

Exploring subsistence and cultural complexes on the south coast of Papua New Guinea using palaeodietary analyses

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ABSTRACT

We present the results of a palaeodietary study of a skeletal sample (~800–300 BP) from the south coast of Papua New Guinea (Nebira, site ACJ) using multiple stable isotope analysis of bone collagen. The carbon, nitrogen and sulphur stable isotope ratios of 28 individuals ($n = 12$ males, $n = 13$ females and $n = 3$ subadults) suggested the diet at Nebira was based on C₃ plants (likely starchy vegetable staples) and included protein resources from the surrounding forested areas and C₃/C₄ savannah grasslands such as wallaby and other wild animals. Domestic species (e.g. *Sus scrofa*, *Canis familiaris* and *Gallus gallus*) may also have been consumed but could not be differentiated from wild species by stable isotope analysis. There were no significant differences in stable isotope values between males and females, but the $\delta^{34}\text{S}$ values of the juveniles suggest they may have consumed varied protein resources. The sulphur stable isotope ratios indicate there was no discernable marine component in the diet of any of the individuals from Nebira. The stable isotope results are interpreted within a wider context of Papuan south coast trade and exchange systems in an attempt to understand local interaction in the region.

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1. Introduction

Within the Pacific islands a number of researchers have used stable isotope analysis for palaeodietary reconstruction, mostly focusing on prehistoric communities from Polynesia (Allen and Craig, 2009; Field et al., 2009; Jones and Quinn, 2009; Richards et al., 2009; Valentin et al., 2006). However, palaeodietary analyses in the Western Pacific remain relatively few (Beavan-Athfield et al., 2008; Leach et al., 2003; Valentin et al., 2010). Papua New Guinea (PNG) is a country with a complex cultural and biological prehistory (Allen, 1977b) and stable isotope analysis may assist in understanding diet and subsistence in the past and how they may have been influenced by social structure and social identity.

Today the south coast of PNG is inhabited by non-Austronesian (NAN) speaking populations already established in PNG before the Lapita expansion into the Pacific from Island Southeast Asia c. 3400–3300 BP, in addition to Austronesian (AN)-speaking people likely descended from these Lapita populations (Bedford and Sand, 2007; Swadling, 1981). Recently discovered Lapita pottery indicates

the arrival of AN-speaking people on the south coast of PNG by 2900 BP (McNiven et al., 2011). Although debate has formed around the settlement history of the Papuan south coast, it is clear there was a substantial amount of settlement and interaction during at least the last 2000 years, which intensified from 1000 to 400 BP (Allen, 1977a, 1977b, 1977c; Bickler, 1997; Irwin, 1991; Summerhayes and Allen, 2007).

Early trade and exchange systems are thought to have influenced the development of seasonal long-distance intensive trading systems established during the Protohistoric Period (AD 1600–1875) along the Papuan south coast. These include the *hiri*, and the emergence of centralised trading systems such as those found on Mailu island (Allen, 1984; Irwin, 1978). In coastal areas settled by the AN-speaking populations there would have been insufficient food resources to support the carrying capacity suggested by the archaeological evidence of habitation sites and historic estimates of population density (Allen, 1977a). In contrast, the inland areas traditionally inhabited by NAN-speaking tribes are more fertile than coastal areas and are extensively used for horticulture today (Vasey, 1982). Historical, ethnographic and oral historical accounts detail trade between AN-speaking coastal Motu tribes and NAN-speaking inland groups, the Koita and Koiari, for essential food items (Allen, 1977a; Dutton, 1969; Oram, 1981). Lawes (1879:373)

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noted that “the Koitapu are hunters, not fishermen. They possess no canoes and have nothing to do with the sea; but they excel in hunting the kangaroo and wild pig, and are superior to the Motu in the chase. They barter large quantities of kangaroo meat to them for fish, &c”.

With the exception of the unique faunal assemblage found on the offshore island of Motupore, there is limited evidence available to identify the possible exchange of food items on the south coast of PNG before European contact (Allen, 1977a; Allen et al., 1997). The habitation period of Motupore (a place likely occupied by the ancestors of the coastal dwelling Western Motu) is contemporary with the site analysed in the current study, Nebira, and both sites were abandoned around 300–400 BP. From material evidence of pottery, shell and stone tools, the people living on Motupore were involved in the manufacture of specialised craft items (Allen, 1978, 1985). Over 90% of the terrestrial fauna found on Motupore was identified as Agile wallaby. In conjunction with the material evidence, the age structure and body part analysis of the wallaby remains led Allen (1985) to suggest the people living on Motupore were engaged in specialised trade with inland communities, such as Nebira.

Allen and Duerden (1982) sourced a limited amount ($n = 23$) of pottery sherds excavated from Nebira to Bootless Bay sites including Motupore, indicating at least some pottery was not manufactured at Nebira and must have been brought to the site, most likely as a trade import. Additionally, from isotope analysis, Shaw et al. (2011) suggested that five individuals from Nebira with higher strontium values than the rest of the burials were originally from coastal areas, suggesting a movement of people to inland settlements during the occupation of the site.

In this paper we address questions of diet, subsistence and interaction through the palaeodietary analysis of human skeletal remains from the inland south coast site of Nebira (site ACJ). Multiple stable isotopes of bone collagen (carbon, nitrogen and sulphur) are used to analyse the protein portion of adult and juvenile diets. Stable isotope analysis of the Nebira sample may assist in identifying possible age and sex differences in diet that may be associated with socio-cultural practices, such as preferential treatment, food taboos or labour specialisation (Muldner and Richards, 2007; Prowse et al., 2005; Schulting and Richards, 2001; Turner et al., 2007). Additionally, the presence or absence of marine foods is also assessed within a wider context of south coast trade and exchange systems in an attempt to understand local interaction in the region and may help clarify the movement of people inland from coastal areas as suggested by Shaw et al. (2011). If substantial amounts of marine foods are identified from the current stable isotope analysis, this may help to identify patterns of trade and exchange on the south coast of PNG c. 800–300 BP.

2. Materials: Nebira, site ACJ and the burials

Nebira was a double peaked hilltop (recent quarrying has removed both peaks), sixteen kilometres from the ocean located on the south coast of Papua New Guinea (Fig. 1). It lies adjacent to the south bank of the Laloki River and within two kilometres of the Waigani swamp (Bulmer, 1978). The skeletal sample used in this study is from the ACJ site, the only large inland settlement with an associated cemetery excavated in the Port Moresby region (Bulmer, 1978). The name of Nebira has been used to classify a number of closely related sites (ACJ, ACI, ACI/T, ACK and ACL), but in this paper is only used in reference to site ACJ, the site located in the central saddle containing a cemetery complex and the two hilltops (Bulmer, 1978). Radiocarbon dates from one burial (burial 3) and four charcoal samples ranged from 720 ± 80 to 280 ± 80 BP (Bulmer, 1975).

Bulmer (1978) excavated 44 burials from Nebira that were subsequently sorted into 38 individuals, including 5 subadults

(<17 years) (Buikstra and Ubelaker, 1994; Pietruszewsky, 1976; Scheuer and Black, 2000). For the current palaeodietary study, 29 adults ($n = 15$ males and $n = 14$ females) and 5 juveniles (aged 10–16 years) were analysed.

Although no substantial midden was excavated from site ACJ, archaeological evidence of subsistence at the site includes 283 shell fragments, of which twenty shellfish species were identified. Around 5–10% of these were endemic to the local mudflat areas close to the site while the remaining shellfish were sourced to ocean reef or reef flat areas, indicating a movement of material from the coast (Bulmer, 1978, 1979). A small amount of faunal material was also found at the site, including pig (*Sus scrofa*), cassowary (*Casuarius casuarius*), dog (*Canis familiaris*), wallaby, dugong (*Dugong dugon*) and fish, although it was not clear whether the fish were from the river, swamp or ocean (Bulmer, 1975). All the faunal remains were found in stratigraphic layers that post-dated the burials and therefore may not be representative of the diet of the people interred in the burial ground. However, they do provide a reference for the potential dietary sources available in the area (Bulmer, 1979).

2.1. Environment and possible diet at Nebira

Characterised by dry savannah grasslands, low rainfall (101–127 cm per annum inland and an average of 78 cm per annum for coastal areas) the south coast region is prone to drought and is unique compared to other areas of Papua New Guinea (Allen, 1983, 1977b; Bulmer, 1978). In areas of low rainfall, dry cultivation of C_3 plants such as yam (*Dioscorea* spp.), banana (*Musa* and *Australimusa* spp.) and sweet potato (*Ipomoea batatas*) constitute the principal vegetable foods, although the consumption of sweet potato would be dependent on the date of the introduction of this vegetable to the south coast of PNG (Vasey, 1982). As Nebira is situated near both the Laloki river and Waigani swamp, taro (*Colocasia esculenta*) may have been cultivated and freshwater fish and shellfish were likely available year-round (Bulmer, 1975; Swadling, 1981). A variety of wild fruits, tubers, vegetables and nuts gathered from the bush are also important supplements to garden foods today and likely constituted some of the C_3 -based dietary items available to the inhabitants of Nebira (Oram, 1977).

Large-scale seasonal wallaby drives, involving deliberately setting fire to the grassland, herding wallabies including the Agile wallaby (*Macropus agilis*) and smaller Scrub wallaby (*Thylogale* spp.) into set nets and spearing the trapped animals, are recorded in the ethnographic literature as being a unique form of hunting of the inland NAN-speaking Koita (Stone, 1876). Single hunting drives have been known to catch upwards of 500–1000 animals, the meat of which was smoked and traded for goods, specifically pottery and fish supplied by the nearby coast dwelling, AN-speaking Western Motu (Allen, 1984; Lawes, 1879). Other important protein resources were likely obtained from hunting and trapping terrestrial animals including cassowary (*C. casuarius* and *Casuarius unappendiculatus*), feral pig (*S. scrofa*) and bandicoots (Peramelidae) from the grassland savannah. Forested areas would have provided a variety of species including tree kangaroos (*Dendrolagus* spp.), Grey Dorcopsis wallabies (*Dorcopsis luctuosa*), cuscuses (*Phalanger* spp.), ringtail possums (*Pseudocheirus* spp.), giant rats (*Mallomys rothschildi*) and a wide variety of smaller rodents and marsupials (Bulmer, 1968). Bats, including flying fox (*Pteropus* spp.), lizards and snakes, frogs, birds such as crown pigeons (*Goura* spp.), palm cockatoos (*Probosciger aterrimus*) and hornbills (*Aceros plicatus*), in addition to a variety of invertebrates, would have been widely eaten (Bulmer, 1968). The close vicinity to both the Laloki River and the Waigani swamp would have

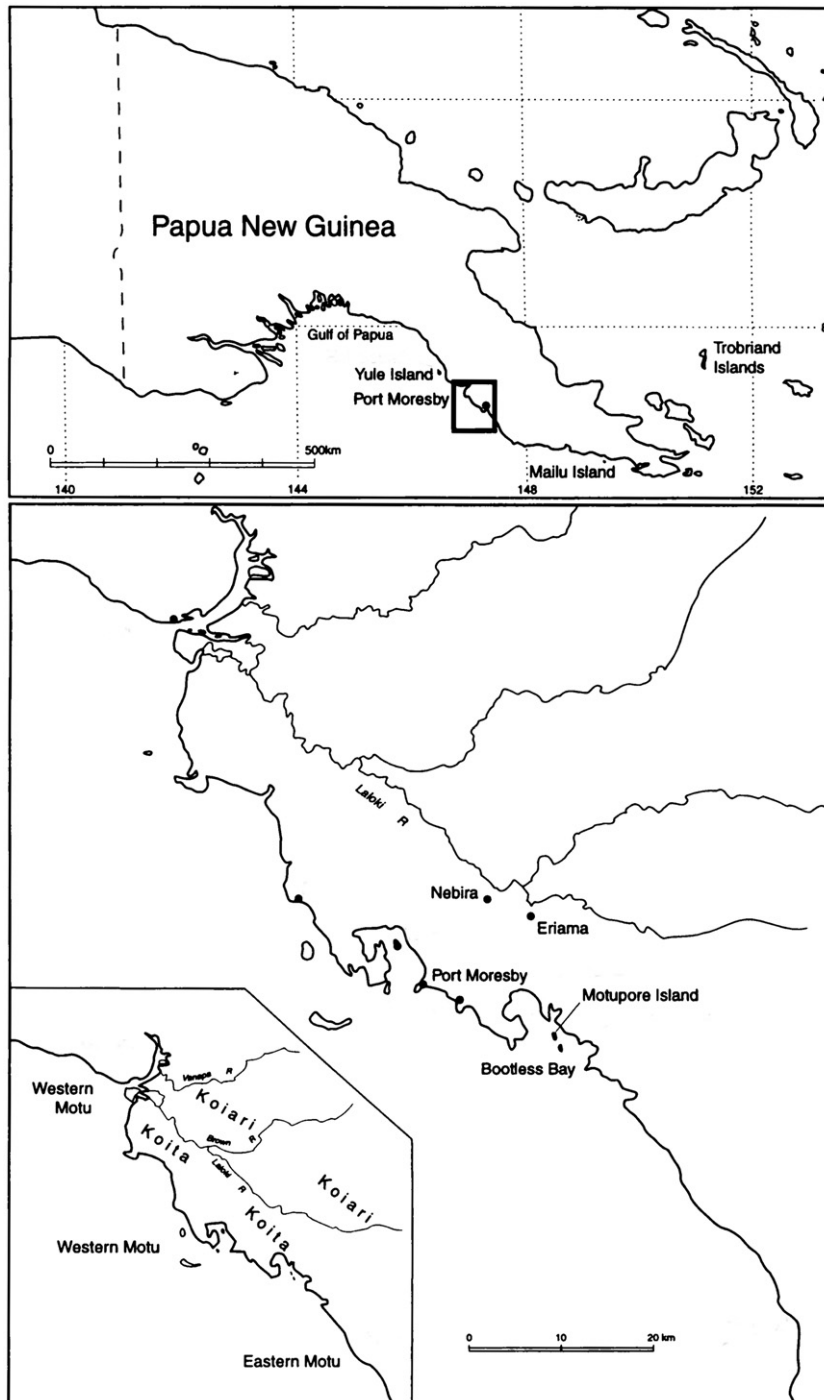


Fig. 1. Map of the south coast of Papua New Guinea, location of the Nebira site and traditional land boundaries of the Motu, Koita and Koiairi (modified from Allen et al., 1997: 13).

provided easy access to freshwater organisms such as fish, frogs and prawns (Berra et al., 1975).

3. Stable isotope analysis

The basis of palaeodietary reconstruction is the principle that the isotopic composition of food is reflected in the tissues of a consumer, including their bones and teeth (Schwarcz and Schoeninger, 1991). Stable isotopes are measured in the form of ratios, the heavy isotope to the lighter isotope ($^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$ and $^{34}\text{S}/^{32}\text{S}$). These isotope ratios are analysed relative to a known

standard, VPDB for carbon, AIR for nitrogen and VCDT for sulphur, and expressed as parts per 1000 or 'permil'. The stable isotope ratios of carbon ($\delta^{13}\text{C}$), nitrogen ($\delta^{15}\text{N}$) and sulphur ($\delta^{34}\text{S}$) are calculated by the equation: $\delta (\text{‰}) = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$ where R represents $^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$ or $^{34}\text{S}/^{32}\text{S}$ (Richards et al., 2003; Schwarcz and Schoeninger, 1991).

Bone collagen is preferred for stable isotope analysis as it is relatively robust in the burial environment compared to bone apatite and parameters have been developed to assess diagenetic alteration that may affect the original isotopic signal (DeNiro, 1985; van Klinken, 1999). The $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values of bone collagen

are mainly representative of the protein portion of the diet as the amino acids in food are preferentially routed to the proteins in bone, the major constituent being Type 1 collagen (Ambrose and Norr, 1993; Tieszen and Fagre, 1993).

Carbon stable isotopes ($\delta^{13}\text{C}$) are used to differentiate between the consumption of C_3 and C_4 plants and the origin of a consumer's protein resources (e.g. marine or terrestrial) (Schwarcz and Schoeninger, 1991). There is an enrichment in ^{13}C resulting from metabolic fractionation, termed diet-tissue spacing (Ambrose and DeNiro, 1986; Kellner and Schoeninger, 2007). A 5.0‰ diet-tissue spacing for $\delta^{13}\text{C}$ is used in the current study to interpret potential diet (Kellner and Schoeninger, 2007).

Bone collagen is a major source of nitrogen within bone and nitrogen stable isotopes ($\delta^{15}\text{N}$) are representative of the source of dietary protein (e.g. terrestrial, marine and/or freshwater). Additionally $\delta^{15}\text{N}$ values are used to identify trophic relationships, as there is a step-wise enrichment in ^{15}N up the food chain of $\sim 3\text{--}5\text{‰}$ (Bocherens and Drucker, 2003). A conservative diet-tissue spacing of 3‰ is used to interpret palaeodiet from the $\delta^{15}\text{N}$ values of the Nebira individuals. This trophic effect can assist in identifying plant vs. animal protein in human diets.

Sulphur stable isotopes ($\delta^{34}\text{S}$) analysed from collagen are representative of the source (marine or terrestrial) of a consumer's dietary protein (Craig et al., 2006). It is important to recognise that the $\delta^{34}\text{S}$ values of individuals living in coastal or near coastal environments may have been influenced by the 'sea spray effect', which results from ^{34}S -enriched ocean water particles travelling inland by precipitation or sea spray, potentially resulting in elevated $\delta^{34}\text{S}$ values of coastal terrestrial food webs (Richards et al., 2003). Relatively little is known about the diet-tissue spacing of $\delta^{34}\text{S}$. The diet-to-tissue spacing for sulphur isotopes within tissues other than bone collagen has been observed to be quite small for terrestrial animals (Peterson and Fry, 1987; Richards et al., 2003) and possibly even result in negative fractionation in marine organisms (Krouse, 1989; Krouse and Herbert, 1988). Thus, the diet-to-tissue spacing suggested by Beavan-Athfield et al. (2008) for $\delta^{34}\text{S}$ of 1.3‰ and -0.9‰ for terrestrial and marine organisms respectively will be used when interpreting the potential dietary items consumed by the individuals in this study.

Stable isotope values from bone collagen represent the average diet over last ~ 10 years of an adult's life and most likely a shorter period of time for juveniles depending on their rate of bone turnover (Hedges et al., 2007; Waters-Rist and Katzenberg, 2009). Further reviews of the application of stable isotopes for palaeodietary interpretations include Katzenberg (2000), Richards et al. (2003) and Schwarcz and Schoeninger (1991).

It is important to understand environmental variation in dietary stable isotope ratios when interpreting human diet by analysing local plants and animals. However, there were no faunal remains available for sampling from the Nebira site at the time of analysis to establish a dietary baseline. Additionally, there has been little research regarding the stable isotope complexities in Papua New Guinean ecosystems. The uncertainties regarding ranges of isotope values in the current context and the lack of site-specific baseline data necessitated the use of a general Pacific island baseline similar to that used by Valentin et al. (2010). This dietary baseline of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values was developed using previously published values for both modern and prehistoric Pacific island plants and animals (Allen and Craig, 2009; Ambrose et al., 1997; Beavan-Athfield et al., 2008; Casu et al., 2009; Dye, 1990; Field et al., 2009; Fry et al., 1983; Jones and Quinn, 2009; Leach et al., 2003; Richards et al., 2009; Valentin et al., 2006; Valentin et al., 2010; Yoshinaga et al., 1991; Yoshinaga et al., 1996). To account for the global decrease in ^{13}C after the Industrial Revolution (i.e. the Suess effect), modern Pacific island plant and animal $\delta^{13}\text{C}$ values within

the baseline were corrected by $+1.5\text{‰}$ for terrestrial and $+0.86\text{‰}$ for marine systems (Beavan-Athfield et al., 2008: 9; Tieszen, 1991). Faunal bone collagen $\delta^{13}\text{C}$ values were corrected for the difference between bone collagen and flesh by subtracting 3.7‰ for fish bone and 1.5‰ for all other animal bone, as flesh is usually the tissue consumed by humans (Beavan-Athfield et al., 2008; Keegan and DeNiro, 1988). Modern plants and both modern and prehistoric animals were divided into general groups and mean values (± 1 SD) were calculated for each dietary group to interpret the potential diet at Nebira from the human stable isotope values.

4. Methods

Collagen was extracted from sections of cortical long bone sampled from either the upper or lower limb. The method used to extract collagen followed a Longin method modified by Brown et al. (1988) and Collins and Galley (1998). Larger quantities of bone (0.5–0.8 g) were sampled to ensure an adequate collagen yield was extracted for sulphur analysis. Specifically, bone chunks were cleaned with alum oxide air abrasive equipment (Bego Easyblast), demineralised in 0.5 M HCl at 4 °C for several days followed by rinsing in de-ionised H_2O until the samples reached a neutral pH. The samples were gelatinised at 70 °C in a pH 3 solution for 48 h, followed by filtering with 5–8 μm Ezee® mesh filters (Elkay Laboratory Products) to remove any reflux-insoluble residues and ultrafiltered with Millipore Amicon Ultra-4 centrifugal filters (30,000 NMWL) to retain molecules larger than 30 kDa. The purified "collagen" was lyophilised for 48 h and analysed by EA-IRMS (Elemental Analyser–Isotope Ratio Mass Spectrometry) at two labs, Iso-Trace (Dunedin, NZ) and Iso-Analytical (Cheshire, UK) as a result of the closure of Iso-Trace (Dunedin, NZ) (Table 1). Analytical error was routinely $\pm 0.1\text{‰}$ for $\delta^{13}\text{C}$, $\pm 0.2\text{‰}$ for $\delta^{15}\text{N}$ and $\pm 0.4\text{‰}$ for $\delta^{34}\text{S}$.

Samples that did not fall within the collagen quality criteria of a C/N ratio of 2.9–3.6 ($n = 6$, 4 adults and 2 subadults) were removed from the following interpretations (Ambrose, 1993). Additionally, samples for sulphur analysis that fell outside the criteria of %S > 0.60, a N/S ratio not within 200 ± 100 and a C/S ratio outside 600 ± 300 were also removed ($n = 8$, 6 adults and 2 subadults) (Nehlich and Richards, 2009).

5. Stable isotope results

The isotope data for all the human samples, including collagen quality indicators are presented in Table 1. The overall mean (± 1 SD) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the Nebira individuals were $-16.7\text{‰} \pm 3.1\text{‰}$ and $9.5\text{‰} \pm 0.7\text{‰}$ respectively. The overall mean $\delta^{34}\text{S}$ value for the Nebira individuals was $3.4\text{‰} \pm 2.1\text{‰}$. The male mean $\delta^{13}\text{C}$ value was $-15.7\text{‰} \pm 2.1\text{‰}$, the female mean $\delta^{13}\text{C}$ value $-17.3\text{‰} \pm 3.5\text{‰}$ and the juvenile mean was $-18.3\text{‰} \pm 4.5\text{‰}$. The male mean $\delta^{15}\text{N}$ value was $9.5\text{‰} \pm 0.6\text{‰}$, the female mean $9.5\text{‰} \pm 0.7\text{‰}$ and the juvenile mean was $9.3\text{‰} \pm 0.9\text{‰}$. The mean male $\delta^{34}\text{S}$ value was $2.9\text{‰} \pm 1.9\text{‰}$, the female mean $3.7\text{‰} \pm 2.0\text{‰}$ and the juvenile was 7.7‰ .

There was a statistically significant negative correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for the overall sample (Spearman's $r = -0.62$, $p < 0.001$) and a statistically significant negative correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for the males (Spearman's $r = -0.75$, $p = 0.005$). Although the females from Nebira also displayed a negative correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (Spearman's $r = -0.46$), this was not statistically significant ($p = 0.112$).

There were no statistically significant differences between the sexes (Student's t -test) for the $\delta^{13}\text{C}$ ($p = 0.170$) and $\delta^{15}\text{N}$ ($p = 0.981$) values of bone collagen, however the mean male $\delta^{13}\text{C}$ value was higher compared to the female mean $\delta^{13}\text{C}$ value by 1.6‰. There

Table 1
Demographic data, bone collagen $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values, and collagen quality indicators for humans from the Nebira ACJ site.

Burial	Age ^a	Sex	$\delta^{15}\text{N}$ (‰)	%N	$\delta^{13}\text{C}$ (‰)	%C	C:N ratio	$\delta^{34}\text{S}$ (‰) ^d	%S	N:S ratio	C:S ratio
1 ^b	15 yrs	N/A	9.9	7.6	-21.5	20.8	3.2	4.75	0.27	64.4	206.9
2 ^b	Mid	Male	8.8	8.3	-13.4	21.7	3.1				
3 ^b	Young	Female	9.6	10.8	-13.9	29.2	3.2	-1.34	0.10	246.0	777.2
4 ^c	Mid	Male	9.5	14.1	-14.2	45.5	3.8	2.29	0.28	114.2	430.1
6 ^c	Mid	Male	9.1	12.3	-14.3	38.4	3.6	4.99	0.27	104.5	379.7
8 ^c	Mid	Male	9.5	14.9	-17.6	43.7	3.4	4.62	0.21	162.6	556.7
9 ^c	Mid	Female	10.7	11.0	-15.0	39.3	4.1				
10 ^c	Young	Male	7.2	12.6	-10.9	43.6	4.0	6.63	0.51	56.9	229.8
11 ^c	Mid	Male	10.0	14.3	-16.9	42.5	3.5	3.53	0.28	117.9	409.8
12 ^b	Young	Female	9.5	10.7	-17.0	27.9	3.1	3.47	0.22	110.8	338.0
16 ^b	Mid	Male	9.7	7.5	-16.8	20.6	3.2	0.98	0.12	143.7	458.6
17 ^c	Young	Female	8.5	14.2	-12.8	40.9	3.4	1.1	0.19	169.5	570.3
19 ^b	UK	Male	10.7	7.6	-19.9	20.5	3.2				
20 ^c	Mid	Male	10.1	15.0	-17.6	43.8	3.4	4.67	0.27	126.7	432.4
22 ^b	Young	Female	8.8	7.2	-14.2	19.8	3.2	4.65	0.25	65.1	208.0
23 ^b	Mid	Female	10.5	6.6	-16.1	17.4	3.1	4.29	0.12	125.2	387.1
24 ^b	Young	Male	8.9	8.6	-13.0	23.6	3.2	3.38	0.12	163.2	525.4
25 ^b	Young	Female	10.6	6.4	-26.7	16.8	3.1				
27 ^b	Mid	Female	9.1	8.2	-21.0	21.7	3.1	5.43	0.26	72.4	221.8
28 ^c	UK	Female	9.7	15.5	-17.7	46.2	3.5	5.77	0.24	150.2	520.6
30 ^b	Mid	Male	9.9	6.2	-14.7	16.5	3.1	0.79	0.12	118.8	367.1
31 ^b	Young	Female	8.5	6.9	-17.7	18.1	3.1	-0.51	0.29	54.1	165.3
32 ^b	Mid	Male	8.9	7.4	-14.5	19.3	3.0	-0.33	0.09	187.6	571.4
33 ^b	UK	Female	10.1	7.5	-18.3	20.9	3.2				
34 ^b	Mid	Male	9.6	6.1	-14.6	16.8	3.2	1.71	0.14	100.0	320.2
35 ^c	13 yrs	N/A	9.3	14.4	-14.8	45.2	3.7	4.86	0.20	165.4	607.1
37 ^b	16 yrs	N/A	9.8	7.7	-20.3	20.3	3.1				
38 ^c	Mid	Female	10.2	12.1	-17.3	37.1	3.6	4.98	0.29	96.3	345.2
39 ^b	UK	Male	8.8	5.1	-14.9	14.1	3.3	5.45	0.08	144.6	469.9
40 ^c	Young	Male	10.8	13.2	-17.4	43.9	3.9	2.8	0.22	137.2	531.2
41 ^c	16 yrs	N/A	8.3	14.3	-13.1	44.5	3.6	7.7	0.27	121.3	440.3
42 ^c	10 yrs	N/A	10.2	13.5	-17.5	44.4	3.8	5.82	0.36	85.4	328.9
43 ^b	Mid	Female	9.4	9.7	-17.3	25.6	3.1				
44 ^c	Young	Female	9.1	13.7	-15.3	42.7	3.6	4.83	0.41	75.9	275.4

Note: Bolded and italicised analyses did not meet the collagen quality criteria as described in the main text.

^a YA = Young adult (20–34 years), MA = Mid adult (35–49 years), UK = Adult with unknown age, juvenile ages are presented in years. Adults aged from standards found in Buikstra and Ubelaker (1994) and subadults from standards found in Scheuer and Black (2000).

^b $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis for these samples was conducted by EA-IRMS at Iso-trace, Dunedin New Zealand. Internal standards IAEA N1 and IAEA N2 for nitrogen and NBS22 and ANU Sucrose for carbon were used as in house standards to ensure the analytical precision of the measurements.

^c $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis for these samples was conducted by EA-IRMS at Iso-Analytical, Cheshire, UK. Internal standards IA-R042, a mixture of IA-R005 and IA-R045 and a mixture of IA-R006 and IA-R046 were used as in house standards to ensure the analytical precision of the measurements.

^d $\delta^{34}\text{S}$ analysis was conducted by EA-IRMS at Iso-Analytical, Cheshire, UK. Internal standards IA-R025, IA-R026 and IA-R036 were used as in house standards to ensure the analytical precision of the measurements.

were no similar differences in between male and female $\delta^{15}\text{N}$ (difference 0.0) or $\delta^{34}\text{S}$ (difference 0.8) values.

The juvenile $\delta^{34}\text{S}$ value was 4.6‰ higher and the mean juvenile $\delta^{13}\text{C}$ value was 1.8‰ lower than the overall adult mean $\delta^{34}\text{S}$ and $\delta^{13}\text{C}$ values respectively, although their mean $\delta^{15}\text{N}$ values were similar (adults 0.2‰ higher than juveniles).

Burials 3, 6, 22, 34 and 42 were identified as non-local from strontium isotope analysis by Shaw et al. (2011). The collagen from one non-local individual, burial 42, fell outside the parameters for good-quality collagen. The four other non-local individuals had average values of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ of -14.2‰, 9.3‰ and 3.4‰ respectively. These individuals had similar $\delta^{15}\text{N}$ values to the rest of the sample (non-local mean was 0.2‰ lower). They also displayed higher $\delta^{13}\text{C}$ values (2.9‰) and the same mean $\delta^{34}\text{S}$ value to the local individuals.

6. Discussion

Solely from the bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, the dietary protein consumed at Nebira would appear to have come from resources that likely included both C₃ and C₄ plants, herbivores and marine shellfish and fish (Fig. 2). The negative correlation between the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values indicates that protein resources at Nebira

originated from the terrestrial environment or consisted of low-trophic level marine foods. Individuals consuming higher trophic level marine protein and C₃ terrestrial protein foods would be expected to show a positive correlation between the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (Richards and Hedges, 1999).

However, the $\delta^{34}\text{S}$ values indicate that the ¹³C-enriched and ¹⁵N-depleted food resources were not from marine ecosystems (Fig. 3 and Fig. 4). The $\delta^{34}\text{S}$ values for the Nebira sample almost entirely fall within the 2–6‰ range found in other parts of the world for terrestrial ecosystems, below the lower range of the $\delta^{34}\text{S}$ values for Pacific island plants and animals (Peterson and Fry, 1987).

It is possible that some freshwater organisms were consumed although it would be expected that the $\delta^{34}\text{S}$ values would be higher if this were the case. As a result of the possible variation in freshwater $\delta^{34}\text{S}$ values, it would be necessary to obtain site-specific baseline data to confirm this (Craig et al., 2006). The negative correlation in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values indicates that the dietary resources at the site included low trophic level C₄ resources and with more protein rich C₃ foods (Hu et al., 2006). At Nebira this may indicate the consumption of animals of a higher trophic level that fed in C₃ systems compared to those that mainly fed on C₄ plants. It may also indicate that there was a large dietary contribution from C₄ plants, although this would seem unlikely as the only Pacific island C₄ domesticated plant is sugar cane.

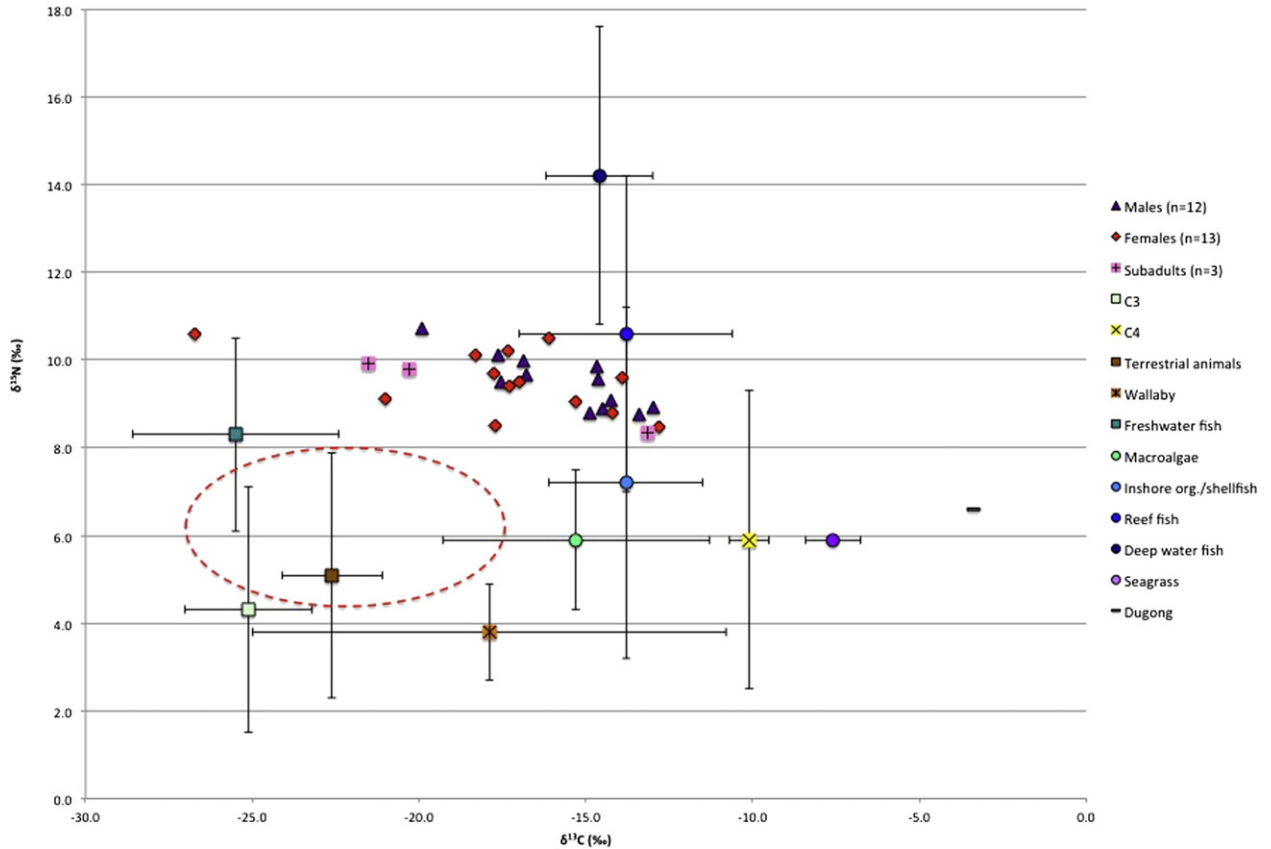


Fig. 2. Nebira bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values with reference to a Pacific island dietary baseline. The red dotted circle delineates the possible protein diet of the individuals using a diet-tissue spacing of 5.0‰ for $\delta^{13}\text{C}$ values and 3.0‰ for $\delta^{15}\text{N}$ values. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The multiple stable isotope analyses of bone collagen ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$) indicate the protein sources of the adults and juveniles were primarily terrestrial and most likely consisted of C_3 and C_4 plants and animals that consumed these plants. Ethnographically, dietary staples of the south coast of PNG and the Pacific islands are

predominantly C_3 starchy vegetables such as yam, taro and sweet potatoes in addition to bananas ($\sim 80\%$ of total diet) served with an accompaniment of leafy vegetable greens and a small amount of protein such as meat, fish or shellfish (Barrau, 1958; Barrau, 1973). In addition to banana, these C_3 starchy domesticates likely

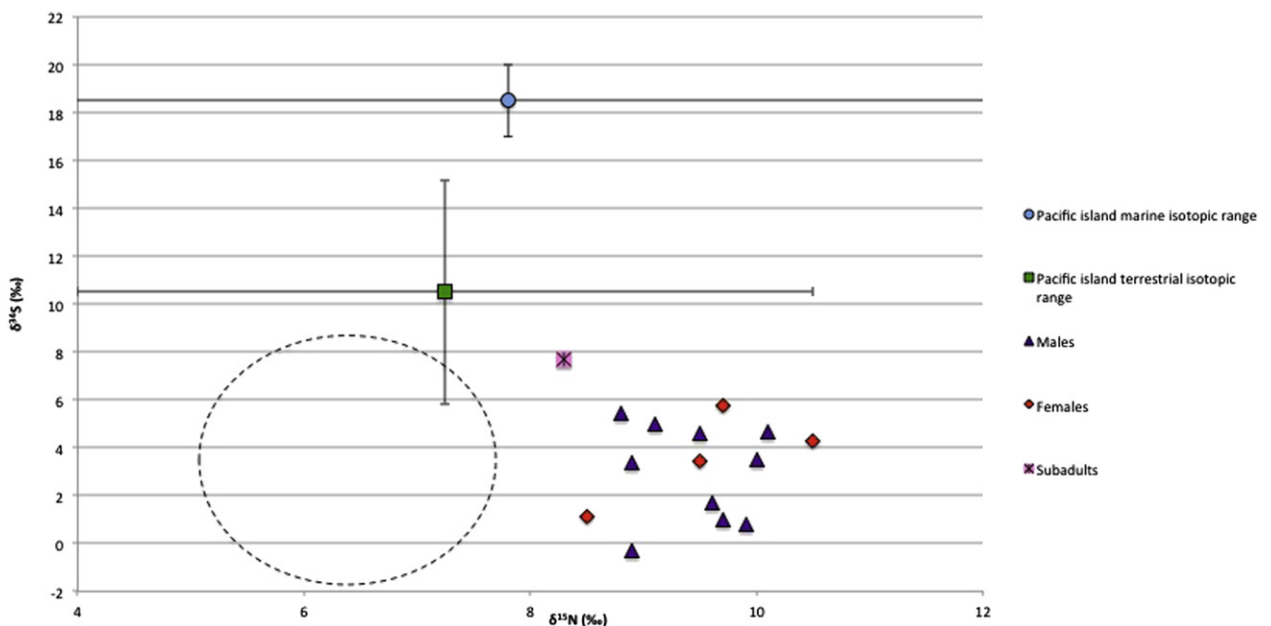


Fig. 3. Nebira mean bone collagen $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values with reference to isotopic ranges from a Pacific island dietary baseline. The black dotted circle delineates the possible diet of the individuals using a diet-to-tissue spacing of 3.0‰ for $\delta^{15}\text{N}$ values and both -0.9‰ (marine systems) and 1.3‰ (terrestrial systems) for $\delta^{34}\text{S}$ values.

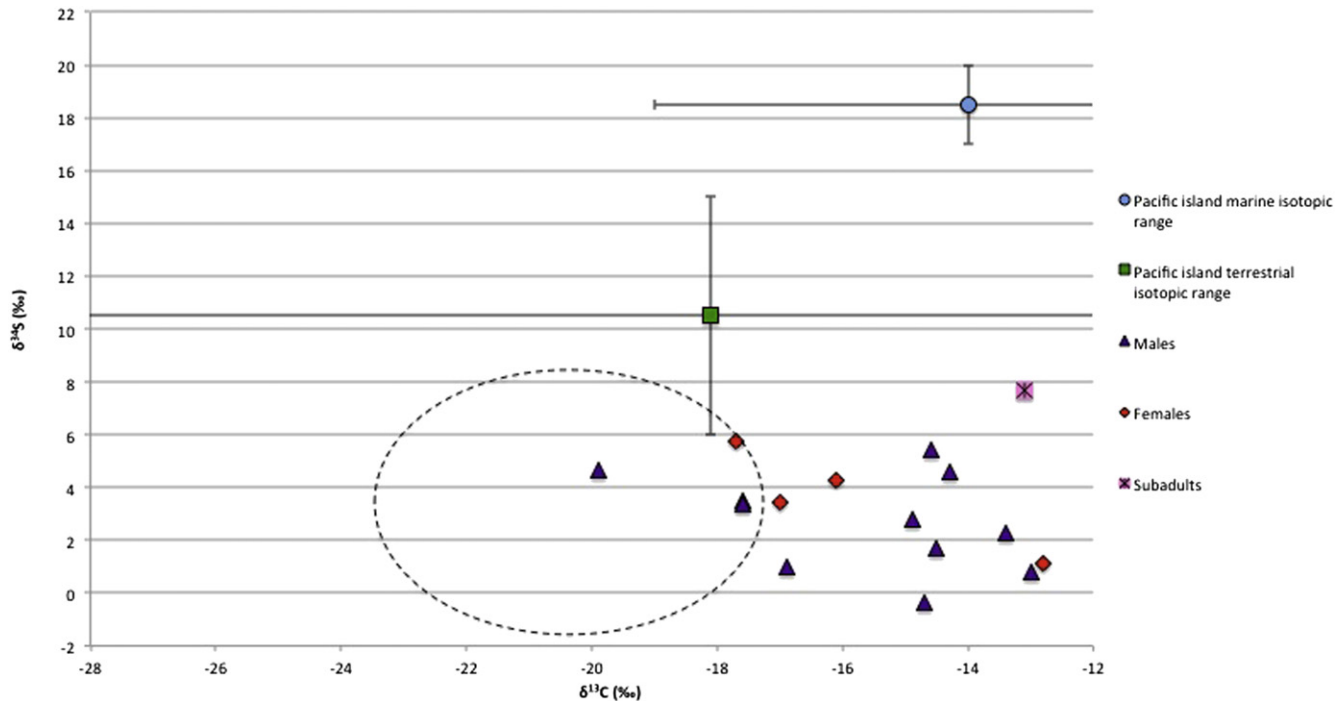


Fig. 4. Nebira mean bone collagen $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ values with reference to isotopic ranges from a Pacific island dietary baseline. The black dotted circle delineates the possible diet of the individuals using a diet-to-tissue spacing of 5.0‰ for $\delta^{13}\text{C}$ values and both -0.9‰ (marine systems) and 1.3‰ (terrestrial systems) for $\delta^{34}\text{S}$ values.

constituted a large proportion of the diet at Nebira but may have been overshadowed by more protein rich resources. Hunting and trapping a large variety of wild animals (discussed above) likely contributed to dietary protein all year round with a large input of meat during the mass wallaby drives if these were undertaken during the time of occupation of the site.

With the exception of a number of domestic and wild types of sugar cane (e.g. *Saccharum officinarum*, *Saccharum edule*, *Saccharum robustum*), there is no historical or ethnographic evidence of the human consumption of C_4 plants in the region (Leach et al., 2003). However C_4 grasses, such as *Saccharum spontaneum*, colonize the productive gardening land (*siriho*) along the south coast of PNG. Other C_4 grasses, such as *Themeda australis*, *Sehima nervosum*, *Heteropogon contortus* and *Imperata cylindrical*, are endemic to the local hills, valley and floodplain terrains surrounding Nebira (Eden, 1974). These C_4 grasses would have contributed to the diet of some south coast herbivores, especially the Agile wallaby, a species known to have been hunted by the local tribes in the region (Allen, 1978, 1991; Bulmer, 1968). The large standard deviation of $\delta^{13}\text{C}$ values of wallabies in the Pacific island dietary baseline is likely a result of habitat and feeding strategies of the three different species analysed; the Grey Dorcopsis (*D. luctuosa*, -25.3‰), the Dusky wallaby (*Thylogale brunii*, -22.7‰) and the Agile wallaby (*M. agilis*, -11.0‰), all of which were flesh stable isotope values from Yoshinaga et al. (1991) and a $\delta^{13}\text{C}$ value of -9.5‰ from a prehistoric bone sample identified as Agile wallaby (Leach et al., 2003). These species feed in forests (as browsers), on the forest edge (as browser/grazers) and savannah grasslands (as browser/grazers) respectively and display the corresponding $\delta^{13}\text{C}$ values of the plants (either C_3 or C_4) in each habitat. This pattern is similar to the $\delta^{13}\text{C}$ values observed for African mammals feeding in similar, but more drought prone habitats compared with the south coast of Papua New Guinea (Ambrose and DeNiro, 1986). Ambrose and DeNiro (1986) also observed that the most drought tolerant African animals displayed higher $\delta^{15}\text{N}$ values than species that were obligate drinkers in the same habitat, a trend which was not observed in any of the

species of wallabies (mean $\delta^{15}\text{N}$ values ± 1 SD of $3.7\text{‰} \pm 1.1\text{‰}$) used for the Pacific island dietary baseline in this study.

The four individuals with good-quality collagen that were identified as non-local from strontium isotope analysis (Shaw et al., 2011) appear to have been consuming foods from a similar trophic level as the rest of the sample. However they were likely eating protein foods that were enriched in ^{13}C compared to the local individuals. The non-local individuals were thought to have moved inland from coastal areas. Although the $\delta^{13}\text{C}$ values may indicate these individuals consumed a high proportion of marine foods, the low $\delta^{34}\text{S}$ values do not support this interpretation. This may either mean they did not consume large amounts of marine protein before they arrived at Nebira or they came to the area after the time of tooth formation when their diets changed to more terrestrial protein resources.

6.1. Sex and age differences

There were no obvious dietary variations suggestive of differential resource access along gender or status lines at the site. Although not statistically significant, the mean male $\delta^{13}\text{C}$ values may suggest that adult males were consuming more protein sources with C_4 isotopic signals, such as wallabies. Females may have eaten the same proportion of protein from similar trophic levels, but from less ^{13}C -enriched sources than the males. The small difference between the sexes may tentatively suggest social differentiation in access to certain types of protein foods or labour specialisation. Men were primarily responsible for hunting and organising seasonal wallaby hunts, which may have allowed preferential consumption of these animals by men (Bulmer, 1968; Lawes, 1879).

Similar types of dietary studies from Europe have suggested that the consumption of high trophic level protein or marine foods by males is evidence of preferential treatment of males in a group (Muldner and Richards, 2007; Richards et al., 2006). From ethnographic accounts of Papua New Guinean and Pacific island food

consumption patterns and social hierarchy (Parkinson, 1999; Pollock, 1992), this pattern may be expected in the Nebira sample. The lack of such dietary differences at Nebira may be a result of the low diversity of terrestrial foods with different trophic levels available, hence trophic differences would be difficult to identify isotopically. It is also possible that the gendered differences in food allocation observed ethnographically in other regions of the Pacific were not occurring during, and preceding, the Protohistoric Period at Nebira.

While the juvenile sample size was too small for inferential statistics ($n = 3$ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ and $n = 1$ for $\delta^{34}\text{S}$), the juvenile $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ values could possibly suggest these individuals were consuming some type of freshwater organisms, as their protein sources were more C_3 -based compared to the adult diet, and/or they were eating less ^{13}C -enriched animal meat compared to the adults. Other palaeodietary studies have also observed similar age-specific variations in diet and attributed this trend to juveniles consuming less protein rich foods and/or protein foods with lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values compared with adult diets (Richards et al., 2002; Turner et al., 2007). As observed by Oomen and Malcolm (1958), many Pacific island children forage for food during the day and Bulmer (1968: 306) speculated that “prior to European contact small vertebrates and invertebrate animals, obtained in gardens, grasslands and bush-fallow, contributed significantly to the diet of women and children”. The slight isotope variation between the sexes, and between adults and children may reflect these minor intra-population differences in consumption patterns.

6.2. Food as an exchange product at Nebira

The abundance of pottery at the Nebira site has been used to suggest site occupation by pottery manufacturing, AN-speaking peoples (Bulmer, 1978). However these new isotope data parallel ethnographic reports of the diet of local NAN-speaking populations, specifically that Nebira’s inhabitants were exploiting animals endemic to the local savannah grassland and nearby forest. The stable isotope evidence supports the local oral traditions that the ancestors of the modern Koita people occupied the site during and preceding the Protohistoric Period (Oram, 1981). Regardless of origin of the site’s inhabitants, these isotope data do not support that marine products constituted a major exchange product during Nebira’s occupation and therefore do not support a parallel with the ethnographic and historical records of the exchange of coastal and inland food resources (Allen, 1977b; Lawes, 1879).

The current isotope evidence does support dietary and cultural trends observed archaeologically on the offshore island of Motupore. It has been suggested that increasing population density on Motupore resulted in the overexploitation of nearby marine resources, the increase importation of local inland food resources (exemplified by wallaby remains) and craft specialization to produce items for export (Allen, 1985; Allen et al., 1997). Although precise dating of Nebira and the offshore island site of Motupore is necessary to clarify temporal associations between the sites, it is possible that the Nebira community was supplying smoked wallaby meat in exchange for pottery and other materials, and possibly people from specialized communities on the coast, such as Motupore (Allen, 1985).

It is also possible the lack of marine products at Nebira is a reflection of the overexploitation occurring along the coast before European contact. The exchange of marine foods observed historically may have been a consequence of a reduction in population density along the Papuan south coast resulting from introduced European diseases (Allen, 1985). Thus, the decline in human predation on these species would have resulted in the reestablishment of marine organisms during the historic period that

preceded the occupation of Nebira. Moreover, El Nino Southern Oscillation (ENSO) events occurring intermittently during the period of occupation of site ACJ (Anderson et al., 2006) may have contributed to environmental pressures on both marine and terrestrial ecosystems causing drought, crop failure and food shortages (Scott and Buckley, 2010). Allen (1984) mentions fish were traded by the Motu only when there was an excess from fishing missions and during seasons when there was adequate food available and this may also be a reason marine foods were not an important dietary resource.

7. Conclusion

The isotope evidence offers new insights into the diet and subsistence at the site of Nebira on the south coast of PNG. Stable isotope analysis suggested the individuals buried in the Nebira cemetery were eating C_3 plants, most likely horticultural products such as yam, taro and bananas, and utilising the surrounding C_3 and C_4 -savannah grasslands and nearby forests for protein resources such as wallaby, feral pig, bandicoots, birds and a large variety of smaller vertebrates and invertebrates. The high proportion of C_4 protein foods likely indicates that animals that grazed the local savannah environment, most likely wallabies, were consumed. Juveniles were likely eating a more diverse diet of terrestrial and possibly freshwater foods. Multiple stable isotope analysis of bone collagen from Nebira indicates the palaeodiet at the site was similar to ethnographic and historical accounts of local inland Koita tribes, supporting the premise that Nebira may represent an ancestral Koita community. Isotopically, there was no indication of marine foods in the diet suggesting that during the period of ~800–300 BP, marine foods did not contribute substantially to the dietary repertoire at Nebira and therefore the historical accounts of trading marine foods inland are not supported. Equally this claim cannot be entirely refuted as marine foods may have been consumed in small amounts that are not observable isotopically.

When interpreted in conjunction with archaeological, ethnographic, historical, linguistic and oral historical evidence, the isotopic data suggest that the Nebira community may have traded locally hunted meat for material items from specialized pottery and shell manufacturing villages to the south, such as Motupore (Allen, 1985). It is suggested that pottery may have been preferentially brought to the site over marine food resources. Using the strontium isotope evidence (Shaw et al., 2011) it can be proposed that people were moving from the coast into the Nebira area after the age of tooth formation, but adapting to an inland diet later in life. This approach to investigating subsistence and social interactions on the south coast of Papua New Guinea emphasises the importance of palaeodietary analyses when addressing questions that are difficult to interpret solely with material culture and ethnographic evidence. Social bioarchaeology can play an important role in assessing the antiquity of recent cultural observations and can potentially illuminate specific trends, such as sex-related differences in diet, which may be related to gendered practices in the past.

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