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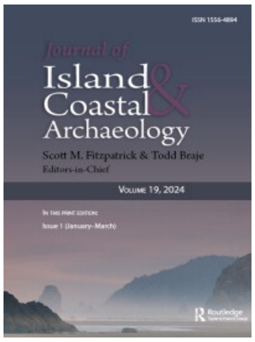

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Reconstructing past lifeways of Indigenous individuals in pre-colonial Bonaire, through multi-isotope analysis

Eleni Seferidou[a], Sebastiaan Knippenberg[b], and Jason E. Laffoon[a]

[a]Faculty of Archaeology, Leiden University, Leiden, The Netherlands; [b]Archeologisch Onderzoek Leiden BV (Archol), Leiden, The Netherlands

ABSTRACT

Archaeological research in the Caribbean has been extensive and has revealed that, since its first settlement, the region has been characterized by continuous interaction between its inhabitants. However, there are certain areas, like the islands of the southern Caribbean (islands off the Venezuelan coast), that are understudied, despite being a source of information regarding connections with the South American mainland. The aim of this research is to investigate the lifeways of eight individuals from the island of Bonaire through isotopic data to identify non-locals, and to examine dietary patterns within the site. In order to establish the residential histories of the eight individuals, strontium ($^{87}Sr/^{86}Sr$) and oxygen ($\delta^{18}O$) isotopes from the dental enamel were analyzed. The results were evaluated based on existing isotopic baselines and indicate that all eight individuals can be considered isotopically local. In order to investigate patterns of paleodiet, carbon isotopes from the dental enamel ($\delta^{13}C_{en}$) and carbon ($\delta^{13}C_{col}$) and nitrogen isotopes ($\delta^{15}N_{col}$) from the dental dentin were also analyzed. Four out of the eight individuals provided results and interestingly, despite the small sample size, they had variable dietary preferences, suggesting a combination of different plants and animal resources were consumed.

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Southern Caribbean; isotope analysis; paleomobility; diet reconstruction

Introduction

Biochemical methods have received increased attention for the potential they offer in archaeological research. One of these methods, isotopic analysis of skeletal remains, can provide unique insights into the lifeways of past populations. In the Caribbean region, stable isotope analysis of biogenic tissues has contributed to answering questions regarding paleomobility (Booden et al. 2008; Laffoon 2012; Schroeder et al. 2009) and paleodiet (Keegan and DeNiro 1988; Laffoon and de Vos 2011; Laffoon et al. 2016; Pestle 2010; Stokes 1998), including breastfeeding and weaning practices (Chinique de Armas et al. 2017, 2021; Chinique de Armas and Pestle 2018). The results of these studies have underlined the importance of mobility for pre-colonial populations, as well as a reliance on a variety of subsistence resources, depending on the local environment, culture, and island setting.

CONTACT Eleni Seferidou eleni_seferidou@eva.mpg.de
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Even though isotopic analysis has been applied in multiple Caribbean contexts, the southern Caribbean islands (those off the northern Venezuelan coast—Aruba, Curaçao, Bonaire—as well as the islands of Las Aves and Los Roques archipelago), with the exception of Aruba (Laffoon 2012; Mickleburgh and Laffoon 2018), have yet to be intensively investigated from a bioarchaeological perspective and little is known about the lifeways of their inhabitants. Contacts between the South American mainland and these islands are believed to be of crucial importance for the sustainability of small island communities (Haviser 1991; Versteeg and Rostain 1997). These contacts have been confirmed through multiple lines of evidence for these southwestern islands (Antczak 1999; Antczak, Urbani, and Antczak 2017; Boomert 2000; Hofman 2019; Hofman and Bright 2010; Hofman et al. 2007).

In other Caribbean islands, parts of the population have been identified as non-local to the place of interment (i.e., Booden et al. 2008; Laffoon et al. 2012) and variable dietary practices have been established (i.e., Laffoon 2012; Pestle 2010; Stokes 1998). The close proximity of Bonaire to the northern coast of Venezuela (80 km) is worth investigating further, for a possible movement of people and associated practices (i.e., diet). The present study is an attempt to reconstruct past lifeways for eight individuals recovered from the Indigenous site of Amboina, on the island of Bonaire, through multi-isotope analysis. More specifically, the aims of this study are to: (1) determine which individuals within the burial assemblage can be identified as "local" versus "non-local"; (2) indicate the main dietary practices of this population; and (3) explore these patterns on a broader level (Caribbean region). This research will attempt to answer the above questions, keeping in mind that, given the limited sample size, the present individuals do not represent the entirety of the community in Amboina.

Archaeological context

Bonaire is part of the southern Caribbean region, which extends from the island of Aruba to the island of Margarita (Figure 1). Bonaire is a semi-arid island, characterized by xerophytic vegetation and predominantly dry conditions, that provide a wide variety and abundance of marine resources, but limited terrestrial ones (Haviser 1991; Newsom and Wing 2004, 21). Radiocarbon dates indicate that Bonaire was first settled around 1500 BC (Haviser 2015), marking the beginning of the Archaic Age on the island. Around AD 400, a new migration, possibly originating in north-western Venezuela, signifies the beginning of the Ceramic Age, which is characterized by more permanent settlements and extensive practice of agriculture. The Ceramic Age for these islands lasted until initial contact with the Spanish in 1499 (Haviser 1991, 3).

The site of Amboina is the second largest and one of the five permanently occupied Ceramic Age settlements identified thus far on the island (Haviser 1991). Discovered and first studied in the early 1960s (van Heekeren 1963), followed by multiple small-scale excavations in the late 1970s and 1980s (Haviser 1991; Knippenberg 2022, 31–33; Tacoma 1980), the site has recently been the focus of a 0.3 ha rescue excavation by Archaeological Research Leiden (Archol) as part of local Cultural Resource Management regulations (Knippenberg 2022). Radiocarbon dates (Haviser 1991, 58–61; Knippenberg 2022, 83–85) and ceramic analyses (Cijntje 2022; Haviser 1991; van

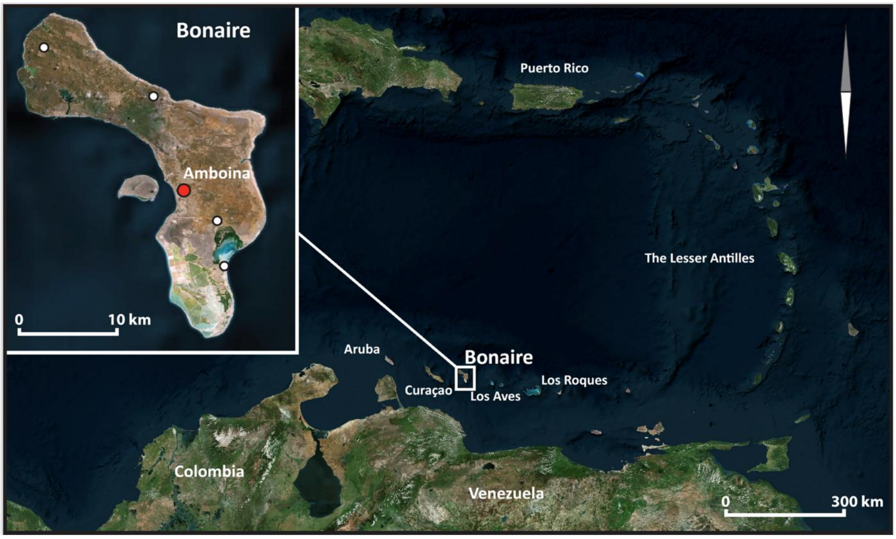

Figure 1. The Caribbean region, with inset map of the island of Bonaire. Amboina is highlighted in red and other permanent occupied Ceramic Age sites are in white (based on Haviser 1991, fig. 45).

Heekeren 1963) have confirmed that Amboina can be attributed to the Dabajuroid culture, a culture originating from western Venezuela (~AD 800–1500), which is commonly accepted to have belonged to Arawakan speaking people, historically known as the Caquetío (Oliver 1989). Previous research (1976) at Amboina has uncovered the remains of an adult male (40–50 years old) dating to AD 1225–1280, buried with a bowl as a grave offering (Tacoma 1980). During the Archol project, the excavated segment of the much larger settlement has revealed five plans of round shaped residential structures in addition to another four clusters of postholes, where the presence of other structures may be assumed (Figure 2). A total of fourteen burials have been uncovered in association with these structures (Fricke and Knippenberg 2022; Knippenberg 2022). The majority of burials were placed inside the perimeter of the different plans. The burials belong to five non-adults and nine adults. Among the adults, one female and four male individuals have been identified, with the remaining four not specified to sex due to incomplete and/or poor preservation. The burials exhibit much variation in position of the interred body, practices regarding the exhumation of the cranium, as well as associated burial gifts and items of body or cloth adornment. Although insight on social stratification is very hard to obtain from this small set of highly variable burials, adult males seem to have been the central figures, with a possibility of abandonment of the house after their death (Fricke 2022; Fricke and Knippenberg 2022; Knippenberg and Fricke 2022). What is worth mentioning is that in six of the fourteen burials the skull is missing. In many cases, it cannot be determined with certainty whether this was a deliberate act or whether the absence of this body part is due to later disturbances. In two graves there are indications that the skull has disappeared due to disturbing activities and only in one grave (grave 6) is there evidence that the skull was removed deliberately (Fricke and Knippenberg 2022).

A series of radiocarbon dates place the occupation of the site between AD 1040 and 1360, possibly extending into the early fifteenth century (Knippenberg 2022, 83–85),

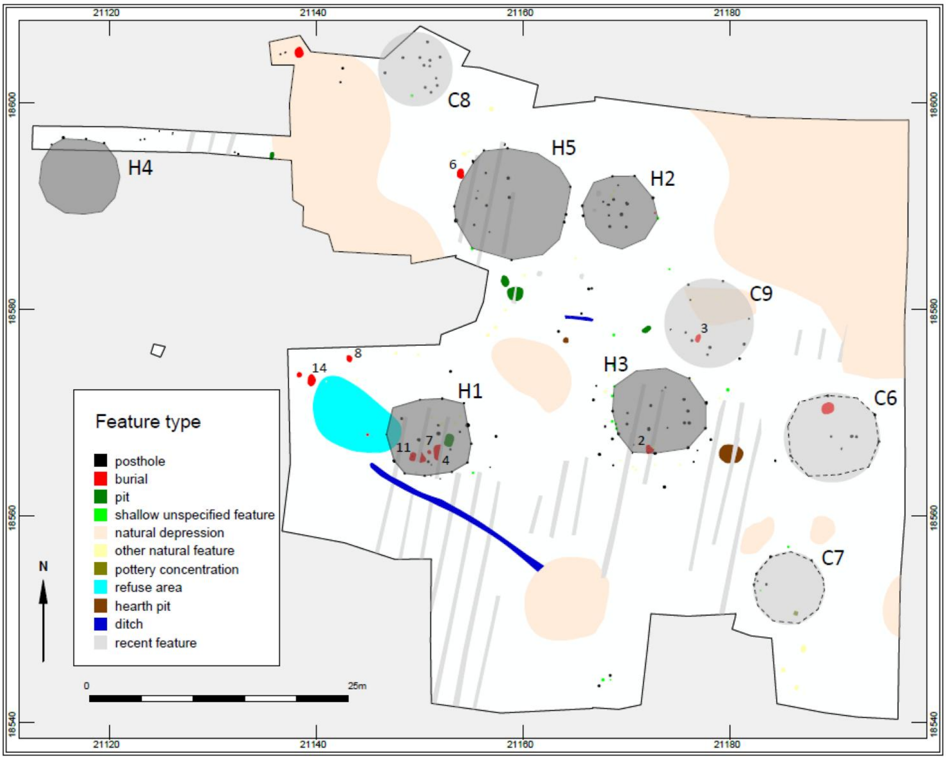

Figure 2. Site map showing the excavated area (white) with documented features in different colors (see legend). Reconstructed house plans (H) are in dark gray and posthole clusters where house plans are assumed (C) in light gray. The burial numbers correspond to the individuals discussed in this paper (map based on Knippenberg (2022, fig. 7.3) with slight modifications; see Table 1 for further details on the burials).

and attest to a prolonged settlement that must have included multiple house phases. Viewing the dispersed distribution of the houses and the extensive period of occupation (up to 300 years), and assuming a house life-span of around one family generation of 25 years, it can be argued that not more than one house at a time was inhabited within the investigated zone (Knippenberg 2022).

So far, archaeological evidence (material culture and material culture influences, faunal remains) has confirmed continuous contact between Venezuela, the inhabitants of Los Roques archipelago, and the islands of Aruba, Bonaire, and Curaçao (Antczak, Antczak, and Jaimes 2018; Antczak and Antczak 2016; Haviser 1991; Laffoon et al. 2018; Versteeg and Rostain 1997). In the centuries before European colonization, during which the site of Amboina was in use, the Caquetío were in close contact with coastal Venezuela and the islands in the Venezuelan archipelago through networks of trade and exchange (Haviser 1991, 55). Material culture found on Amboina resembles that found in Aruba, Curaçao, as well as in the Las Aves and Los Roques archipelagos, testifying to a Dabajuroid occupation of the southern Caribbean region and adjacent northern Venezuelan mainland (Antczak 1999; Antczak 2000; Antczak and Antczak 2016; Cijntje 2022; Haviser 1991; Versteeg and Rostain 1997). Given such evidence, this study investigates whether these eight individuals from Amboina could originate from neighboring islands and/or the adjacent region of coastal Venezuela.

Stable isotopes and mobility reconstruction

Strontium isotope ratios ($^{87}Sr/^{86}Sr$) present global variation, which facilitates provenance studies. Bedrock geology is the primary source of strontium inputs into ecosystems. Through the process of weathering, strontium enters the soil, and consequently plants from a certain geographic location will have similar strontium isotope ratios as the "local" soil and rocks (Bentley 2006). The same is true for herbivores that feed on these plants and carnivores that consume the herbivores (Bentley 2006). Strontium does not significantly fractionate, therefore the strontium isotope ratio of an organism's tissues generally will reflect the strontium isotope ratio of the local environment (Ericson 1985, 506). Strontium isotope ratios of dental enamel will provide information on the environment where the individual has spent their youth, from several months in utero until ~10–14 years of age depending on the tooth type (AlQahtani, Hector, and Liversidge 2010). Dental enamel is the most highly mineralized substance in the human body (White and Folkens 2005, 130), which makes it highly resistant to diagenesis (postmortem alteration or post-burial isotopic contamination).

Oxygen isotopes can also contribute to provenance studies (Fricke, O'Neil, and Lynnerup 1995). The oxygen isotope values in skeletal tissues are reflective of the individual's body water, which reflects that of the drinking water and water present in food (Luz, Kolodny, and Horowitz 1984). For most small-scale societies, drinking water is derived from local sources, which reflect the meteoric (water from precipitation) ^{18}O (relative to ^{16}O) values (Fricke, O'Neil, and Lynnerup 1995). This provides an oxygen isotopic signature for every area, as oxygen values vary between geographical regions. This variation is dependent on climatic conditions with lower $\delta^{18}O$ in colder areas/seasons, and on the geographical position of the region with lower $\delta^{18}O$ values at higher altitudes and latitudes. The $\delta^{18}O$ value in rainwater also decreases when moving further away from a water source or in regions with lower rates of precipitation (Dansgaard 1964, 444). However, the range of global variability in $\delta^{18}O$ is limited, especially in tropical regions where multiple areas present similar values (−8.0‰ to −2.0‰), making distinctions harder to identify (Bowen, Wassenaar, and Hobson 2005).

For this reason, the majority of studies (including this one) uses multi-isotopic approaches to investigate mobility, especially in island settings like the Caribbean region. However, although oxygen isotope values may be of limited utility for identifying migration within the Antilles (Laffoon, Hofman, and Rojas 2013), they can potentially provide relevant information about migration between the mainland and the islands as the former possesses higher variation in $\delta^{18}O$ with distinctly lower $\delta^{18}O$ values further inland (Laffoon et al. 2018, 126).

Stable isotopes and dietary reconstruction

Carbon isotope analysis is a well-established method for studying paleodiet, as it can indicate the relative contributions of different food categories to an individual's diet. The principle of this method is that the isotopic composition of the diet is reflected in the isotopic values of the consumer's tissues (Ambrose 1990). By comparing the isotope values in human tissues with those of plants and animals, we can obtain an estimate of their proportions in the diet, since certain food groups (i.e., terrestrial vs. marine protein, different types of plants) have distinct isotope signatures (DeNiro and Epstein 1978, 1981). Plants incorporate carbon dioxide (CO_2) using three different pathways: C_3, C_4, and CAM (Crassulacean Acid Metabolism), which affects their $\delta^{13}C$ signature, with more negative $\delta^{13}C$ values for C_3 plants and more positive for C_4 (DeNiro and Epstein 1978). Carbon isotope values vary between terrestrial and marine resources as well, with marine food webs having higher (less negative) values (DeNiro and Epstein 1978). Carbon isotope values can be obtained from both bone and dentin collagen ($\delta^{13}C_{col}$) and bone/enamel hydroxyapatite ($\delta^{13}C_{en/ap}$), which reflect (primarily) protein consumption and an average of the whole diet (proteins, fats/lipids, carbohydrates) respectively (Ambrose and Norr 1993).

Nitrogen isotopes have also contributed to studies of paleodiet. $\delta^{15}N$ increases by ~3–5‰ in every successive trophic level in the food web (Schoeninger and DeNiro 1983). Marine ecosystems often have more complex food webs, with more trophic levels and diverse environments that can potentially complicate diet inferences (Schoeninger, DeNiro, and Tauber 1983). $\delta^{15}N$ values of bone collagen can distinguish between marine and terrestrial-derived diets, with marine diets demonstrating more positive values (DeNiro and Epstein 1981). In contexts of shallow water coral reef ecosystems, nitrogen fixation causes lower $\delta^{15}N$ values, closer to those of terrestrial organisms making the distinction between diets from coral reef environments and from terrestrial ones more complex (Keegan and DeNiro 1988).

Oxygen, carbon, and nitrogen isotope results are reported as delta (δ) values in per mil (parts per thousand). The internationally agreed standard for oxygen is VSMOW (Vienna Standard Mean Ocean Water), but oxygen values are also reported on the VPDB (Vienna Pee Dee Belemnite) scale (Coplen 1995). The standard for carbon isotope measurements is the VPDB (Vienna Pee Dee Formation) and for nitrogen measurements is atmospheric nitrogen (AIR) (Schoeninger and DeNiro 1983).

Mobility and diet in the Antilles

Archaeological research in the Caribbean region has revealed the existence of extensive networks of communication and exchange between pre-colonial populations. Mobility has been inferred by changes in material culture (Hofman, Hoogland, and van Gijn 2008; Knippenberg 2006), settlement patterns (Hofman and Hoogland 2004), and mortuary practices (Hoogland, Hofman, and Panhuysen 2010). Patterns of human mobility, animal and artifact movement and exchange have been identified (Boomert 2000; Bright 2011; Curet 2005; Giovas, LeFebvre, and Fitzpatrick 2012; Hofman 2019; Hofman and Bright 2010; Hofman and Hoogland 2011; Hofman and van Duijvenbode 2011; Laffoon et al. 2018; Plomp 2013). Some of these interactions were more intense and continuous, connecting specific islands and regions tighter than others.

Isotope studies in the Caribbean have addressed the issue of mobility between the islands, and between the islands and the South American mainland, to reconstruct population relationships, their intensity, and extent. Research has revealed the presence of a large number of non-local individuals amongst numerous archaeological sites (Booden et al. 2008; Laffoon 2016; Laffoon and de Vos 2011; Valcárcel Rojas et al. 2011). Moreover, the presence of a limited number of migrants originating from regions outside the Antilles, including a possible mainland-born individual in Aruba, has been identified (Laffoon 2012).

Since first occupation, human subsistence in the islands has been affected by multiple factors (i.e., variability in environmental and climatic conditions, introduction of new species, and overexploitation of others) and experienced changes through time, such as variation in the reliance on cultivates, and/or specific marine or terrestrial resources (Pestle 2010; Stokes 1998). Archaic Age populations seem to have relied on the local resources available to them depending on site and island, but also the translocation, production, and consumption of domestic plants, cultivates, and other local botanical resources (Chinique de Armas et al. 2015, 2022; Mickleburgh and Pagán-Jiménez 2012; Pag*á*n-Jim*é*nez et al. 2005, 2015; Pagán-Jiménez and Mickleburgh 2022). Ceramic Age populations practiced agriculture, which seems to have intensified with time. Based on the available information, these communities were utilizing the resource abundance of their environments, as their broad-spectrum diets comprised a wide range of plants and animals. During the Late Ceramic Age, when the site of Amboina was occupied, their subsistence was based on home gardening, cultivating staple food plants (such as maize, manioc, and sweet potato), together with a range of fruits, vegetables, meat, and fish (deFrance 2013; Newsom and Wing 2004; Pagán-Jiménez and Mickleburgh 2022). Isotopic studies have revealed highly variable diets across space and time, combining different contributions of marine and terrestrial resources. Factors such as site size, proximity to the ocean, and local ecology affected the availability of resources, and in combination with cultural differences, led to the variability in dietary habits that is observed. Larger islands generally have increased biodiversity and resource abundance, and thus a broader range of terrestrial-based dietary options than smaller ones, where people tend to rely more on marine resources (Laffoon and de Vos 2011; Laffoon et al. 2016; Pestle 2010; Stokes 1998).

Materials and methods

Based on preservation, eight of the fourteen individuals recovered from the site were selected for isotopic analyses. Sample information and demographic indicators can be found in Table 1. The preservation of skeletal material on the site was very poor (Fricke 2022), leading to a selection of specific teeth for the analyses, while bone material was avoided. Additionally, seven of the burials were missing skulls, and some skeletons with skulls did not possess intact, well-preserved teeth, further limiting the number of individuals available for study. Sampling targeted molars (M1, M2, M3), one per individual, and focused on intact teeth with no severe dental wear, indications of pathology, or cultural modification in order to preserve these teeth for future research (Table 1). This sampling strategy permitted us to obtain substantial information (five isotope proxies), while limiting destructive analysis to several milligrams of a single tooth per individual. Results obtained from enamel and dentin of the same tooth do not represent the same exact period of tissue development (earlier for enamel compared to dentin collagen),

Table 1. Information and sampling data for the individuals from Amboina analyzed in this study (Knippenberg and Fricke 2022).

Burial context	Lab/ Archaeological ID	Osteological sex	Age at-death	Analyzed tooth	^{14}C dating (95%)
Burial 2 [House 3]	C936/V184	Unobservable	Adult	Unidentified Molar	/
Burial 3 [Cluster 9]	C937/V244	Male	Adult (>29)	3rd Molar (M3)	/
Burial 6 [House 5]	C938/V278	Male	Adult (>53)	2nd Molar (M2)	1162–1231, 1242–1258 cal. AD
Burial 7 [House 1]	C939/V320	Non-applicable	Non-adult (>3)	1st Molar (M1)	/
Burial 11 [House 1]	C940/V337	Female	Adult (>29)	3rd Molar (M3)	1270–1300, 1372–1377 cal. AD
Burial 8 [western cluster]	C941/V317	Non-applicable	Non-adult (7–8)	2nd Molar (M2)	992–1051, 1080–1154 cal AD
Burial 14 [western cluster]	C942/V364	Male	Adult (>53)	1st Molar (M1)	/
Burial 4 [House 1]	C943/V237	Unobservable	Adult	2nd Molar (M2)	/

but bulk sampling produces results that reflect an average over several years during non-adult years, reflecting broader trends as opposed to snapshots in time.

A selection of teeth from the individuals buried at the site of Amboina ($n = 8$) underwent strontium ($^{87}Sr/^{86}Sr$), oxygen ($\delta^{18}O/^{16}O$), and carbon ($\delta^{13}C_{en}$) isotope analysis of the tooth enamel, and carbon ($\delta^{13}C_{col}$) and nitrogen ($\delta^{15}N_{col}$) analysis of the tooth dentin. Strontium and oxygen isotopes are interpreted to infer the localness of the individuals, while carbon and nitrogen data inform paleodiet reconstruction. More specifically, carbon from the tooth enamel apatite ($^{13}C_{en}$) reveals information regarding the whole diet (including all three macronutrients: proteins, carbohydrates, and fats/lipids), and carbon ($^{13}C_{col}$) and nitrogen ($\delta^{15}N_{col}$) data from the tooth dentin collagen provide information primarily (but not solely) regarding the protein resources consumed. Locality in this study is considered at a regional level, one that encompasses the southern Caribbean islands (i.e., Aruba, Curaçao, Las Aves, and Los Roques archipelago), since this island group presents non-distinguishable isotope values.

The remains of the skeletal material used in this project are currently stored at SKAL Museum, Kralendijk. In consideration of ethical obligations to minimize unnecessary destructive analysis, only those human remains with a high chance of producing meaningful results were sampled. In addition, communication with the local community of Bonaire was an important aspect of ethical practice. The community engagement process and public outreach strategies followed during the excavation can be found in Knippenberg (2022).

Analytical procedures

Sample preparations and processing were conducted under controlled conditions at the Laboratory for Archaeological Chemistry, Department of Archaeological Sciences, Leiden University, and measurements of isotope compositions *via* mass spectrometry were conducted at the Laboratory for Isotope Geochemistry, Faculty of Science, Vrije Universiteit Amsterdam. All sample preparation protocols used here can be found in Ambrose (1990) and Bocherens et al. (2011). In short, a specific surface (the one with the least superficial deposits and the least fragile) of the tooth was chosen for sample extraction and was thoroughly cleaned with a drill to remove superficial deposits and the outer layer and to expose the inner core enamel. Approximately 4–5 mg of enamel powder was extracted per tooth using a hand-held drill equipped with a pre-cleaned, diamond-tipped rotary burr, from which 1–3 mg is used for strontium analysis and the rest for oxygen and carbon analysis. A chemical pretreatment (following the protocol highlighted in Bocherens et al. [2011, 3]) was followed to remove possible contaminants that included powdered samples to be soaked in 2–3% sodium hypochlorite (NaOCl) to oxidize organic residues, then to be rinsed with distilled water, and finally to be treated with 1 M acetic acid–Ca (calcium) acetate buffer (pH = 4.75) to remove exogenous carbonate. Due to the lower diagenetic contamination of enamel and the application of the pretreatment protocol, there is no indication of postmortem contamination. Therefore, it is assumed that the enamel isotope results are reliable and reflect the original biogenic signal of the tissue.

For strontium isotope analysis, ~2 mg of enamel powder was dissolved in 0.5 ml of 3 N nitric acid (HNO_3). The strontium was extracted using ion chromatography by loading nitrated samples onto ultra-clean ion exchange columns, with strontium-specific crown ether resin (Sr-Spec, Eichrom Inc.). $^{87}Sr/^{86}Sr$ ratios were measured on a Thermo Triton Thermal Ionization Mass Spectrometer (TIMS). Long term measurements of an international standard reference material (NBS-987) produced a mean $^{87}Sr/^{86}Sr$ of 0.710247 ± 0.00002 (2σ) and the typical analytical error for all samples is <0.00001 (2SE). Typical total procedural blanks (<100 pg Sr) were negligible compared to the strontium content of enamel samples.

For oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C_{en}$) isotope analyses, pre-cleaned powdered enamel samples (~0.5 mg) were weighed into glass vials and placed in a hot block at 45°C for 24 h, after the addition of 100% orthophosphoric acid (H_3PO_4). Isolation of the produced carbon dioxide (CO_2) followed with a GasBench II universal automated interface. Measurements were conducted on a Finnigan Delta-Plus Isotope Ratio Mass Spectrometer (IRMS). Typical analytical uncertainty for both $\delta^{18}O$ and $\delta^{13}C$ measurements is <0.2‰.

Oxygen isotope analysis was conducted on the carbonate component of the teeth. In order to associate enamel $\delta^{18}O_{ap}$ values with those of drinking water ($\delta^{18}O_{dw}$), to compare with meteoric water ($\delta^{18}O_{prec}$), a conversion formula mentioned in Chenery et al. (2012) was applied.

To isolate the dentin, the teeth were sectioned transversely just below the crown. Collagen was extracted following standard procedures modified from Ambrose (1990). Samples were demineralized in 0.6 M hydrochloric acid (HCl) for several days (~6–10) at 4°C, with decanting processes in-between. Then, the acid was decanted again and the sample was rinsed in Milli-Q water and centrifuged. This process was repeated two to three times. A solution of 10 ml of 0.125 M sodium hydroxide (NaOH) was added for approximately 20 h to remove humid acids and other possible organic contaminants. Afterwards, the acid was decanted, the sample was rinsed in Milli-Q water, was centrifuged. The sample then was gelatinized in 0.001 M HCl (pH 3) at 80°C for 48 h. After, it was filtered using Ezee (Elkay) filters and prepared for freeze-drying. Around 0.5 mg of purified collagen is needed for analysis. Carbon ($\delta^{13}C_{col}$) and nitrogen ($\delta^{15}N_{col}$) isotope measurements were analyzed on a ThermoQuest IRMS Delta XP plus interfaced with a Flash elemental analyzer. International standards USGS40 and USGS41, and

IAEA-310(A) and IAEA-NO3 were used for sample calibration for $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ isotope analyses respectively, with a typical analytical uncertainty of <0.2‰.

Dietary reconstruction models

A dietary reconstruction model was used to examine the contributions of potential food groups to the individual diets. The Bayesian mixing model FRUITS (Food Reconstruction Using Isotopic Transferred Signals) is used for the analysis (Fernandes et al. 2014). Multiple dietary proxies were input in the mixing model ($\delta^{13}C_{col}$, $\delta^{13}C_{en}$, $\delta^{15}N_{col}$) and the contributions from the following food groups were examined: terrestrial animals, inshore/reef and pelagic marine resources, and C_3 and C_4 plants. Due to fractionation, there is an offset in the measurements from isotopic analysis of human skeletal tissues (the consumer) and the diet. For the $\delta^{15}N_{col}$ dietary proxy, an offset of 3.6 ± 1.2‰ was calculated (Ambrose 2002). For the $\delta^{13}C_{en}$, the offset applied was 10.1 ± 0.4‰ (Fernandes et al. 2014), while for $\delta^{13}C_{col}$ the offset was calculated individually using the formula from Pestle et al. (2015):

$$\delta^{13}C_{protein} = \left(0.78 \text{ x } \delta^{13}C_{col}\right) - \left(0.58 \text{ x } \Delta\delta^{13}C_{apa-col}\right) - 4.7.$$

Food group isotope values were collected from various studies in the Caribbean region (Supplemental Table S1). Macronutrient composition of each food group was determined using the USDA National Nutrient Database for Standard Reference (United States Department of Agriculture 2013).

The data were tested against two models. The first model uses a single category—marine animals—for all marine organisms (inshore, tidal, reef, and pelagic ecosystems). Given the faunal assemblage retrieved from the site of Amboina (also from suspected waste middens) being heavily marine oriented, with a high abundance in shellfish and sea turtle remains (Nieweg 2022), a second model was applied to distinguish between the marine organisms, which included organisms living in reef and inshore ecosystems (i.e., reef fish, mollusks, sea turtles), and pelagic fish (i.e., tuna, cartilaginous fish).

Results

All isotope analyses results are summarized in Table 2. Strontium isotope ratios ($^{87}Sr/^{86}Sr$) for the eight individuals from Amboina range from 0.70880 to 0.70909. The values cluster closely to each other and display minimal variation (see also Figure 4 below). Oxygen ($\delta^{18}O$) isotope values range from −4.7 to −3.2‰, with minimal variation as well (~1.5‰). The $\delta^{13}C_{en}$ values range from −7.9 to −4.3‰ (mean value of −5.8‰).

Collagen yields for dentin collagen were between 1.35 and 8.48% (Supplemental Table S2). Only four out of the eight samples yielded enough collagen for reliable stable isotope analysis. Quality control indicators to establish the preservation and reliability of collagen isotope values can be found in Ambrose (1990). These indicators (weight percentage per element, and C:N ratio) showed that for sample V237 (burial 4), collagen results may be unreliable, and therefore the sample was excluded from the diet

Table 2. Isotope results for Amboina.

Lab/Archaeological ID	Element	$^{87}Sr/^{86}Sr$	2 SE	$\delta^{18}O$ (‰ vs VPDB)	$\Delta^{18}O_{dw}$ (‰ vs VSMOW)	$\delta^{13}C_{en}$ (‰ vs VPDB)	Diet $\delta^{13}C_{en}$	$\delta^{13}C_{col}$ (‰ vs VPDB)	Diet $\delta^{13}C_{col}$	$\Delta\delta^{13}C_{ap\text{-}col}$ (‰ vs PDB)	$\delta^{15}N_{col}$ (‰ vs Nair)	Diet $\delta^{15}N_{col}$
C936/V184	M	0.70884	0.00008	−3.7	−5.6	−5.8	−15.9	/	/	/	/	/
C937/V244	M3	0.70889	0.00007	−3.5	−5.2	−7.9	−18.0	/	/	/	/	/
C938/V278	M2	0.70891	0.00007	−4.0	−6.0	−4.3	−14.4	−8.6	−13.9	4.3	14.2	10.6
C939/V320	M1	0.70899	0.00007	−3.1	−4.6	−6.1	−16.2	/	/	/	/	/
C940/V337	M2	0.70909	0.00008	−4.7	−7.2	−5.4	−15.5	−11.7	−17.4	6.3	13.3	9.7
C941/V317	M2	0.70902	0.00008	−4.3	−6.5	−5.2	−15.3	/	/	/	/	/
C942/V364	M1	0.70880	0.00007	−4.6	−7.1	−6.6	−16.7	−11.0	−15.8	4.4	12.6	9.0
C943/V237	M2	0.70895	0.00006	−4.3	−6.6	−4.7	−14.8	−10.8	−16.7	6.1	13.0	9.4
Mean	/	0.70894	0.00007	−4.0	−6.1	−5.8	−15.8	−10.5	−15.9	5.2	13.3	9.7
Median	/	0.70893	0.00007	−4.1	−6.2	−5.6	−15.7	−10.9	−16.2	5.2	13.2	9.6
SD	/	0	0	0.55	0.92	1.12	1.14	1.33	1.53	1.07	0.66	0.66

reconstruction model. The $\delta^{13}C_{col}$ values range from −11.7 to −8.6‰ (mean value of −10.5‰) and $^{15}N_{col}$ values between 13.0 and 14.2‰ (mean value of 13.3‰).

Dietary reconstruction models

Figure 3 and Table 3 present the results of the dietary reconstruction models. The results are quite mixed, with various contributions from the food sources in the three samples. For the first model where four food sources were used, we observe an average of 55.5 ± 0.2 consumption of animals and 42.2 ± 0.2 consumption of plants. The model also revealed a slight predominance of marine resources in the diets of two out of three individuals. When it comes to plant consumption, C_4 plants are the predominant plant contributors to the diet, with contributions ranging from 25% to 35%. For the second model, the one with the five food sources, we observe an average of 59.2 ± 0.2 animal consumption and 38.2 ± 0.1 plant consumption. The model did not result in a clear pattern for the consumption of either reef or pelagic resources. With the addition of one food source, the ratios of each group were rearranged. In this model, there is individual variation, which has been observed for the general isotope values among the sample. The contribution of reef resources ranges from 4% to 48% and that of pelagic resources from 13% to 42%. Both models present high variance in their results, with the standard deviation as high as 15%, indicating that they need to be treated with caution and corroborated with other evidence.

Discussion

Investigating patterns of mobility

In order to establish the locality of the individuals, their strontium and oxygen isotope ratios were compared against existing databases and previously published values from the Caribbean region. First, the strontium isotope results were compared against strontium isotope ratios that originate from the bedrock geology and previously published values of biologically available strontium isotopes (Laffoon 2012). According to its geology, Bonaire is expected to have ratios between ∼0.708 and 0.710 (Laffoon et al. 2012). Biosphere $^{87}Sr/^{86}Sr$ from the island provided a range of 0.70806–0.70915 (Laffoon 2012, 133). According to a strontium isotope map (iso-scape) for the circum-Caribbean region, the $^{87}Sr/^{86}Sr$ ratio range for the Leeward Antilles (ABC islands and Venezuelan archipelago) is estimated between 0.708 and 0.710 (Bataille, Laffoon, and Bowen 2012). All these values place the general strontium range for Bonaire between 0.708 and 0.710. Therefore, the isotope values obtained from the eight individuals indicate a local origin. However, the possibility of migration from a place with similar values cannot be excluded. The neighboring islands (Aruba, Curaçao), present bioavailable strontium isotope ratios very similar to Bonaire. Most of mainland Venezuela can be excluded from the list of potential places of origin, as samples of biologically available strontium from coastal Venezuela have provided higher $^{87}Sr/^{86}Sr$ ratios that are not consistent with those from Amboina (Figure 4). In addition, geologically available strontium from many continental regions provides values that are elevated (>0.710) relative to the Antilles (Laffoon et al. 2018).

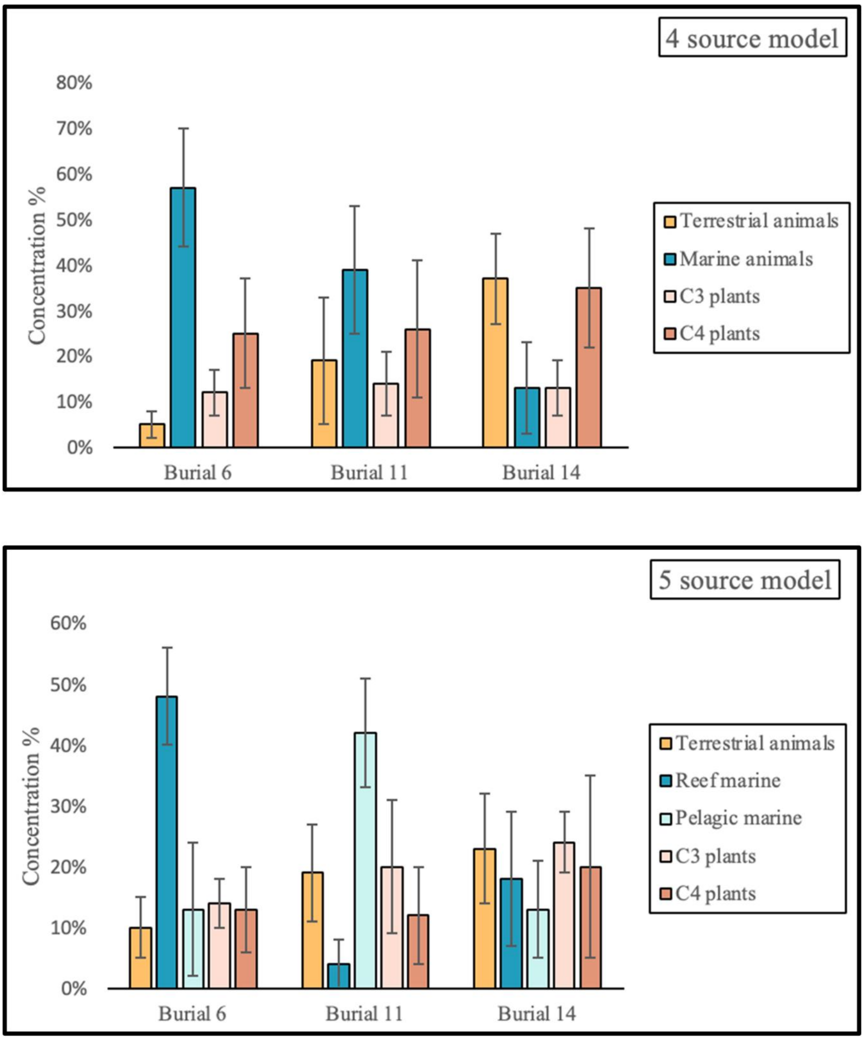

Figure 3. Results of FRUITS per individual using four (top) and five (bottom) food source models.

Table 3. Results of FRUITS per individual using four (top) and five (bottom) food source models.

Burial	ID	Terrestrial animals	SD	Marine animals	SD	C_3 plants	SD	C_4 plants	SD
Burial 6	V278	0.05	0.03	0.57	0.13	0.12	0.05	0.25	0.12
Burial 11	V337	0.19	0.14	0.39	0.14	0.14	0.07	0.26	0.15
Burial 14	V364	0.37	0.10	0.13	0.10	0.13	0.06	0.35	0.13

Burial	ID	Terrestrial animals	SD	Reef marine	SD	Pelagic marine	SD	C_3 plants	SD	C_4 plants	SD
Burial 6	V278	0.10	0.05	0.48	0.08	0.13	0.11	0.14	0.04	0.13	0.07
Burial 11	V337	0.19	0.08	0.04	0.04	0.42	0.09	0.20	0.11	0.12	0.08
Burial 14	V364	0.23	0.09	0.18	0.11	0.13	0.08	0.24	0.05	0.20	0.15

The second isotope system that was used to investigate the localness of the individuals was oxygen. Amboina's oxygen values were compared with the oxygen values in precipitation and with previously published values obtained from skeletal remains (Laffoon 2012; Laffoon,

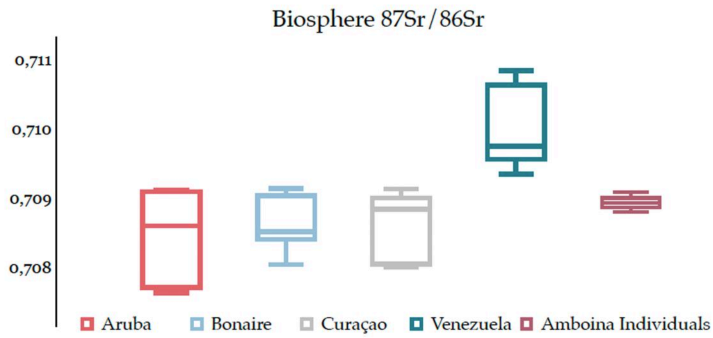

Figure 4. Boxplot with biosphere $^{87}Sr/^{86}Sr$ local ranges for the ABC islands and northern coastal Venezuela (Laffoon 2012; Laffoon et al. 2018), with the values of the eight individuals from Amboina.

Hofman, and Rojas 2013; Schroeder et al. 2009). An iso-scape has been created for the circum-Caribbean region, depicting the spatial variation of $\delta^{18}O$ in precipitation (Laffoon et al. 2014). According to this, the $\delta^{18}O$ values expected for Bonaire range between −4 and −1‰. There are certain limitations to be considered here, such as the conversion of values, associated regression errors, and fractionation differences between carbonate and phosphate oxygen (Daux et al. 2008; Pollard, Pellegrini, and Lee-Thorp 2011). Therefore, oxygen isotopes need to be interpreted with caution. In addition, in this study, for two individuals, the first molar (M1) was sampled (V320 and V364). Because M1 enamel mineralizes between time of birth and 3 years (AlQahtani, Hector, and Liversidge 2010), their isotope values could be influenced by breastfeeding/weaning practices. Higher $\delta^{18}O$ and lower $\delta^{13}C$ are expected during breastfeeding, as breast milk is more enriched in $\delta^{18}O$ than drinking water (Britton et al. 2015). After the cessation of breastfeeding, $\delta^{18}O$ is excepted to gradually reduce and $\delta^{13}C$ to gradually increase as the infant is weaning (Wright and Schwarcz 1999).

Using previously published values allows for comparison between the same tissues and the same component (structural carbonate). The Caribbean region presents a relative homogeneity in its values due to broadly similar climatic and environmental conditions. The $\delta^{18}O$ values from individuals interred in Caribbean sites vary between −6.2 and −1.1‰ (Laffoon 2012; Laffoon, Hofman, and Rojas 2013; Schroeder et al. 2009). There is a difference of −1.3‰ between the mean values from the Antilles and those from Amboina, even for samples V320 and V364, which is not large enough to indicate a non-local origin for the individuals. For mainland Venezuela, there is a lack of data from analysis of skeletal remains. For this reason, estimates are based on modern precipitation $\delta^{18}O$ data from the GNIP (Global Network of Isotopes in Precipitation). According to the $\delta^{18}O$ values in precipitation (Supplemental Table S3), the coastal area presents similarities in values to those from the insular Caribbean (−4 to −1‰), and based on this parameter alone, this coastal zone cannot be excluded as the origin for the Amboina individuals. Further inland/highland areas in northern South America, however, present lower values (−9 to −4‰) and can be excluded (Laffoon et al. 2014).

Both strontium and oxygen isotope results from the eight individuals seem to fall within the range of both Bonaire and the rest of the southern Caribbean region (i.e., Aruba, Curaçao, Las Aves, and Los Roques archipelago), however they largely fall outside of the range of mainland Venezuela. Therefore, all can be considered isotopically local. The issue of identifying non-local individuals using isotopic analysis is a complicated one. Strontium and oxygen isotope ranges present spatial variation but the spatial patterning is not absolute, especially in island settings. What is observed is an issue of equifinality, where multiple regions/islands present similar values, especially when measuring geologically available strontium or oxygen isotope ratios in precipitation, given the similar geological, climatic, and environmental conditions between many of the islands (Price, Burton, and Stoltman 2007). Therefore, values between the Greater Antilles and Lesser Antilles might present enough spatial variation to identify non-local individuals, however this is not always true for islands within the same archipelago or island cluster. For the region in question, isotopic values are very similar across the Leeward Antilles. Consequently, the terms "locals" vs "non-locals" should be defined more clearly to establish whether they refer to locality to the site under investigation, to the island, or to the broader region in order to account both for the complexity of the method and of human mobility. Strontium and oxygen isotopes, in their current state, are not able to answer whether the eight individuals are local to the site of Amboina, the island of Bonaire, the ABC islands, or whether they originate from another place with similar isotope values.

Investigating patterns of diet

Focusing on diet, the carbon apatite values ($\delta^{13}C_{ap}$) mainly reveal the contribution of different plant resources to an individual's whole diet (C_3 and C_4). C_3 plants in the Caribbean have been calculated to range between −32 and −20‰, while C_4/CAM plants, between −14 and −8‰ (Pestle 2010, 241). Taking into account a diet–tissue offset (isotopic fractionation factor), the eight individuals from Amboina provided a mean $\delta^{13}C_{en}$ value of −15.8‰ for their whole diet (Table 2), placing them in-between those of C_3 and C_4/CAM plants. The individuals from Amboina seem to have had mixed contributions of both these plant categories. Some C_3 plants that have been identified as parts of indigenous diets in the pre-colonial Caribbean are wild bean (*Fabaceæ*), sweet potato (*Ipomoea batatas*), manioc (*Manihot esculenta*), and marunguey (*Zamia* sp.) (Pagán-Jiménez and Mickleburgh 2022). Regionally available C_4/CAM plants include maize (*Zea mays*), amaranth (*Amaranthus* sp.), century plant (*Agave antillarum*), pineapple (*Ananas comosus*), and prickly pear cactus (*Opuntia* sp.) (Pestle 2010). The less negative carbon ($\delta^{13}C_{en}$) isotope values observed in Amboina, could be indicative of slightly heavier reliance on C_4/CAM plants. The consumption of cultivates (maize, manioc) has been attested for regions of Venezuela, multiple islands in the Caribbean (including Aruba), and therefore could be probable for Bonaire, which presents similar ecological conditions that facilitate crop cultivation (Mickleburgh and Pagán-Jiménez 2012; Pagán-Jiménez and Mickleburgh 2022; Pagán-Jiménez et al. 2015). However, no macro-botanical remains have been recovered from the site that could positively identify the exact plants consumed (Knippenberg 2022, 199).

The second proxy used is the carbon ($\delta^{13}C_{col}$) and nitrogen ($\delta^{15}N_{col}$) collagen values, which primarily represent the protein component of the diet. In general, marine/aquatic organisms have higher carbon and nitrogen isotope values than terrestrial ones (DeNiro and Epstein 1981; Schoeninger and DeNiro 1983). The collagen isotope values ($n = 4$)

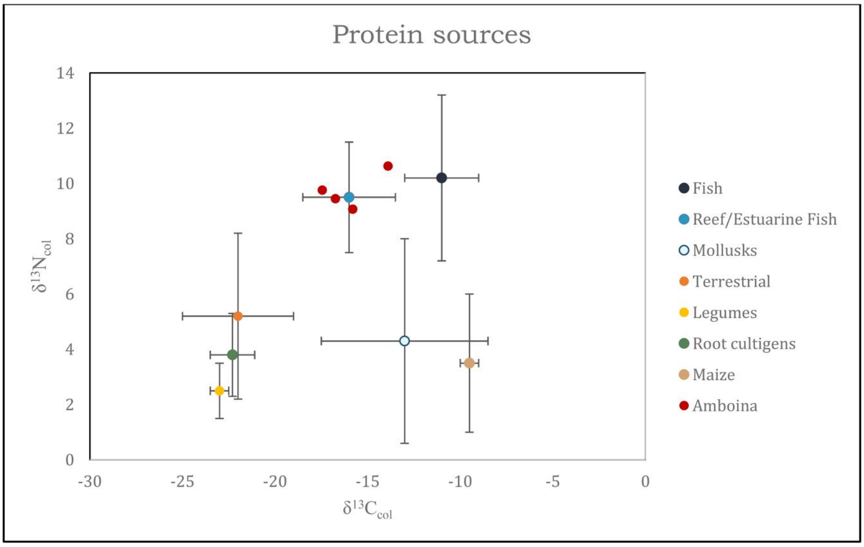

Figure 5. δ^{13}C and δ^{15}N values of various food groups available in the Caribbean, together with the values for the Amboina individuals that represent protein intake (food sources values from Chinique de Armas et al. 2015).

seem to fall into the range of marine resources and marine animals (Figure 5). The small island location of the Amboina site provides access to marine resources, including both reef environments and the open sea. In general, a large variety of marine resources has been reported for the ABC islands and the Las Aves and Los Roques archipelagos, which conditioned the subsistence practices of their inhabitants, since terrestrial resources are rather limited (Newsom and Wing 2004, 58). In Amboina, remains of mollusks, sea turtles, marine crabs, and fish indicate their consumption by the local population, again with a predominance of sea turtles and fish. At the site, mainly remains of parrotfish *Sparisoma viride* and *Sparisoma* sp. are found, and a single doctor fish (Acanthuridae). Cartilaginous fish (sharks) were also found at the site. An abundance of shells and mollusks was encountered among the faunal assemblage, which includes gastropods (i.e., *Aliger gigas*, *Cittarium pica*), a number of bivalves (i.e., *Codakia* sp, *Pinctada imbricata radiata*), and smaller mollusks (Nieweg 2022). The species with a clear abundance at the site is the large shellfish, *Aliger gigas*, which was commonly consumed throughout the Caribbean. This shellfish is rich in nutritional value, as it is high in protein, and low in fat and carbohydrates (Antczak 1999, 167). The consumption of this shellfish could explain the elevated values of $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ observed for the measured individuals.

Terrestrial vertebrate diversity on Bonaire is low. Reptiles and bird remains are the main terrestrial vertebrates encountered at the site of Amboina. Although the most common reptile species on the site is a sea turtle, cf. *Chelonia mydas*, green iguana (*Iguana iguana*) is also encountered in small numbers in the assemblage (Nieweg 2022). Cut and burn marks on the faunal remains indicate human consumption. Birds, which were mostly small and likely not part of the diet, complement the terrestrial faunal assemblage in Amboina (Nieweg 2022). Therefore, the archaeological evidence for the consumption of terrestrial animals is limited.

The three isotopic proxies analyzed here indicate a diet with contributions of both C_3 and C_4/CAM plants and a mix of terrestrial and marine organisms as a protein source. The results of the dietary reconstruction model confirm these highly mixed diets, and also add a variation in the contributions of reef marine animals and pelagic fish. Consumption of terrestrial animals and/or C_3 plants, reaches up to 37% (i.e., adult male of Burial 14 [V364]). However, due to the paucity of archaeological evidence supporting the presence of terrestrial animals on the site this signal is possibly mainly driven by the consumption of C_3 plants. Marine and reef resource contributions reach 57% (i.e., older adult male of Burial 6 [V278]).

The variation in stable isotope values between the individuals is notable. Despite small sample size, the differences between minimum and maximum values are distinct, reaching up to 3.5‰ for $\delta^{13}C_{en}$, and 3‰ for $\delta^{13}C_{col}$, especially in one individual (V278) compared to the others. Moreover, the dietary reconstruction model results are highly variable between the individuals where values ranging up to 44% for certain food groups (i.e., marine animal consumption) are observed. There appears to be a variation in diet and access/consumption of different resources. The reasons behind these discrepancies can be multi-fold. First, the possibility of different origins for these individuals should be considered. Even though strontium and oxygen isotope analyses indicated an isotopically local origin, a potential migration to Amboina from a place with different dietary habits could explain the dietary variability observed. Moreover, other cultural practices could have affected the individuals' consumption behaviors, such as those related to status or breastfeeding and weaning. Lastly, it is important to keep in mind that all individuals were not necessarily living at the site at the same time. ^{14}C measurements from four skeletons provided a range between AD 992 and 1387 (Knippenberg 2022). Temporal variation in resource availability or the dietary practices on the site could also account for the variability in the isotope values. Possible fluctuations in the climatic conditions (periods of drought or changes in temperature) throughout this time period could be another reason why different resources were consumed, as climatic conditions could have affected resource availability. However, the data we have from the site are limited and inferences regarding these parameters cannot be made with certainty.

The limited sample size analyzed from Amboina cannot be considered representative of the whole population from the site. However, it is notable that one individual (Burial 6—V278), who has been identified as a male over 53 years old, presents the highest carbon ($\delta^{13}C_{en}$ and $\delta^{13}C_{col}$), and the highest nitrogen values ($\delta^{15}N_{col}$), indicating a diet rich in more C_4/CAM plants and/or marine resources, which is also attested in the dietary reconstruction model. This individual seems to have had a more important role in the community based on the rich and partly exotic set of grave goods associated with him and the fact that he was interred within the perimeter of the largest residential structure at the site. This older male individual was buried together with a shell disk, a shell bead, and an anklet with 28 small shell beads, something that contrasts with the poorer grave goods inventory found in other burials. In addition, as mentioned earlier, the skull of the individual seems to have been deliberately removed from the burial (Fricke and Knippenberg 2022; see also Figure 2).

In the Caribbean, past isotope research (Laffoon 2012; Laffoon and de Vos 2011; Laffoon, Hofman, and Rojas 2013; Laffoon et al. 2016; Mickleburgh and Laffoon 2018; Pestle 2010; Reid 2018; Stokes 1998) indicates that in the majority of Ceramic Age sites, $\delta^{13}C_{ap}$ values are around −9.8‰, $\delta^{13}C_{col}$ values around −16.5‰, and $\delta^{15}N_{col}$ around 10.4‰ (Figure 6). The main patterns observed indicate mixed diets, with variable consumption of C_3/C_4 plants and marine/terrestrial resources. The larger islands of the Greater Antilles are characterized by increased variety in fauna and flora, and a diet based more on C_3 plants and on small terrestrial mammals (Stokes 1998). Smaller islands or coastal sites are more oriented toward marine resources, which are more abundant as part of either nearshore, reef, or pelagic ecosystems (Stokes 1998). A good example of this is observed in Carriacou in the southern Lesser Antilles, where stable isotopic analysis indicates individuals relied primarily on marine-based diet involving a high consumption of shellfish (Krigbaum, Fitzpatrick, and Bankaitis 2013). In St. Lucia, another island in the Lesser Antilles, the diet seems to be rather mixed, with inputs from both terrestrial and marine resources, as is often observed in the Caribbean (Laffoon et al. 2016). In general, the isotope results indicate a slight predominance of C_3 plants amongst most pre-colonial Caribbean populations, with a more limited presence of C_4 plants, including maize (Laffoon, Hofman, and Rojas 2013; Stokes 1998). New evidence from starch analysis, indicates a widespread consumption of maize throughout Caribbean sites, starting from the Archaic and Early Ceramic Age. In addition, traces of maize consumption have been identified within Dabajuroid contexts for the island of Aruba, a neighboring island to Bonaire (Pagán-Jiménez and Mickleburgh 2022).

Isotopic analysis in Aruba revealed the highest carbon ($\delta^{13}C_{en}$ and $\delta^{13}C_{col}$) isotope values in the pre-colonial Antilles, and higher nitrogen ($\delta^{15}N_{col}$) values, indicating a

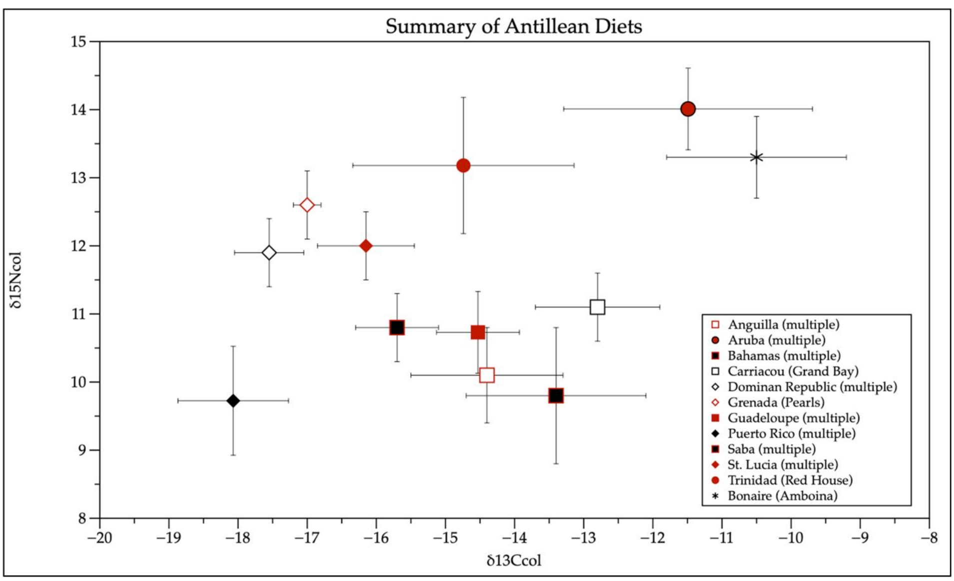

Figure 6. Chart of $\delta^{13}C_{col}$ and $\delta^{15}N$ results showing mean values and standard deviation values (arrow bars) for previously published isotope values from Caribbean islands (single or multiple sites mentioned in the parentheses).

preference for marine resources in terms of protein (Mickleburgh and Laffoon 2018). This accords with the Amboina values and could represent a broader dietary pattern characteristic of the ABC islands, dictated by local resource availability. To a lesser extent, less negative collagen (both $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$) isotope values are also observed in the Grenadines, which could be a signal of more marine-oriented diets in the southern Caribbean (Krigbaum, Fitzpatrick, and Bankaitis 2013). Greater consumption of marine protein could be due to the limited presence of terrestrial animals (Newsom and Wing 2004). However, the consumption of marine resources should be expected in the majority of Caribbean islands, especially the smaller ones in the Lesser Antilles. The elevated ($\delta^{15}N_{col}$) and less negative ($\delta^{13}C_{en}$ and $\delta^{13}C_{col}$) isotopic values in Bonaire could be investigated in the quantity and frequency of marine protein consumption that could differentiate it from other sites. Alternatively, the higher values could be attributed to the increased consumption of maize and other C_4/CAM plants (agave, pineapple) that are available in the region. Maize starch grain has been identified in Aruban dental calculus samples (Mickleburgh and Pagán-Jiménez 2012). Lastly, it should be noted that dietary habits are to a great extent also influenced by cultural factors and practices that could differ between communities residing in the same region.

Conclusion

This project employed a multi-isotope approach to investigate patterns of mobility and diet at the pre-colonial site of Amboina in Bonaire. All eight individuals examined provided strontium and oxygen isotope values that fell within the range calculated for the island of Bonaire, and therefore were deemed isotopically local. However, due to equifinality, the nature of "local" is complicated. Neighboring islands have similar geological and environmental settings, and therefore present similar strontium and oxygen isotope values to those of Bonaire.

Carbon and nitrogen isotopic values, despite being highly variable, are indicative of consumption of both C_3 and C_4 plants and an increased consumption of marine resources and marine animals. The dietary models also suggest mixed and highly variable diets with a generally low consumption of terrestrial animals—supported also by the faunal record for the site. Despite the small sample size, variation in diet and access to/consumption of different resources is observed. These discrepancies could be due to different origins for the individuals (from other sites and/or neighboring islands that are isotopically indistinguishable based on strontium isotopes) or the possibility that the analyzed individuals lived during different time periods subject to differing climatic conditions and resource availability. In the Amboina case, however, the strongest support is for explanations that relate to social status differences or intra-societal variability.

To deal with the issue of equifinality in the future, the incorporation of additional isotopic systems, such lead, sulfur, zinc, or hydrogen, could complement the reference material to which isotope results are being compared. In addition, there are other methodologies that permit further investigation of diet to establish more clearly the contributions of specific food groups. One of these is the analysis of starch granules in dental calculus, which can reveal the specific plants that were consumed. Starch analysis is a very effective and minimally invasive tool as the extraction of calculus does not require destructive tissue sampling. Another method is the analysis of ancient proteins, which focuses on the identification of amino acids in different biological tissues to distinguish subsistence practices. Lastly, aDNA would provide answers regarding the genetic affinity between individuals and their interpersonal relationships. Collectively these such studies could enhance the isotopic analyses to provide a fuller understanding of Amboina and its connectivity to other Ceramic Age communities.

Supplemental Material

Supplemental Table S1. FRUITS1 input values. Isotope values and macronutrient composition of food groups used for the dietary mixing model.
Supplemental Table S2. Dentine collagen quality controls.
Supplemental Table S3. δ18O data from GNIP stations associated to Bonaire.

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Disclosure statement

The authors report there are no competing interests to declare.

ORCID

Eleni Seferidou http://orcid.org/0009-0000-0066-477X

References

AlQahtani, S. J., M. P. Hector, and H. M. Liversidge. 2010. Brief communication: The London atlas of human tooth development and eruption. *American Journal of Physical Anthropology* 142 (3):481–90. 10.1002/ajpa.21258

Ambrose, S. H. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* 17 (4):431–51. 10.1016/0305-4403(90)90007-R

Ambrose, S. H. 2002. Controlled diet and climate experiments on nitrogen isotope ratios of rats. In *Biogeochemical approaches to paleodietary analysis*, ed. S. H. Ambrose and M. A.

Katzenberg, 5:243–59. Advances in Archaeological and Museum Science. Boston: Kluwer Academic Publishers.

Ambrose, S. H., and L. Norr. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In *Prehistoric human bone*, ed. J. B. Lambert and G. Grupe, 1–37. Berlin: Springer.

Antczak, A. T. 1999. Late prehistoric economy and society of the islands off the Coast of Venezuela: A contextual interpretation of the non-ceramic evidence. Doctoral diss., University College.

Antczak, A. T., M. M. Antczak, and A. Jaimes. 2018. Debating lithics from pre-colonial sites in Los Roques Archipelago, Venezuela (AD 1000–1500). In *Multas per Gentes et Multa per Saecula. Amici Magistro et Collegea Sua Ionni Christopho Kozłowski Dedicant [Many through nations and many through ages: Friends and colleagues dedicated to his master John Christopher Kozłowski]*, ed. P. Valde-Nowak, K. Sobczyk, M. Nowak, and J. Zrałka, 669–88. Krakow: Alter Publishing House.

Antczak, A. T., B. Urbani, and M. M. Antczak. 2017. Re-thinking the migration of Cariban-speakers from the Middle Orinoco River to North-Central Venezuela (AD 800). *Journal of World Prehistory* 30 (2):131–75. 10.1007/s10963-017-9102-y

Antczak, M. M. 2000. "Idols" in exile: Making sense of prehistoric human pottery figurines from Dos Mosquises Island, Los Roques Archipelago, Venezuela. Doctoral diss., University of London, University College London.

Antczak, M. M., and A. T. Antczak. 2016. Late pre-colonial and early colonial archaeology of the Las Aves Archipelagos, Venezuela. *Contributions in New World Archaeology* 8:7–44.

Bataille, C. P., J. E. Laffoon, and G. J. Bowen. 2012. Mapping multiple source effects on the strontium isotopic signatures of ecosystems from the circum-Caribbean region. *Ecosphere* 3 (12):1–24. 10.1890/ES12-00155.1

Bentley, R. A. 2006. Strontium isotopes from the earth to the archaeological skeleton: A review. *Journal of Archaeological Method and Theory* 13 (3):135–87.

Bocherens, H., O. Sandrock, O. Kullmer, and F. Schrenk. 2011. Hominin palaeoecology in Late Pliocene Malawi: First insights from isotopes (^{13}C, ^{18}O) in mammal teeth. *South African Journal of Science* 107 (3/4):1–6. 10.4102/sajs.v107i3/4.331

Booden, M. A., R. G. A. M. Panhuysen, M. L. P. Hoogland, H. N. Jong, G. R. Davies, and C. L. Hofman. 2008. Tracing human mobility with $^{87}Sr/^{86}Sr$ at Anse à La Gourde, Guadeloupe. In *Crossing the borders new methods and techniques in the study of archaeology materials from the Caribbean*, ed. A. L. van Gijn, M. L. P. Hoogland, and C. L. Hofman, 215–25. Tuscaloosa: University of Alabama Press.

Boomert, A. 2000. Trinidad, Tobago and the Lower Orinoco interaction sphere. Doctoral diss., Leiden University.

Bowen, G. J., L. I. Wassenaar, and K. A. Hobson. 2005. Global application of stable hydrogen and oxygen isotopes to wildlife forensics. *Oecologia* 143 (3):337–48. 10.1007/s00442-004-1813-y

Bright, A. J. 2011. *Blood is thicker than water: Amerindian intra- and inter-insular relationships and social organization in the pre-colonial Windward Islands*. Leiden: Sidestone Press.

Britton, K., B. T. Fuller, T. Tutken, S. Mays, and M. P. Richards. 2015. Oxygen isotope analysis of human bone phosphate evidences weaning age in archaeological populations. *American Journal of Physical Anthropology* 157 (2):226–41. 10.1002/ajpa.22704

Chenery, C. A., V. Pashley, A. L. Lamb, H. J. Sloane, and J. A. Evans. 2012. The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite. *Rapid Communications in Mass Spectrometry* 26 (3):309–19. 10.1002/rcm.5331

Chinique de Armas, Y., W. M. Buhay, R. R. Suarez, S. Bestel, D. Smith, S. D. Mowat, and M. Roksandic. 2015. Starch analysis and isotopic evidence of consumption of cultigens among fisheregatherers in Cuba: The archaeological site of Canímar Abajo, Matanzas. *Journal of Archaeological Science* 58:121–32. 10.1016/j.jas.2015.03.003

Chinique de Armas, Y., U. M. González Herrera, I. Reyes Serrano, W. M. Buhay, S. Skelton, R. Rodríguez Suárez, M. Roksandic, and J. E. Laffoon. 2022. Multiproxy paleodietary reconstruction using stable isotopes and starch analysis: The case of the archaeological site of Playa Del

Mango, Granma, Cuba. *Journal of Archaeological Science: Reports* 46:103671. 10.1016/j.jasrep.2022.103671
Chinique de Armas, Y., A. M. Mavridou, J. G. Dominguez, K. Hanson, and J. E. Laffoon. 2021. Tracking breastfeeding and weaning practices in ancient populations by combining carbon, nitrogen and oxygen stable isotopes from multiple non-adult tissues. *PLoS One* 17 (2):1–28.
Chinique de Armas, Y., and W. J. Pestle. 2018. Assessing the association between subsistence strategies and the timing of weaning among Indigenous archaeological populations of the Caribbean. *International Journal of Osteoarchaeology* 28 (5):492–509. 10.1002/oa.2695
Chinique de Armas, Y., M. Roksandic, D. Nikitovic, R. R. Suarez, D. Smith, N. Kanik, D. G. Jorda, and W. M. Buhay. 2017. Isotopic reconstruction of the weaning process in the archaeological population of Canimar Abajo, Cuba: A Bayesian probability mixing model approach. *PLoS One* 12 (5):e0176065. 10.1371/journal.pone.0176065
Cijntje, D. 2022. Aardewerk. In *Wonen En Begraven Op Amboina Resultaten van Archeologisch Onderzoek Op Een van de Omvangrijkste Nederzettingssites Uit de Ceramische Tijd Op Bonaire [Living and burial on Amboina results of archaeological research at one of the most extensive ceramic age settlement sites on Bonaire]*, ed. S. Knippenberg, 91–117. Leiden: Archol Excavation Report 598.
Coplen, T. B. 1995. Reporting of stable carbon, hydrogen and oxygen isotopic abundances. *Geothermics* 24 (5–6):707–12. 10.1016/0375-6505(95)00024-0
Curet, L. A. 2005. *Caribbean paleodemography: Population, culture history, and sociopolitical processes in ancient Puerto Rico*. Tuscaloosa: University of Alabama Press.
Dansgaard, W. 1964. Stable isotopes in precipitation. *Tellus* 16 (4):436–68. 10.1111/j.2153-3490.1964.tb00181.x
Daux, V., C. Lécuyer, M.-A. Héran, R. Amiot, L. Simon, F. Fourel, F. Martineau, N. Lynnerup, H. Reychler, and G. Escarguel. 2008. Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution* 55 (6):1138–47. 10.1016/j.jhevol.2008.06.006
deFrance, S. D. 2013. Zooarchaeology in the Caribbean: Current research and future prospects. In *The Oxford handbook of Caribbean archaeology*, ed. W. F. Keegan, C. L. Hofman, and R. R. Ramos, 378–90. Oxford: Oxford University Press.
DeNiro, M. J., and S. Epstein. 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42 (5):495–506. 10.1016/0016-7037(78)90199-0
DeNiro, M. J., and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45 (3):341–51. 10.1016/0016-7037(81)90244-1
Ericson, J. E. 1985. Strontium isotope characterization in the study of prehistoric human ecology. *Journal of Human Evolution* 14 (5):503–14. 10.1016/S0047-2484(85)80029-4
Fernandes, R., A. R. Millard, M. Brabec, M.-J. Nadeau, and P. Grootes. 2014. Food reconstruction using isotopic transferred signals (FRUITS): A Bayesian model for diet reconstruction. *PLoS One* 9 (2):e87436. 10.1371/journal.pone.0087436
Fricke, F. J. 2022. Osteology report. In *Wonen En Begraven Op Amboina Resultaten van Archeologisch Onderzoek Op Een van de Omvangrijkste Nederzettingssites Uit de Ceramische Tijd Op Bonaire [Living and burial on Amboina results of archaeological research at one of the most extensive ceramic age settlement sites on Bonaire]*, ed. S. Knippenberg, 224–83. Leiden: Archol Excavation Report 598.
Fricke, F. J., and S. Knippenberg. 2022. Graven. In *Wonen En Begraven Op Amboina Resultaten van Archeologisch Onderzoek Op Een van de Omvangrijkste Nederzettingssites Uit de Ceramische Tijd Op Bonaire [Living and burial on Amboina results of archaeological research at one of the most extensive ceramic age settlement sites on Bonaire]*, ed. S. Knippenberg, 68–76. Leiden: Archol Excavation Report 598.
Fricke, H. C., J. R. O'Neil, and N. Lynnerup. 1995. Oxygen isotope composition of human tooth enamel from medieval Greenland: Linking climate and society. *Geology* 23 (10):869–72. 10.1130/0091-7613(1995)023<0869:SROICO>2.3.CO;2
Giovas, C. M., M. J. LeFebvre, and S. M. Fitzpatrick. 2012. New records for prehistoric introduction of neotropical mammals to the West Indies: Evidence from Carriacou, Lesser Antilles. *Journal of Biogeography* 39 (3):476–87. 10.1111/j.1365-2699.2011.02630.x

Haviser, J. 1991. *The first Bonaireans*. Curaçao: Archaeological-Anthropological Institute of the Netherlands Antilles.

Haviser, J. 2015. *Managing our past into the future. Archaeological heritage management in the Dutch Caribbean*. Ed. C. L. Hofman. Leiden: Sidestone Press.

Hofman, C. L. 2019. Indigenous Caribbean networks in a globalizing world. In *Power, political economy, and historical landscapes of the modern world: Interdisciplinary perspectives*, ed. C. R. DeCorse, 55–79. Albany: State University of New York Press.

Hofman, C. L., and A. J. Bright. 2010. Towards a pan-Caribbean perspective of pre-colonial mobility and exchange. *Journal of Caribbean Archaeology* SP3:2008–10.

Hofman, C. L., A. J. Bright, A. Boomert, and S. Knippenberg. 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 (3):243–68. 10.2307/25478180

Hofman, C. L., and M. L. P. Hoogland. 2004. Social dynamics and change in northern Lesser Antilles. In *Late ceramic age societies in the Eastern Caribbean*, ed. A. Delpuech and C. L. Hofman, 33–44. Oxford: BAR International Series 1273. Archaeopress.

Hofman, C. L., and M. L. P. Hoogland. 2011. Unravelling the multi-scale networks of mobility and exchange in the pre-colonial circum-Caribbean. In *Communities in contact. Essays in archaeology, ethnohistory & ethnography of the Amerindian circum-Caribbean*, ed. C. L. Hofman and A. van Duijvenbode, 15–44. Leiden: Sidestone Press.

Hofman, C. L., M. L. P. Hoogland, and A. L. van Gijn. 2008. Crossing disciplinary boundaries and national borders. New methods and techniques of archaeological materials from the Caribbean. In *Caribbean archaeology and ethnohistory; crossing the borders. New methods and techniques in the study of archaeological materials from the Caribbean*, ed. C. L. Hofman and A. L. van Gijn, 1–20. Tuscaloosa: University of Alabama Press.

Hofman, C. L, and A. van Duijvenbode, eds. 2011. *Communities in contact: Essays in archaeology, ethnohistory & ethnography of the Amerindian circum-Caribbean*. Leiden: Sidestone Press.

Hoogland, M. L. P., C. L. Hofman, and R. G. A. M. Panhuysen. 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*, ed. S. M. Fitzpatrick and A. H. Ross, 148–62. Gainesville, FL: University Press of Florida.

Keegan, W. F., and M. J. DeNiro. 1988. Stable carbon- and nitrogen-isotope ratios of bone collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. *American Antiquity* 53 (2):320–36. 10.2307/281022

Knippenberg, S. 2006. Stone artefact production and exchange among the Lesser Antilles. Doctoral diss., Leiden University.

Knippenberg, S. 2022. *Wonen En Begraven Op Amboina Resultaten van Archeologisch Onderzoek Op Een van de Omvangrijkste Nederzettingssites Uit de Ceramische Tijd Op Bonaire*. Leiden: Archol Excavation Report 598.

Knippenberg, S., and F. J. Fricke. 2022. Beschouwing Graven. In *Wonen En Begraven Op Amboina. Resultaten van Archeologisch Onderzoek Op Een van de Omvangrijkste Nederzettingssites Uit de Ceramische Tijd Op Bonaire [Living and burial on Amboina results of archaeological research at one of the most extensive ceramic age settlement sites on Bonaire]*, ed. S. Knippenberg, 79–82. Leiden: Archol Excavation Report 598.

Krigbaum, J., S. M. Fitzpatrick, and J. Bankaitis. 2013. Human paleodiet at Grand Bay, Carriacou, Lesser Antilles. *The Journal of Island and Coastal Archaeology* 8 (2):210–27. 10.1080/15564894.2012.756082

Laffoon, J. E. 2012. Patterns of paleomobility in the ancient Antilles: An isotopic approach. Doctoral diss., Leiden University.

Laffoon, J. E. 2016. Human mobility and dietary patterns in precolonial Puerto Rico integrating multiple isotope data. In *Cuban archaeology in the Caribbean*, ed. I. Roksandic, 147–67. Gainesville: University of Florida Press.

Laffoon, J. E., A. T. Antczak, M. M. Antczak, and T. F. Sonnemann. 2018. Sourcing nonnative mammal remains from Dos Mosquises Island, Venezuela: New multiple isotope evidence. *Archaeological and Anthropological Sciences* 10 (6):1265–81. 10.1007/s12520-016-0453-6

Laffoon, J. E., G. R. Davies, C. L. Hofman, and M. L. P. Hoogland. 2012. 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 (7):2371–84. 10.1016/j.jas.2012.02.002

Laffoon, J. E., and B. R. de Vos. 2011. Diverse origins, similar diets: An integrated isotopic perspective from Anse à La Gourde, Guadeloupe. In *Communities in contact: Essays in archaeology, ethnohistory & ethnography of the Amerindian circum-Caribbean*, ed. C. L. Hofman and A. van Duijvenbode, 187–204. Leiden: Sidestone Press.

Laffoon, J. E., C. L. Hofman, and R. V. Rojas. 2013. Oxygen and carbon isotope analysis of human dental enamel from the Caribbean: Implications for investigating individual origins. *Archaeometry* 55 (4):742–65. 10.1111/j.1475-4754.2012.00698.x

Laffoon, J. E., M. L. P. Hoogland, G. R. Davies, and C. L. Hofman. 2016. Human dietary assessment in the pre-colonial Lesser Antilles: New stable isotope evidence from Lavoutte, Saint Lucia. *Journal of Archaeological Science: Reports* 5:168–80. 10.1016/j.jasrep.2015.11.020

Laffoon, J. E., R. R. Ramos, L. C. Baik, Y. N. Storde, M. R. Lopez, G. R. Davies, and C. L. Hofman. 2014. Long-distance exchange in the precolonial circum-Caribbean: A multi-isotope study of animal tooth pendants from Puerto Rico. *Journal of Anthropological Archaeology* 35: 220–33. 10.1016/j.jaa.2014.06.004

Luz, B., Y. Kolodny, and M. Horowitz. 1984. Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. *Geochimica et Cosmochimica Acta* 48 (8):1689–93. 10.1016/0016-7037(84)90338-7

Mickleburgh, H. L., and J. E. Laffoon. 2018. Assessing dietary and subsistence transitions on prehistoric Aruba: Preliminary bioarchaeological evidence. In *The archaeology of Caribbean and circum-Caribbean farmers (5000 BC–AD 1500)*, ed. B. A. Reid, 279–306. Gainesville, FL: University of Florida Press.

Mickleburgh, H. L., and J. R. Pagán-Jiménez. 2012. New insights into the consumption of maize and other food plants in the pre-Columbian Caribbean from starch grains trapped in human dental calculus. *Journal of Archaeological Science* 39 (7):2468–78. 10.1016/j.jas.2012.02.020

Newsom, L. A., and E. S. Wing. 2004. *On land and sea: Native American uses of biological resources in the West Indies*. Tuscaloosa: The University of Alabama Press.

Nieweg, D. C. 2022. Archeozo€ologische Resten. In *Wonen En Begraven Op Amboina Resultaten van Archeologisch Onderzoek Op Een van de Omvangrijkste Nederzettingssites Uit de Ceramische Tijd Op Bonaire [Living and burial on Amboina results of archaeological research at one of the most extensive ceramic age settlement sites on Bonaire]*, ed. S. Knippenberg, 161–76. Leiden: Archol Excavation Report 598.

Oliver, J. R. 1989. The archaeological, linguistic and ethnohistorical evidence for the expansion of Arawakan into Northwestern Venezuela and Northern Columbia. PhD thes., University of Illinois.

Pagán-Jiménez, J. R., R. Lopez, M. A. Chanlatte Baik, and Y. Narganes Storde. 2005. La Temprana Introduccíon y Uso de Algunas Plantas Dom.esticas, Silvestres y Cultivos En Las Antillas Precolombinas [The Early Introduction and Use of Some Domestic, Wild and Cultivated Plants in the Pre-Columbian Antilles]. Diálogo Antropologico 3:7–33.

Pagán-Jiménez, J. R., and H. L. Mickleburgh. 2022. Caribbean deep-time culinary worlds revealed by ancient food starches: Beyond the dominant narratives. *Journal of Archaeological Research* 31 (1):55–101. 10.1007/s10814-021-09171-3

Pagán-Jiménez, J. R., R. Rodríguez Ramos, B. A. Reid, M. van den Bel, and C. L. Hofman. 2015. Early maize dispersal into the Southern Caribbean and Northeastern South America. *Quaternary Science Reviews* 123:231–46. 10.1016/j.quascirev.2015.07.005

Pestle, W. J. 2010. Diet and society in prehistoric Puerto Rico: An isotopic approach. Doctoral diss., University of Illinois.

Pestle, W. J., M. Hubbe, E. K. Smith, and J. M. Stevenson. 2015. Technical note: A linear model for predicting δ^{13}C protein. *American Journal of Physical Anthropology* 157 (4):694–703. 10.1002/ajpa.22743

Plomp, E. 2013. Dogs on the move: A study concerning the mobility and exchange of dogs in prehistoric and contemporary circum-Caribbean Amerindian societies. Master of Arts diss., Leiden University.

Pollard, A. M., M. Pellegrini, and J. A. Lee-Thorp. 2011. Technical note: Some observations on the conversion of dental enamel $d^{18}Op$ values to $d^{18}Ow$ to determine human mobility. *American Journal of Physical Anthropology* 145 (3):499–504. 10.1002/ajpa.21524

Price, T. D., J. H. Burton, and J. B. Stoltman. 2007. Place of origin of prehistoric inhabitants of Aztalan, Jefferson Co., Wisconsin. *American Antiquity* 72 (3):524–38. doi:10.2307/40035859.

Reid, B. A., ed. 2018. *An archaeological study of the Red House: Port of Spain, Trinidad and Tobago*. Kingston, Jamaica: University of the West Indies Press.

Schoeninger, M. J., and M. J. DeNiro. 1983. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48 (4):625–39. 10.1016/0016-7037(84)90091-7

Schoeninger, M. J., M. J. DeNiro, and H. Tauber. 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220 (4604): 1381–3. 10.1126/science.6344217

Schroeder, H., T. C. O'Connell, J. A. Evans, K. A. Shuler, and R. E. M. Hedges. 2009. Trans–Atlantic slavery: Isotopic evidence for forced migration to Barbados. *American Journal of Physical Anthropology* 139 (4):547–57. 10.1002/ajpa.21019

Stokes, A. V. 1998. A biogeographic survey of prehistoric human diet in the West Indies using stable isotopes. Doctoral diss., University of Florida.

Tacoma, J. 1980. Studies on the physical anthropology of the Netherlands Antilles IV. A prae-Columbian skeleton from Bonaire. *New West Indian Guide/Nieuwe West-Indische Gids* 54 (1): 229–58. 10.1163/22134360-90002137

Valcárcel Rojas, R., A. D. Weston, H. L. Mickleburgh, and J. E. Laffoon. 2011. El Chorro de Maíta: A diverse approach to a context of diversity. In *Communities in contact: Essays in archaeology, ethnohistory and ethnography of the Amerindian circum-Caribbean*, ed. C. L Hofman and A. van Duijvenbode, 225–52. Leiden: Sidestone Press.

van Heekeren, H. R. 1963. Studies on the archaeology of the Netherlands Antilles: III. Prehistorical research on the Island of Curaçao, Aruba and Bonaire in 1960. *Nieuwe West-Indische Gids* 43:1–24.

Versteeg, A. H., and S. Rostain. 1997. *The archaeology of Aruba: The Tanki Flip site*. Oranjestad, Aruba: Archaeological Museum Aruba.

White, T. D., and P. A. Folkens. 2005. *The human bone manual*. San Diego: Elsevier Science & Technology.

Wright, L. E., and H. P. Schwarcz. 1999. Correspondence between stable carbon, oxygen and nitrogen isotopes in human tooth enamel and dentine: Infant diets at Kaminaljuyu. *Journal of Archaeological Science* 26 (9):1159–70. 10.1006/jasc.1998.0351

Online sources

Global isotopes in precipitation. https://www.iaea.org/services/networks/gnip

Regionalized Cluster-based Water Isotope Prediction (RCWIP) model. http://www-naweb.iaea.org/napc/ih/IHS_resources_rcwip.html

United States Department of Agriculture. 2013. National Nutrient Database for Standard Reference, Release 26. http://www.ars.usda.gov/Services/docs.htm?docid=8964