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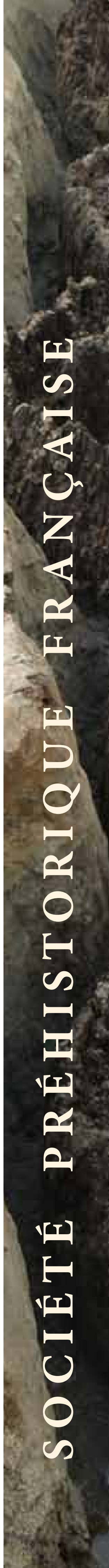

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PARIS 30 janvier-1er février 2014

Textes publiés sous la direction de

Frédérique Valentin et Guillaume Molle

Société préhistorique française
www.prehistoire.org

2016

ISBN : 2-913745-66-0 (en ligne)
ISSN : 2263-3847

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Paris
2016

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Illustration de couverture : Tarodière du col des Roussettes, Nouvelle-Calédonie (© IANCP, cliché C. Sand).

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Société préhistorique française
(reconnue d'utilité publique, décret du 28 juillet 1910). Grand Prix de l'Archéologie 1982.
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Publié avec le concours du ministère de la Culture et de la Communication (sous-direction de l'Archéologie),
du Centre national de la recherche scientifique,
de l'université Paris I – Panthéon-Sorbonne, de l'université Paris Ouest Nanterre,
de l'université de la Polynésie française (Faa'a), de l'Australian National University (Canberra),
de l'UMR 7041 « Archéologie et sciences de l'Antiquité (ArScAn) » et de son équipe « Ethnologie préhistorique » (Nanterre),
de l'Institut d'archéologie de la Nouvelle-Calédonie et du Pacifique (IANCP, Nouméa)
et du Centre international de recherche archéologique sur la Polynésie (CIRAP, Faa'a).

Dépôt légal : 4e trimestre 2016

ISSN : 2263-3847 – ISBN : 2-913745-66-0 (en ligne)

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Paris, Société préhistorique française, 2016
(Séances de la Société préhistorique française, 7), p. 111-124
www.prehistoire.org
ISSN : 2263-3847 – ISBN : 2-913745-2-913745-66-0

The impact of gender, age, social status and spatial distribution on the ancient Easter Islanders' diet

Caroline Polet

Abstract: Easter Island (or Rapa Nui), famous worldwide for its gigantic stone statues, is the most isolated inhabited island in the Pacific. Yet the history of its inhabitants has been far from peaceful: they have faced deforestation, slave raids, epidemics and colonialism. This paper aims to study the diet of the ancient Easter Islanders and focuses on dietary reconstruction through the analysis of human teeth and bones, more particularly, on the impact of gender, age, social status and spatial distribution. However, retrieving information on their dietary habits is difficult, due to the absence of written archives and the disappearance of most of the bearers of the indigenous culture during the slave raids and epidemics of the nineteenth century. Therefore our primary source of direct information are food remains (animal bones and plant remnants) and human bones. The individuals studied came from twenty sites, which date mainly from the seventeenth to the nineteenth centuries. The greater part had been buried in monuments (funerary stone platforms called *ahu*), or caves. These individuals are currently stored at the Royal Belgian Institute of Natural Sciences and the Father Sebastian Englert Anthropological Museum of Easter Island. Dietary reconstruction is based on stress indicators, dental microwear and stable carbon and nitrogen isotope analyses. Stress indicators are skeletal markers which reveal poor living conditions during growth. Two indicators were studied: dental enamel hypoplasia (localised defects in the tooth crown generally expressed in the form of horizontal depressions) and *cribra orbitalia* (porotic lesions in the bony orbital roof). Dental microwear is the study of the microscopic features that form on the teeth's surfaces as a result of use. Their density, dimensions, and orientation are a direct result of diet. Stable isotope analyses are based on the fact that the isotopic composition of an individual's tissues is determined by the proportion of the various foods consumed. Carbon and nitrogen stable isotope composition were analysed in the bone collagen. Dental microwear patterns indicated a large proportion of tubers in the Easter islanders' diet. Additionally, the stable isotopes showed that, on average, one third of the dietary proteins were of marine origin and that children were breastfed until three years of age. Stress indicators suggest that infantile malnutrition was not severe. Our results also demonstrated gender disparity in access to food resources. Furthermore, the isotopic signatures clustered according to the place of burial *(ahu)*, indicating family dietary specificities. Finally, our study revealed the influence of social status on food intake: individuals from Ahu Nau Nau, which is said to be the royal ahu, displayed the highest value of nitrogen and carbon isotopes and the lowest number of microwear features. A greater consumption of marine products may explain this distinction.

Keywords: Polynesia, Easter Island, diet, stress indicators, dental microwear, stable isotopes.

L'impact du genre, de l'âge, du statut social et de la répartition spatiale sur l'alimentation des anciens Pascuans

Résumé : L'île de Pâques (ou Rapa Nui), célèbre dans le monde entier pour ses gigantesques statues de pierre, est l'île habitée la plus isolée du Pacifique. L'histoire de ses habitants, les Pascuans, fut des plus tourmentée. Ils durent tour à tour faire face à la déforestation, aux raids esclavagistes, aux épidémies et au colonialisme. Les fouilles archéologiques menées à partir de la fin du xixe siècle ont permis la mise au jour de restes humains appartenant à plusieurs centaines d'individus. L'attribution chronologique des squelettes, est cependant problématique, car la plupart des monuments ont été utilisés pendant de longues périodes. En outre, les datations ont été effectuée principalement sur des objets en obsidienne mais rarement directement sur des restes humains. Cet article traite du régime alimentaire des anciens Pascuans. Collecter des informations sur leurs habitudes alimentaires n'est pas une tâche facile compte tenu de l'absence d'archives écrites et de la disparition de la majorité des détenteurs de la culture ancestrales au cours des raids d'esclavagistes et des épidémies du xixe siècle. Les principales sources d'information directe sur le régime des anciens habitants de l'île sont les déchets alimentaires (restes animaux et végétaux) et les restes humains. Notre étude concerne ces derniers : nos reconstitutions alimentaires sont basées sur l'étude de leurs dents et de leurs ossements et, portent plus particulièrement, sur l'impact du sexe, de l'âge, du statut social et de la répartition spatiale.

Les individus étudiés proviennent de vingt sites datant principalement du xviie au xixe siècle. La majorité de ces individus ont été inhumés dans des monuments (plates-formes funéraires en pierre appelées *ahu*) ou dans des grottes. Ce matériel anthropologique fait partie des collections de l'Institut royal des sciences naturelles de Belgique et du musée anthropologique Père-Sébastien-Englert de l'île de

Pâques. Les reconstitutions du régime alimentaire sont basées sur l'analyse des indicateurs de stress, de la micro-usure dentaire et des isotopes stables du carbone et de l'azote. Les indicateurs de stress sont des marqueurs osseux ou dentaires qui révèlent de mauvaises conditions de vie pendant la croissance. Deux indicateurs ont été étudiés: l'hypoplasie de l'émail dentaire (défauts localisés dans la couronne de la dent généralement exprimés sous forme de dépressions horizontales) et les *cribra orbitalia* (lésions porotiques localisées dans le toit de l'orbite). La micro-usure dentaire consiste en des altérations microscopiques (stries et puits) qui se forment à la surface des dents suite à leur utilisation. Leur densité, leurs dimensions et leur orientation sont fonction du type d'aliment consommé. Les analyses des isotopes stables sont basées sur le fait que la composition isotopique des tissus d'un individu reflète la proportion des différents aliments qu'il a consommés. La composition isotopique du carbone et de l'azote a été mesurée dans le collagène osseux. Le *pattern* de micro-usure dentaire indique une forte proportion de tubercules dans l'alimentation des Pascuans. Les isotopes stables montrent que, en moyenne, un tiers des protéines alimentaires étaient d'origine marine et que les enfants étaient allaités jusqu'à l'âge de 3 ans. Les indicateurs de stress suggèrent que la malnutrition infantile n'était pas sévère. Nos résultats mettent également en évidence des disparités entre les hommes et les femmes dans l'accès aux ressources alimentaires : les hommes consommaient davantage de protéines d'origine animale. En outre, les signatures isotopiques des individus varient en fonction de leur lieu d'inhumation *(ahu)* indiquant des spécificités alimentaires familiales. Enfin, notre étude révèle une influence du statut social sur la consommation alimentaire : les individus de l'Ahu Nau Nau, connu comme étant l'*ahu* royal, présentent des valeurs des isotopes de l'azote et du carbone les plus élevées et un nombre plus réduit de microtraces d'usure dentaire. Une plus grande consommation de produits d'origine marine pourrait expliquer cette distinction..

Mots-clés : Polynésie, île de Pâques, régime alimentaire, indicateurs de stress, micro-usure dentaire, isotopes stables.

Easter Island (or Rapa Nui), famous worldwide for its gigantic stone statues, is the most isolated inhabited island in the Pacific (fig. 1). It is located at 27°09'30" S and 109°26'14" W, 3,600 km from the Chilean coast and 4,200 km from Tahiti. Today, its closest populated neighbour is Pitcairn Island, 2,075 km to the west. Easter Island is of volcanic origin with a land area of 160.5 km^2 (Fischer and Love, 1993).

According to some authors, the first human settlements on Easter Island took place between the eighth and the tenth century AD (Bahn, 1993). For others, it occurred more recently, during the twelfth century (Hunt and Lipo, 2006). Anthropological (Turner and Scott, 1977; Gill and Owsley, 1993), palaeogenetic (Hagelberg et al., 1994), ethnographic (Métraux, 1940) and linguistic (Du Feu and Fischer, 1993) research agrees that the Easter Islanders were of Polynesian origin.

The population of the island continued to expand and had reached 9,000 islanders by 1550, according to Patrick Kirch (Kirch, 1984). A demographic decline then began at about 1650 accompanied by great upheavals in the social organisation, including religious and funerary practices. This may have been related to the disappearance of available resources. The palynological (Flenley and King, 1984) and anthracological analyses (Orliac and Orliac, 1998) show that Easter Island definitely had, until the beginning of the seventeenth century, a forest cover where palm trees dominated. However, when the European navigators visited the island in the eighteenth century [(1)], there were estimated to be no more than 1,000 or 2,000 inhabitants and the forests had completely disappeared.

Three main theories have been used to explain this deforestation. The first is the 'ecocide' theory, which suggests that the Rapa Nui society destroyed itself by overexploiting its own resources destroying their forests, degrading the island's topsoil, wiping out their plants and driving the animals to extinction (Heyerdahl and Ferdon, 1961; McCoy, 1979; Kirch, 1984; Bahn and Flenley, 1992). The second gives priority to climate change and more particularly to the Little Ice Age droughts (McCall, 1993; Orliac and Orliac, 1998). The third involves the impact of the Polynesian rat with its predation of the *Jubea* palm nuts (Hunt, 2007).

For many scholars (e.g. Heyerdahl and Ferdon, 1961; Young, 1991; Ponting, 1992, p. 1–7; Bahn and Flenley, 1992), the result of this environmental devastation, was the pre-contact collapse of the Rapa Nui complex society. Based on stories collected by early twentieth century ethnographers (Routledge, 1919; Métraux, 1940), they specified that the Easter Islanders descended into civil war, starvation, cannibalism and finally self-destruction. This scenario was popularized by the best-selling environmentalist author Jared Diamond in his 2005 book Collapse: *How Societies Choose to Fail or Survive*. Recent studies, however, demonstrate that the Easter Islanders had already successfully struggled against natural environmental modifications, and that the real collapse only occurred in the nineteenth century (Stevenson et al., 2015; Boersema, 2015) when several tragic episodes did indeed decimate the population (Lavachery, 1935; Fischer, 2005). Between December 1862 and March 1863, Peruvian slave traders captured approximately 1,400 natives (men, women and children) to work on farms and to harvest the guano, primarily on the Chincha Islands, Peru (Maude, 1981). Among those captured was the island's paramount chief *(ariki-mau)*, his heir and many of the bearers of the indigenous culture. More than ninety percent of them perished due to bad working conditions, maltreatment and disease. In August 1863, international protests put an end to slave trade, and the survivors, carrying smallpox and tuberculosis, were repatriated back to the island. An epidemic of smallpox then decimated over a thousand islanders. Several years later, in 1868, Jean-Baptiste Dutrou-Bornier, a French adventurer, established himself on the island and began a reign of terror. However, by 1873, due to a disagreement with the Frenchman, his missionaries evacuated all the remaining inhabitants to the Gambier Islands and Tahiti. The only inhabitants that were forced to stay were the 111 Rapa Nui people who J.-B. Dutrou-Bornier had requisitioned as labourers (Métraux, 1940). His subjugation finally came to an end when he was assassinated in 1876. In 1888, the island was annexed by Chile and exploited from 1897 by a Chilean businessman. In 1903, the lands were rented to a Scottish sheep breeding company (Williamson-Balfour Company). Until 1954, this small Polynesian island became no more than a large farm with the Rapa Nui people being forced to live in a single village: Hanga Roa, the capital of the Chilean province of Easter Island (Fischer, 2005).

Throughout this tumultuous history, the Rapa Nui people lived within strict 'kinship groups' called *mata* (tribes; McCall, 1979) made up of the descendants of a common ancestor (Métraux, 1940, p. 123). During her stay on the island, in 1913–1915, the British archaeologist Katherine Routledge recorded ten tribes (she called them 'clans') which were associated with different parts of the island (Routledge, 1919, p. 221–224; fig. 1). One tribe, named Miru, ranked above all the other tribes (Routledge, 1919, p. 240–243). Its 'territory' was a strip of land located on the north of the island. The *ariki-mau* or king of Easter Island was a member of the Miru tribe and possessed a supernatural power *(mana)*, which was manifested through a system of restrictions *(tapu)* governing the right to use various resources (Métraux, 1940, p. 130–132).

Given the absence of written archives and the disappearance of most of the bearers of the indigenous culture during the slave raids and epidemics of the nineteenth century (Lavachery, 1935; Maude, 1981; Fischer, 2005), retrieving information on the Easter islanders' dietary habits was difficult. Therefore, we focused on the only main source of direct information on the ancient Easter islanders' diet: food remains (middens) and human bones. This study focuses on dietary reconstruction through the analysis of human teeth and bones and, more particularly, on the impact of gender, age, social status and spatial distribution.

MATERIAL

Archaeological surveys undertaken from the end of the nineteenth century on Easter Island uncovered the remains of several hundred individuals, the greater part of which had been buried in monuments *(ahu)*. In most cases, only the skulls were collected. In ancient periods (thirteenth–fifteenth centuries), the dead were generally cremated and their ashes gathered in stone-lined cists located at the rear of the *ahu* (Ayres and Saleeby, 2000; Huyge et al., 2002; Polet, 2003). After the period of deforestation, the progressive abandonment (and eventual destruction) of the giant statues *(moai)* cult, the Easter Islanders continued to bury their dead in the *ahu*, though

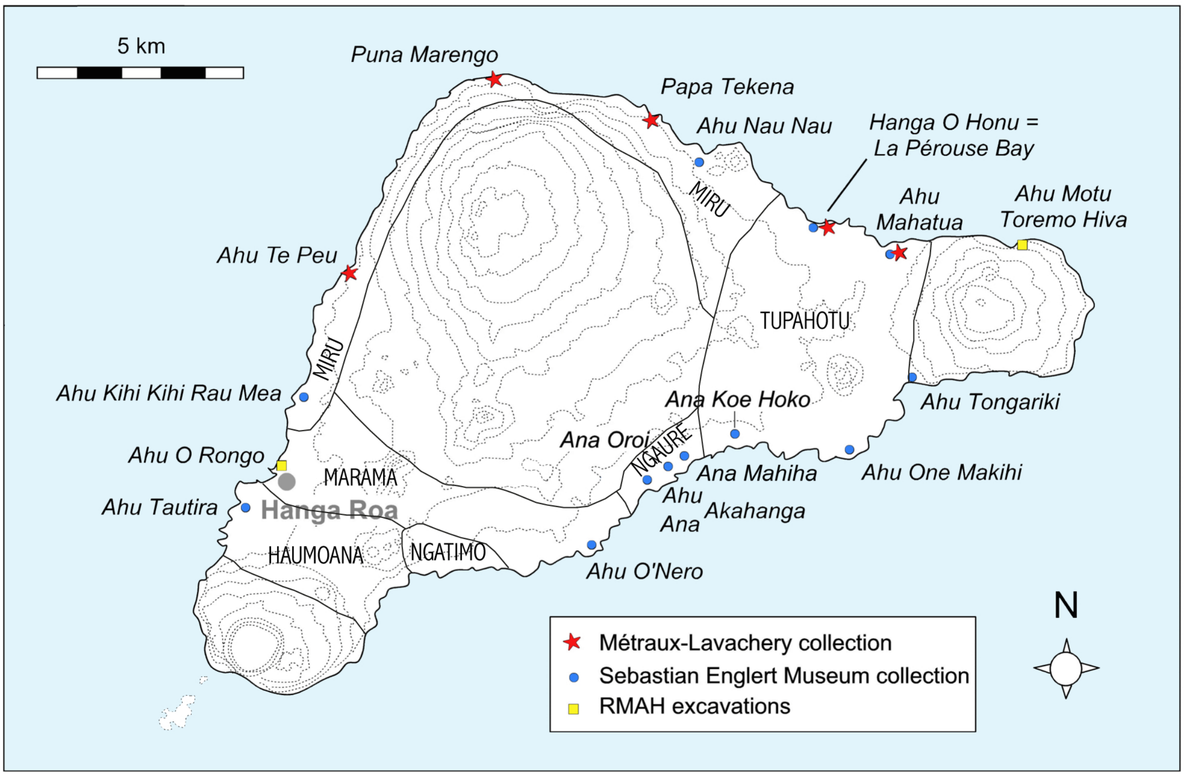

Fig. 1 – Easter Island and its tribal divisions (after Routledge, 1919), and the location of the different sites studied. RMAH = Royal Museums of Art and History.

Fig. 1 – *L'île de Pâques, les limites territoriales des tribus (d'après Routledge, 1919) et la localisation des différents sites étudiés. RMAH = Musées Royaux d'Art et d'Histoire.*

they mostly favoured niches dug into the platform or under lying *moai* (Seelenfreund, 2000; Cauwe, 2011). In addition, there were also cave burials that seem to have started after the discovery of the island by the Europeans (Shaw, 2000). Indeed, some may have contained individuals who died during the great epidemics of the nineteenth century.

However, the chronological attribution of the skeletons is problematic as most of the monuments were used over a long period of time. Moreover, dating was mainly carried out on obsidian artefacts (Seelenfreund, 2000; Shaw, 2000) or wood charcoal (Mulrooney, 2013) but rarely directly on human remains, though a total of twenty-six ^{14}C dates do exist (Commendador et al., 2014).

The samples studied here came from twenty sites (mainly *ahu* and caves) which date principally from the seventeenth to the nineteenth century (fig. 1 and table 1). They were composed of:

– skulls and long bones brought back to Europe in 1935 by A. Métraux and H. Lavachery (Lavachery, 1935). These come from the north of the island and belong to the collections of the Royal Belgian Institute of Natural Sciences (RBINS);

– skeletons exhumed at the end of the 1970s by G. Gill (Gill and Owsley, 1993). These skeletons are stored at the Father Sebastian Englert Anthropological Museum, Easter Island which contains the greater part of the recently excavated anthropological material;

– fragmentary human remains collected in 1996 by C. M. Stevenson and S. Haoa from cult and settlement sites at La Pérouse Bay (Stevenson and Haoa, 1998). These are also kept at the Father Sebastian Englert Anthropological Museum;

– skeletons recently discovered by N. Cauwe and D. Huyge (Huyge et al., 2002; Cauwe et al., 2006; Cauwe, 2011). Again, these are stored at the Father Sebastian Englert Anthropological Museum (except for the individual from Ahu Motu Toremo Hiva, who was reburied in accordance with a request from the local authorities).

METHODS

In order to obtain information on the dietary habits of ancient Easter Islanders, we recorded stress indicators and applied dental microwear and stable isotope analyses.

Site		Excavated by	Antiquity	N microwear	N stress indicators	N stable isotopes
Ahu	Nau Nau	G	15th–19th c.	28	41	19
	Tautira	G	?	1		
	Tongariki	G	17th–20th c.	4		
	Kihi Kihi Rau Mea	G	17th–20th c.	1	14	14
	O'Nero	G	end 17th–19th c.	2	12	9
	Akahanga	G	17th–19th c.	5	8	8
	One Mahiki	G	18th–19th c.	2	3	2
	Mahatua	G	19th–20th c.	6		13
	Hanga O Onu = La Pérouse Bay	LM	19th c.?	3		7
	Papa Tekena	LM	19th c.?	1		3
	Tepeu	LM	19th c.?			2
	O Rongo	CH	end 13th c.–beginning 14th c.	2		3
	Motu Toremo Hiva	CH	end 19th c.–beginning 20th c.	1		
Caves	Akahanga	G	18th–19th c.	1	4	4
	Koe Hoko	G	18th–19th c.	2	8	8
	Mahiha	G	18th–19th c.	3	6	6
	Oroi	G	18th–19th c.	6	17	11
Other	Puna Marengo	LM	19th c.?	2		
	La Pérouse	SH	1700–1850	1		
TOTAL				**71**	**113**	**109**

Table 1 – Composition of the samples studied for stress indicators, dental microwear and stable isotopes. G = Gill, LM = Lavachery and Métraux, SH = Stevenson and Haoa, CH = Cauwe and Huyge. Data come from Lavachery, 1935; Gill and Owsley, 1993; Stevenson and Haoa, 1998; Huyge et al., 2002; Cauwe et al., 2006; Cauwe, 2011; Commendador et al., 2013.

***Tabl. 1** – Composition de l'échantillon étudié pour les indicateurs de stress, la micro-usure dentaire et les isotopes stables. G = Gill ; LM = Lavachery et Métraux ; SH = Stevenson et Haoa ; CH = Cauwe et Huyge. Les données proviennent de Lavachery, 1935 ; Gill et Owsley, 1993 ; Stevenson et Haoa, 1998 ; Huyge* et al.*, 2002 ; Cauwe* et al.*, 2006 ; Cauwe, 2011 ; Commendador* et al.*, 2013.*

Stress indicators

To assess the general health status of the ancient Easter Islanders, we studied two skeletal markers in order to reveal poor living conditions during growth (stress indicators): dental enamel hypoplasia and cribra orbitalia.

Dental enamel hypoplasia consists of localised defects in the tooth crown (fig. 2a). It is generally expressed in the form of horizontal depressions due to a temporary disturbance in amelogenesis (Goodman and Rose, 1990). In most cases, hypoplasia originates from malnutrition and/or health problems (i.e. high fever or infection). The formation of a defect requires several weeks, at least, of continuous stress. As enamel does not remodel once it is formed, hypoplasia leaves permanent markers on the tooth. We recorded the presence of hypoplasia on the deciduous and permanent incisors and canines (Polet, 2006).

Cribra orbitalia is a porotic lesion in the bony orbital roof (fig. 2). For a long time, it was strictly associated with iron deficiency anaemia (Stuart-Macadam, 1992) but recent studies show that it can also be related to a vitamin-B12-deficiency, scurvy or chronic infections (Walker et al., 2009; Oxenham and Cavill, 2010). We recorded the presence of cribra orbitalia in individuals who presented at least one complete orbital roof (Polet, 2006).

Dental microwear

Dental microwear is the study of the microscopic scratches and pits formed on the surface of teeth as a result of use (Teaford, 1994). The density, dimensions, and the orientation of these microstructures, are dependent on the type of food consumed and its preparation (Molleson et al., 1993; Lalueza et al., 1996). On the vestibular surface of the teeth, the vertical and long striations are caused by meat being chewed quickly; while the short horizontal and oblique striations result from crushing harder (more abrasive) vegetal food. Vegetarians exhibit more striations than carnivores.

Dental microwear was examined on the buccal (vestibular) surface of the first and second permanent molars with scanning electron microscopy at × 178 magnification (Philips SEM 515 of the RBINS; Polet et al., 2008). The total number of striations, their length and their orientation in relation to the cement-enamel junction were recorded in a circular area of 300 µm diameter (fig. 2a),

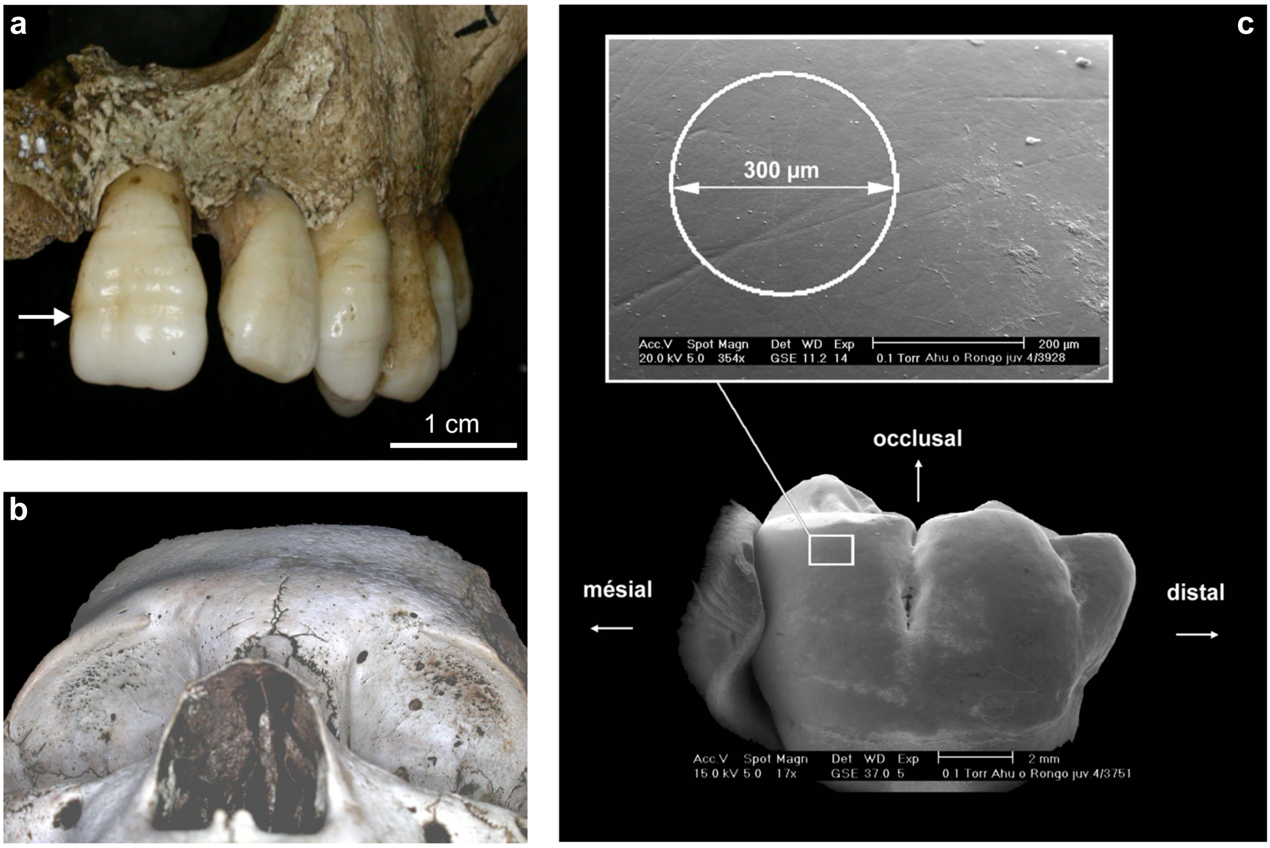

Fig. 2 – a: enamel hypoplasia in a child of approximately 12 years from Ahu O Nero; b: *cribra orbitalia* in a young woman from Oroi cave; c: positive replica of a molar from Ahu O Rongo seen from its buccal side. The selected zone (rectangle) is located on the mesio-buccal cusp near the occlusal surface. Microwear was recorded in a circular area of 300 µm diameter.

Fig. 2 *– a : hypoplasie de l'émail dentaire chez un enfant de l'Ahu O Nero âgé d'environ 12 ans ; b :* cribra orbitalia *chez une jeune femme de la grotte Oroi ; c : réplique positive d'une molaire de l'Ahu O Rongo, vue de sa face vestibulaire. La zone sélectionnée (rectangle) est localisée sur le cuspide mésio-vestibulaire à proximité de la surface occlusale. La micro-usure a été relevée dans une aire circulaire de 300 µm de diamètre.*

using the software Microware 4.02 of P. Ungar (Ungar, 1995). The lengths were divided into ten classes with increments of 30 µm (L1 to L10) and the orientations into four classes: horizontal (0–20° and 160–180°), horizontal/oblique (20–40° and 140–160°), oblique (40–60° and 120–140°) and vertical (60–120°).

Carbon and nitrogen stable isotope analyses

Carbon (C) and nitrogen (N) stable isotope analyses have proved to be efficient methods for reconstructing palaeodiets (Tykot, 2004; Bocherens and Drucker, 2005), based on the fact that the differences in chemical composition between different categories of food are reflected in the bones or teeth of the consumer. Consequently, they can give a direct measure of long term diets at an individual level, enabling associations to be highlighted between diet and other attributes such as social status, age or sex (Polet, 2008).

C and N stable isotope compositions are chiefly measured in bone (and dentine) collagen, the main component of their organic fraction. Results are expressed as isotopic ratios (= ratio of abundance of the heavy to light isotope) relative to an international standard. They are reported as a delta (δ) notation in units per mil (‰). δ is calculated in the following way for carbon and nitrogen stable isotopes:

$$\delta^{13}C\ (‰) = [(^{13}C/^{12}C)\ \text{sample} / (^{13}C/^{12}C)\ \text{standard} - 1] \times 1000$$

$$\delta^{15}N\ (‰) = [(^{15}N/^{14}N)\ \text{sample} / (^{15}N/^{14}N)\ \text{standard} - 1] \times 1000$$

δ is positive if the sample is enriched in heavy isotopes compared to the standard, a negative δ indicates the opposite. For carbon isotopes, the internationally defined standard is V-PDB (for Vienna Pee Dee Belemnite). The nitrogen isotopes are reported relative to AIR (for atmospheric air).

We sampled 200–300 mg of compact bone with a drill. Collagen was extracted by acidic demineralization followed by a treatment to remove the contaminants (Bocherens et al., 1991). The carbon and nitrogen isotopic compositions were measured with a NC 2500 Elemental Analyzer connected to a Thermo Quest Delta + XL isotopic ratio mass spectrometer at the Geochemistry department of the University of Tübingen, Germany.

RESULTS

Stress indicators

No enamel hypoplasia was observed in the seven deciduous dentitions of Easter Island. On the island of Guam, however, 12.7% (17/134) of the individuals displayed this stress indicator in their primary teeth (Stodder, 1997). This pathology concerned 18% of the permanent teeth of Rapa Nui (table 2).

Cribra orbitalia was present in 12.7% of our Easter Island samples (table 2).

The percentage of permanent teeth with enamel hypoplasia and the percentage of *cribra orbitalia* are in the range of variation of other historic and prehistoric Pacific samples (Polet, 2006; here: fig. 3). However, these are much lower than European medieval populations from the sixth to the fifteenth century AD (Polet, 2006).

Within the Rapa Nui sample, women showed significantly higher hypoplasia frequencies than men (table 2 and fig. 4a). The percentage of *cribra orbitalia* was higher in children than in adults (table 2). The Ahu Nau Nau individuals are characterized by a lower rate of *cribra orbitalia* than the other Easter Islanders (Polet, 2006).

Dental microwear

In the sampled circular area, the total number of microscratches on the Easter Islanders' teeth varied between 21 and 119 with an average of 53.9 features (or 77 scratches/mm²). Their average length was 50.9 µm. Most of the scratches belonged to the classes L1 and L2 (1 to 60 µm). The first two classes alone accounted for 75% of all the features. A horizontal orientation predominated (33%; fig. 5). The horizontal, horizontal-oblique and oblique striations totalized 82%.

As there are no corresponding dental microwear studies for alternative Polynesian populations, we thus decided to compare our group to the prehistoric and medieval samples studied by C. García-Martín (García-Martín, 2000). Compared to these samples, Easter Islanders displayed a small total number of striations.

	Freq. enamel hypoplasia			Freq. *cribra orbitalia*	
	Absolute	Relative (%)		Absolute	Relative (%)
> 20 yrs	6/31	19.4	> 20 yrs	3/51	5.9
13–20 yrs	1/8	12.5	< 20 yrs	6/21	28.6
Male	1/19	5.3	Male	1/28	3.6
Female	4/11	36.4	Female	5/25	20.0
Total	**7/39**	**18.0**	**Total**	**9/71**	**12.7**

Table 2 – Proportion of individuals affected by enamel hypoplasia (on permanent teeth) and by *cribra orbitalia* amongst Easter Islanders.
***Tabl. 2** – Proportion d'individus atteints d'hypoplasie de l'émail (pour les dents permanents) et de* cribra orbitalia *chez les Pascuans.*

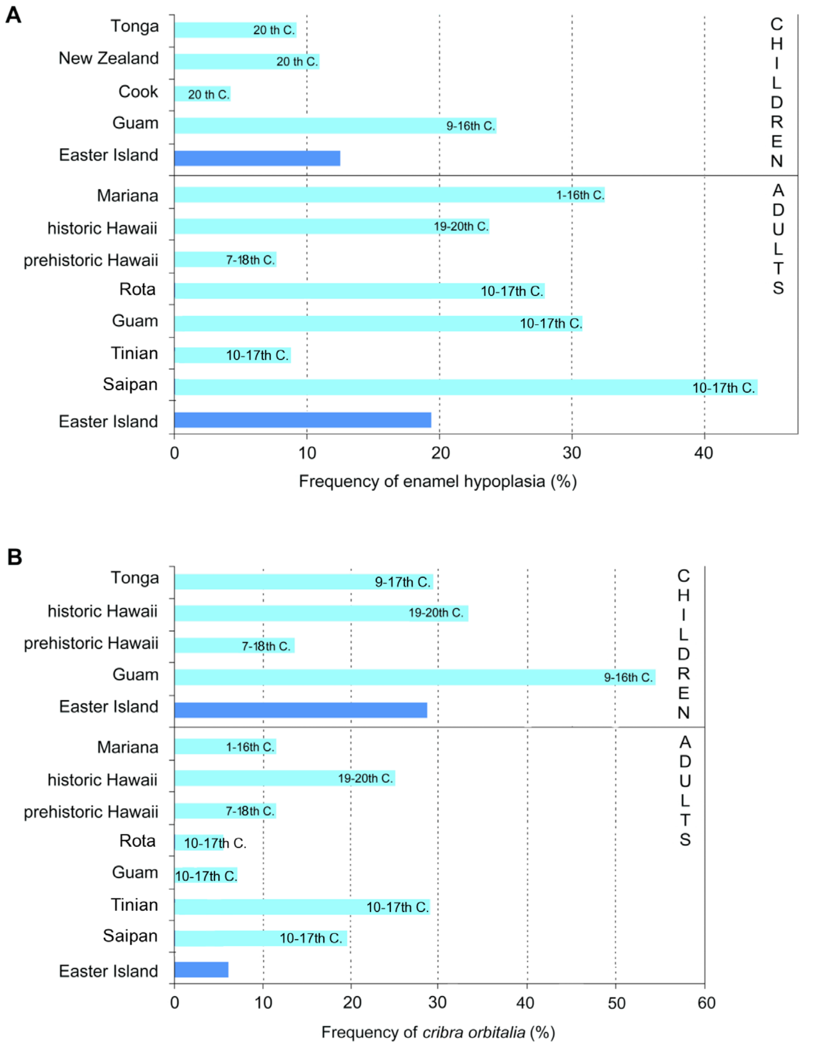

Fig. 3 – A: frequencies of enamel hypoplasia on permanent teeth from the Easter Island sample compared to those collected from eight archaeological and three extant Polynesian samples (see references in Polet, 2006; Pietrusewsky et al., 2014); B: frequencies of *cribra orbitalia* in the Easter Island sample compared to those collected from five archaeological Polynesian samples (see references in Polet, 2006; Pietrusewsky et al., 2014).

***Fig. 3** – A : fréquences d'hypoplasie de l'émail pour les dents permanents de l'échantillon pascuan comparées à celles relevées dans huit échantillons polynésiens archéologiques et trois échantillons actuels (les références sont dans Polet, 2006 ; Pietrusewsky* et al.*, 2014) ; B : fréquences de* cribra orbitalia *pour l'échantillon pascuan comparées à celles relevées dans cinq échantillons polynésiens archéologiques (les références sont dans Polet, 2006 ; Pietrusewsky* et al.*, 2014).*

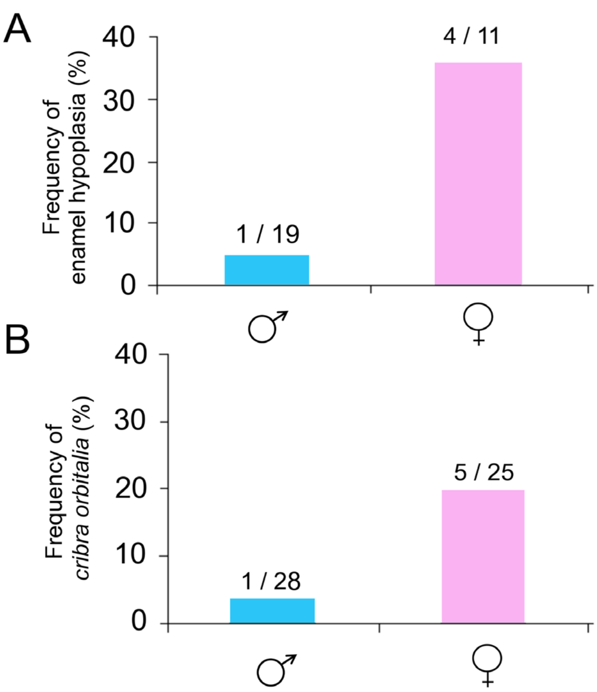

Fig. 4 – A: frequencies of enamel hypoplasia on permanent teeth in male and female Easter Islanders; B: frequencies of *cribra orbitalia* in male and female Easter Islanders.

***Fig. 4** – A : fréquences d'hypoplasie de l'émail pour les dents permanents des Pascuans de sexe masculin et féminin ; B : fréquences de* cribra orbitalia *chez des Pascuans de sexe masculin et féminin.*

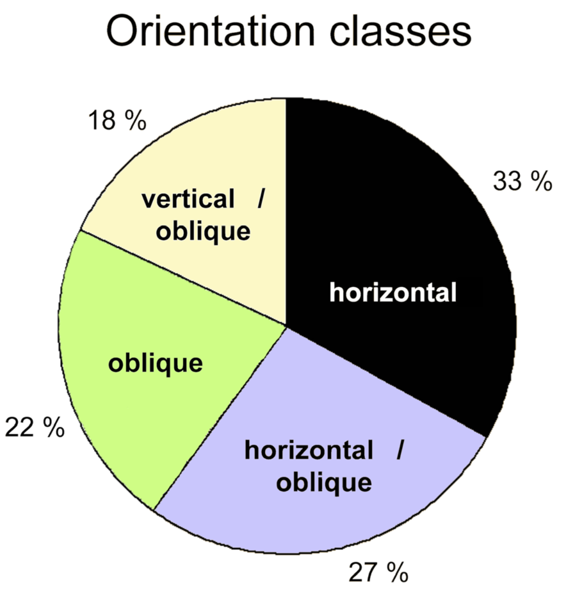

Fig. 5 – Distribution (pie-chart) of the Easter Islanders micro-striations over four orientation classes (horizontal, horizontal/oblique, oblique and vertical/oblique).
Fig. 5 – *Répartition des micro-stries des Pascuans dans quatre classes d'orientation (horizontale, horizontale/oblique, oblique and verticale/oblique).*

Furthermore, multivariate statistical analyses, based on the length and orientation of the scratches, revealed that the microwear pattern of the Easter Islanders were most similar to those of the coastal medieval sample of Coxyde (Polet et al., 2008).

Within our adult sample, we did not observe any sex or age-related differences in microwear pattern (Polet et al., 2008). With regard to social status, our study showed that Ahu Nau Nau, the royal *ahu*, was distinguishable from the other sites on the basis of its dental microwear (Polet et al., 2008): it was characterized by a lower number of striations and fewer short features (0–30 µm).

We also observed that the individuals dated to before the deforestation presented significantly less horizontal scratches than those dated after this event (Polet et al., 2008).

Carbon and nitrogen stable isotope analyses

The results for the 109 Rapanui individuals analysed produced the following results: their bone collagen $\delta^{15}N$ ranged from 10.6‰ to 16.9‰ with an average of 13.4‰; and their $\delta^{13}C$ ranged from −21.0‰ to −15.5‰ with an average of −18.4‰. (Polet and Bocherens, 2016).

We also tried to identify trends within our sample by comparing the individuals buried in the *ahu* to the individuals buried in caves, but they did not display any significant differences in their isotopic signals (table 3).

Regarding sex differences in adult individuals, males displayed higher carbon and nitrogen isotopic values than females (fig. 6 and table 3).

We also studied the isotope distribution according to age at death (fig. 7). The sample was divided into four age classes: 0–3 years, 4–11 years, 12–18 years and adults. The first category produced the most individuals with the highest value of nitrogen isotopes, aside from two young children: a two-year old child and a baby.

The spatial distribution of the isotopic signatures also provided interesting results with individuals clustered according to their place of burial (fig. 8).

The individuals from Ahu Nau Nau, displayed the highest value of nitrogen and carbon isotopes (except for one male individual).

DISCUSSION

Stress and malnutrition

The enamel hypoplasia and *cribra orbitalia* study revealed that the stress level of Easter Islanders during childhood was not higher than that of other ancient populations of the Pacific, but was lower than that of European

	Ahu			Caves			Student's t-test	
	N	Average	Standard deviation	N	Average	Standard deviation	p	Significance level
$\delta^{13}C$	79	−18.3	0.87	28	−18.2	1.09	0.36	NS
$\delta^{15}N$	79	13.4	1.23	28	13.3	1.02	0.32	NS
	Males			Females			Student's t-test	
	N	Average	Standard deviation	N	Average	Standard deviation	p	Significance level
$\delta^{13}C$	32	−18.2	0.98	30	−18.6	0.73	0.0407	*
$\delta^{15}N$	32	13.5	0.95	30	12.8	0.46	0.00016	***

Table 3 – Statistical parameters of the comparison of isotopic signatures ($\delta^{13}C$ and $\delta^{15}N$ in ‰) between individuals buried in *ahu* and individuals buried in caves, between males and females. NS = not significant; * = significant; *** = highly significant.
Tabl. 3 – *Paramètres statistiques des comparaisons de signatures isotopiques ($\delta^{13}C$ et $\delta^{15}N$ en ‰) entre individus inhumés dans les* ahu *et ceux inhumés dans les grottes, entre les hommes et les femmes. NS = non significatif ; * = significatif ; *** = très hautement significatif.*

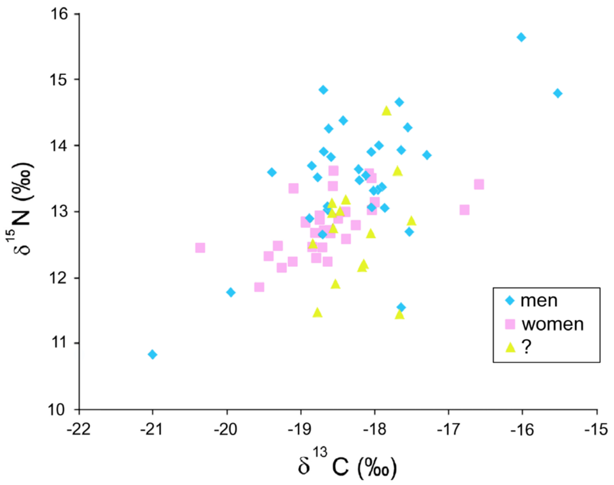

Fig. 6 – Bivariate plot of δ15N and δ13C values from males, females and adults of unspecified sex from Easter Island.
Fig. 6 *– Graphique bivarié présentant les valeurs de δ15N et de δ13C des hommes, des femmes et des adultes de sexe indéterminé de l'île de Pâques.*

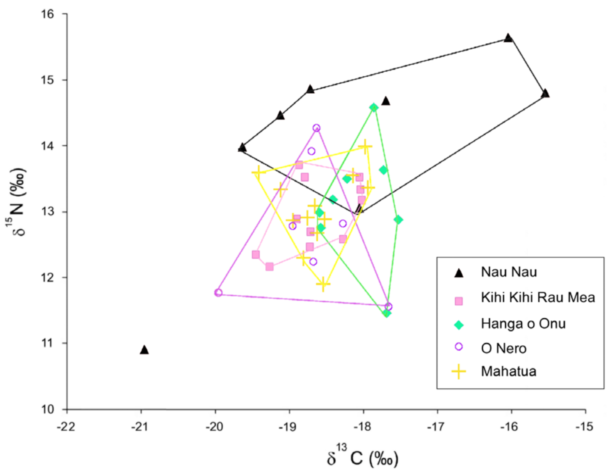

Fig. 8 – Bivariate plot of δ15N and δ13C values from Easter Islanders aged over 12 years and buried in different *ahu*.
Fig. 8 *– Graphique bivarié présentant les valeurs de δ15N et de δ13C de Pascuans âgés de plus de 12 ans et inhumés dans différents* ahu.

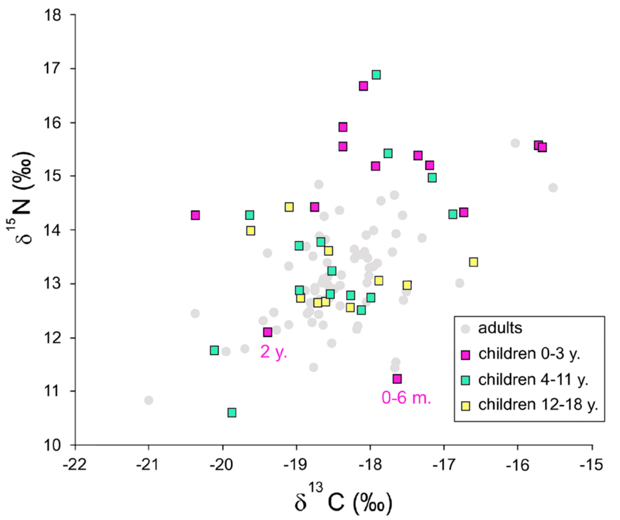

Fig. 7 – Bivariate plot of δ15N and δ13C values from Easter Islanders belonging to different age categories. The individuals that displayed the highest nitrogen isotope signatures belong to the category 0–3 years. Two children were exceptions: a 2-year old child and a baby who died between 0 and 6 months.
Fig. 7 *– Graphique bivarié présentant les valeurs de δ15N et de δ13C de Pascuans appartenant à différentes catégories d'âge. Les individus qui présentent les signatures isotopiques de l'azote les plus élevées appartiennent à la catégorie d'âge 0-3 ans. Font exception : un enfant âgé de 2 ans et un bébé mort entre 0 et 6 mois.*

medieval populations. Therefore, we can state that child malnutrition on Rapa Nui was far from severe. This result is in direct opposition to the catastrophist theories (i.e. chaos, war and famine following deforestation) popularised by Jared Diamond (Diamond, 2005, p. 79–119).

General composition of the diet

The Easter Islanders' microwear was characterized by few features: short and mainly horizontal or oblique scratches. These results can be related to the dominance of sweet potato *(Ipomoea batatas)* in their daily meals as stated by historical (Pollock, 1993; Flenley, 1993), ethnographical (Routledge, 1919, Métraux, 1940) and archaeobotanical (Flenley, 1993; Cummings, 1998) data. The high percentage of caries recorded by D. Owsley and colleagues (Owsley et al., 1983 and 1985) also confirms this hypothesis as the sweet potato and the other tubers consumed by the inhabitants of Rapa Nui (i.e. taro, yam and arrow-root) are rich in starches and are highly cariogenic (Lingström et al., 2000).

The microwear pattern of the Easter Islanders is most similar to that of the Cistercians of Coxyde (Polet et al., 2008), a medieval coastal population where marine fish consumption has already been attested to. The ichthyophagy of the Rapa Nui people is also confirmed by the marine faunal remains (Steadman et al., 1994; Ayres et al., 2000) and fishing implements (e.g. Lavachery, 1935; Ayres, 1985) discovered in Easter Island archaeological sites.

To estimate the proportion of marine food in their diet, we applied the linear mixing model of S. Mays (Mays, 1997) based on carbon isotopes. In this model, an entirely terrestrial diet leads to a value of −21.5‰ and a wholly marine-based one to −12‰. The contribution in marine products for Easter Islanders varied between 4.8 and 57%, with an average of 29.5%.(2) Moreover, A. Commendador and coworkers (Commendador et al., 2013) compared the carbon and nitrogen isotopic ratios of forty-one Rapa Nui human teeth coming from seven archaeological sites (i.e. Ahu Tongariki, Ahu Kihi Kihi Rau Mea, Ahu Nau Nau, Ahu Akahanga, Ahu One Makihi, Ahu Mahatua, and Ana Oroi) with 132 animal remains from one archaeological site on Easter Island (Anakena Beach) and came to the conclusion that their diet was predominantly terrestrial.

A. Commendador and colleagues (Commendador et al., 2013) compared their data with twelve other Pacific islands. They observed that their Rapa Nui material was within a similar range of δ ^{13}C but consistently higher in δ ^{15}N. They suggested that the Easter Islanders' diet was more focused on terrestrial resources than the other Pacific islanders. We reached the same conclusion with our 109 isotopic dataset (Polet et Bocherens, 2016).

Gender effect

Women of Rapa Nui showed significantly higher hypoplasia frequencies than men (table 2 and fig. 4A), which leads to the assumption of a preferential investment in boys (Guatelli-Steinberg and Lukacs, 1999): as the tooth crown records stress events that occurred during its formation (i.e. childhood).

These sex differences continued during adulthood with males displaying higher carbon and nitrogen isotopic values than females (fig. 6 and table 3). This result indicates they had a higher intake in animal protein than the women.

There is little mention of gender difference in diet in the ancient population of Rapa Nui. A. Métraux (Métraux, 1940, p. 164) quotes a description of a banquet by Father Zumbohm in 1879, which details the order in which the guests received their food: the best pieces were given to the missionaries, then the chief and his friends were served, the commoners helped themselves, and the women and children were served last. "From a delicacy like chicken or fish all they got was the bones to chew and these bones were already chewed once or twice".

Age effect

A higher percentage of *cribra orbitalia* in children, compared to adults (table 2), has already been recorded in numerous other populations (Polet and Orban, 2001, p. 120; Pietrusewsky et al., 1997) and can be explained by the healing and disappearance of the lesions with age.

The higher nitrogen isotopes for the 0–3 year class can be explained by the fact that they were breastfed. Prior to and immediately after birth, the δ ^{15}N values of babies are the same as those of their mothers (Fuller et al., 2006). Afterwards, by exclusively consuming their mother's milk, a human product, babies are one trophic level higher than their mother: they show 2–3‰ higher δ ^{15}N values (Fogel et al., 1997). After the introduction of supplementary foods, infant δ ^{15}N values decrease and gradually approach the values found in adults.

The low δ ^{15}N values in two of the young children can be explained by the fact that the 2-year old child was probably already weaned, and that the baby probably died at birth without consuming any of its mother's milk.

The diet of the children from 4 years up was more or less similar to that of adults, indicating that they were fully weaned.

Spatial distribution effect

On the basis of the stable isotope analysis, we can state that there was no noteworthy difference in diet between individuals buried in the *ahu* or individuals buried in caves. Leslie Shaw (Shaw, 2000) mentioned that burial patterns were very similar in both caves and *ahu* tombs, which may indicate that we are probably dealing with the same groups, each with its own dietary habits, burying their dead in both structures.

We observed clusters of individuals according to their place of burial as this can often indicate family or tribe dietary specificities. However, the isotopic variations did not match the tribal land divisions recorded by Katherine Routledge (Routledge, 1919, p. 221–224). For example, the individuals from Ahu Nau Nau and those from Ahu Kihi Kihi Rau Mea, both located on the Miru tribe land (fig. 1), displayed quite different nitrogen and carbon isotopic values (fig. 8). It should also be mentioned that these land divisions were recorded as late as the twentieth century, and they may have changed over time.

A greater consumption of marine products may explain the dental microwear pattern in Ahu Nau Nau and its higher value of nitrogen and carbon isotopes. This 'privileged' diet is probably related to the taboos *(tapu)* they imposed on the other islanders (Métraux, 1940, p. 130–132). Fishing *tapu* was applied from May to October but did not apply to the nobles. During these months, only the royal canoe could be used for fishing, with a crew composed of important men (Métraux, 1940, p. 173). All the fish caught from the royal canoe were presented to the king, who kept them for his own use or, more often, distributed them among the elders (this may have also played a role in dietary gender difference). Other arguments also support a dietary difference between the individuals buried in Ahu Nau Nau and those buried elsewhere: the remains of offshore fishing hooks were more prevalent in the west and north of the island, which is where the royal *ahu* was (Ayres, 1979): the only harpoon head was discovered in Anakena Bay (Wallin, 1996) and the majority of petroglyphs depicting marine organisms, canoes or implements relating to deep-water fishing activities are located in the north of the island (Lee, 1992, p. 74–96, 104–112, and 113–115).

Furthermore, Ahu Nau Nau individuals are characterized by a lower rate of *cribra orbitalia* than the other Easter Islanders (Polet, 2006). Suggesting that they were less anaemic or less vitamin B12 deficient (Walker et al., 2009), probably thanks to a higher intake of iron- and/or cobalamin rich foods, such as meat and seafood.

Temporal changes in diet

The dental microwear data (orientation and length of scratches) indicated a decrease in the consumption of animal products post deforestation (Polet et al., 2008). However, the small number of individuals analyzed clearly date to the second half of the seventeenth century, which prevents us from drawing firm conclusions.

Nevertheless, the stable isotopes study of A. Commendador and coworkers (Commendador et al., 2013) demonstrated a decline in nitrogen isotopes ratios through time during the pre-contact period. They interpreted this result as a chronological decrease of the consumption of terrestrial animal proteins. Surprisingly though they did not observe changes after the historic contact.

As most of the burial sites we studied were used over long periods of time, we can assume that the dietary differences between genders and lineages continued during the post-contact period or at least until the disappearance of most of the population following the Peruvian slave trade and subsequent epidemics.

CONCLUSION

This study aimed to document the diet of ancient Easter Islanders from the seventeenth to the nineteenth century.

The dental microwear data confirmed that tubers were their staple food. Stable isotopes indicated that on average one third of their proteins originated from the sea. Stress indicators showed that child malnutrition was far from severe. The dental microwear data also suggested a decrease of animal product consumption related to deforestation, which was confirmed by the stable isotopes data of A. Commendador and coworkers (Commendator et al., 2013). Similarly, we deduced that the Easter Islanders relied more on terrestrial food resources than other Pacific islanders.

Within our sample, we observed sex differences in stable isotopes revealing that women ate significantly less animal products. Stress indicators also suggested gender disparities in the access to basic resources, resulting from a preferential investment in sons. We showed that children were breastfed until three years old. The clustering of isotopic signatures according to the place of burial *(ahu)* may indicate family dietary specificities. However, no difference in diet was observed between individuals buried in the ahu or individuals buried in caves, suggesting the same groups of people used both structures for funerary purpose. With regard to social status, our study showed that the royal *ahu* can be distinguished from other ahu on the basis of the stable isotopes data, the dental microwear pattern and the frequency of cribra orbitalia. A greater consumption of marine products could be the origin of this distinction.

Acknowledgements: The Belgian Federal Science Policy financially supported the Belgian expeditions to Easter Island. I am most indebted to Francisco Torres Hochstetter, director of the Father Sebastian Englert Anthropological Museum (Easter Island) for giving me access to the anthropological collections. I thank Nicolas Cauwe (RMAH) and Dirk Huyge (RMAH) for enabling my discovery of Easter Island and for inviting me to take part in their archaeological expeditions. Julien Cillis (RBINS) produced the SEM photographs. The analyses of stable carbon and nitrogen isotopes were performed by mass spectrometry at the Institut für Geowissenschaften, Eberhard-Karls Universität Tübingen (Germany) under the supervision of Hervé Bocherens. My thanks go to Eric Dewamme (RBINS) and Patrick Semal (RBINS) for the photographs of the skeletons. I am especially thankful to Rosine Orban (RBINS) and Serge Lemaitre (RMAH) for helpful discussions on drafts of the manuscript. I appreciate the help of Tara Chapman (ULB) for the correction of my English.

NOTES

(1) The Dutch explorer Jacob Roggeveen was the first European to discover the island in 1722 on Easter Day, hence its name.

(2) The actual proportion of marine food in their diet must have been lower since collagen is preferentially produced from dietary proteins (Ambrose and Norr, 1993)

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