International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. (2013)
Published online in Wiley Online Library
(wileyonlinelibrary.com) **DOI**: 10.1002/oa.2313

The Movement and Exchange of Dogs in the Prehistoric Caribbean: An Isotopic Investigation

J. E. LAFFOON,[a]* E. PLOMP,[a] G. R. DAVIES,[b] M. L. P. HOOGLAND[a] AND **C. L. HOFMAN[a]**
[a] *Faculty of Archaeology, Leiden University, Leiden, The Netherlands*
[b] *Faculty of Earth and Life Sciences, VU University Amsterdam, Amsterdam, The Netherlands*

ABSTRACT This study explores the feasibility of using strontium isotope ($^{87}Sr/^{86}Sr$) analyses of enamel from domestic dogs (*Canis familiaris*) to investigate networks of exchange in the prehistoric Circum-Caribbean. Dog teeth were obtained from burial and domestic contexts from two prehistoric sites (Anse à la Gourde and Morel) on Grande-Terre, Guadeloupe (Lesser Antilles). Strontium isotope results were compared with local biosphere $^{87}Sr/^{86}Sr$ data at the scale of the site, island and archipelago. The isotope results indicate both local and nonlocal origins with three dogs (30%) identified as nonlocal (one from Anse à la Gourde and two from Morel). The variance in $^{87}Sr/^{86}Sr$ ratios of the nonlocal dog teeth is consistent with diverse multiple origins external to the island of Grande-Terre but consistent with origins from other islands of the Lesser Antilles. The diverse origins of the nonlocal dog samples indicate that the prehistoric circulation of dogs occurred at multiple scales from regional to long distance. Significantly, the $^{87}Sr/^{86}Sr$ ratios of some of the dog teeth are comparable with values of nonlocal humans at Anse à la Gourde determined in previous studies. It is possible that these comparable $^{87}Sr/^{86}Sr$ ratios result from similar natal origins, for example if individuals were migrating to Guadeloupe with dogs. The results of this study contribute to an ongoing regional investigation of the economic, social and political roles of animals and animal remains and the multiscalar networks of prehistoric mobility and exchange in the Circum-Caribbean region. Copyright © 2013 John Wiley & Sons, Ltd.

Key words: Antilles; Caribbean; dog; exchange; isotope; mobility; strontium; trade

Introduction

The prehistoric exchange of resources and artefacts in the Caribbean has recently received increased attention (e.g. Hofman *et al.*, 2007; Hofman *et al.*, 2008a; Hofman *et al.*, 2010; Hofman & Hoogland, 2011; Hofman *et al.*, 2011). Provenance studies in the region have greatly benefited from progress in the characterization of different lithic (Knippenberg, 2006; Harlow *et al.*, 2006; García-Casco *et al.*, 2009; Schertl *et al.*, 2012;) and ceramic (Carini, 1991; Lundberg, 2002; Hofman *et al.*, 2005; Descantes *et al.*, 2008; Meniketti, 2011) materials. These studies have revealed the existence of centuries-old networks of exchange that existed at multiple scales within and between different islands and archipelagos of the Antilles and between the insular Caribbean and the mainland regions of Central and South America (Watters & Scaglion, 1994; Hofman *et al.*, 2008b; Rodríguez Ramos, 2010; Hofman & Hoogland, 2011, Hofman *et al.*, 2011). The identification of these networks and the ways in which they varied over space and time are important as they bear upon ongoing debates and discussions concerning the nature, extent and types of intercommunity interactions and social relationships amongst the prehistoric communities of this region (Hofman *et al.*, 2010; Hofman & van Duijvenbode, 2011). However, investigations of the exchange of faunal resources in the Caribbean have been generally limited, with some notable exceptions (e.g. Giovas *et al.*, 2011).

Research concerning prehistoric acquisition and circulation of animals and artefacts produced from animal remains has primarily relied on traditional zooarchaeological approaches. These approaches are based on the morphological identification of exotic animals found outside of their natural geographic ranges. Owing to the principles of island biogeography, most of the insular Caribbean is characterised as

* Correspondence to: Jason E. Laffoon, Faculty of Archaeology, Leiden University, P.O. Box 9515, 2300 RA, The Netherlands.
e-mail: j.e.laffoon@arch.leidenuniv.nl

Received 16 January 2013
Revised 6 March 2013
Accepted 18 March 2013

generally impoverished in terrestrial fauna, especially of medium-bodied and large-bodied mammals (Newsom & Wing, 2004). Thus, the identification of non-native (mainland) species in archaeological contexts in the Antilles can often be attributed to translocation via human agency. One example of the intentional movement of a mainland species to the Antilles is the introduction of domestic dogs (*Canis familiaris*). Archaeological dog remains have been found throughout much of the Antilles although dog burials themselves (Table 1) have a patchy and uneven temporal and geographic distribution (e.g. Wing, 1972; Wing, 1991; Grouard, 2001; Wing, 2001; Newsom & Wing, 2004). Previous studies have indicated that the roles of dogs in prehistoric societies of the region were highly variable and that dogs may have had a special (symbolic) significance in the Caribbean (Roe, 1995; Rodríguez, 2007). The widespread occurrence of dog remains suggests that it is possible that dogs may have been circulated as companions, food, ritual items or social valuables (Plomp, 2011). The practice of exchanging living dogs has been recorded for several South American societies such as the Trio (Mans, 2012), Wai Wai (Fock, 1962; Howard, 2001) and the Achuar (Descola, 1994). However, the presence of modified skeletal remains of dogs (i.e. perforated dog teeth, usually interpreted as pendants) found at several sites in the Antilles, raises the possibility that their remains may have also been transported (as artefacts as opposed to the movement of live animals). Nevertheless, as traditional zooarchaeological approaches are limited to the identification of animals found outside of their natural ranges, such approaches are not well-suited to investigate the circulation and exchange of dogs in the Circum-Caribbean owing to their widespread prehistoric distribution in this region.

Isotopic analysis provides a direct means for identifying nonlocal specimens and exploring their possible origins. Isotopic analysis is increasingly applied worldwide to the identification and sourcing of nonlocal faunal remains in a broad range of archaeological contexts (e.g. Shackleton & Elderfield, 1990; Hobson, 1999; Vanhaeren *et al.*, 2004; White, 2004; Sykes *et al.*, 2006; Dufour *et al.*, 2007; Bendrey *et al.*, 2009; Britton *et al.*, 2009; Hedman *et al.*, 2009; Shaw *et al.*, 2009; Freiwald, 2010; Towers *et al.*, 2010; Viner *et al.*, 2010; Widga *et al.*, 2010; Thornton, 2011; Sjögren & Price, 2013). Additionally, recent applications of isotopic analysis have shown great promise for elucidating patterns of human paleomobility in the Caribbean and provide a useful isotopic baseline for the region (Laffoon, 2012; Laffoon *et al.*, 2012b; Laffoon *et al.*, 2012a). Nonetheless, to our knowledge, such methods have not yet been applied to animal provenance studies in the Caribbean.

Strontium (Sr) isotope ratios ($^{87}Sr/^{86}Sr$) obtained from dental enamel can be used to identify nonlocals and assess natal origins. The principle of the method

Table 1. Summary of known dog burials in the Antilles.

Site	Island	*n*	Reference
Heywoods	Barbados	1	Drewett, 1991; Drewett, 2004
Goddard	Barbados	1	Hackenberger, 1991
Silver Sands	Barbados	7+	Drewett, 1991
BA 016	Barbuda	1	Perdikaris *et al.*, 2008
Corrales de Ojo del Toro	Cuba	1	Ortega *et al.*, 2006
Cueva Bélica	Cuba	50	Ortega *et al.*, 2006
Cueva de los Perros	Cuba	n/a	Ortega *et al.*, 2006
Cueva de Pío Domingo	Cuba	n/a	Ortega *et al.*, 2006
Birama	Cuba	1	Ortega *et al.*, 2006
El Carril de Valverde	Dominican Rep.	n/a	Lawrence, 1977
Boca del Soco	Dominican Rep.	1+	Calderón, 1985
La Caleta	Dominican Rep.	1	Rodríguez, 2007
Ramon Santana	Dominican Rep.	n/a	Lawrence, 1977
Cabo San Rafael	Dominican Rep.	n/a	Lawrence, 1977
Morel	Guadeloupe	14	Hofman *et al.*, 1999
Bas Saline	Haiti	1	Newsom, 1995
White Marl	Jamaica	1	Wing, 1972
Trants	Montserrat	1	Petersen & Watters, 1995
Hacienda Grande	Puerto Rico	3	Walker, 1985
Punta Candelero	Puerto Rico	6	Crespo, 1991; Rodríguez, 1991
Aguacate	Puerto Rico	1	Pérez Merced, 2000
Hope Estate	Saint Martin	n/a	Grouard, 2004
Sorcé	Vieques	23+	Wing, 1991

is that the Sr isotope composition of skeletal tissues reflects that of the biogeochemical environment in which they are formed. As an animal consumes local food and water resources, some of the ingested Sr replaces calcium in the mineral phase of teeth and bone (see Bentley, 2006 for an extensive review of the application of Sr isotope analyses in archaeology). Unlike light stable isotopes (carbon, nitrogen and oxygen), Sr is not substantially fractionated by most naturally occurring physical processes, and thus, most animals sharing a particular ecosystem will also possess broadly similar Sr isotope ratios regardless of their trophic level (Blum *et al.*, 2000; Price *et al.*, 2002). Sr in dental enamel represents cations incorporated into the skeletal system during the period of crown formation and mineralization. Unlike bone, enamel is not significantly remodelled throughout life, and thus, it preserves the biogenic signal of an individual's early years (Hillson, 1996). Dental enamel has also been shown to be highly resistant to diagenetic alteration (Budd *et al.*, 2000; Hoppe *et al.*, 2003; Lee-Thorp & Sponheimer, 2003; Trickett *et al.*, 2003), and teeth are furthermore often the best preserved skeletal elements (especially in tropical settings) thus making them ideally suited to isotopic analyses.

This study aims to assess the potential of using Sr isotope ($^{87}Sr/^{86}Sr$) analysis of archaeological dog teeth to investigate prehistoric patterns of exchange in the Circum-Caribbean region. Archaeological faunal remains of dogs from domestic and burial contexts were sampled from two prehistoric sites on Guadeloupe (Figure 1), namely Anse à la Gourde and Morel (Grouard, 2001; Hofman *et al.*, 2001). The Sr isotope data from this study are interpreted in reference to extant isotopic data sets for the Antilles (Laffoon, 2012; Laffoon *et al.*, 2012a), and this study provides an independent yet complementary means of examining patterns of prehistoric animal resource acquisition, exchange and deposition in this region. The Sr isotope results presented herein also contribute to the further development of baseline isotope databases for the Circum-Caribbean region that can be of utility for a wide range of archaeological, ecological and forensic provenance applications.

Strontium isotope variation in the Caribbean

Variations in Sr isotope ratios in geological materials are primarily a function of time and the original rubidium/strontium (Rb/Sr) composition of the parent material, as ^{87}Sr is produced by the radioactive decay of ^{87}Rb. In many geographic contexts, the underlying bedrock geology is the primary proximate source of Sr to the local biosphere. However, atmospheric and marine sources can be substantial contributors of Sr to terrestrial ecosystems, especially in coastal settings (Vitousek *et al.*, 1999). The islands of the Caribbean possess highly diverse geology (Dengo & Case, 1990; Donovan & Jackson, 1994) with relatively variable associated biosphere $^{87}Sr/^{86}Sr$ ratios (Laffoon *et al.*, 2012a). On the basis of a recent large-scale Sr isotope mapping project, $^{87}Sr/^{86}Sr$ variation in the Caribbean biosphere has been well-characterised, and it has been demonstrated that despite the complexities of multiple sources of Sr in this archipelagic setting, bedrock geology is the primary source of biosphere Sr to terrestrial ecosystems in the Antilles (Bataille *et al.*, 2012; Laffoon *et al.*, 2012a). Thus, although absolute bioavailable $^{87}Sr/^{86}Sr$ ranges in specific regions cannot be accurately predicted on the basis of the Sr isotope composition of underlying geological deposits, biosphere $^{87}Sr/^{86}Sr$ is, in most cases, well-correlated with lithosphere $^{87}Sr/^{86}Sr$. Therefore, in the Caribbean, volcanic regions generally possess the lowest bioavailable $^{87}Sr/^{86}Sr$ ratios (usually less than 0.707), older carbonate deposits possess intermediate $^{87}Sr/^{86}Sr$ (approximately 0.707–0.709), younger carbonates possess bioavailable $^{87}Sr/^{86}Sr$ ratios similar to modern seawater values (~0.7092) and noncarbonate sedimentary deposits and metamorphic rocks possess higher bioavailable $^{87}Sr/^{86}Sr$ ratios (>0.7095) (Laffoon *et al.*, 2012a).

In the insular Caribbean, the lowest $^{87}Sr/^{86}Sr$ ratios are found amongst volcanic and intrusive deposits, for example in the mountainous interiors of some of the Greater Antilles (e.g. Cuba, Hispaniola and Puerto Rico) and amongst the relatively young volcanic deposits in many of the Volcanic Caribbees in the Lesser Antilles (Figure 1). Somewhat higher $^{87}Sr/^{86}Sr$ ratios can be found in areas underlain by older (Late Cretaceous to Paleocene) carbonate formations such as the limestone foothills of the Greater Antilles and several of the composite islands (e.g. Antigua, St. Barths and St. Martin) of the Limestone Caribbees in the northern Lesser Antilles. More recent limestone deposits characterise most of the remainder of the Limestone Caribbees (e.g. Anguilla, Barbados, Barbuda, Grande-Terre and Marie-Galante) and much of the coastal regions of the Greater Antilles. These islands possess $^{87}Sr/^{86}Sr$ ranges that are very similar to modern seawater (~0.709). The island of Trinidad, located only a few kilometres from the coast of Venezuela, is geologically an extension of northern South America, and as such, it

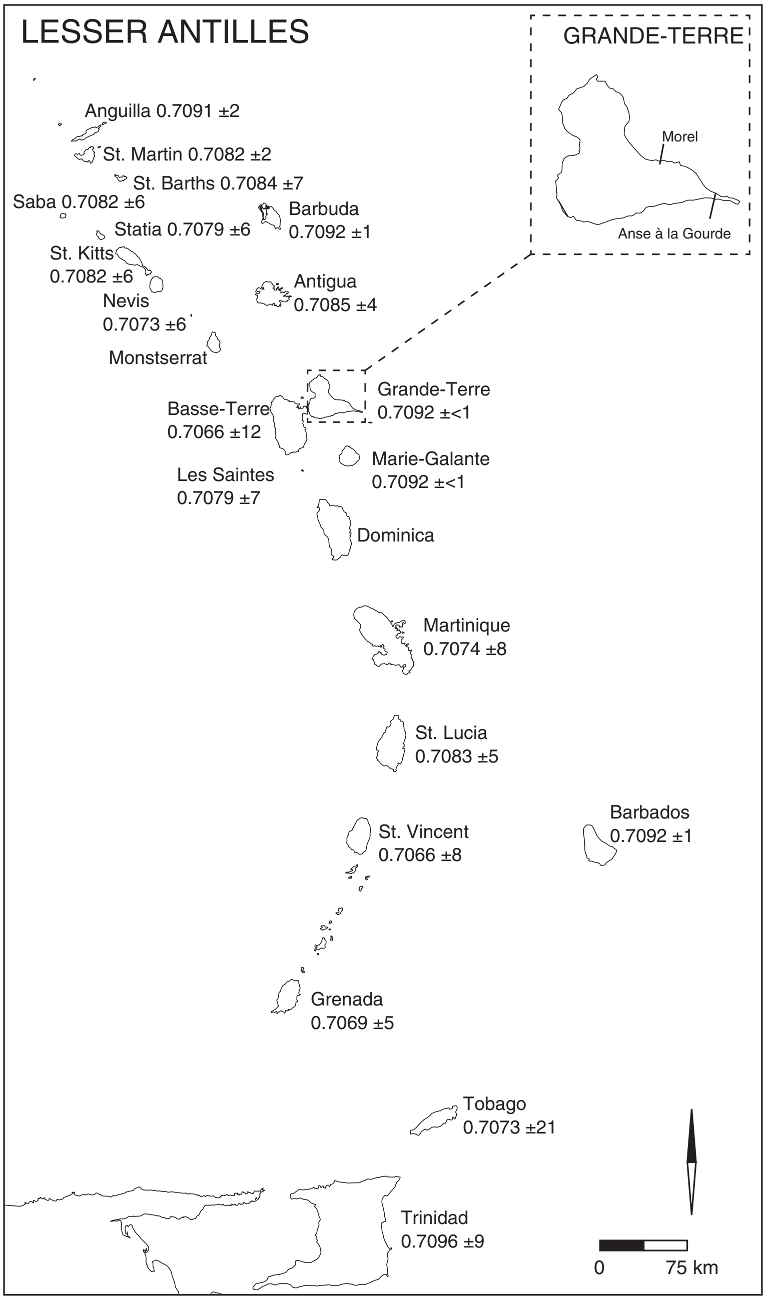

Figure 1. Map of the Lesser Antilles with inset of Guadeloupe showing the location of sites mentioned in the text, and the mean (± 1σ) biosphere $^{87}Sr/^{86}Sr$ ratio for each island.

is characterised by a complex mixture of marine and nonmarine sedimentary deposits and metamorphic rocks with generally higher $^{87}Sr/^{86}Sr$ compositions (usually greater than 0.709) than the rest of the Antilles (Figure 1) (Laffoon, 2012; Laffoon *et al.*, 2012a). Northern and northeastern South America are characterised by highly diverse geological settings including substantial areas underlain by continental bedrock and the Precambrian Guiana Shield craton, and therefore possesses more variable and generally higher biosphere $^{87}Sr/^{86}Sr$ ranges (generally greater than 0.710) than the Antilles (Poszwa *et al.*, 2002; Bataille *et al.*, 2012; Laffoon, 2012; Laffoon *et al.*, 2012a).

In summary, there is substantial interisland variation in biosphere $^{87}Sr/^{86}Sr$ in the Antilles but also significant overlap in the ranges of $^{87}Sr/^{86}Sr$ between certain islands. The implication of this pattern for mobility/provenance studies in the Caribbean is that although it is not possible to precisely determine an origin solely from $^{87}Sr/^{86}Sr$ data, many islands/regions can be eliminated as possible origins on the basis of comparisons with biosphere $^{87}Sr/^{86}Sr$ ranges. Ideally, once the number of possible origins is narrowed down via assessment of $^{87}Sr/^{86}Sr$ data, it would be possible to more precisely determine origins through the incorporation of other lines of evidence such as, morphological, genetic and/or (complementary) isotopic data. On the other hand, even in cases where exact origins cannot be determined, interesting patterns relevant to prehistoric patterns of mobility and exchange can be elucidated through the determination of local versus nonlocal origins.

Site descriptions and context

The site of Anse à la Gourde is situated at the northeast end of Grande-Terre, Guadeloupe on the Atlantic coast. Anse à la Gourde has been subjected to extensive archaeological investigations between 1995 and 2000 by Leiden University and the Direction Régionale des Affaires Culturelles of Guadeloupe (e.g. Grouard, 2001; Hofman *et al*., 2001; Lammers-Keijsers, 2007; Booden *et al*., 2008, Hoogland *et al*., 2010; Laffoon & de Vos, 2011; Laffoon, 2012). These investigations revealed that the site has a surface area of approximately 4 ha, of which 1424 m^2 has been excavated (Hofman *et al*., 2001). Four successive occupation phases have been identified, which are radiocarbon dated to approximately A.D. 400–1400. Material remains associated with the largest occupation phase (A.D. 850–1400) belong to the Troumassoid ceramic series. In this ceramic assemblage, influences from both the northern (Mamoran Troumassoid) and the southern (Suazan Troumassoid) Lesser Antilles are found. The dog teeth from Anse à la Gourde have been found in the habitation area, and date to the latest (Troumassoid) occupation at the site.

Morel is a site located roughly 1 km to the east of the modern village of Moule, facing the Atlantic Ocean on the northeast coast of Grande-Terre (Figure 1). Morel was occupied during the Ceramic Age from about 300 B.C. to A.D. 1400 (Hofman *et al*., 1999). Hurricanes, natural erosion, sand pillages and looting have contributed to the near complete destruction of the site. The site is situated on a low coastal terrace, 1 to 4 m a.s.l. The site of Morel has been known since the 19th century, but it was not until the mid-20th century that excavations took place under the direction of Edgar Clerc (1968), Bullen & Bullen (1973) and Bodu (1984). These excavations uncovered several human and dog burials. Subsequently, in the 1990s, large-scale rescue excavations were conducted by the Direction Régionale des Affaires Culturelles of Guadeloupe and Leiden University. During the excavations, a total of 10 human and 15 animal (including 14 canine) inhumations were found and recorded (Hofman *et al*., 1999; Grouard, 2001). The presence of such a large number of dog burials at this site is very rare for prehistoric Caribbean contexts, and some of the only other known cases with substantial numbers of dog burials come from the contemporaneous sites of La Huaca/Sorce on Vieques and Punta Candelero on Puerto Rico. The ceramic materials excavated at Morel are associated with both the Huecoid and Cedrosan Saladoid subseries. Both styles have been found mixed in a single archaeological level, suggesting that they are contemporaneous.

Guadeloupe is an ideal location for the application of the Sr isotope method, not only because the baseline Sr isotope variation has been well-characterised (Booden *et al*., 2008; Laffoon *et al*., 2012a) but because of the possible roles that the prehistoric populations of this island group played in widespread networks of exchange in the larger region (Hoogland *et al*., 2010; Hofman & Hoogland, 2011). Situated in the central Lesser Antilles, Guadeloupe was clearly integrated in networks of exchange with populations from both the northern and southern Lesser Antilles. Additionally, the material culture and isotopic evidence indicates that prehistoric native populations from Guadeloupe were also interacting with more distant locales such as the Greater Antilles and northern South America (Hoogland *et al*., 2010; Hofman & Hoogland, 2011).

At both Anse à la Gourde and Morel, a diverse array of foreign, exotic and/or imported raw materials and bone, ceramic, shell and lithic artefacts have been uncovered (Knippenberg, 2006; Lammers-Keijsers, 2007; Hofman & Hoogland, 2011). As such, the extant evidence supports the hypothesis that Guadeloupe represented an important node in the circulation of many different types of objects and materials across the Antillean landscapes throughout much of the Ceramic Age (~500 B.C. to A.D. 1500). Furthermore, Sr isotope analysis of 68 individual humans from Anse à la Gourde indicates that a large proportion of nonlocals resided at this site throughout the course of its occupation (25%, $n = 17$) (Booden *et al*., 2008; Hoogland *et al*., 2010; Laffoon & de Vos, 2011; Laffoon, 2012). These nonlocals not only possess diverse origins with possible homelands in the northern and southern Lesser Antilles and possibly Trinidad but the nonlocal grave goods were buried exclusively with nonlocal women (Hoogland *et al*., 2010). As such, it is interesting to explore the hypothesis that dogs (as hunters, companions, ritual items, valued trade objects, pets or food sources) had been widely traded and/or had accompanied prehistoric humans on their interisland travels and migrations throughout the prehistoric Caribbean.

Materials and methods

In total, 10 dog teeth were sampled and analysed for Sr isotope composition. The seven dog tooth samples from Morel derive from dog burials (see Figure 2) and the three samples from the site of Anse à la Gourde represent loose teeth found in association with domestic contexts. Sampling focused on intact teeth with no indications of pathology or cultural modification. Samples were processed and analysed using standard procedures for the extraction and measurement of Sr from archaeological dental enamel. Details of the process are presented elsewhere (Booden *et al.*, 2008). Briefly, the outer surface of each individual tooth was mechanically cleaned using a diamond-tipped rotary burr attached to a variable-speed, hand-held drill to remove any encrusted soil and other contaminants to expose the inner core enamel. Approximately 1–3 mg of core enamel was removed from each tooth. Sr was extracted from the sample matrix using Sr-specific crown ether resin (Eichrom©) loaded onto quartz cation exchange columns under controlled conditions in a laminar flowhood in a class 100 clean lab. Sr isotope ratios were analysed on a ThermoFinnegan MAT 262 RPQ plus, thermal ionisation mass spectrometer at the Faculty of Earth and Life Sciences, VU University Amsterdam. The standard reference material (SRM-987) was measured for each set of samples, external precision based on repeat measurement of this standard in static mode over the last few years is 0.00003 (2σ). A correction was applied to each sample measurement that is equal to the difference between the measured value for the international standard and its generally accepted $^{87}Sr/^{86}Sr$ ratio of 0.710240. Typical internal precision is less than 0.00001 (2 SE).

Results

The Sr isotope results of the dog teeth samples are provided in Table 2. The local Sr isotope range for the island of Grande-Terre is well-established based on multiple measurements of baseline archaeological faunal (n = 10) and soil (n = 4) samples (Booden *et al.*, 2008; Laffoon *et al.* 2012a). The local range for the island of Grande-Terre is 0.7090–0.7092, similar to the value of modern seawater as expected based on the Pliocene/Quaternary limestone that covers the entire island (Figure 3). Of the three analysed dog tooth samples from Anse à la Gourde, two of them possess $^{87}Sr/^{86}Sr$ ratios that are indistinguishable from the local samples and are thus likely local (at least at the scale of the island, if not the site itself). One dog sample from

Figure 2. Photograph of a human (upper) and dog (lower right) burial from Morel, Grande-Terre, Guadeloupe.

Table 2. Relevant sample information and $^{87}Sr/^{86}Sr$ ratios of dog tooth enamel samples from Anse à la Gourde and Morel, Guadeloupe (Lesser Antilles).

Lab ID	Site	$^{87}Sr/^{86}Sr$	2 SE
S382	Anse à la Gourde	0.709110	0.000009
S383	Anse à la Gourde	0.707620	0.000010
S384	Anse à la Gourde	0.709150	0.000010
255	Morel	0.709141	0.000010
262	Morel	0.708021	0.000010
263	Morel	0.707977	0.000009
706.1	Morel	0.709022	0.000010
706.3	Morel	0.709144	0.000009
1969A	Morel	0.709127	0.000010
1969B	Morel	0.709125	0.000008

this site has a much lower $^{87}Sr/^{86}Sr$ ratio (0.70762) that is outside of the local range of $^{87}Sr/^{86}Sr$ variation for the island of Grande-Terre (Figure 3).

Of the seven dog teeth from Morel, five possess $^{87}Sr/^{86}Sr$ ratios that fall within the local range for Grande-Terre. Two dog teeth from Morel have substantially lower $^{87}Sr/^{86}Sr$ ratios (0.70798 and 0.70802) that fall outside of the local range for Grande-Terre and are thus nonlocal to this island (Figure 3). Interestingly, the $^{87}Sr/^{86}Sr$ values of these two samples are very similar to each other, which would be expected if they had originated from the same location or island. In addition, the dog teeth interpreted as of local origin from both sites have $^{87}Sr/^{86}Sr$ values nearly identical to local human samples from both Anse à la Gourde (n = 50) and Morel (n = 3) (Figure 3).

It is important to note that the most parsimonious interpretation of a local $^{87}Sr/^{86}Sr$ ratio is a local origin. However, and as is always the case with isotope provenance studies, movement within a single isotope zone (in this case within Grande-Terre) or between regions with similar biosphere $^{87}Sr/^{86}Sr$ ranges

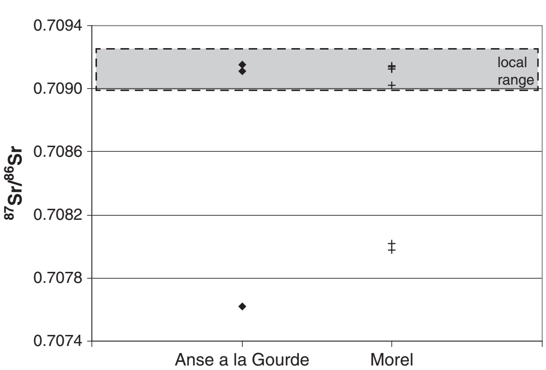

Figure 3. Strontium isotope ratios of dog tooth enamel samples from two prehistoric sites on Grande-Terre, Guadeloupe. Grey box indicates the local range of $^{87}Sr/^{86}Sr$ for Grande-Terre.

(forexample from Anguilla, Barbados, Barbuda or Marie-Galante) would not be distinguishable from an actual local origin on the basis of Sr isotope data alone. We purposely take the conservative approach of only identifying samples as nonlocal if their $^{87}Sr/^{86}Sr$ ratio clearly falls outside of the local biosphere $^{87}Sr/^{86}Sr$ range. One potential bias of this approach is the possibility of missing an unknown number of actual nonlocal individuals (false negatives) with similar $^{87}Sr/^{86}Sr$ ratios as the local range. This is not perceived as overly problematic in that interpretively it is much more likely to underestimate, rather than overestimate, the number of nonlocals in the sample population.

Discussion

Owing to the fact that many of the islands of the Caribbean have been mapped for biosphere Sr isotope variation (Table 3), it is possible to explore the possible origins of the nonlocal dogs at Guadeloupe in more detail. The nonlocal dog from Anse à la Gourde (S383) could have originated from a number of different locations in the Lesser Antilles. This individual's Sr isotope signal falls within the biosphere $^{87}Sr/^{86}Sr$ range for the nearby islands of Basse-Terre and Les Saintes (both part of the Guadeloupe archipelago). Within the Lesser Antilles, islands with $^{87}Sr/^{86}Sr$ ranges that match this sample include Martinique and Tobago to the south and St. Kitts, Nevis and St. Martin to the north. Further afield, similar biosphere $^{87}Sr/^{86}Sr$ ranges can also be found in the Greater Antilles, for example on Puerto Rico. Although it is not possible at this time to identify a specific origin for this dog, it should be noted that many of the islands of the Lesser Antilles can be eliminated as possible origins on the basis of comparisons with measured baseline $^{87}Sr/^{86}Sr$ data. The two nonlocal dogs from Morel (S262 and S263) have $^{87}Sr/^{86}Sr$ values that are also consistent with nearby origins in the southern Lesser Antilles, such as Les Saintes, Martinique, St. Lucia and Tobago. In contrast to the nonlocal dog from Anse à la Gourde, however, the two dogs from Morel possess $^{87}Sr/^{86}Sr$ ratios that are also consistent with origins from many islands of the northern Lesser Antilles (Saba, St. Barths, St. Eustatius, St. Kitts and St. Martin). Additionally, the $^{87}Sr/^{86}Sr$ ratios of these nonlocals are also consistent with origins in some regions of the Greater Antilles, particularly parts of Puerto Rico (although not Vieques). In contrast, Venezuela and the Guianas can probably be dismissed as potential origins for all three of the nonlocal dogs from Guadeloupe as these

Table 3. Statistical summary of biosphere $^{87}Sr/^{86}Sr$ variation in the Lesser Antilles.

Island	*n*	Mean	Median	Minimum	Maximum	S.D.
Anguilla	12	0.70907	0.70911	0.70872	0.70925	0.00016
Antigua	13	0.70851	0.70851	0.70775	0.70913	0.00040
Barbados	4	0.70918	0.70918	0.70918	0.70918	0.00010
Barbuda	9	0.70917	0.70915	0.70909	0.70928	0.00006
Basse-Terre	10	0.70663	0.70672	0.70480	0.70872	0.00115
Grande-Terre	10	0.70915	0.70914	0.70910	0.70921	0.00004
Grenada	5	0.70689	0.70682	0.70622	0.70740	0.00047
Les Saintes	2	0.70791	0.70791	0.70744	0.70838	0.00067
Marie-Galante	4	0.70917	0.70915	0.70914	0.70923	0.00004
Martinique	11	0.70738	0.70702	0.70634	0.70898	0.00082
Nevis	5	0.70731	0.70760	0.70670	0.70789	0.00055
Saba	50	0.70821	0.70837	0.70644	0.70920	0.00056
St. Barths	4	0.70840	0.70849	0.70761	0.70903	0.00066
St. Eustatius	8	0.70821	0.70836	0.70726	0.70897	0.00063
St. Kitts	8	0.70778	0.70786	0.70673	0.70862	0.00062
St. Lucia	11	0.70830	0.70830	0.70761	0.70900	0.00053
St. Martin	11	0.70819	0.70815	0.70714	0.70916	0.00078
St. Vincent	8	0.70659	0.70651	0.70566	0.70812	0.00075
Tobago	5	0.70726	0.70734	0.70475	0.71026	0.00211
Trinidad	16	0.70955	0.70934	0.70832	0.71152	0.00090

regions are characterised by much higher biosphere $^{87}Sr/^{86}Sr$ ranges relative to the Antilles.

In summary, Sr isotope analysis was successfully applied to a number of dog samples from two prehistoric sites on Grande-Terre, Guadeloupe. The results indicate that prehistoric dogs at these sites have diverse origins with most ($n = 7$) likely (but not definitively) originating from the island of Grande-Terre, whereas three of the dogs are nonlocal. The two nonlocal dogs from Morel may share similar distant origins, for example from one of the composite or volcanic islands in the Lesser Antilles. The single nonlocal dog from Anse à la Gourde, probably possesses a distinct origin from the nonlocal dogs at Morel, and may have originated from one of the neighbouring volcanic islands of the Lesser Antilles.

It is important to stress that it is not possible, based on the available data, to determine a precise origin for these nonlocal dogs. Nonetheless, it is interesting, although perhaps not overly surprising, that dogs would have been transported between islands in the first place, considering the evidence that local dogs were available to these populations. Furthermore, the available evidence is consistent with the importation or movement of dogs from a number of different islands to Grande-Terre. It is possible that the nonlocal dogs identified in this study were traded between populations on different islands owing to certain traits or qualities that they possessed (Howard, 2001). The perceived value of dogs in general amongst the native societies of these regions may have been further enhanced if they possessed distant or exotic origins (Helms, 1988). Alternatively, given the relatively large proportion of nonlocal humans (i.e. with non-Guadeloupe origins) identified at these sites (Booden *et al.*, 2008; Hoogland *et al.*, 2010; Laffoon, 2012), the nonlocal dogs may represent animals that accompanied their owners on their migration(s) to Guadeloupe. The diversity of origins reflected in the variable Sr isotope results may also indicate that multiple mechanisms conditioning the patterns of dog mobility and exchange may have been operating in the prehistoric Caribbean.

Conclusions

This study has highlighted the utility of applying Sr isotope analysis to faunal provenance studies in the Caribbean region. Clearly, isotope provenance studies in general have a great potential for contributing to research on the topics of mobility and exchange in this region. The intriguing results of this study have justified the expansion of Sr isotope analyses not only to larger populations of dog samples but also to a wider variety of prehistoric faunal skeletal remains from the Caribbean. In particular, we are currently investigating the potential of isotopic approaches to assess the origins of different types of faunal remains from different archaeological contexts (animal tooth pendants, burials and refuse deposits). The investigation of individual origins would also clearly benefit from a larger and more extensive database of biosphere Sr isotope variation, not only in the insular Caribbean but also from the surrounding mainland regions of South and Central America. Additionally, to further advance isotopic applications to archaeological materials in general and specifically to attempt to further refine the identification of geographic origins for nonlocal specimens, we are continuing to test the usefulness of other isotope systems on ancient Caribbean faunal materials. Lastly, complementary to these ongoing isotopic investigations, a pilot study involving ancient DNA analysis of the dog remains presented herein is also being undertaken in collaboration with the Center for Geogenetics at the University of Copenhagen.

Acknowledgements

Funding for this research was provided by the NWO (Netherlands Organization for Scientific Research) through the VICI grant 'Communicating Communities in the Circum-Caribbean' (NWO grant #016084621) awarded to Prof. Corinne Hofman and an academy assistantship awarded to Esther Plomp from the Faculty of Archaeology, Leiden University. Dog tooth samples from Morel were generously provided by Musée Edgar Clerc, Moule, Guadeloupe and Service Régional de l'archéologie de la Guadeloupe, FWI. We would also like to thank Sandrine Grouard for the skeletal analysis and identification of the dog remains and Richard Smeets for his invaluable assistance with sample processing and analysis. This paper greatly benefited from the insightful comments of several anonymous reviewers.

References

Bataille CP, Laffoon J, Bowen GJ. 2012. Mapping multiple source effects on the strontium isotopic signatures of ecosystems from the Circum-Caribbean region. *Ecosphere* **3**: 118.

Bendrey R, Hayes TE, Palmer MR. 2009. Patterns of Iron Age horse supply: an analysis of strontium isotope ratios in teeth. *Archaeometry* **51**: 140–150.

Bentley RA. 2006. Strontium isotopes from the earth to the archaeological skeleton: a review. *Journal of Archaeological Method and Theory* **13**: 135–187.

Blum JD, Taliaferro EH, Weisse MT, Holmes RT. 2000. Changes in Sr/Ca, Ba/Ca and $^{87}Sr/^{86}Sr$ ratios between trophic levels in two forest ecosystems in the northeastern U.S.A. *Biogeochemistry* **49**: 87–101.

Booden MA, Panhuysen RGAM, Hoogland MLP, de Jong HN, Davies GR, Hofman CL. 2008. Tracing human mobility with $^{87}Sr/^{86}Sr$ at Anse a la Gourde, Guadeloupe. In Crossing the Borders: New Methods and Techniques in the Study of Archaeological Materials from the Caribbean, CL Hofman, MLP Hoogland, AL van Gijn (eds). University of Alabama Press: Tuscaloosa, AL; 214–225.

Britton K, Grimes V, Dau J, Richards MP. 2009. Reconstructing faunal migrations using intra-tooth sampling and strontium and oxygen isotope analyses: a case study of modern caribou (*Rangifer tarandus granti*). *Journal of Archaeological Science* **36**: 1163–1172.

Budd P, Montgomery J, Barreiro B, Thomas RG. 2000. Differential diagenesis of strontium in archaeological human dental tissues. *Applied Geochemistry* **15**: 687–694.

Bullen RP, Bullen AK. 1973. Stratigraphic tests at two sites on Guadeloupe. In *Proceedings of the Fourth International Congress for the Study of the Pre-Columbian Cultures of the Lesser Antilles*, St. Lucia Archaeological and Historical Society: St. Lucia; 192–196.

Calderón FL. 1985. Antropologia y paleopatologia de los pobladores del soco. In *Proceedings of the Tenth International Congress for the study of the Pre-Columbian cultures of the Lesser Antilles*, Centre de Recherches Caraïbes. Montreal; 287–294.

Carini SP. 1991. Compositional analysis of West Indian Saladoid ceramics and their relevance to Puerto Rican prehistory. Ph.D. dissertation, Department of Anthropology, University of Connecticut, Storrs-Mansfield.

Clerc E. 1968. Sites précolombiens de la côte nord-est de la Grande Terre de Guadeloupe. In *Proceedings of the Second - International Congress for the Study of Pre-Columbian Cultures in the Lesser Antilles*, Barbados Museum: Barbados; 47–59.

Crespo E. 1991. Informe preliminar sobre los enterramientoss humanos en el yacimiento de Punta Candelero, Puerto Rico. In *Proceedings of the Thirteenth International Congress for Caribbean Archaeology*, EN Ayubi, JB Haviser (eds). Curaçao; 840–853.

G Dengo, JE Case (eds). 1990. The Geology of North America. Volume H. The Caribbean Region. Geological Society of America: Boulder.

C Descantes, RJ Speakman, MD Glascock, MT Boulanger (eds). 2008. An exploratory study into the chemical characterization of Caribbean ceramics. *Journal of Caribbean Archaeology* Special Publication #2.

Descola P. 1994. In the Society of Nature: A Native Ecology in Amazonia. Cambridge University Press: Cambridge.

SK Donovan, TA Jackson (eds). 1994. Caribbean Geology: An Introduction. University of the West Indies Publishers' Association: Kingston.

Drewett PL. 1991. Prehistoric Barbados. University College London: London.

Drewett PL. 2004. Post-Saladoid society on Barbados. In Late Ceramic Age Societies in the Eastern Caribbean, A Delpuech, CL Hofman (eds). British Archaeological Reports, International Series 127, Archaeopress: Oxford; 215–230.

Dufour E, Holmden C, Van Neer W, Zazzo A, Patterson WP, Degryse P, Keppens E. 2007. Oxygen and strontium isotopes as provenance indicators of fish at archaeological sites: the case study of Sagalassos, SW turkey. *Journal of Archaeological Science* **34**: 1226–1239.

Fock N. 1962. Waiwai: Religion and Society of an Amazonian Tribe. National Museum: Copenhagen.

Freiwald CR. 2010. Dietary diversity in the upper Belize river valley: a zooarchaeological and isotopic perspective. In Precolumbian Foodways: Interdisciplinary Approaches to Food, Culture, and Markets to Ancient Mesoamerica, JE Staller, M Carrasco (eds). Springer: New York; 399–420.

García-Casco A, Rodríguez Vega A, Cárdenas Párraga J, Iturralde-Vinent MA, Lázaro C, Blanco Quintero I, Rojas Agramonte Y, Kröner A, Nunez Cambra K, Millán G, Torres-Roldán RL, Carrasquila S. 2009. A new jadeitite jade locality (Sierra Del Convento, Cuba): first report and some petrological and archeological implications. *Contributions to Mineralogy and Petrology* **158**: 1–16.

Giovas CM, LeFebvre MJ, Fitzpatrick SM. 2011. New records for prehistoric introduction of Neotropical mammals to the West Indies: evidence from Carriacou, Lesser Antilles. *Journal of Biogeography* **39**: 476–487.

Grouard S. 2001. Subsistance, systèmes techniques et gestion territoriale en milieu insulaireantillais précolombien - exploitation des vertébrés et des crustacés aux époques Saladoïdes et Troumassoïdes de Guadeloupe (400 av. J.-C. à 1 500 ap. J.-C.). PhD dissertation, Université de Nanterre, Paris.

Grouard S. 2004. Variation des stratégies de subsistance des Précolombiens à Hope Estate, Saint Martin (F.W.I.), d'après l'analyse des restes des petits vertébrés. In *XXIVèmes Rencontres Internationales d'Archéologie et d'Histoire d'Antibes – "Petits animaux et sociétés humaines: du complément alimentaire aux resources utilitaires"*, Rencontres d'Antibes - 23-24-25 oct. 2003, JP Brugal, J Desse (eds)., Éd. APDCA: 451–467.

Hackenberger S. 1991. An abstract of archaeological investigations by the Barbados Museum, 1986. In *Proceedings of the Twelfth International Congress for Caribbean Archaeology*, LS Robinson (ed.). Martinique; 163–174.

Harlow GE, Murphy AR, Hozjan J, de Mille CN, Levinson AA. 2006. Pre-Columbian jadeite axes from Antigua, West Indies: description and possible sources. *The Canadian Mineralogist* **44**: 305–321.

Hedman KM, Curry BB, Johnson TM, Fullagar PD, Emerson TE. 2009. Variation in strontium isotope ratios of archaeological fauna in the Midwestern United States: a preliminary study. *Journal of Archaeological Science* **36**: 64–73.

Helms M. 1988. Ulysses' Sail: An Ethnographic Odyssey of Power, Knowledge, and Geographical Distance. Princeton University Press: Princeton.

Hillson S. 1996. Dental Anthropology. Cambridge University Press: Cambridge.

Hobson KA. 1999. Tracing origins and migration of wildlife using stable isotopes: a review. *Oecologia* **20**: 314–326.

Hofman CL, Hoogland MLP. 2011. Unravelling the multiscale networks of mobility and exchange in the precolonial Circum-Caribbean. In Communities in Contact: Essays in Archaeology, Ethnohistory & Ethnography of the Amerindian Circum-Caribbean, CL Hofman, A van Duijvenbode (eds). Sidestone Press: Leiden; 15–44.

CL Hofman, A van Duijvenbode (eds). 2011. Communities in Contact: Essays in Archaeology, Ethnohistory & Ethnography of the Amerindian Circum-Caribbean. Sidestone Press: Leiden.

Hofman CL, Hoogland M, Delpuech A, Hamburg T, Knippenberg S, Lammers-Keijsers Y, Mol J, Nieweg D, Nokkert M, Pélissier E, Romon T. 1999. Guadeloupe, Le Moule, Site Précolombien de Morel: Fouilles Archéologiques de 1999. Basse-Terre: Guadeloupe.

CL Hofman, MLP Hoogland, A Delpuech (eds). 2001. Le Site de l'Anse à la Gourde, St. François, Grande- Terre, Guadeloupe: Fouille Programmée Pluriannuelle, 1995–2000. Direction Régionale des Affaires Culturelles/Université de Leiden: Basse-Terre/Leiden.

Hofman CL, Isendoorn AJD, Booden MA. 2005. Clays collected. Towards an identification of source areas for clays used in the production of Pre-Columbian pottery in the northern Lesser Antilles. *Leiden Journal of Pottery Studies* **21**: 9–26.

Hofman CL, Bright AJ, Boomert A, Knippenberg S. 2007. Island rhythms: the web of social relationships and interaction networks in the Lesser Antillean archipelago between 400 B.C. and A.D. 1492. *Latin American Antiquity* **18**: 243–268.

Hofman CL, Bright AJ, Hoogland MLP, Keegan WF. 2008a. Attractive ideas, desirable goods: examining the late Ceramic Age relationships between greater and Lesser Antillean societies. *Journal of Island and Coastal Archaeology* **3**: 17–34.

CL Hofman, MLP Hoogland, AL van Gijn (eds). 2008b. Crossing the Borders. New Methods and Techniques in the Study of Archaeological Materials from the Caribbean. University of Alabama Press: Tuscaloosa, AL.

Hofman CL, Bright AJ, Rodríguez Ramos R. 2010. Crossing the Caribbean Sea: towards a holistic view of Pre-colonial mobility and exchange. *Journal of Caribbean Archaeology* Special Publication #3: 1–18.

Hofman CL, Boomert A, Bright AJ, Hoogland MLP, Knippenberg S, Samson AVM. 2011. Ties with the homelands: archipelagic interaction and the enduring role of the South and Central American mainlands in the pre-Columbian Lesser Antilles. In Islands at the Crossroads: Migration, Seafaring, and Interaction in the Caribbean, LA Curet, MW Hauser (eds). University of Alabama Press: Tuscaloosa, AL; 73–86.

Hoogland MLP, Hofman CL, Panhuysen RGAM. 2010. Interisland dynamics: evidence for human mobility at the site of Anse à la Gourde, Guadeloupe. In Island Shores, Distant Pasts: Archaeological and Biological Approaches to the Pre-Columbian Settlement of the Caribbean, SM Fitzpatrick, AH Ross (eds). University Press of Florida, Gainesville, FL; 148–162.

Hoppe KA, Koch PL, Furutani TT. 2003. Assessing the preservation of biogenic strontium in fossil bones and tooth enamel. *International Journal of Osteoarchaeology* **13**: 20–28.

Howard CV. 2001. Wrought identities: the Waiwai expeditions in search of the "unseen tribes" of Northern Amazonia. PhD dissertation, University of Chicago, Chicago.

Knippenberg S. 2006. Stone artefact production and exchange among the northern Lesser Antilles. PhD dissertation, Leiden University, Leiden.

Laffoon JE. 2012. Patterns of paleomobility in the ancient Antilles: an isotopic approach. PhD dissertation, Leiden University, Leiden.

Laffoon JE, de Vos B. 2011. Diverse origins, similar diets. An integrated isotopic perspective from Anse à la Gourde, Guadeloupe. In Communities in Contact. Essays in Archaeology, Ethnohistory and Ethnography of the Amerindian Circum-Caribbean, CL Hofman, A van Duijvenbode (eds). Sidestone Press: Leiden; 187–203.

Laffoon JE, Davies GR, Hoogland MLP, Hofman CL. 2012a. Spatial variation of biologically available strontium isotopes ($^{87}Sr/^{86}Sr$) in an archipelagic setting: a case study from the Caribbean. *Journal of Archaeological Science* **39**: 2371–2384. DOI: 10.1016/j.jas.2012.02.002

Laffoon JE, Valcárcel Rojas R, Hofman CL. 2012b. Oxygen and carbon isotope analysis of human dental enamel from the Caribbean: implications for investigating individual origins. *Archaeometry*. Article first published online 19 JUL 2012. DOI: 10.1016/j.jas.2012.02.002

Lammers-Keijsers Y. 2007. Tracing traces from present to past. A functional analysis of Pre-Columbian shell and stone artefacts from Anse à la Gourde and Morel, Guadeloupe, FWI. PhD Dissertation, Leiden University, Leiden.

Lawrence B. 1977. Dogs from the Dominican Republic. *Cuadernos del Cendia* **268**: 3–19.

Lee-Thorp J, Sponheimer M. 2003. Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for paleodietary studies. *Journal of Anthropological Archaeology* **22**: 208–216.

Lundberg ER. 2002. Investigation of ceramic variability at the tutu site through acid-extraction elemental analysis. In The Tutu Archaeological Village Site: A Multidisciplinary Case Study in Human Adaptation, E Righter (ed.). Routledge: London; 199–208.

Mans J. 2012. Amotopoan Trails: A Recent Archaeology of Trio Movements. Sidestone Press: Leiden.

Meniketti M. 2011. Preliminary comparative pXRF analyses of indigenous Saladoid wares and colonoware from Nevis, West Indies. *Caribbean Connections* I (1).

Newsom L. 1995. Mangroves and root crops: the archaeobotanical record from En Bas Saline, Haïti. In *Proceedings of the Sixteenth International Congress for Caribbean Archaeology*, G Richard (ed.). Guadeloupe; 52–66.

Newsom LA, Wing ES. 2004. On Land and sea: Native American Uses of Biological Resources in the West Indies. University of Alabama Press: Tuscaloosa, AL.

Ortega RF, Galvahe DG, Gonzáles Tendero JB, Huartt JC. 2006. Sobre la presencia del perro en el legado rupestre de los aborígenes de las Antilles, *Ponencia presentada en la VIII Conferencia Internacional Antropología*. Instituto Cubano de Antropología, La Habana.

Perdikaris S, McGovern T, Brown M, Look C, McGovern D, Palsdottir A, Smiarowski K. 2008. Field report Barbuda historical ecology project 2008. Antigua and Barbuda National Parks Dept. and City University of New York.

Pérez Merced CA. 2000. Excavaciones en aguacate: una comunidad ceramista del este de Puerto Rico. In Proceedings of the Seventeenth International Congress for Caribbean Archaeology, J Winter (ed.). Rockville Center, Molloy College: New York; 157–165.

Petersen JB, Watters DR. 1995. A preliminary analysis of Amerindian ceramics from the Trants site, Montserrat. In *Proceedings of the Fifteenth International Congress for Caribbean Archaeology*, RE Alegria, M Rodríguez (eds). Centro de Estudios Avanzados dé Puerto Rico y el Caribe: San Juan, Puerto Rico; 131–140.

Plomp E. 2011. Neither human nor beast: the role of the dog in Pre-Columbian Caribbean societies. Bachelor thesis, Leiden University.

Poszwa A, Dambrine E, Ferry B, Pollier B, Loubet M. 2002. Do deep tree roots provide nutrients to the tropical rainforest? *Biogeochemistry* **60**: 97–118.

Price TD, Burton JH, Bentley RA. 2002. The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry* **44**: 117–135.

Rodríguez ML. 1991. Arquelogía de Punta Candelero, Puerto Rico. In *Proceedings of the Thirteenth International Congress for Caribbean Archaeology*, EN Ayubi, JB Haviser (eds). Curaçao; 605–627.

Rodríguez M. 2007. Tras las Huellas del Perro Indígena: Estudio Arqueológico del Llamado Perro "Mudo" de Nuestros Indios Taínos. Publicaciones Puertorriqueñas: Hato Rey, PR.

Rodríguez Ramos R. 2010. Rethinking Puerto Rican Precolonial History. University of Alabama Press: Tuscaloosa, AL.

Roe PG. 1995. Eternal companions: Amerindian dogs from Tierra Firme to the Antilles. In *Proceedings of the XV International Congress for Caribbean Archaeology*. Centro de Estudios Avanzados dé Puerto Rico y el Caribe: San Juan, Puerto Rico; 155–172.

Schertl HP, Maresch WV, Stanek KP, Hertwig A, Krebs M, Baese R, Sergeev SS. 2012. New occurrences of jadeitite, jadeite quartzite and jadeite-lawsonite quartzite in the Dominican Republic, Hispaniola: petrological and geochronological overview. *European Journal of Mineralogy* **24**: 199–216.

Shackleton J, Elderfield H. 1990. Strontium isotope dating of the source of Neolithic European spondylus shell artefacts. *Antiquity* **64**: 312–315.

Shaw BJ, Summerhayes GR, Buckley HR, Baker JA. 2009. The use of strontium isotopes as an indicator of migration in human and pig Lapita populations in the Bismarck archipelago, Papua New Guinea. *Journal of Archaeological Science* **36**: 1079–1091.

Sjögren KG, Price TD. 2013. A complex Neolithic economy: isotope evidence for the circulation of cattle and sheep in the TRB of western Sweden. *Journal of Archaeological Science* **40**: 690–704.

Sykes NJ, White J, Hayes TE, Palmer MR. 2006. Tracking animals using strontium isotopes in teeth: the role of fallow deer (*Dama dama*) in Roman Britain. *Antiquity* **80**: 948–959.

Thornton EK. 2011. Reconstructing ancient Maya animal trade through strontium isotope ($^{87}Sr/^{86}Sr$) analysis. *Journal of Archaeological Science* **38**: 3254–3263.

Towers J, Montgomery J, Evans J, Jay M, Parker Pearson M. 2010. An investigation of the origins of cattle and aurochs deposited in the Early Bronze Age barrows at Gayhurst and Irthlingborough. *Journal of Archaeological Science* **37**: 508–515.

Trickett MA, Budd P, Montgomery J, Evans J. 2003. An assessment of solubility profiling as a decontamination procedure for the $^{87}Sr/^{86}Sr$ analysis of archaeological human skeletal tissue. *Applied Geochemistry* **18**: 653–658.

Vanhaeren M, D'Errico F, Billy I, Grousset F. 2004. Tracing the source of Upper Palaeolithic shell beads by strontium isotope dating. *Journal of Archaeological Science* **31**: 1481–1488.

Viner S, Evans J, Albarella U, Pearson MP. 2010. Cattle mobility in prehistoric Britain: strontium isotope analysis of cattle teeth from Durrington Walls (Wiltshire, Britain). *Journal of Archaeological Science* **37**: 2812–2820.

Vitousek PM, Kennedy MJ, Derry LA, Chadwick OA. 1999. Weathering versus atmospheric sources of strontium in ecosystems on young volcanic soils. *Oecologia* **121**: 255–259.

Walker J. 1985. A preliminary report on the lithic and osteological remains from the 1980, 1981 and 1982 field season at Hacienda Grande (12 PSJ7-5). In *Proceedings of the Tenth International Congress for the study of the Pre-Columbian cultures of the Lesser Antilles*, Centre de Recherches Caraïbes. Montreal; 181–224.

Watters DR, Scaglion R. 1994. Beads and pendants from Trants, Montserrat: implications for the prehistoric lapidary industry of the Caribbean. *Annals of Carnegie Museum* **63**: 215–237.

White CD. 2004. Stable isotopes and the human-animal interface in Maya biosocial and environmental systems. *Archaeofauna* **13**: 183–198.

Widga C, Walker JD, Stockli LD. 2010. Middle Holocene Bison diet and mobility in the eastern Great Plains (USA) based on $\delta^{13}C$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ analyses of tooth enamel carbonate. *Quaternary Research* **73**: 449–463.

Wing ES. 1972. Identification and interpretation of faunal remains from the white marl site in Jamaica. In The White Marl Site in Jamaica: Report of the 1964 Robert R. Howard Excavation, J Silverberg, RL Vanderwal, ES Wing (eds). University of Wisconsin-Milwaukee: Milwaukee, WI; 18–35.

Wing ES. 1991. Dog remains from the Sorcé Site on Vieques Island, Puerto Rico. In Beamers, Bobwhites, and Blue-Points: Tributes to the Career of Paul W. Parmalee (Scientific Papers 23), JR Purdue, WE Klippel, BH Styles, PW Parmalee (eds). Illinois State Museum: Springfield, IL; 379–386.

Wing ES. 2001. Native American use of animals in the Caribbean. In Biography of the West Indies, Patterns and Perspectives, CA Woods, FE Sergile (eds). CRC Press: Boca Raton, FL; 481–518.