ARCHAEOLOGY IN NEW ZEALAND

Sugar Cane Consumption on Rapanui (Easter Island) and the Incidence of Caries: Evidence from Stable Isotope Values of Human Bone

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Abstract

Pre-European people on Rapanui are known to have had a high rate of dental caries. One proposed explanation for this is that the people consumed a considerable amount of sugar cane, as a thirst quencher, since fresh water is scarce on the island. Human bone samples were analysed by isotope analysis to see if this explanation could be sustained. Results for three isotopes $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ were then used in a stochastic model to estimate the proportions of five main food types in the diet of these people. This indicated that daily consumption of dry raw sugar cane was only about 32 to 42 g per day. This is very low and sugar cane consumption is therefore unlikely to be the only cause of the high rate of dental caries.

Keywords: **Rapanui, Easter Island, Isotope Analysis, ^{13}C, ^{15}N, ^{34}S, Diet Reconstruction, Sugar Cane, Dental Caries**

Introduction

In 1986 Owsley *et al*. published a paper reviewing the evidence of carious lesions amongst a very large sample of skeletal remains from late in the sequence of occupation of Rapanui (Easter Island). This was an interesting and very thorough review, clearly documenting a very high rate of caries compared with that of other groups of people in the Pacific region. The authors attributed this high index to three factors – a diet rich in carbohydrates, the availability of natural sugar, and poor oral hygiene (ibid.: 420). While not necessarily stressing one of these factors more than another, they drew attention to the limited supply of water on Rapanui, noting that the people overcame this problem by using the juice of sugar-cane as a liquid substitute, and that until the 1900s they consumed great quantities of the sweet juice to relieve thirst (ibid.: 419). The evidence for this was cited as Metraux (1940). Further support was offered for this possibility by the observation that “the anterior teeth, including the incisors and canines, were affected by caries in the mid-20s, an unusual phenomenon for any pre-contact population. Unusually high frequencies of anterior tooth caries may relate to the cultural practice of sucking sugar-cane to relieve thirst" (ibid.: 420). They also noted that genetic factors, such as those relating to the Founder Effect, should not be ruled out. The figures they cited in their study, with an overall mean rate of caries of 27.1%, are certainly high alongside other groups they tabulate, but the distribution around the mouth does not strongly support the notion of high incidence in the anterior dentition:

Tooth Region	**Maxillary**	**Mandibular**
Incisors	11.1	28.2
Canines	22.2	23.7
Premolars	13.3	25.2
Molars	28.4	47.5

Unfortunately, very little is known of the role of sugar-cane in Pacific Island societies before the European era, mainly because botanical macro-fossils are not routinely kept and identified by archaeologists. However, one way in which the use of this plant can be documented is through isotope values in samples of human bone. An isotope study of human remains from the island of Watom off the coast of New Britain suggested that sugar cane was used by the people there as well as some other plants which have a distinct isotope signature (Leach *et al*., 2000). Since we had samples of human bone from Rapanui, it seemed useful to examine these for evidence of this distinctive isotope signature. This might help to verify if the high rate of caries was indeed caused by significant use of this plant in the diet.

Sugar cane, *Saccharum officinarum*, is one species of a special group of plants, known as C4 plants, which photosynthesise by a different pathway than most other species, known as C3 plants. In the western Pacific, particularly in Papua New Guinea, there are extensive grasslands which are dominated by C4 plants, such as members of the *Saccharum* genus and *Imperata cylindrica* (sword grass or kunai). Of the former the following can be mentioned: *Saccharum officinarum* (sugar cane), *S. spontaneum* (pitpit), *S. edule* (edible pitpit, also called kunai by some people – see Waddell, 1972: Appendix 5), and *S. robustum* (wild sugar cane, also called pitpit, refer Mihalic, 1971: 356). Values have been reported for $\delta^{13}C$ from *Imperata cheesmanii* and *I. cylindrica* as -12.8‰ and -12.2‰ (Troughton and Card, 1972). Our own analysis of *I. cylindrica* from Taurama Beach near Motupore Island in Papua New Guinea gave a value of -10.9‰. These values are typical of C4 plants.

So far as is known, sugar cane is indigenous to Melanesia and is found in all gardens. It is propagated vegetatively (Barrau, 1955: 60). It is a general item of diet, chewed between meals, primarily used for thirst quenching. Edible pitpit is a type of wild sugar cane with edible fruit resembling an unripe ear of maize. The stems of pitpit are also used for light walls and fences. Waddell (1972) provides dietary data on these plants for the Raiapu people at Modopa in the Papua New Guinea highlands. Another important factor to consider is the possibility that herbivorous animals may browse on C4 plants, such as sugar cane, so that when people eat the meat they acquire part of the distinct isotope signature of the original plant foods. In our study of the Watom people, we found evidence of both forms of isotope signature, directly from C4 plants, and indirectly from browsing herbivores (pigs and wallabies).

There is some quantitative information about the role of C4 plants in diet amongst the Raiapu people, which is a useful yardstick against which to examine the Rapanui evidence. Waddell found that the average consumption per day (percent of total weight) was 4.87% for sugar cane and 0.75% for edible pitpit (ibid.: 114). This gives a total direct consumption of C4 plants of 5.62%. Although these people kept pigs and engaged in some hunting (ibid.:101), meat contributed very little to their diet. It is also of interest that their domesticated pigs were largely fed on sweet potato, with sugar cane contributing only 0.05% of their diet (ibid.: 119). Elsewhere Wadell reported that sugar cane made up 7% by weight of the diet and meat and fish 1.5% (ibid.: 124). On the basis of this information, it seems unlikely that C4 plants would have contributed more than 10% by weight from direct consumption of plants and domesticated pigs.

In our study of the Watom people, we obtained a value of 2.7% by weight for average daily consumption of C4 plants, which includes primary ingestion of plants such as sugar cane in addition to a secondary derivation from wild browsing herbivores. There is no reason to think that this rate is excessive, or was forced on these people by lack of water, as is suggested for the Rapanui people. As far as is known, the incidence of caries is low for the Watom people (Evans, 1987: 98), although this is based on a very small sample. If the high incidence of caries on Rapanui was due to excessive use of sugar cane, we would expect that the isotope signature would indicate this in far greater measure than was the case in the Watom study, or for the modern Raiapu people.

Isotope Analysis

Samples from 11 burials from Rapanui from Ahu Kihi Kihi Rau Mea, Site 8-374 (Figure 2); Oroi Caves, Sites 12-471a, 12-469; Ahu Mahatua, Site 31-1; Ahu One Makihi, Site 14-21; Ahu Akahanga, Site7-584; Akahanga Cave, Site 7-598; and Ahu Poe Poe, Site 31-4 (See Figure 1) were sent to Otago University for analysis from the Museo Antropológico P. Sebastian Englert (MAPSE) on Easter Island by Seelenfreund in 1986 (Table 1).

Figure 1. Ahu Poe Poe at Hanga o Miti.

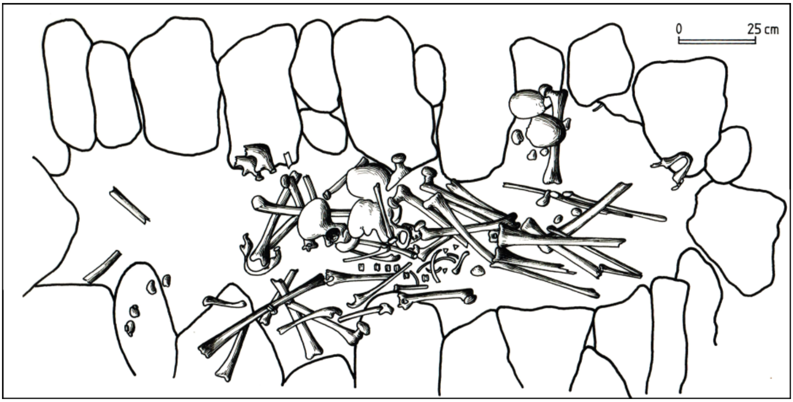

Figure 2. Ahu Kihi Kihi Rau Mea. Site 8-374, Tomb F.

These samples are not ideal for this type of research, being very small amounts of rib bone. When carrying out research on trace elements and isotopes on human bone it is advisable to use the interior part of thick cortical bone to minimise any problems of soil chemical diagenesis. Even then a watchful eye is kept on the atomic C/N ratio, which is used to monitor the possibility of contamination. DeNiro (1985: 808) suggests that this ratio should be in the range of 2.9 to 3.6 to be sure there are no soil chemical diagenic effects. The Rapanui samples gave values between 3.0 and 3.5, so this does not appear to be a problem for the analysis of ^{13}C and ^{15}N. In the case of ^{34}S no simple test like this has been developed to help identify such problems. The δ^{34}S isotope signatures for foods deriving from the land also depend on the extent to which land sulphates derive from the marine environment. Where plants are grown on coral soils, for example, they will have distinctly marine looking values for this isotope. The same type of problem can occur with soils in geothermal areas, or where there is strong sea-spray affecting nearby vegetation. It is not known whether such problems exist on Rapanui, so a conservative approach should be adopted. We therefore examined the diet indicators for these samples, assuming firstly that the isotope signatures would be dominated by land effects, and secondly by marine effects. As will be seen below, as far as sugar cane is concerned, this makes very little difference. Isotope values for all floral and fauna material used in this present analysis are derived from Leach *et al*. (1996), and Leach *et al*. (2003).

Sufficient bone was available from four individuals to extract collagen for determination of δ^{13}C, but as there was insufficient material for the analysis of δ^{15}N, this was done on bone powder. This is not ideal, and a small adjustment is required to bring the final values into line with those obtained on collagen extract. All samples were carefully cleaned of obvious surface contaminants and washed in distilled water in an ultrasonic bath. Checks were made for soil bearing nitrates during chemical pre-treatment for δ^{15}N. Bone samples were powdered with a tungsten carbide Temma mortar, and a sub-sample of this used for δ^{15}N determination.

Table 1: Details of Skeletal Remains from Rapanui
The yields of collagen from the largest bone samples were quite high and are indicated as percent figures. Most samples were very small. Those listed as 0.4 g were the measured amounts used for $\delta^{15}N$ determination, but there was very little residue from any of these samples. AX and AA catalogue numbers in Tables 1 and 2 are those allocated by Otago Anthropology department. The original RH catalogue numbers are those of the original excavations by Seelenfreund (2000), and Shaw (2000a and 2000b).

Cat No	Wgt	%Collagen	Details
AX859	5.03	7.16	Site Number 8-324. Ahu Kihi Kihi Rau Mea. Burial No 1. Five rib fragments.
AX860	5.85	12.99	Site Number 8-324. Ahu Kihi Kihi Mea. Burial No 1. Tomb F. Three rib fragments.
AX861	1.92	21.33	Site Number 12-471a. Oroi Cave. Burial No 1. Two rib fragments.
AX862	0.40	-	Site Number 12-469. Oroi Cave. Burial No 1. RH0286. One rib fragment.
AX863	0.40	-	Site Number 12-469. Oroi Cave. Burial No 2. RH0285. One rib fragment.
AX864	0.40	-	Site Number 31-1. Ahu Mahatua. Burial No 2. RH0219. Male. 55+ years. One rib fragment.
AX865	1.37	16.06	Site Number 14-21a. Ahu One Makihi. Burial No 2. Two rib fragments.
AX866	0.40	-	Site Number 7-584. Ahu Akahanga. Burial Number 4A. RH0104. male. 30-40 years. Two rib fragments.
AX867	0.40	-	Site Number 7-598. Akahanga Cave. Burial No 1. RH0270. One rib fragment.
AX868	0.40	-	Site Number 7-584. Ahu Akahanga. Burial No 1. RH0092. Female ?. 25-30 years. Two rib fragments.
AX869	0.40	-	Site Number 31-4. Ahu Poe Poe. Burial Number 1. RH0235. Female. One fragment of rib.
AX870	0.40	-	Site Number 31-4. Ahu Poe Poe. Burial No 2. RH0234. Female. Two fragments of rib.

In the case of $\delta^{13}C$ and $\delta^{34}S$ it was necessary to extract the inorganic component, in order to cut down on the sheer bulk of the samples; and for $\delta^{13}C$ analysis, to eliminate those sources of carbon which may have come from surrounding soil. The samples were digested using 5% phosphoric acid, and then washed to neutral pH, centrifuged and freeze dried. The final sample was a powder with a variable colour ranging from light to dark brown. Hydroxyproline analysis of samples of this showed there to be approximately 63% collagen in this residue, which is referred to here as collagen extract. The sulphur was extracted from this collagen extract using Parr bomb treatment yielding barium sulphate (Quinn, 1990: 97 ff).

The isotope values for $\delta^{34}S$ and $\delta^{13}C$ were obtained at the then Institute of Nuclear Sciences, and $\delta^{15}N$ at the Ruakura Agricultural Research Centre. The results are provided in Table 2. We also provide isotope results for sugar cane in this table.

Table 2: Stable Isotopes Results for Rapanui

Human Bone	**$\delta^{13}C$**	**$\delta^{15}N$**	**$\delta^{34}S$**	**C/N**
AX859	-18.14	+13.441	-	3.0
AX860	-18.77	+13.498	+14.4	3.0
AX861	-19.33	+13.825	-	3.0
AX862	-	+13.942	-	-
AX863	-	+13.107	-	-
AX864	-	+14.052	-	-
AX865	-17.40	+13.062	-	3.5
AX866	-	+13.670	-	-
AX867	-	+12.734	-	-
AX868	-	+14.176	-	-
AX869	-	+13.740	-	-
AX870	-	+15.094	-	-
Raw Mean	**-**	**+13.695**	**-**	**-**
Adjustment	-	-0.2	-	-
Means	**-18.41**	**+13.495**	**+14.40**	**3.13**
Sugar Cane				
AA350	-11.35	+3.47	-	-
AA350	-11.56	-	+9.8	-

Note 1: All $\delta^{13}C$ and $\delta^{34}S$ values listed for human bones were obtained on collagen extract at the then Institute of Nuclear Science in 1986.

Note 2: All $\delta^{15}N$ were obtained on bone powder at the then Ruakura Agricultural Research Centre, requiring a small adjustment of 0.2‰ to be consistent with values for collagen extract (Quinn, 1990: 180).

Note 3: The analysis of $\delta^{15}N$ for specimen AX868 was duplicated, giving results of +13.932 and +14.420, and an average of +14.176.
Note 4: In the case of specimen AA350 the first values given for $\delta^{13}C$ and $\delta^{15}N$ were from the then Ruakura Agricultural Research Centre, while the second value for $\delta^{13}C$ and $\delta^{34}S$ value were obtained from the then Institute of Nuclear Sciences.

The mean isotope values obtained for these people from Rapanui were $\delta^{13}C$ = -18.4, $\delta^{15}N$= +13.5, and $\delta^{34}S$ = +14.4. The $\delta^{13}C$ result is very clearly at the end of the spectrum, which is dominated by land based foods. There is an offset value of about 5‰ between collagen extract and the foods people eat, so that the mean value of -18.4‰ obtained for Rapanui is equivalent to eating foods in the region of +23.4‰. The mean $\delta^{13}C$ value for C3 plants is -26.0‰, while that for C4 plants is -11.5‰. We obtained two values for sugar cane of -11.35 and -11.56 ‰.

It is fairly clear that sugar cane could not have figured prominently in the overall diet of these people from Rapanui. The $\delta^{13}C$ value is simply too far away from sugar cane for any other conclusion. However, this simple qualitative assessment could be augmented by considering how the combination of all three isotopes sheds light on the diet of these individuals.

Before attempting this, we should make some comments about the other two isotopes individually. The $\delta^{15}N$ value obtained for Rapanui is in the centre of the distribution between marine and terrestrial sources of food. This must be interpreted as an indication that these people did receive a significant amount of their daily food from the sea. Rapanui is not considered rich in marine foods compared with many Polynesian islands, so this result was somewhat surprising. Ayers, for example, in his paper on Easter island subsistence states: "fishing appeared to be relatively insignificant as a food source during the historic period due to limited marine biota" (Ayers, 1985: 105). This limitation of marine resources around the island is frequently cited by marine biologists. "All of the published work has inevitably reached the same conclusion: the marine fauna of Easter island, including fish, is depauperate compared with other islands of the Indo Pacific (Massin, 1996; Rehder, 1980)..." (Boyko 2003:156).

There are not many published values for $\delta^{15}N$ in C4 plants, but a mean value of +10.0‰ is often cited. Our value for sugar cane was +3.47‰, which is at the far end of the spectrum. Once again, using a simple yardstick like this, it is unlikely that sugar cane could have figured prominently in Rapanui diet.

Finally, the Rapanui result of +14.4 for $\delta^{34}S$ is notable for its marine-looking value, considerably different from the sugar cane value of +9.8‰. As noted above, when interpreting human isotope values, it is sometimes necessary to allow for a marine influence on the values of terrestrial foods in the case of the ^{34}S isotope. From the foregoing comments on the individual isotope values for Rapanui, those for $\delta^{34}S$ stand out as being considerably more marine-looking than either $\delta^{13}C$ or $\delta^{15}N$. It is therefore possible that the $\delta^{34}S$ values are influenced by land plants and animals which have derived a considerable portion of their sulphur from sea-spray or unusual volcanic residues.

It is possible to assess the relative importance in ancient diet of the major food types available in the Pacific region directly from these three isotopes in human bone using a computer simulation model (Leach *et al*. 1996). This was applied to these Rapanui results, using both options relating to $\delta^{34}S$ derivation of 'land-dominated' and 'marine-dominated' (Table 3 and Fig.3). The standard deviations of the main food types are reasonably small, giving some confidence in the main results.

Table 3: Rapanui Diet Composition from Computer Simulation

Assumptions used for Simulations: For each of five main food types, random numbers were used to generate possible food proportions in the range of 0-100%. Since there is no coral reef around Rapanui food from this environment was ignored. Also, it was assumed that sea mammals did not form a significant part of the diet. The target isotope values specified below are the mean values obtained for the Rapanui people. The tolerance figures are the limits around these mean values which were used in the simulation.

Isotope	**Target**	**Land Tolerance**	**Marine Tolerance**
$\delta^{13}C$	-18.4	3.0	1.9
$\delta^{15}N$`	+13.3	2.0	2.1
$\delta^{34}S$	+14.4	4.0	2.1

	Land Dominated		**Marine Dominated**	
Isotopes	**Mean**	**SD**	**Mean**	**SD**
$\delta^{13}C$	-15.6	0.2	-16.7	0.2
$\delta^{15}N$	+12.2	0.4	+11.4	0.1
$\delta^{34}S$	+10.6	0.2	+16.5	0.0

Food Weight %/day				
C3 Plant Foods	44.0	3.1	40.8	3.2
C4 Sugar cane	1.8	1.3	2.8	2.2
Land Animals	4.6	3.7	24.5	3.1
Shellfish	10.3	5.8	1.1	0.8
Fish	39.3	6.2	30.9	2.0
Protein g/day				
C3 Plant Foods	16.0	1.8	13.3	1.8
C4 Sugar cane	0.1	0.1	0.2	0.1
Land Animals	17.1	13.2	83.1	7.9
Shellfish	22.3	13.0	2.0	1.5
Fish	127.7	19.7	89.8	5.4
Total	183.2	-	188.4	-
Energy kcal/day				
C3 Plant Foods	1057	119	876	115
C4 Sugar cane	12	8	16	13
Land Animals	115	89	557	53
Shellfish	119	69	11	8
Fish	648	100	45	28
Total	1951	-	1916	-

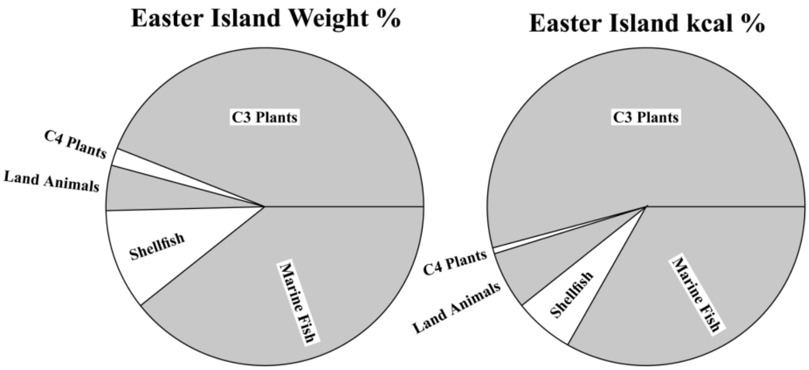

Figure 3. Estimated proportions of the main foods in the diet (land dominated stochastic model)

The first thing to be noticed is that sugar-cane, the only C4 plant known to be a source of food on the island, is quantitatively low, providing either 12 or 16 kcal per day, depending on whether one assumes the $\delta^{34}S$ derivation to be 'land-dominated' or 'marine-dominated.' This is equivalent to 32 to 42 g per day raw sugar cane, which is a very low figure.

The most important food to these people as a source of caloric energy was C3 plant foods, which, bearing in mind the early historic evidence, would be from kumara, *Ipomoea batatas,* taro, *Colocasia esculenta*, and Pacific yam, *Dioscoria* sp. It is interesting that Tromp and Dudgeon have identified kumara starch grains in the dental calculus of Easter Island burials, and their intact nature suggests that they had not been cooked (Tromp and Dudgeon 2015: 58). They state that "sweet potato does not require processing or cooking before eating, and indeed was probably eaten raw as a source of both carbohydrates and water" (*ibid.* :60). This is a most surprising suggestion, considering that in the raw state the digestible nutrients of sweet potato constitute only about 47% (Yoshida *et al.* 2014: 682), although this is higher than other tuberous foods such as potato which, when raw, is only about 32% digestible, and 98% when cooked (Hellendorn *et al.* 1970: 72, Figure 1, *et passim.* See also Lawton, 2016: 136). According to Dominguez, "the uncooked starch of the sweet potato is very resistant to the hydrolysis by amylase [the enzyme made by the pancreas gland that helps humans to digest carbohydrates]. When cooked, their susceptibility to the enzyme increases. Thus, after cooking the easily hydrolysable starch fraction of sweet potato increases from 4% to 55%" (Dominguez 1992: 217).

The assumptions concerning the derivation of $\delta^{34}S$ make a big difference to which is the second most important food. If the assumption is 'land-dominated' then fish assumes this role, whereas the 'marine-dominated' hypothesis favours land animals, which in this case would be chicken, *Gallus gallus,* and Polynesian rat, *Rattus exulans*. It is important to note that the amount of plant foods in this reconstruction would not provide adequate protein intake, and there must have been another significant source, which we judge to be from fish and chicken. It is interesting that regardless of which hypothesis is chosen, the role of shellfish is seen to be relatively minor, something which is supported by archaeological excavations (Ayres 1985: 105). It is also in keeping with the small population of available molluscs and low number of species in the marine environment (Osorio and Cantuarias 1986).

Conclusions

Owsley *et al*. (1986) showed that the pre-European people of Rapanui had a very high rate of carious lesions in their teeth, and one suggestion they offered to explain this was that it may have been caused by an exorbitant use of sugar cane, since fresh water is scarce on the island. Our analysis of isotope levels in human bone from Rapanui does not support this theory. The isotope analysis does show the presence in the diet of C4 plants, of which sugar-cane is the only known species on Rapanui, but its role in the diet was clearly minor, contributing at most 30-40 g per day. We suggest that sugar cane consumption is unlikely to be the only cause for the high incidence of caries in this society.

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