variation for Grande-Terre. The vast majority of nonlocal humans and the

nonlocal dogs at both of these sites possess $^{87}Sr/^{86}Sr$ values that are lower than the local range for Grande-Terre (Laffoon 2012; Laffoon et al. 2012) based on measurements of archaeological rice rat enamel ($n = 10$), human bone ($n = 8$), and soil ($n = 4$) samples.

Based on the patterning of bioavailable $^{87}Sr/^{86}Sr$ within the Lesser Antilles archipelago (Bataille, Laffoon, and Bowen 2012; Laffoon et al. 2012), we can exclude certain nearby islands of the Limestone Caribbees (e.g. Marie-Galante, La Desirade, Barbuda), as well as any other locations in the region with comparable bioavailable $^{87}Sr/^{86}Sr$, as possible origins. Mainland origins (e.g. from northern South America) can also likely be excluded, as these areas are underlain by continental bedrock and possess higher bioavailable $^{87}Sr/^{86}Sr$ values (>0.7095) than nearly all of the islands of the Antilles (0.7055–0.7095), with the exception of Trinidad and Tobago (Bataille, Laffoon, and Bowen 2012; Laffoon et al. 2012). We propose that these nonlocals likely originated from islands characterised by lower bioavailable $^{87}Sr/^{86}Sr$, such as can be found throughout much of the Volcanic Caribbees (the western arc of The Lesser Antilles archipelago); although owing to the high degree of overlap in $^{87}Sr/^{86}Sr$ between most of these islands it is difficult to identify more precise origins at this stage.

For the sites in the Dominican Republic, at El Flaco the human samples ($n = 5$) possess $^{87}Sr/^{86}Sr$ ratios ranging from 0.7069 to 0.7083 and the dogs ($n = 2$) from 0.7076 to 0.7078. At El Cabo, the humans ($n = 3$) have $^{87}Sr/^{86}Sr$ values from 0.7091 to 0.7092, and the dogs ($n = 2$) have values from 0.7090 to 0.7092. In contrast to the two sites on Guadeloupe, which possess equivalent ranges in local $^{87}Sr/^{86}Sr$, the local (bioavailable) $^{87}Sr/^{86}Sr$ ranges at El Flaco and El Cabo are quite distinct from each other. This is primarily a reflection of the very different geological settings of the two sites with El Flaco situated in mountainous terrain underlain by complexes of igneous and metamorphic deposits (Donovan and Jackson 1994) with an associated lower bioavailable $^{87}Sr/^{86}Sr$, while El Cabo is located on a karstic plateau of marine carbonates, which in combination with Sr from sea-spray, results in a local $^{87}Sr/^{86}Sr$ range that is indistinguishable from that of Grande-Terre (Laffoon et al. 2012). Independent assessments of the local $^{87}Sr/^{86}Sr$ ranges based on archaeological faunal remains provide initial estimates of local ranges of 0.7062–0.7080 for El Flaco ($n = 4$) based on archaeological hutia dental enamel, and 0.7090–0.7092 for El Cabo based on archaeological pig enamel and land snail shell ($n = 4$), the latter range applicable to much of the far eastern peninsula of Hispaniola (Laffoon 2012).

Based on assessments of the human and dog $^{87}Sr/^{86}Sr$ data relative to these local range estimates, we identify one nonlocal human at El Flaco, while the other four humans and both dog specimens have

Table 2. List of samples and isotope results.

Site	Region	Sample ID	Type	Element	$^{87}Sr/^{86}Sr$	$\delta^{13}C$
Morel	Guadeloupe	80.2	Human	M1	**0.70905**	**−12.6**
		F338	Human	PM1	**0.70910**	**−11.5**
		F90.07	Human	C	**0.70903**	**−12.1**
		F90.12*	Human	C	**0.70864**	**−12.9**
		F91.01*	Human	PM1	**0.70881**	**−11.9**
		F91.08*	Human	M1	**0.70710**	**−11.7**
		F91.10*	Human	M1	**0.70857**	**−11.3**
		255	Dog	PM	0.70914	–
		262*	Dog	PM	0.70802	**−11.1**
		263*	Dog	unid.	0.70798	–
		706.1	Dog	unid.	0.70902	**−12.7**
		706.3	Dog	M	0.70914	**−11.1**
		1969A	Dog	unid.	0.70913	–
		1969B	Dog	M	0.70913	–
Anse à la Gourde	Guadeloupe	F0050	Human	PM1	0.70917	**−13.1**
		F0089	Human	PM1	0.70916	**−10.1**
		F0108	Human	PM1	0.70917	**−11.9**
		F0108A	Human	PM	**0.70911**	**−12.0**
		F0137A	Human	M2	0.70913	**−10.4**
		F0139	Human	PM	0.70903	**−11.9**
		F0159	Human	PM2	0.70915	**−10.8**
		F0171*	Human	M1	0.70864	**−11.9**
		F0195	Human	M1	**0.70919**	**−10.4**
		F0196	Human	PM1	0.70904	**−11.9**
		F0197	Human	PM2	0.70913	**−10.2**
		F0200	Human	M3	0.70901	**−11.6**
		F0202	Human	PM1	0.70913	**−10.4**
		F0206	Human	PM	0.70913	–
		F0207	Human	M1	0.70912	−12.1
		F0212	Human	PM2	0.70908	–
		F0219	Human	PM1	0.70905	**−11.6**
		F0238B	Human	M2	0.70915	**−12.3**
		F0241	Human	PM1	0.70906	–
		F0253	Human	PM	0.70916	**−11.9**
		F0288*	Human	PM2	0.70865	**−10.8**
		F0291	Human	M2	0.70909	**−12.1**
		F0292*	Human	PM2	0.70876	**−11.5**
		F0304	Human	PM2	0.70912	**−11.9**
		F0307	Human	PM	0.70917	**−10.2**
		F0311*	Human	PM2	0.70885	**−11.1**
		F0332*	Human	PM2	0.70828	–
		F0335*	Human	M2	0.70773	–
		F0337*	Human	PM2	**0.70831**	–
		F0339	Human	I1	0.70910	–
		F0342	Human	PM2	0.70903	**−11.2**
		F0348	Human	I1	0.70913	—
		F0349A	Human	PM2	0.70914	**−10.4**
		F0349C*	Human	I1	0.70859	**−10.5**
		F0350	Human	PM1	0.70918	**−10.4**
		F0377	Human	dc	0.70907	**−10.1**
		F0378*	Human	PM2	0.70749	**−10.9**
		F0430*	Human	PM2	0.70879	−11.5
		F0447	Human	PM2	0.70909	**−10.8**
		F0450*	Human	PM1	0.70869	−11.1
		F0451	Human	PM2	0.70911	**−10.5**
		F0452	Human	PM2	0.70918	**−9.9**
		F0454	Human	I2	0.70916	**−10.6**
		F0529	Human	PM	0.70911	**−10.9**
		F0706	Human	PM2	0.70917	**−9.8**
		F0726	Human	PM2	0.70923	**−11.1**
		F0953	Human	PM1	0.70916	**−10.5**
		F1126A	Human	I2	0.70912	**−11.2**
		F1126B*	Human	M3	**0.70866**	**−10.2**
		F1203	Human	PM2	0.70913	**−10.7**
		F1207*	Human	PM1	0.70896	**−10.7**
		F1226	Human	PM1	0.70907	**−10.8**
		F1413	Human	dm	0.70919	**−11.5**
		F1496	Human	PM2	0.70916	**−9.8**
		F1651	Human	PM2	0.70917	**−10.0**
		F1922	Human	dc	0.70914	**−9.9**
		F1944	Human	dm	0.70929	**−10.7**
		F1945	Human	PM1	0.70917	**−10.8**
		F1947	Human	PM1	0.70924	**−11.6**
		F1948*	Human	PM2	0.70890	**−11.2**
		F1958	Human	C	0.70900	**−10.8**
		F2005*	Human	PM1	0.70848	**−10.7**
		F2106	Human	C	0.70914	**−9.8**

(Continued)

Table 2. Continued.

Site	Region	Sample ID	Type	Element	$^{87}Sr/^{86}Sr$	$\delta^{13}C$
		F2107	Human	PM2	0.70915	**−11.5**
		F2109	Human	I2	0.70907	**−9.4**
		F2211*	Human	di	0.70941	**−10.5**
		F2212	Human	PM2	0.70910	−11.0
		F2213*	Human	PM	0.70885	**−10.3**
		F2214	Human	PM	0.70916	**−9.2**
		F2215*	Human	PM1	0.70775	−11.2
		F2216	Human	PM2	0.70917	−10.8
		F2217	Human	PM2	0.70917	**−11.3**
		64-55-2	Dog	PM	0.70911	**−11.0**
		64-55-2.4*	Dog	I	0.70762	**−10.6**
		64-45-1	Dog	PM	0.70915	**−9.0**
El Flaco	Domin. Rep.	FNR.1216A	Human	M1	**0.70692**	**−12.2**
		FNR.1216B	Human	dm	**0.70705**	**−12.6**
		FNR.1894	Human	PM	**0.70711**	**−12.1**
		FNR.2365	Human	PM2	**0.70786**	**−11.6**
		FNR.2382*	Human	I1	**0.70829**	**−12.1**
		FNR.1227B	Dog	C	**0.70760**	**−11.8**
		FNR.2295	Dog	PM	**0.70779**	**−11.1**
El Cabo	Domin. Rep.	F85-40-17	Human	PM1	**0.70918**	**−12.9**
		F85-31-01	Human	PM1	**0.70915**	**−12.6**
		DR.EC-B1	Human	PM2	**0.70918**	**−12.7**
		FNR1604	Dog	I	**0.70898**	**−11.4**
		FNR2722	Dog	M	**0.70922**	**−11.6**

Note: * Indicates sample is a nonlocal. Isotope data from Booden et al. (2008), Laffoon (2012), Laffoon et al. (2012, 2013, 2015) in plain text; data from this study in bold.

local values. At El Cabo, all three humans and both dog samples possess local $^{87}Sr/^{86}Sr$ values. The single non-local individual at El Flaco has an $^{87}Sr/^{86}Sr$ signal of 0.7083, which is higher than the local range and other individuals at this site. It is difficult to propose a possible natal origin as Hispaniola is not yet well mapped in terms of bioavailable $^{87}Sr/^{86}Sr$; however, similar $^{87}Sr/^{86}Sr$ values have been recorded for human and bioavailable samples at various sites throughout north-eastern Dominican Republic (Laffoon 2012; Laffoon et al. 2012).

The Morel human samples have $\delta^{13}C$ values ranging from −12.9 to −11.3‰ ($n = 7$), and the Morel dog samples have $\delta^{13}C$ from −12.7 to −11.1‰ ($n = 3$). At Anse à la Gourde the human samples range from −13.1 to −9.2‰ ($n = 64$), and the dog samples from −11 to −9‰ ($n = 3$). At El Flaco, the human samples possess $\delta^{13}C$ from −12.6 to −11.6‰ ($n = 5$) and the dog samples from −11.8 to −11.1‰ ($n = 2$), and at El Cabo the human $\delta^{13}C$ results range from −12.9 to −12.6‰ ($n = 3$) and the dog samples range from −11.6 to −11.4‰ ($n = 2$). Comparing the $\delta^{13}C$ results between sites, the range of values (ca. −13 to −11‰) for Morel, El Flaco, and El Cabo are all nearly identical,

while the range for Anse à la Gourde is twice as large (−13 to −9‰) with roughly half of the samples (including all three dogs) for this population having $\delta^{13}C$ >−11‰. The fact that the range of $\delta^{13}C$ values for Anse à la Gourde is much larger than the other three sites, possibly reflects the much larger number of analysed samples (64 humans; 3 dogs) from this site. Alternatively, this observed pattern may reflect a higher degree of inter-individual variability in diets at Anse à la Gourde with varying proportions of isotopi-cally distinct food sources.

Taking into account a diet-tissue offset (isotopic fractionation factor) for human bioapatite $\delta^{13}C$ of 10.1‰ (Fernandes, Nadeau, and Grootes 2012), provides estimates for average whole diet $\delta^{13}C$ of −23.2 to −19.1‰ for humans at these sites. The lower end of this range corresponds to the range of $\delta^{13}C$ recorded in C_3 plants in the Caribbean (Keegan and DeNiro 1988; Pestle 2010; Stokes 1998), although some of the higher values in the entire data set likely indicate minor contributions to whole diet from either marine or C_4 resources, or both. These slightly elevated values, however, fall within the range of reported enamel $\delta^{13}C$ values (Laffoon, Valcárcel Rojas, and Hofman 2013) for most other archaeological populations in the Antilles analysed to date with the clear exception of Aruba, where individuals have elevated enamel $\delta^{13}C$ (Mickle-burgh and Laffoon 2017). In fact, the range of values reported to date for most pre-colonial Antillean populations are readily contrasted with those from Mesoamerica where both human and dog apatite $\delta^{13}C$ are clearly elevated, likely as a result of higher rates of consumption of C_4 resources, probably resulting from both the direct consumption of maize as a staple crop and indirectly by consuming animals that fed on maize

Table 3. Statistical summary of isotope results by site.

Site	Type	$^{87}Sr/^{86}Sr$			$\delta^{13}C$		
		Mean	1σ	n	Mean	1σ	n
Morel	Human	0.70861	0.00070	7	−12.0	0.6	7
	Dog	0.70879	0.00054	7	−11.6	0.9	3
Anse à la Gourde	Human	0.70898	0.00035	72	−10.9	0.8	64
	Dog	0.70863	0.00087	3	−10.2	1.0	3
El Flaco	Human	0.70745	0.00060	5	−12.1	0.4	5
	Dog	0.70769	0.00014	2	−11.4	0.5	2
El Cabo	Human	0.70917	0.00002	3	−12.8	0.2	3
	Dog	0.70910	0.00017	2	−11.5	0.1	2

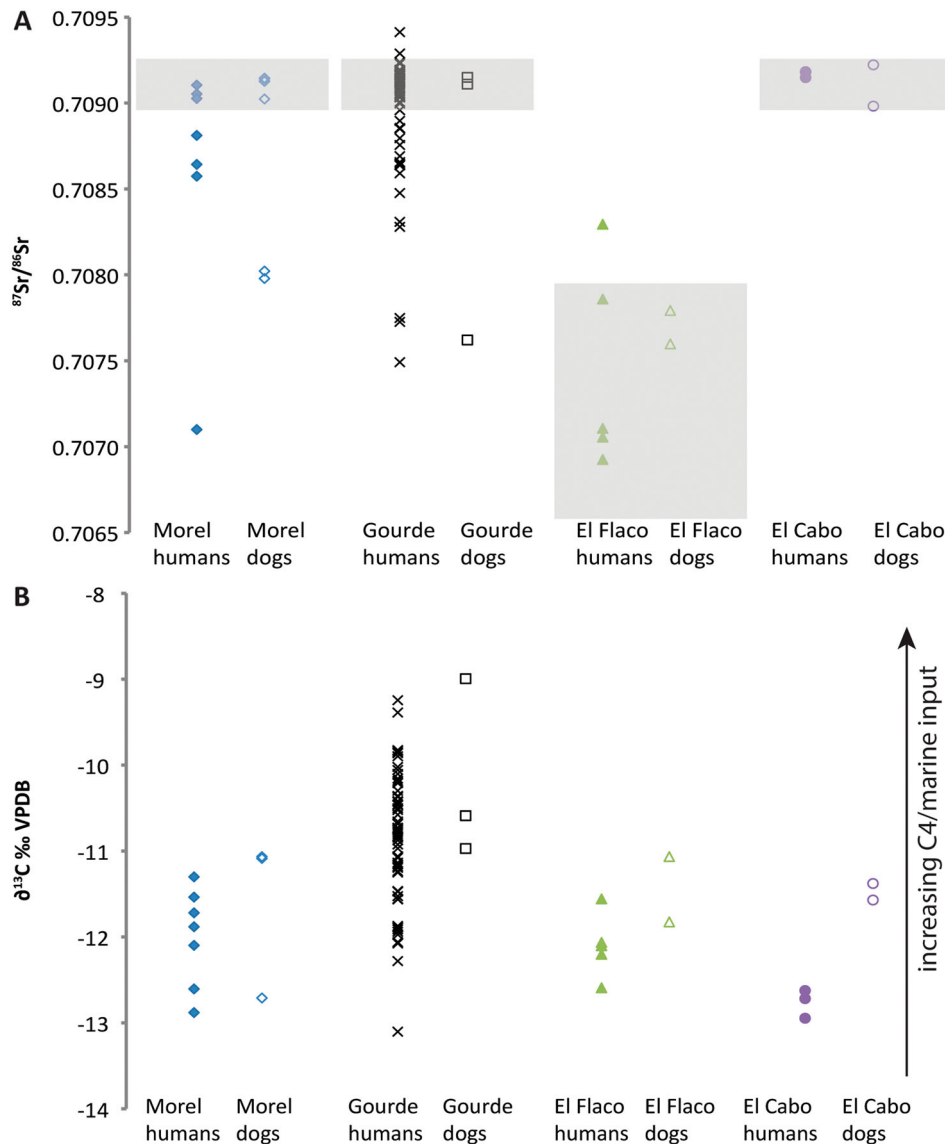**Figure 2.** Distributions of human and dog enamel ^{87}Sr/^{86}Sr (A) and δ^{13}C (B) isotope results by site. Isotope data from Booden et al. (2008), Laffoon (2012), Laffoon et al. (2012, 2013, 2015, this study). Gray-shaded boxes indicate approximate local range of bioavailable ^{87}Sr/^{86}Sr.

and other C$_4$ plants (e.g. Emery, Wright, and Schwarcz 2000; Gerry and Krueger 1997; White et al. 2001).

In summary, the overall pattern indicates that average whole diets of humans at all four sites from this study were likely dominated by terrestrial C$_3$ resources, although previously published collagen δ^{13}C data from Anse à la Gourde (Laffoon and de Vos 2011; Stokes 1998) indicates non-trivial contributions of marine resources to the protein component of diet for this population. These contrasting results are not, however, contradictory but simply reflect the fact that bioapatite and collagen isotope data reflect different components of dietary intake. This point bears further elaboration, given ongoing debates amongst Caribbean archaeologists concerning the relative importance of maize (a C$_4$ crop) versus root crops such as manioc (C$_3$ plants). The data presented here provides further support to the observation that despite the early and widespread presence of maize in the pre-colonial Antilles (Mickleburgh

and Laffoon 2017; Mickleburgh and Pagán-Jiménez 2012; Newsom and Wing 2004; Pagan Jiménez 2011, 2013; Pagán-Jiménez et al. 2015), its overall contribution to diet for most individuals was not substantial (Laffoon, Hoogland et al. 2016; Pestle 2010). In other words, despite the presence of maize and the associated knowledge concerning cultivation and processing of this plant crop, Amerindian communities in the Caribbean seemed to incorporated maize into a broad spectrum food economy, rather than relying on it as a staple crop.

Comparing the data chronologically, the one site dated to the Early Ceramic Age, Morel, has generally lower human and dog enamel δ^{13}C values than the Late Ceramic Age site of Anse à la Gourde. The human values from these sites display substantial overlap with all of the Morel values ($n = 7$) falling within the broad range for Anse à la Gourde ($n = 64$). A notable difference is observed between the dog δ^{13}C values
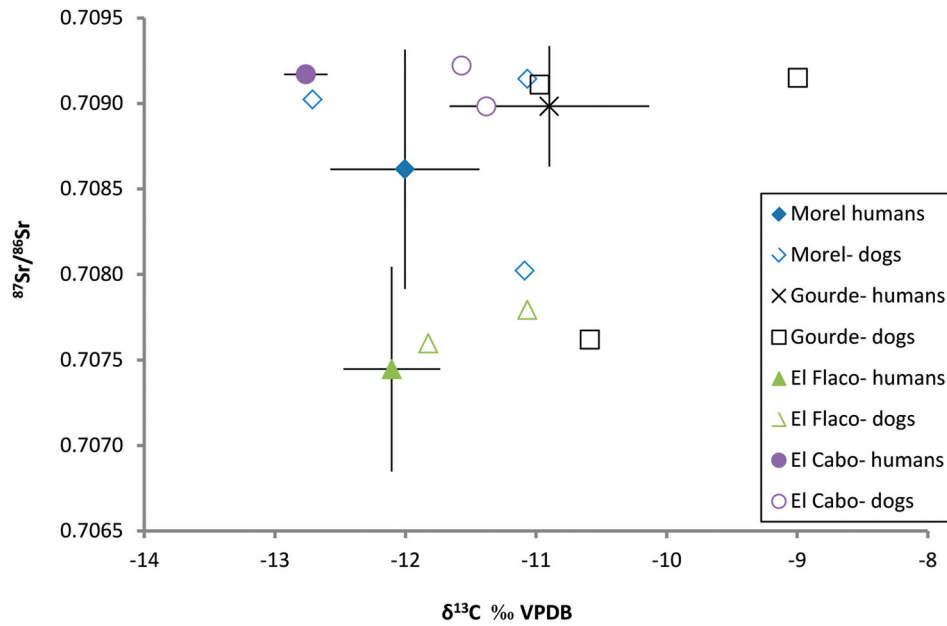
Figure 3. Bivariate plot of mean (±1σ) human and individual dog enamel $^{87}Sr/^{86}Sr$ and $\delta^{13}C$ results (includes only samples for which both isotope proxies were measured). Isotope data from Booden et al. (2008), Laffoon (2012), Laffoon et al. (2012, 2013, 2015, this study).

from Morel ($n = 3$), which are all lower than those from Anse à la Gourde ($n = 3$), possibly indicating a slightly higher contribution of C_4/marine resources for dogs at the latter site. These patterns bears further investigation via larger data sets and expanded sampling and analyses of both apatite and collagen stable isotopes, as it has important implications for ongoing debates concerning temporal changes in diet and subsistence linked to other variables such as resource resilience and depletion, adaptive strategies, responses climate change, and others (e.g. Beets et al. 2006; Giovas 2016; Pestle 2013).

Although the diet to apatite offset in $\delta^{13}C$ for dogs is not well characterised and previous research has indicated non-trivial variation between taxa (e.g. Passey et al. 2005), the fact that both humans and dogs are omnivorous mammals with similar digestive physiology may suggest that they possess comparable diet-apatite offsets. If so, then the dog $\delta^{13}C$ data can be taken to indicate that their average whole diets were similarly dominated by C_3 resources. Nevertheless, it should be noted that although there is a large degree of overlap in the ranges of $\delta^{13}C$ values between humans and dogs at three of the four sites, the highest values at each location are from dog samples. The difference in human and dog $\delta^{13}C$ is most pronounced at El Cabo with no overlap in values but this site also has the smallest number of samples. Overall, the datasets are too small to conduct reliable statistical tests of these differences and although this pattern could indicate a slightly higher degree of marine/C_4 food consumption for dogs compared to humans at each of the sites, this hypothesis can only be tested with larger and more representative data sets.

Despite the presence of both locals and nonlocals at three of the four sites, there does not appear to be any clear systematic differences in $\delta^{13}C$ between locals and nonlocals for either humans or dogs. As the strontium and carbon isotope data were generated from enamel of the same teeth and represent tissues that form during early years of development, this pattern may indicate that source populations (of nonlocal individuals) and destination (in this case local) populations possessed highly comparable dietary regimes. Similar observations of intra-population homogeneity in stable isotope values (i.e. the lack of dietary distinctions between locals and nonlocals) had previously been reported for other pre-colonial Antillean communities, such as Lavoutte, St. Lucia (Laffoon, Hoogland et al. 2016), and including the Anse à la Gourde human population based on collagen data (Laffoon and de Vos 2011) but it was unclear if this pattern reflected similarities in diets between locations or simply that nonlocals adapted their diets to local practices over time. The enamel data from this study seems to support the former interpretation at least for these specific populations but this generalisation cannot be extended to the entire Caribbean, as there is tentative evidence for distinct dietary differences between locals and nonlocals at other sites in the broader region including Tutu, St. Thomas (Laffoon and Hoogland 2012); Maisabel, Puerto Rico (Laffoon 2016); and El Chorro de Maíta, Cuba (Valcárcel Rojas et al. 2011).

Conclusions

This study represents a novel approach combining strontium and carbon isotope analyses of dental

enamel from four different sites in the pre-colonial Antilles to study patterns of human and dog paleomobility and paleodiet. The isotopic data provides new insights on patterns of human migration and demonstrated a very high rate of immigration at the Early Ceramic Age site of Morel, Guadeloupe with four out of seven individuals identified as nonlocals. The origins of these nonlocals are external to the region of Grande-Terre where the site is located and they possibly originate from within the Volcanic Caribbees archipelago of the western Lesser Antillean island arc.

The fact that the majority of individuals from Morel are nonlocal migrants is interesting given that higher rates of nonlocals have been found amongst Early Ceramic Age populations in the Antilles compared to Late Ceramic Age populations (Laffoon 2012). These higher proportions of nonlocals at earlier sites may reflect higher rates of migration linked to lower population densities, and by consequence longer marriage distances, amongst exogamous communities in the earlier period (see discussions in e.g. Keegan 2009; Siegel 2010). Furthermore, network analyses of spatio-temporal distributions of various lithic raw materials and manufactured goods, such as Long Island flint and carnelian beads, indicate that the site of Morel was an important actor in regional networks of exchange (Hofman et al. 2014), which would have been interconnected with patterns of human mobility. Although based on relatively small datasets, nonlocal dogs were identified from burial contexts amongst early Ceramic Age assemblages at Morel, and from domestic refuse deposits deriving from Late Ceramic Age deposits at Anse à la Gourde. These results may indicate that that dogs continued to be exchanged and/or directly transported to Guadeloupe despite the likelihood that their social and economic roles in Amerindian societies of the region may have varied considerably over time (Grouard, Perdikaris, and Karyne 2013; Laffoon et al. 2015; Plomp 2013). In summary, the $^{87}Sr/^{86}Sr$ data for humans and dogs at both Morel and Anse à la Gourde provides additional evidence indicating that this area of eastern Guadeloupe may represent a nexus of human and animal mobility (Booden et al. 2008; Hoogland, Hofman, and Panhuysen 2010; Laffoon et al. 2012, 2015), as well as the circulation of materials and goods within the Lesser Antilles and beyond throughout much of the pre-colonial period (Hofman and Hoogland 2011; Hofman, Bright, and Rodríguez Ramos 2010; Hoogland and Hofman 2013).

The newly generated isotopic data from the sites of El Flaco and El Cabo in the Dominican Republic address various lacunae in regional migration and dietary studies as Hispaniola has not yet received adequate attention despite its central role in many socio-cultural developments in the pre-colonial Antilles (Rouse 1992). Compared to the results from the Guadeloupe sites, the $^{87}Sr/^{86}Sr$ data from the Dominican

sites indicated the presence of one nonlocal human (at El Flaco) and that all four dog specimens from both sites were local. To date, the only other site in the Dominican Republic that has been intensively analysed in terms of $^{87}Sr/^{86}Sr$ is Punta Macao (Laffoon 2012), and only one individual from this site ($n = 21$) was identified as a nonlocal immigrant. These proportions of nonlocals, based on strontium isotope analysis, are much lower than reported for all other pre-colonial Antillean populations to date (Laffoon 2012, 2013) and provide a distinct contrast to the relatively high proportions detected at the Guadeloupian sites of Morel and Anse à la Gourde. The causes of these differences are not known and may reflect spatial, chronological, cultural, socio-political, or even isotopic differences between different locations within the overall region.

The $\delta^{13}C$ data for both the human and dog data sets presented herein demonstrated several patterns including, generally low $\delta^{13}C$ values suggestive of C_3 predominance in average whole diets (probably biased by carbohydrate contributions from plant foods); significant overlap in $\delta^{13}C$ values between the four sites; a much higher degree of heterogeneity amongst the Anse à la Gourde humans possibly reflecting the much larger sample set ($n = 64$) from this site; and slightly higher $\delta^{13}C$ values for dogs relative to humans at each site possibly indicative of higher rates of, marine resource consumption and/or C_4 plants such as maize, (or perhaps even differences in $\delta^{13}C$ diet-apatite isotopic fractionation factors). The relatively high degree of correspondence between the human and dog $\delta^{13}C$ may indicate that dogs were intentionally fed with human food refuse, or that dogs scavenged on human food refuse (or both). However, the number of sites and samples presented here is too small to conclude to what extent dogs are reliable proxies for human consumption patterns at broader scales as suggested by the 'canine surrogacy approach' (Guiry 2012, 2013), and this issue merits increased research attention.

An additional issue that was considered was whether enamel $\delta^{13}C$ data from the Caribbean displays sufficient geographic structuring such that it is useful as a provenance indicator. It has been previously demonstrated that human collagen isotope data from a large number of circum-Caribbean populations display clear spatial patterning, likely reflecting biogeographical principles and variable resource availability (Chinique de Armas et al. 2016; Laffoon 2016; Laffoon, Hoogland et al. 2016; Pestle 2010; Stokes 1998). Nevertheless, the extant bone and enamel apatite datasets (Krigbaum, Fitzpatrick, and Bankaitis 2013; Laffoon, Valcárcel Rojas, and Hofman 2013; Norr 2002; Pestle 2010; Stokes 1998), including the newly generated human and dog data presented here, show much less clustering in $\delta^{13}C$ than the collagen data. In other words the high degree of overlap between different

sites/populations in apatite (both bone and enamel) $\delta^{13}C$ indicate that this data is likely not very useful as a provenance proxy, despite its clear utility for paleodietary purposes.

Returning to the implications of our results for the application of the CSA to Caribbean contexts, a few observations are worth noting. First, there are broad similarities between human and dog enamel $\delta^{13}C$ values with most dog $\delta^{13}C$ values falling within the range of human values at each site. As previously noted however, there is a slight difference observable with the highest $\delta^{13}C$ values at each site represented by dogs. This data set provides preliminary indications of the suitability of dog enamel isotope $\delta^{13}C$ values data for human paleodiet assessment but whether this observed pattern extends throughout the Antilles will require further research.

The presence of traded living (nonlocal) dogs potentially possessing collagen stable isotopes values reflective of their location of origin, rather than their location of disposal, was one of the many possible complicating factors in CSA approaches noted by Guiry (2012: 367). The use of enamel as a sampling material permits direct testing of these effects by permitting discrimination between nonlocal and local (endogenous) individuals and because enamel (unlike bone) does not remodel, it retains the isotopic signal of the region of natal origin. In this study, although several dogs from Guadeloupe were identified as nonlocal, no systemic differences in diet were observed between local and nonlocal dogs. It has also been noted that geographic isolation may be factor in the exchange of domestic dogs owing to their tendency to return to their original owner (Guiry 2012: 367). In this regard, it is notable that the nonlocal dogs identified from sites on Guadeloupe possess $^{87}Sr/^{86}Sr$ ratios indicating nonlocal origins not only at the site level but nonlocal to Grande-Terre. It is highly unlikely that dogs could have migrated between the main islands of the archipelago by swimming and as such inter-island trade of living dogs may have been an expedient mechanism to overcome the behavioural tendency of dogs to return to their original social group.

In reference to whether dog $^{87}Sr/^{86}Sr$ data can be used as a proxy for human paleomobility, the humans and dogs analysed for this study possessed broadly similar $^{87}Sr/^{86}Sr$ ranges and both local and nonlocal humans and dogs were identified at the two sites on Guadeloupe. Nonetheless, the data presented herein are not sufficient to determine the efficacy of using dog isotope data for inferring human mobility patterns. This trepidation is not only owing to the small samples sizes, but also because of the difficulty in distinguishing between the anthropic transport of living animals from the exchange of animal remains/artefacts (see also Giovas this issue), and the possibility that various factors

may have influenced the patterns of dog mobility and exchange including differences in their social, economic, or symbolic roles (as companions, hunters, guards, food sources).

In summary, we briefly return to the four hypotheses proposed in the Introduction section. Hypothesis (1) Human–Dog Diets: humans and dogs possessed broadly similar ranges of $\delta^{13}C$ but most of the dogs were slightly elevated relative to the mean human $\delta^{13}C$ at each site. Hypothesis (2) Regional Patterning in Dietary Ecology: the subtle geographic patterning evident in the published Antillean apatite isotope data set was not evident in the sample populations chosen for this study which displayed a degree of overlap, although the Anse à la Gourde population has a broader range of $\delta^{13}C$ values (4‰) compared to the other sites (2‰). Hypothesis (3) Human–Dog Mobility: the humans and dogs at each site possessed very comparable $^{87}Sr/^{86}Sr$ values and ranges, with both sites in the Dominican Republic having only local humans and dogs, and both sites on Guadeloupe possessing both local and nonlocal humans and dogs in similar proportions. Hypothesis (4) Human–Dog Linkages between Diet and Mobility: there was no systematic difference in $\delta^{13}C$ values between local and nonlocal individuals (based on their associated $^{87}Sr/^{86}Sr$ signatures). All four hypotheses clearly require further testing with larger more robust data sets.

Based on these conclusions several avenues for future research can be proposed. First, the generated $^{87}Sr/^{86}Sr$ results contribute to an expanding corpus of evidence concerning regional patterns in human and dog paleomobility. The insights provided by this research clearly justify further expansion of these approaches both geographically and temporally. Secondly, more refined assessments of geographic origins can be proposed as empirical databases of regional bioavailable $^{87}Sr/^{86}Sr$ (Giovas et al. 2016; Laffoon et al. 2012; Pestle, Simonetti, and Curet 2013) become larger and more representative and as predictive models of regional $^{87}Sr/^{86}Sr$ isoscapes (Bataille, Laffoon, and Bowen 2012; see also Laffoon, Sonnemann et al. 2017) are improved. Thirdly, in reference to the paleodietary issues raised here, we are currently expanding both the human and dog enamel $\delta^{13}C$ data sets in terms of both the number of samples and the diversity of sites and contexts, to more extensively assess chronological and spatial patterns in dietary relationships between humans, dogs, and local ecological conditions. We are also initiating a large-scale study of carbon and nitrogen isotope analyses of dog (bone and dentine) collagen data to more accurately assess protein intake and various possible causes of the observed dietary patterns. Additionally, culturally modified dog teeth (e.g. perforated and/or incised) were excluded from this study as these are expected

to display different mechanisms of movement and exchange, and are therefore currently the focus of an ongoing parallel study conducted by our research group. Lastly, similar multi-isotopic approaches are currently being applied to other domesticated and wild animal species from both pre-colonial and colonial contexts in the circum-Caribbean and offer the potential to provide important new insights into the nature and variability of human-animal interactions in this dynamic region.

Acknowledgments

Disclosure Statement

Funding

Notes on contributors

Jason E. Laffoon obtained his PhD in archaeology from Leiden University in 2012 and conducted postdoctoral research at the Faculty of Earth and Life Sciences, VU University Amsterdam and the Faculty of Archaeology, Leiden University, where he is currently an assistant professor. Laffoon has conducted archaeological investigations in mainland North America and South America, the Caribbean, and the Netherlands. His current research focuses on integrating isotopic, archaeological, and bioarchaeological evidence to investigate human and animal paleomobility and paleodietary patterns in the circum-Caribbean region.

Menno L. P. Hoogland is an associate professor in Caribbean archaeology at the Faculty of Archaeology, Leiden University. Hoogland previously studied cultural anthropology in Leiden with a focus on prehistory and physical anthropology and wrote his PhD thesis on settlement patterns of the Amerindian population of Saba, Netherlands Antilles. In

2009, he founded the Laboratory for Human Osteoarchaeology at the Faculty of Archaeology and presently he conducts archaeological and osteoarchaeological research in the Caribbean and the Netherlands. The analysis of burial practices and settlement organisation are the primary focus of his research.

Gareth R. Davies became a professor of Petrology in 2004 after heading the mass spectrometry department at the VU for 12 years. Davies is from a dominantly mantle geochemistry background but has a wide range of interests in petrology-isotope geochemistry. A key philosophy has been to maintain state-of-the-art analytical techniques and develop methodologies that allow new research areas to be explored. This philosophy, coupled with strong international collaborations, has led to the development of a world leading provenance group that applies multi-isotope techniques to art history, forensic science, and archaeology, including Co-PI on the ERC-synergy project NEXUS1492.

Corinne L. Hofman is the dean of the Faculty of Archaeology, professor of Caribbean archaeology and directs the Caribbean Research Group at Leiden University, the largest of its kind worldwide. Hofman has conducted fieldwork throughout the Caribbean over the past 30 years. Her research is highly multi-disciplinary and her interests lie in settlement archaeology, artefact analyses, provenance studies, bioarchaeological investigations, network science, and ethnohistoric and ethnographic studies. She obtained many grants and prizes for her work. Currently, she is corresponding PI of the ERC-synergy project NEXUS1492 (2013-2019).

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