Willis, Anna, Roberts, Patrick, Kyaw, Myo Min, Win, Thu Thu, Pradier, Baptiste, King, Charlotte, Ilgner, Jana, Lucas, Mary, Cook, Amanda, Piper, Philip, and Pryce, T.O. (2023) ***Living in the dry zone: Stable isotope insights into palaeodiet in ancient Myanmar.*** **Journal of Archaeological Science: Reports, 48 .**

https://doi.org/10.1016/j.jasrep.2023.103900

Living in the dry zone: Stable isotope insights into palaeodiet in ancient Myanmar

Anna Willis[1] ✉
Patrick Roberts[2,7]
Myo Min Kyaw[3]
Thu Thu Win[4]
Baptiste Pradier[5]
Charlotte King[6]
Jana Ilgner[7]
Mary Lucas[7]
Amanda Cook[8]
Philip Piper[8]
T.O. Pryce[9]

[1]College of Arts, Society and Education, James Cook University, Townsville, Australia
[2]isoTROPIC Research Group, Max Planck Institute of Geoanthropology, Jena, Germany
[3]Deceased
[4]Independent researcher
[5]Technologie et Ethnologie des Mondes Préhistoriques, UMR 8068, MAE, Université de Paris-Nanterre, 92000 Nanterre Cedex, Paris, France
[6]Department of Anatomy, University of Otago, Dunedin, New Zealand
[7]Department of Archaeology, Max Planck Institute of Geoanthropology, Jena, Germany
[8]College of Arts and Social Sciences, Australian National University, Canberra, Australia
[9]Centre National de la Recherche Scientifique, Institut de Recherche sur les Archéomatériaux, Laboratoire "Archéomatériaux et Prévision de l'Altération,UMR 7065 IRAMAT, UMR3685 NIMBE, CEA/CNRS, Université Paris-Saclay, CEA Saclay 91191 Gif-sur-Yvette, Paris, France

✉ Corresponding author
Anna Willis anna.willis1@jcu.edu.au

Living in the dry zone: Stable isotope insights into palaeodiet in ancient Myanmar

Key Words
Myanmar; Southeast Asia; Isotope; Tooth Enamel; Carbon; Oxygen; Palaeodiet

Highlights

- Oakaie and Nyaung'gan are prehistoric sites in Myanmar (ca. 1300-700BC).
- 1300-700BC is the transitional late Neolithic to the early Bronze Age period.
- Individuals have higher $\delta^{13}C$ values than those from Mainland Southeast Asian sites.
- Individuals have comparable $\delta^{13}C$ values to those from Chinese sites.
- $\delta^{13}C$ and $\delta^{18}O$ provide an insight into ancient subsistence in Myanmar.

Abstract
Southeast Asia is becoming a region of increasing interest in discussions of past migration, the origins of agriculture, and past impacts of human land-use change on environments. Myanmar, situated at a geographic and cultural crossroads between East, South and Mainland Southeast Asia, is potentially a critical region for exploring these themes. However, direct data relating to subsistence in the region has been lacking. Here, we apply stable carbon and oxygen isotope analysis to tooth enamel from humans and associated fauna to examine the subsistence economy of two communities from Myanmar, Oakaie and Nyaung'gan, spanning the transitional period from the late Neolithic to the early Bronze Age (ca. 1300-700BC). Situated within the broader regional and local environmental context, our data demonstrate the $\delta^{13}C$ values of the individuals from the communities of Oakaie and Nyaung'gan are significantly higher, and the $\delta^{18}O$ values are significantly lower, than individuals from the other sites in Southeast Asia, however, neither are significantly different to the Chinese sites and they overlap broadly with individuals from Mayutian in Southern Yunnan Province. These findings provide a unique insight into the subsistence economy of the ancient inhabitants of the Central Dry Zone of Myanmar.

1. Introduction

The prehistory of Mainland Southeast Asia is a complex and intriguing story of migration, intermixture and adaptation. Bioarchaeological and linguistic evidence has long suggested that Neolithic rice farmers migrated around 4,000 years ago from southern China into and throughout Southeast Asia, integrating with, rather than replacing, regional hunter-gatherer populations (Bellwood, 2005, Bellwood, et al., 2011, Chi and Hung, 2012, Oxenham, et al., 2011). Genetic data support this hypothesis, providing clarity on the timings and waves of dispersal (Lipson, et al., 2018, McColl, et al., 2018). The cultivation of wild cereals began in central China around 7000-5000BC (Chi and Hung, 2012, Cohen, 2011, Stevens and Fuller, 2017). In the Yellow River basin the cereals were broomcorn (*Panicum miliaceum*) and foxtail (*Setaria italica*) millets (Liu and Chen, 2012), while in the Yangtze River basin it was short grained rice (*Oryza sativa japonica*) (Fuller, et al., 2009). Following domestication around 4000BC Neolithic communities with established rice and millet farming began to spread, and there is increasing evidence that some communities favoured coupling the cultivation of both crops (Stevens and Fuller, 2017). The presence of mixed rice and millet, both broomcorn and foxtail, agriculture occurred in Yunnan from ca. 2600BC onwards (d'Alpoim Guedes, et al., 2013, d'Alpoim Guedes, et al., 2020, Dal Martello, et al., 2018) with the dispersal of predominantly rice, with some foxtail millet, economies occurring in Southeast Asia potentially as early as ca. 2500-2000BC (Weber, et al., 2010) and becoming more common after ca. 2000BC (Stevens and Fuller, 2017).

Early agricultural practices in Southeast Asia likely involved the cultivation of dry rice and millet, which are less labour intensive but also produce lower yields (Fuller and Castillo, 2021). The more labour intensive, but higher yielding, practice of wet rice farming developed later, for example in Northeast Thailand with the transition to plough-based irrigated rice farming (Castillo, et al., 2018, Wohlfarth, et al., 2016), along with the introduction of pulses from India including mungbean, pigeon pea and cotton during the Iron Age (Castillo, et al., 2018, Castillo, et al., 2016, d'Alpoim Guedes, et al., 2019). In comparison to the rich archaeological knowledge of prehistory in Thailand and Vietnam, Myanmar remains enigmatic in our understanding of the origin, adoption and intensification of agriculture due to a paucity of appropriate archaeological and archaeobotanical data. Although the presence of rice, and both broomcorn and foxtail millet, are documented linguistically (Bradley, 2011) it is not clear how deep that antiquity is. Hope et al. (2019 p 18) clearly articulate the significant gap left by Myanmar in archaeobotanical and palaeoenvironmental research, a sentiment echoed by others (Silva, et al., 2018 p 1752). Archaeological research in Southeast Asia is becoming increasingly focused on past migrations and the origin and transmission of agriculture. Myanmar situated between East, South and Southeast Asia, was likely influenced by communities and cultural practices from surrounding regions but little is known about the timing and dispersal of agricultural crops into the area. This is pivotal to better understanding the biosocial context of the communities of prehistoric Myanmar as agriculture played an important role in shaping the dynamic relationship within and between prehistoric communities and their ecological and technological environment.

While archaeobotanical and zooarchaeological analyses can provide unparalleled detail into the plants and animals managed and consumed by past human societies (Amano, et al., 2013, Castillo, et al., 2016, Piper, et al., 2014), they are often reliant on preserved snapshots of particular meals or waste accumulation. By contrast, stable isotope analysis of human and animal tissues has been regularly utilised in archaeology to provide longer term insights into dietary reliance on specific food groups (King, et al., 2014, King, et al., 2013, Rowley-Conwy, et al., 2012). Stable carbon isotope measurements ($\delta^{13}C$), in particular, have the potential to assist in understanding which crops were staples, therefore addressing an important gap in our knowledge on the origin and transmission of agriculture in the region. Importantly, $\delta^{13}C$ measurements can easily distinguish the use of C_4 crops such as millet from the use of C_3 crops such as rice, and has been used to explore the arrival of agriculture in different parts of Southeast Asia (Krigbaum, 2003, Krigbaum, 2005). This approach has been a research focus among researchers in Mainland Southeast Asia (Bentley, et al., 2009, Bentley, et al., 2005, Bentley, et al., 2007, Cox, et al., 2011, King, et al., 2014, King, et al., 2013, King, et al., 2015, Liu, 2018) and China (Lanehart, et al., 2011, Tian, et al., 2008, Zhang, et al., 2014), leading to the development of a solid conceptual and data-rich framework to examine subsistence economies in the region, and a wealth of comparative studies with which to contextualise data from Myanmar. Nevertheless, analyses from the latter region have remained absent thus far, hindering insights into broad dietary changes across major economic and social thresholds.

Recently, research has been undertaken at two sites in Myanmar as a part of the multidisciplinary research project *Mission Archéologique Française au Myanmar - MAFM* (Pryce, et al., 2018b). The sites excavated include two Late Neolithic/Early Bronze Age (ca. 1300-700BC) cemetery sites, Oakaie and Nyaung'gan, situated in the Central Dry Zone (CDZ) of Myanmar. Characterised as a savannah like environment, the CDZ is prone to extreme weather events, including high temperatures in the monsoon season, and serious droughts and water shortages in the dry season. The nature of this semiarid environment contrasts with the rest of Southeast Asia, which is mainly humid (Matsuda, 2013). Here, we apply stable isotope analysis to teeth from both domesticated fauna and humans to examine palaeodiet in prehistoric Myanmar. Specifically, we use $\delta^{13}C$ to assess whether there is evidence for consumption of either millet or rice, and whether, in the absence of any archaeobotanical data, it can be used as a proxy to understand the subsistence economies of individuals from the ancient communities of Oakaie and Nyaung'gan. Finally, we examine whether the environmental context influenced the subsistence economy of individuals buried at these sites, and whether it differed from neighbouring Mainland Southeast Asia and Yunnan.

1.1 The Geographical and Archaeological context of Myanmar and the Central Dry Zone (CDZ)

Geographically, Myanmar is a long, narrow country about 2050km north-south and 930km west-east. The geopolitical borders are landlocked between East Asia, Southeast Asia and South Asia with the remaining south-southwest coastal area bounded by the Indian Ocean. This study focuses on the Oakaie/Nyaung'gan complex, a significant archaeological landscape excavated by Myanmarese in 1998 and 1999, and more recently *Mission Archéologique Française au Myanmar* (MAFM), that has provided insights into a previously unexplored area of Myanmar and a unique opportunity to examine the ancient subsistence practices between 1300-700BC, locally, and compare them regionally. It is situated 18km east of the Chindwin River in Budalin Township, near Monywa in the Sagaing Division, Myanmar (Figure 1). The area comprises a SW-NE alignment of Late Cenozoic volcanic craters comprised of shoshonitic basalt (Lee, et al., 2016, Maury, et al., 2004). Located towards the northern edge of the CDZ, at the intersection between the 'arid, steppe, hot' (BSh) and 'tropical, savannah' (Aw) Köppen–Geiger climate classification zones (Beck, et al., 2018), the climate ranges from semiarid to semihumid. The area has an annual rainfall of between 500-1000mm, but the Monywa region itself is semiarid (Matsuda, 2013). Surrounded by mountain ranges to the north, east and west, and the Irrawaddy delta ca. 670km to the south the area is relatively low lying (Herridge, et al., 2019).

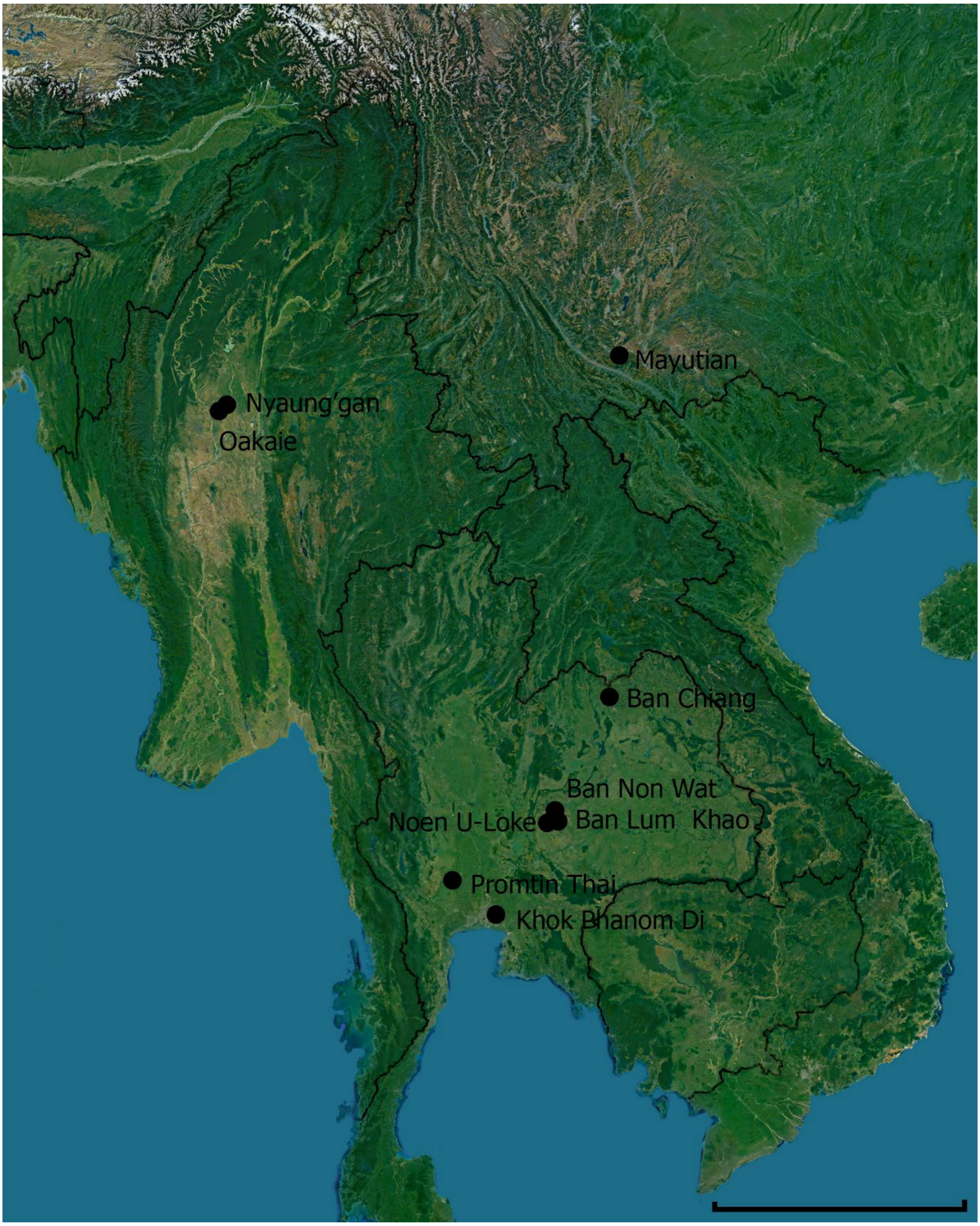


Figure 1. Location of Oakaie and Nyaung'gan in Myanmar, and other key sites in Mainland Southeast Asia and China, where the EASM and ISM systems overlap. Scale 500km. Circles are illustrative and not to scale. Map data: Google 2022. Image Landsat/Copernicus Data SIO, NOAA, U.S Navy, NGA, GEBCO. US Department of State Geographer.

The climate of Myanmar is complex due to its variable geography and topography, and the influence of overlapping monsoon systems (D'Arrigo and Ummenhofer, 2015, Xu, et al., 2012). Unfortunately, no specific regional or local palaeoclimatic reconstructions have been produced, and, due to the paucity of data, analogies must be drawn from proxies. There is evidence for climatic variability during the Holocene, both spatially and temporally, within the intersection zone, where the East Asian summer monsoon (EASM) and Indian summer monsoon (ISM) systems overlap, and between the intersection zone and the EASM and the ISM zones, east and west respectively. There is also variability in the specific timings of the late Holocene monsoon amelioration (Hamilton, et al., 2019). Despite this, there is a broad consensus among researchers for a weakening of the Indian Summer Monsoon after ca. 4000BC, which is consistent with the regional model based on palynology (Hope, et al., 2019) and sedimentology, mineralogy, and geochemistry (Hamilton, et al., 2019, Sebastian, et al., 2019). This palaeoclimatic change has important implications for understanding the past environment within which people lived, and for interpreting subsistence economies, including the transmission and adoption of agriculture (Hope, et al., 2019, Silva, et al., 2018).

The Oakaie and Nyaung'gan cemeteries are situated 3km apart and have slight intra-site and inter-site differences in burial orientation and grave goods. At both sites the graves were aligned in several rows and oriented either N-S or NNW-SSE, with most burials containing a single individual in a supine extended position, however, several were multiple interments. Mortuary artefacts associated with burials varied in their number and frequency but the most common were pottery vessels. Personal ornaments including stone and shell beads, polished stone and bone bracelets, and utilitarian items including a spindle whorl and bronze artefacts were also found. Finally, faunal remains including bivalve shells, incomplete remains of a turtle carapace, scant bovine remains, and two complete dogs were intentionally interred with different individuals. Despite the systematic sediment flotation protocols, where sediment from every context was floated, no datable charcoal was recovered from either cemetery. The interpretation of potential diachronic phasing was based on the spatial organisation of the graves, their chrono-stratigraphic relationship, and variability in mortuary practices and associated artefacts (Pradier, et al., 2019) guided by the technostylistic pottery seriation (Favereau, et al., 2018). In turn, this chronology is anchored on the radiocarbon chronology established at the settlement/industrial sites (Pryce, et al., 2018b).

Currently, the only information about the subsistence economy at Oakaie and Nyaung'gan is derived from archaeozoological evidence. Faunal remains were recovered from all the excavation areas and preliminary archaeozoological data indicate the inhabitants were engaging in the management of pigs (*Sus scrofa*), dogs (*Canis familiaris*), cattle (*Bos tarus*) and water buffalo (*Bubalus bubalus*) and collecting local flora and fauna, including fish, the remains of which were very few, likely because they were fed to the pigs and dogs. Based on their size and age profiling, the pigs and dogs were domestic. The present-day agricultural economy in the region focuses on a narrow range of crops, the majority of which are pulse and oilseed legumes, and sesame and sunflower (*Helianthus annus*) (Matsuda, 2013). In the region of Monywa itself, the most common crops grown are pigeon peas (*Cajanus cajan*) and sesame (*Sesamum indicum*) followed by other pulses including butter beans (*Phaseolus lunata*), green grams (*Vigna radiata*), chickpeas (*Cicer arietinum*), and lablab beans (*Lablab purpurea*). Sorghum (*Sorghum bicolour*) is also grown, the leaves, stems and seeds of which are used as animal fodder (Matsuda, 2013). Although rice is a staple among modern communities in Monywa, it is normally purchased, as the CDZ is not suitable for growing rice and the crop cannot be successfully cultivated, except in some areas of the lowland (Herridge, et al., 2019, Matsuda, 2013, Ministry of Agriculture, 2016). Nothing is known about prehistoric agricultural practices in Myanmar, including the CDZ in which our sites are located, and no archaeobotanical remains were recovered from either Oakaie or Nyaung'gan despite extensive flotation. Examining palaeodiet, using stable isotope analysis, provides the opportunity to investigate whether there was a focus on one staple crop, for example millet or rice, and how this compares to other sites in Mainland Southeast Asia and China.

1.2 Stable isotope background

Isotope analysis has become a fundamental tool for archaeologists and bioarchaeologists seeking to understand the lives and lifestyles of prehistoric individuals (Larsen, 2015). Significantly, stable isotope analysis of human tissues, animal remains, and plant remains has been increasingly used to explore questions relating to changes in diet, domesticate management, and environment linked to transitions in agriculture and settlement in different parts of the world (Styring, et al., 2019, Vaiglova, et al., 2020). In the context of human and animal remains, the methodology works on the principle of 'you are what you eat', whereby isotopic variation in food sources can be tracked into the tissues of their consumers (DeNiro and Epstein, 1976). In general, such work has focused on stable carbon and nitrogen isotope analysis of bone collagen, which offers insights into food sources and trophic level (DeNiro and Epstein, 1976). However, in tropical environments, bone collagen is often poorly preserved. As a consequence, in Southeast Asia, many bioarchaeologists have turned to the isotopic analysis of human and animal tooth enamel, a material that is more resistant to diagenetic change and has been shown to preserve *in vivo* isotopic variation across millions of years (Krigbaum, 2003, Krigbaum, 2005, Roberts, et al., 2020).

Stable carbon isotope ($\delta^{13}C$) variability in tropical terrestrial ecosystems is primarily driven by differences in photosynthetic pathway between C_3 plants, which dominate forest settings and include crops such as rice, and C_4 plants which are found more frequently in open grassland habitats and include crops such as millet (Katzenberg, 2008, Krigbaum, 2003, Krigbaum, 2005). These plants have distinct and non-overlapping $\delta^{13}C$ values that are passed into the tissues of their consumers with an approximate shift of 1‰ per trophic level (Schwarcz and Schoeninger, 2011). Environmental and climatic variation can lead to variation in $\delta^{13}C$ and variations in the local ecological baseline, particularly among C_3 plants, as a result of the 'canopy effect' (van der Merwe and Medina, 1991), temperature, and aridity impacts. This makes the development of a 'baseline' of associated animal values important for interpreting human dietary information from $\delta^{13}C$. Here, we interpret values between -14 and -12‰ as 100% C_3 and values between 0 and 2‰ as 100% C_4 (Lee-Thorp, et al., 1989, Levin, et al., 2008, Roberts, et al., 2020, Tykot, 2006, Tykot, et al., 2009). Future developments in local baseline studies should help to refine this further for Myanmar. Unlike bone collagen $\delta^{13}C$, which is heavily influenced by the protein components of the diet, tooth enamel $\delta^{13}C$ reflects whole diet inputs (Ambrose and Norr, 1993). Tooth enamel $\delta^{13}C$ will record the diet of an individual spanning the period over which that tooth formed. For example, for human M3s this is approximately 8.5-13.5 years of age (AlQahtani, et al., 2010). Stable oxygen isotope ($\delta^{18}O$) analysis can provide further insights into the water imbibed by an individual during tooth formation. This approach has frequently been used to track the origins of individuals in a given region, though interpretation has been found to be complex in a Mainland Southeast Asian setting (King, et al., 2015).

2. Materials and Methods

2.1 Sites

The Franco-Myanmar mission excavated seven areas within the Oakaie/Nyaung'gan complex over three field seasons between 2014-2016, described in Pryce et al. (2018b). Four were located at Oakaie (OAI 1-4) and three at Nyaung'gan (NYG 1-3). The four focal areas at Oakaie included intentional occupation and burial areas, and provided evidence for settlement and habitation, domestic and industrial activity, and mortuary activity. Oakaie 1 (OAI 1) was a designated cemetery area, Oakaie 2 (OAI 2) was a residential area with underfloor infant jar burials, Oakaie 3 (OAI 3) and 4 (OAI 4) were both settlement areas representing domestic and industrial activities. The three areas at Nyaung'gan (NYG 1-3) were all part of another designated cemetery area near to an onsite museum, which had been constructed over the burials previously excavated in 1998-1999, and left *in situ* (Moore and Pauk, 2001, Tayles, et al., 2001). During the excavation of Oakaie 1, fifty-five graves containing fifty-seven individuals covered with a brown sandy-loam sediment were clearly visible against the volcanic tuff matrix into which they were dug (Pradier, et al., 2019). In contrast to Oakaie, only six burials containing seven individuals were found during the 2016 excavation at Nyaung'gan and they were harder to identify against the surrounding friable ashy matrices.

Oakaie is represented by three phases. Phase 1 represents the earliest group and includes burials with pottery vessels from ceramic ensembles 1 and 2 and Phase 2 includes burials with ceramic ensembles 3 and 4. Pottery-bearing burials 2, 3b, 4 and 7 from Nyaung'gan are consistent with the ceramic ensemble 3 from Phase 2 at Oakaie, however, they contain distinctive miniature pottery vessels not found at Oakaie. Phase 3 includes the single burial at Oakaie (OAI1S15) with a bronze artefact and ceramic ensemble 5, which is technostylistically consistent with the pottery vessels interred with Burial 6 (NYGB6), some of the individuals from the 1998-1999 excavation at Nyaung'gan, and with the ceramic vessels recovered from Oakaie 2 and 3. Phase 3 represents the only clear link between the Oakaie and Nyaung'gan cemeteries. As a whole, this suggests some burials found at Nyaung'gan are perhaps contemporaneous with the Phase 2 burials from Oakaie, and others are strongly associated with Phase 3. Unfortunately, due to the lack of appropriate dating materials within the cemeteries it was not possible to provide any further temporal resolution to the transitions or phasing observed in burial orientation and mortuary grave goods, however, the use of these cemeteries across multiple generations, as the region transitioned from the Late Neolithic to the early Bronze Age, is highly consistent with the broader observations of the complex (Pryce, et al., 2018b) and existing knowledge of regional exchange networks (Pryce, et al., 2018a).

2.2 Samples

The individuals from Oakaie and Nyaung'gan were documented and described following standardised bioarchaeological data collection protocols (Buikstra and Ubelaker, 1994). Age estimation for subadults (<1-14 years) was based on tooth formation and eruption (AlQahtani, et al., 2010, Ubelaker, 1989), epiphyseal fusion, and long bone length (Scheuer and Black, 2000). Adults were placed within groups 15-19, young, middle, and old based on morphological assessment of the pubic symphysis and auricular surface of the pelvis (Berg, 2008, Brooks and Suchey, 1990, Buckberry and Chamberlain, 2002, Lovejoy, et al., 1985) and tooth wear (Scott, 1979). Sex estimation for adults was based on pelvic morphology, cranial morphology and metric measurements (Albanese, 2003, Brůžek, 2002, Phenice, 1969, Walrath, et al., 2004). Third molars with a matching antimeric tooth were preferentially sampled to provide the most accurate proxy for adult diet. Where this was not possible due to oral pathology or the young age of the individual, the second molars or first molars were sampled. Eighteen individuals met the sampling criteria, 14 from Oakaie and four from Nyaung'gan (Table S1). Permission to undertake the research, and appropriate permits to export samples were approved each field season by the (then) Ministry of Culture. Ethics approval for research involving human subjects was granted (H8312) by a University Human Research Ethics Committee (HREC).

Faunal remains from the cemeteries at Oakaie 1 and Nyaung'gan were scarce as they were deliberate burial areas with no evidence for habitation. The exception were animals deliberately included within the mortuary context of a given burial. The majority of faunal remains came from Oakaie 2, 3 and 4. Identification was undertaken with the aid of digital database images and modern comparative reference collections housed in the College of Asia and the Pacific, Australian National University (ANU), along with manuals by Miller et al. (1964), Pales and Garcia (1981), Hillson (1986), and White and Folkens (2005). To complement the human data, second or first molars were sampled from 39 bovines, 19 pigs, and one dog from Oakaie 2, 3, 4 and Nyaung'gan (Table S2). These contexts provide a reasonable number of specimens from each species to interpret subsistence. Fauna from Oakaie 3 were sampled using a strategy that captured the entire chronological sequence of the greater area, and ensured secure stratigraphic control (Table S3). The results from these fauna can therefore be used to assess possible temporal changes to animal foddering/foraging strategy ($\delta^{13}C$) and water availability/usage ($\delta^{18}O$).

To contextualise the human diet, at Oakaie and Nyaung'gan, more broadly, published data from the Southeast Asian sites of Khok Phanom Di (Bentley, et al., 2007), Ban Chiang (Bentley, et al., 2005), Noen U-Loke (Cox, et al., 2011), Ban Lum Khao (Bentley, et al., 2009), Ban Non Wat (King, et al., 2015) and Promtin Thai (Liu, 2018), and the Chinese sites of Zhongba (Tian, et al., 2008), Liangchengzhen (Lanehart, et al., 2011) and Mayutian (Zhang, et al., 2014) were used for comparative purposes. Data from subadults, adolescents and adults with permanent dentition were included for consideration. Subadults with deciduous dentition were excluded from consideration, and outliers were identified and omitted before statistical analysis.

2.3 Stable isotope analysis

All carbon and oxygen isotope analysis was conducted at the Max Planck Institute for the Science of Human History (now the Max Planck Institute of Geoanthropology), Jena according to established protocols (Ventresca Miller, et al., 2018). 10-20mg enamel chips were powdered using an agate pestle and mortar, pretreated with 1% NaClO then rinsed with MilliQ H_2O. Secondary carbonate contaminants were removed using 0.1M acetic acid for 10 minutes following by three rinses with MilliQ H_2O. Samples were freeze dried prior to being weighed into borosilicate glass vials for analysis and sealed with rubber septa. These vials were flush/filled with helium, and CO_2 was liberated from the samples following reaction with 100% phosphoric acid. Isotopic analysis of the liberated CO_2 was conducted using a Thermo Gas Bench 2 connected to a Thermo Delta V Advantage Mass Spectrometer.

$\delta^{18}O$ values were calibrated against International Standards IAEA-603 ($\delta^{18}O$ = -2.4) and IAEA-CO-8 ($\delta^{18}O$ = -22.7) using a two-point calibration method, while $\delta^{13}C$ values were calibrated against International Standards IAEA-603 ($\delta^{13}C$ = 2.5), IAEA-CO-8 ($\delta^{13}C$ = -5.8) and USGS44 ($\delta^{13}C$ = -42.2) using a three-point calibration methodology. Replicate analysis of in-house MERCK standards suggests long-term machine measurement error is ± 0.1‰ for $\delta^{13}C$, and ± 0.2‰ for $\delta^{18}O$. Overall measurement precision was determined by analysing repeat extracts from an in-house bovid tooth enamel standard prepared alongside the samples to determine the impacts of pre-treatment (n = 20, ± 0.3‰ for $\delta^{18}O$, ± 0.2‰ for $\delta^{13}C$). Duplicate isotopic analysis of samples suggests the technical error measurement (TEM) (Perini, et al., 2005) is 0.2‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{18}O$. All $\delta^{18}O$ values here are reported relative to Standard Mean Ocean Water (SMOW) (Kim, et al., 2015) (Table S1 and 2).

Independent sample t-tests were used to test intra-sample differences of the mean between two independent groups (unless stated otherwise). If the data were not normally distributed a Mann-

Whitney U test was used. Results are presented with equal variance assumed unless homogeneity of variance was violated then the results are presented with equal variance not assumed. One way analysis of variance (ANOVA) was used to test inter-sample differences of the mean among more than two independent groups (unless stated otherwise). Tukeys post-hoc tests (unless stated otherwise) were used where analysis of variance showed statistical significance. An alpha level of .05 was used for all statistical tests. If the data were not normally distributed a Kruskal-Wallis H test was used. If homogeneity of variance was violated a Welch ANOVA and Games Howell post-hoc test was undertaken.

3. Results

3.1 Human stable carbon and oxygen isotope data

The $\delta^{13}C$ values derived from the tooth enamel of human individuals from Nyaung'gan and Oakaie were relatively similar, ranging from -8.6‰ to -4.9‰ with a mean of -7.1‰, and no statistical outliers (Table 1). The variation in $\delta^{13}C$ data at Nyaung'gan (-7.7‰ to -5.9‰) was lower than at Oakaie (-8.6‰ to -4.9‰). The mean $\delta^{13}C$ value at Nyaung'gan (-6.8‰) was consistent with that of Oakaie (-7.2‰), and no statistical significance between the sites was observed ($t(16)=-0.610, p=0.550$) (Table 2). The $\delta^{18}O$ values of the human individuals analysed from Nyaung'gan and Oakaie had a small range of variation (22.6‰ to 25.1‰), with a mean of 23.7‰ (Table 1). When examining the range of variation by site, as with the $\delta^{13}C$ data, the range in $\delta^{18}O$ values at Nyaung'gan (23.3‰ to 24.9‰) fell within the range observed at Oakaie (22.6‰ to 25.1‰). The mean oxygen value at Nyaung'gan (24.0‰) was highly consistent with that observed for Oakaie (23.7‰), with no statistical difference between the sites ($t(16)=-.700$, $p=0.494$) (Table 1 and Table 2).

The range of variation in $\delta^{13}C$ values observed in males from both Nyaung'gan and Oakaie (-7.9‰ to -4.9‰) showed no differences when compared to the females (-8.6‰ to -6.4‰) and individuals of indeterminate sex (-7.7‰ to -5.4‰), with no significant differences ($F(2,15) = 2.424$ $p=0.122$) observed between the mean values of those three groups respectively (-6.8‰, -7.7‰ and -6.6‰) (Table 2) or between just males and females ($t(12)=1.827$, $p=0.093$). The range among the $\delta^{18}O$ data observed in males from both Nyaung'gan and Oakaie (22.9‰ to 24.3‰) was consistent with that for females (22.6‰ to 25.1‰) and individuals of indeterminate sex (23.3‰ to 24.9‰), with no significant difference ($F(2,15) = 1.009$ $p= 0.388$) among the means of those groups (23.5‰, 23.7‰ and 24.2‰ respectively) (Table 2) or between just the males and females ($t(12)=-.327$, $p=0.750$). When examining the range of variation in $\delta^{13}C$ values among males (-7.9‰ and -4.9‰), females (-8.6‰ and -6.4‰) and indeterminate individuals (7.7‰ to -5.4‰) (Table 1 and Figure 2) there were no significant intra-site differences among the mean values of those three groups respectively (-6.5‰, -7.8‰ and -6.8‰) ($F(2,11) = 2.802, p=0.103$) (Table 2). Similarly there were no intra-site differences in the range of $\delta^{18}O$ values among males (22.9‰ to 23.8‰), females (22.6‰ to 25.1‰) or individuals of indeterminate sex (23.3‰ to 24.4‰) (Table 1 and Figure 3), and no significant differences (F(2,11 = 0.471, p=0.636) among the mean values of those three groups respectively (23.4‰, 23.7‰ and -23.9‰) (Table 2). Unfortunately, the sample size at Nyaung'gan was too small to undertake meaningful statistical testing of isotopic differences.

Table 1. Carbon and oxygen isotope results for the humans from Oakaie and Nyaung'gan

	Oakaie				Nyaung'gan				Total			
	Males	Females	Indeterminate	Total	Males	Females	Indeterminate	Total	Males	Females	Indeterminate	Total
$\delta^{13}C$ (‰ VPDB)												
N	4	7	3	14	2	1	1	4	6	8	4	18
Mean	-6.5	-7.8	-6.8	-7.2	-7.4	-6.7	-5.9	-6.8	-6.8	-7.7	-6.6	-7.1
Minimum	-7.9	-8.6	-7.7	-8.6	-7.7	-	-	-7.7	-7.9	-8.6	-7.7	-8.6
Maximum	-4.9	-6.4	-5.4	-4.9	-7.1	-	-	-5.9	-4.9	-6.4	-5.4	-4.9
Range	2.9	2.2	2.3	3.6	0.6	-	-	1.8	2.9	2.2	2.3	3.6
SD	1.3	0.7	1.2	1.1	0.4	-	-	0.8	1.1	0.8	1.1	1.0
$\delta^{18}O$ (‰ VSMOW)												
N	4	7	3	14	2	1	1	4	6	8	4	18
Mean	23.4	23.7	23.9	23.7	23.8	23.3	24.9	24.0	23.5	23.7	24.2	23.7
Minimum	22.9	22.6	23.3	22.6	23.3	-	-	23.3	22.9	22.6	23.3	22.6
Maximum	23.8	25.1	24.4	25.1	24.3	-	-	24.9	24.3	25.1	24.9	25.1
Range	0.9	2.5	1.1	2.5	1.0	-	-	1.7	1.5	2.5	1.6	2.5
SD	0.4	1.0	0.6	0.8	0.7	-	-	0.8	0.5	0.9	0.7	0.8

Table 2. Summary statistics for carbon and oxygen isotope results for the humans from Oakaie and Nyaung'gan

	Oakaie				Oakaie and Nyaung'gan				Oakaie and Nyaung'gan		
	Male	Female	Indeterminate		Male	Female	Indeterminate		Oakaie	Nyaung'gan	
	Mean			*p*	Mean			*p*	Mean		*p*
$\delta^{13}C$ (‰ VPDB)	-6.5	-7.8	-6.8	0.103*	-6.8	-7.7	-6.6	0.122*	-7.2	-6.8	0.550**
$\delta^{18}O$ (‰ VSMOW)	23.4	23.7	23.9	0.636*	23.5	23.7	24.2	0.388*	23.7	24.0	0.494**

*One-Way ANOVA

**t-test

Figure 2. Stable carbon isotope results for the humans by sex from Oakaie and Nyaung'gan

Figure 3. Stable oxygen isotope results for the humans by sex from Oakaie and Nyaung'gan

3.2 Faunal stable carbon and oxygen isotope data

Figure 4 shows the faunal isotope values alongside the humans from all sites. The range of $\delta^{13}C$ values derived from the tooth enamel of bovines from Nyaung'gan and Oakaie was wider than that of humans (-7.7‰ to 0.6‰) (Table 3) with a statistically significantly higher mean value (-2.0‰, $t(49.419)=14.597$, $p=<0.001$) (Table 4), excluding one bovine from Nyaung'gan which was a statistical outlier, with the lowest $\delta^{13}C$ value of -7.7‰. When examining the variation in $\delta^{13}C$ values of bovines between sites, the results of a Kruskal-Wallis test demonstrated there was a statistically significant difference H(3) = 8.751, p =0.033. A pairwise comparison indicated the $\delta^{13}C$ data from the Nyaung'gan Bovinae (-5.0‰) were statistically significantly different to the sites of Oakaie 2 (-1.7‰ p = 0.017), Oakaie 3 (-1.7‰ p = 0.008) and Oakaie 4 (-0.3‰ p = 0.013) (Table 4).

Faunal samples from Oakaie 3 were used in order to examine changes over time, as this was the only site represented by a reasonable number of faunal samples throughout the sequence (Table S3) and provided the opportunity to identify any differences between the layers representing the Neolithic and Bronze Age. This chronological analysis was not possible at the Oakaie and Nyaung'gan cemeteries due to the absence of appropriate material for radiogenic dating. The results of a Mann-Whitney U test demonstrated there were no significant differences in the $\delta^{13}C$ values of the Bovinae between the Neolithic and Bronze Age layers at Oakaie 3 (Table 4). The range of variation in Bovinae $\delta^{18}O$ values from Nyaung'gan and Oakaie was wider, 24.7‰ to 29.9‰, with a significantly higher mean value, (27.0‰ $t(50.625)=12.149$, $p=<0.001$), than the humans (Table 3 and Table 4). There were no differences in the $\delta^{18}O$ values of Bovinae between the sites (Table 4). The mean $\delta^{18}O$ value of the Bovinae from the Neolithic layers was significantly lower 25.9‰ than those from the Bronze Age layers 27.2‰ ($t(19)=-2.882$, p =0.010) (Table S2 and Table 4).

Suidae data were limited, however, **t**here were no significant differences in suid $\delta^{13}C$ results between Oakaie 3 and 4, and they were similar to those of humans with a range from -7.9‰ to -3.3‰ (Table 3 and Table 5). However, the mean carbon isotope value (-5.3‰) of the Suidae was statistically higher ($t(35)=-4.638$, $p=<0.001$) than that of the humans. The range of $\delta^{18}O$ values of Suidae from Oakaie 3 and 4 was wider than that of humans ranging from (22.0‰ – 26.8‰) with a statistically significantly higher mean value of 24.6‰ ($t(27.059)=-2.152$, $p=0.041$) (Table 3 and Table 5). There were no differences in the $\delta^{18}O$ values of Suidae between the sites. There was only one canid sample from Oakaie 4 with a $\delta^{13}C$ value of -4.0‰ which falls outside the range of human values but is within the range of Suidae and Bovinae. This canid's $\delta^{18}O$ value (24.0‰) falls within the range observed for humans and Suidae, but is outside that of Bovinae (Table 3).

When examining the $\delta^{13}C$ data among the humans, the Bovinae and the Suidae, the results of a Welch ANOVA demonstrate a statistically significant difference (F(2,42.269) =106.394 , p =<0.001) (Table 5). A Games-Howell post-hoc test indicated the $\delta^{13}C$ values of the humans (-7.2‰) were significantly different to the Bovinae (-2.0‰ $p=<0.001$), and the Suidae (-5.3‰ $p=<0.001$), and they were significantly different to one another ($p=<0.001$). When examining the $\delta^{18}O$ data among the humans, the Bovinae, and the Suidae, the results of a Welch ANOVA indicated there was a statistically significant difference (F(2,39.465) =73.970 , p =<0.001) (Table 5). A Games-Howell post-hoc test demonstrated that the $\delta^{18}O$ values of the humans (23.7‰) were significantly different to Bovinae (27.0‰ $p=<0.001$) and the Bovinae were significantly different to the Suidae (24.6‰ $p=<0.001$).

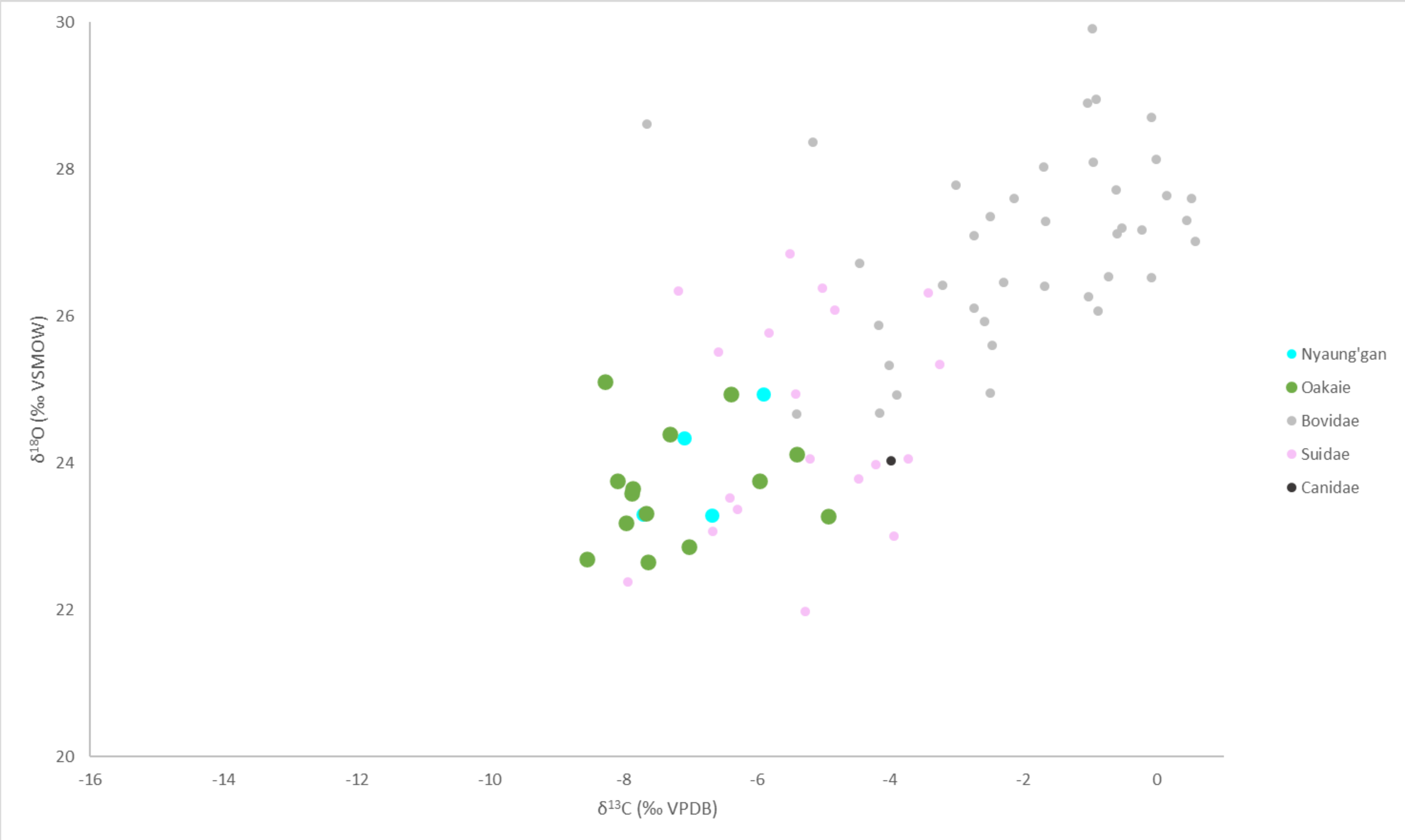


Figure 4. $\delta^{13}C$ and $\delta^{18}O$ isotope values for humans and fauna from Oakaie and Nyaung'gan

Table 3. Carbon and oxygen isotope results for the fauna from Oakaie and Nyaung'gan

	Oakaie 2			Oakaie 3			Oakaie 4			Nyaung'gan			All		
	Bovinae	Suidae	Canidae	Bovinae	Suidae	Canidae	Bovinae	Suidae	Canidae	Bovinae	Suidae	Canidae	Bovinae	Suidae	Canidae
$\delta^{13}C$ (‰ VPDB)															
N	12	-	-	21	14	-	2	5	1	4	-	-	39	19	1
Mean	-1.7	-	-	-1.7	-5.4	-	-0.3	-5.2	-4.0	-5.0	-	-	-2.0	-5.3	-4.0
Minimum	-4.5	-	-	-5.4	-7.2	-	-1.0	-7.9	-	-7.7	-	-	-7.7	-7.9	-
Maximum	0.6	-	-	0.5	-3.7	-	0.4	-3.3	-	-3.9	-	-	0.6	-3.3	-
Range	5.0	-	-	5.9	3.5	-	1.5	4.7	-	3.7	-	-	8.2	4.7	-
SD	1.4	-	-	1.7	1.1	-	1.1	2.0	-	1.8	-	-	1.9	1.3	-
$\delta^{18}O$ (‰ VSMOW)															
N	12	-	-	21	14	-	2	5	1	4	-	-	39	19	1
Mean	27.5	-	-	26.8	24.5	-	28.1	24.8	24.0	26.0	-	-	27.0	24.6	24.0
Minimum	26.4	-	-	24.7	22.0	-	27.3	22.4	-	24.7	-	-	24.7	22.0	-
Maximum	29.9	-	-	28.7	26.8	-	28.9	26.4	-	28.6	-	-	29.9	26.8	-
Range	3.5	-	-	4.0	4.9	-	1.6	4.0	-	3.9	-	-	5.2	4.9	-
SD	1.1	-	-	1.1	1.4	-	1.1	1.8	-	1.8	-	-	1.3	1.5	-

Table 4. Summary statistics for carbon and oxygen isotope results for the Bovinae from Oakaie and Nyaung'gan

	Oakaie and Nyaung'gan					Oakaie and Nyaung'gan			Oakaie 3		
	Oakaie 2	Oakaie 3	Oakaie 4	Nyaung'gan		Human	Bovinae		Neolithic	Bronze Age	
	Mean				*p*	Mean		*p*	Mean		*p*
$\delta^{13}C$ (‰ VPDB)	-1.7	-1.7	-0.3	-5.0	**0.033***	-7.1	-2.0	**<0.001*****	-2.7	-1.2	0.062****
$\delta^{18}O$ (‰ VSMOW)	27.5	26.8	28.1	26.0	0.082**	23.7	27.0	**<0.001*****	25.9	27.2	**0.010*****

*Kruskal-Wallis H test
**One-Way ANOVA
***t-test
****Mann-Whitney U test

Table 5. Summary statistics for carbon and oxygen isotope results for the Suidae from Oakaie and Nyaung'gan

	Oakaie and Nyaung'gan				Oakaie and Nyaung'gan			Oakaie		
	Human	Bovinae	Suidae		Human	Suidae		Oakaie 3	Oakaie 4	
	Mean			*p*	Mean		*p*	Mean		*p*
$\delta^{13}C$ (‰ VPDB)	-7.1	-2.0	-5.3	**<0.001**[*]	-7.1	-5.3	**<0.001**[**]	-5.4	-5.2	0.789[**]
$\delta^{18}O$ (‰ VSMOW)	23.7	27.0	24.6	**<0.001**[*]	23.7	24.6	**0.041**[**]	24.5	24.8	0.750[**]

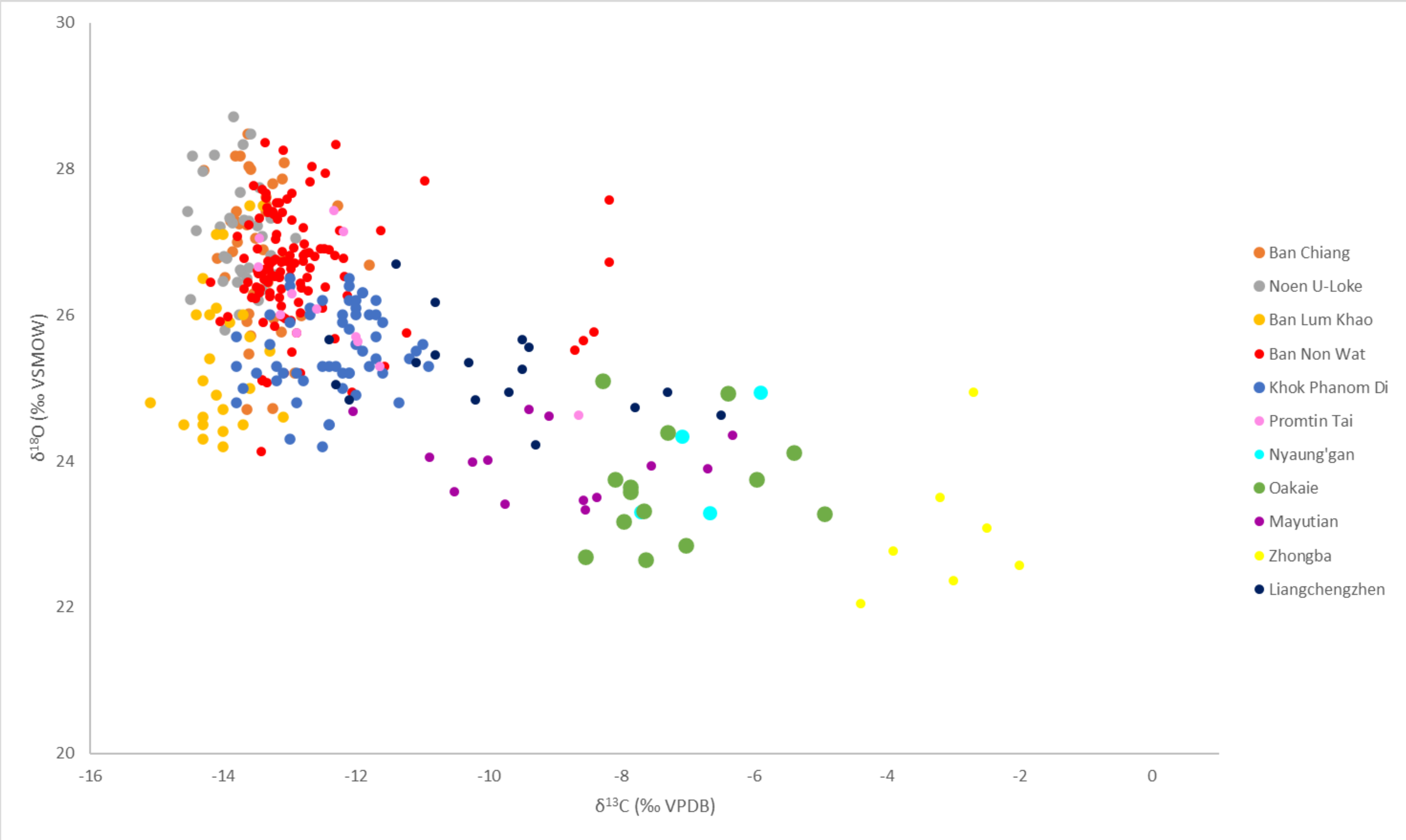
[*]One-Way ANOVA

[**]t-test

3.3 Comparative Southeast Asian and Chinese stable carbon and oxygen isotope data

Figure 5 shows the $\delta^{13}C$ and $\delta^{18}O$ isotope values for Oakaie and Nyaung'gan in comparison to other sites in Mainland Southeast Asia and China, using published data, and including outliers. Before comparing the $\delta^{13}C$ data from Oakaie and Nyaung'gan, statistically, outliers were identified and excluded. These included two samples from Ban Chiang (BCES31, BCES34), nine from Ban Non Wat (B28, B211, B255, B259, B292, B304, B390, B461, B463), and one from Promtin Thai (B2) and Liangchengzhen (M33), respectively. The results of a Kruskal-Wallis H test demonstrated there was a statistically significant difference between the stable carbon isotope values of the sites analysed (H(10) = 240.737, p = 0.000). A pairwise comparison of the sites demonstrated there was a statistically significant difference in the mean $\delta^{13}C$ values of individuals from both Oakaie and Nyaung'gan, respectively, and individuals from the Southeast Asian sites of Khok Phanom Di (p = 0.001, p = 0.050), Ban Chiang (p = <0.001, p = <0.001), Noen U-Loke (p = 0.000, p = <0.001), Ban Lum Khao (p = 0.000, p = <0.001), Ban Non Wat (p = <0.001, p = 0.001) and Promtin Thai (p = 0.005, p = 0.042). However, there were no statistically significant differences between individuals from both Oakaie and Nyaung'gan, respectively, and individuals from the Chinese sites of Zhongba (p = 0.711, p = 0.841) Liangchengzhen (p = 0.398, p = 0.525) and Mayutian (p = 0.660, p = 0.707) (Table 6).

Before examining the $\delta^{18}O$ data from Oakaie and Nyaung'gan to published data from other sites in Southeast Asia and China, outliers were identified and excluded. These included four from Ban Non Wat (B160, B246, B247, B566), and one from Zhongba (99ZZM81) and Liangchengzhen (M44), respectively. The results of a Kruskal-Wallis H test demonstrated there was a statistically significant difference between the stable carbon isotope values of all of the sites analysed (H(10) = 200.179, p = 0.000). A pairwise comparison of the sites demonstrated there was a statistically significant difference in the mean $\delta^{18}O$ values of individuals from both Oakaie and Nyaung'gan, respectively, and individuals from the Southeast Asian sites of Ban Chiang (p = <0.001, p = <0.001), Noen U-Loke (p = <0.001, p = <0.001), Ban Non Wat (p = <0.001, p = <0.001) and Promtin Thai (p = <0.001, p = 0.013), however, there were no statistically significant differences between individuals from both Oakaie and Nyaung'gan, respectively, and individuals from the Chinese sites of Zhongba (p = 0.705, p = 0.694) Liangchengzhen (p = 0.093, p = 0.330) and Mayutian (p = 0.916, p = 0.958). Oakaie was statistically significantly different to Khok Phanom Di (p = 0.002) and Ban Lum Khao (p = 0.004) whereas Nyaung'gan was not significantly different to either of those sites (p = 0.103 and p = 0.100, respectively) (Table 7).



514

515 Figure 5. $\delta^{13}C$ and $\delta^{18}O$ isotope values for Oakaie and Nyaung'gan in comparison to other sites in Southeast Asia and China

Table 6. *P* values from pairwise comparison of $\delta^{13}C$ isotope values for Oakaie and Nyaung'gan in comparison to other sites in Southeast Asia and China

	Oakaie	Nyaung'gan	Mayutian	Zhongba	Liangchengzhen	Noen U-Loke	Promtin Tai	Khok Phanom Di	Ban Chiang	Ban Lum Khao
Oakaie										
Nyaung'gan	0.935									
Mayutian	0.660	0.707								
Zhongba	0.711	0.841	0.465							
Liangchengzhen	0.398	0.525	0.697	0.289						
Noen U-Loke	**0.000**	**<0.001**	**<0.001**	**<0.001**	**<0.001**					
Promtin Tai	**0.005**	**0.042**	**0.016**	**0.007**	**0.034**	**<0.001**				
Khok Phanom Di	**0.001**	**0.050**	**0.007**	**0.004**	**0.020**	**<0.001**	0.605			
Ban Chiang	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.147	**<0.001**	**<0.001**		
Ban Lum Khao	**0.000**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.413	**<0.001**	**<0.001**	**0.029**	
Ban Non Wat	**<0.001**	**0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.124	**<0.001**	**<0.001**	**<0.001**

Table 7. P values from pairwise comparison of $\delta^{18}O$ isotope values for Oakaie and Nyaung'gan in comparison to other sites in Southeast Asia and China

	Oakaie	Nyaung'gan	Mayutian	Zhongba	Liangchengzhen	Noen U-Loke	Promtin Tai	Khok Phanom Di	Ban Chiang	Ban Lum Khao
Oakaie										
Nyaung'gan	0.903									
Mayutian	0.916	0.958								
Zhongba	0.705	0.694	0.645							
Liangchengzhen	0.093	0.330	0.116	0.095						
Noen U-Loke	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**					
Promtin Tai	**<0.001**	**0.013**	**<0.001**	**<0.001**	**0.020**	**0.008**				
Khok Phanom Di	**0.002**	0.103	**0.003**	**0.011**	0.291	**<0.001**	0.062			
Ban Chiang	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.347	**0.041**	**<0.001**		
Ban Lum Khao	**0.004**	0.100	**0.006**	**0.012**	0.285	**<0.001**	0.114	0.864	**<0.001**	
Ban Non Wat	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.044**	0.106	**<0.001**	0.328	**<0.001**

4. Discussion

4.1 Is there any evidence at either Nyaung'gan or Oakaie for the consumption of rice or millet as a staple in the subsistence economy?

Stable carbon isotope values for the human individuals from Nyaung'gan and Oakaie are higher than would be expected for a community with a subsistence economy focused purely on a C_3 staple, such as rice. These higher $\delta^{13}C$ values could theoretically be explained through consumption of marine resources. This is unlikely due to the inland location of the sites, although there is the possibility that some marine resources were acquired from coastal trading via riverine transport. Consumption of freshwater fish sourced from the Chindwin River or littoral fish from lacustrine ecosystems is also a possibility, although the carbon values of these species are variable based on consumption of a variety of freshwater plants with variable carbon sources (Katzenberg, 2008, Katzenberg and Weber, 1999). It is more likely that the higher values observed among the individuals from Oakaie and Nyaung'gan reflect the consumption of C_4 plants, either those directly collected and consumed, which could include millet or Job's Tears (King, 2008), or from consumption of animals whose diet consisted either of natural forage (e.g. wild C_4 grasses) or surplus domestic C_4 plants (e.g. millet, sorghum).

C_4 plants such as pearl millet, currently grown in upland systems in Myanmar (Herridge, et al., 2019, Ministry of Agriculture, 2016), may have been more common in the CDZ in prehistory. The archaeozoological remains are instrumental in further exploring this, providing valuable data with which to investigate their contribution to human diets. The faunal remains at Nyaung'gan and Oakaie indicate the inhabitants were engaging in the management of Suidae and Bovinae and supplementing this with local flora and fauna. The high stable carbon isotope values of the bovines are clearly different from all other species and are consistent with a pure C_4 diet, which may indicate they were foddered on millet or the only forage in the area were wild C_4 savannah grasses, the latter of which seems most likely, but unfortunately the contribution of either of these cannot be differentiated. Suidae represent a good proxy for analysing human diet as they require a balance of protein, carbohydrates, and essential vitamins and minerals, and cannot subsist solely on grass like ruminants. The diet of the Suidae and Canid is more analogous to the human individuals from Nyaung'gan and Oakaie than of the Bovinae (Figure 4), indicating they were likely being fed leftover human scraps.

Ultimately, the $\delta^{13}C$ values of the individuals from Oakaie and Nyaung'gan were very homogenous and suggest they were consuming a combination of C_3 and C_4 resources in their diet. The savannah-like environmental context, with no forests or woodlands, suggests a significant contribution of rice (C_3) to the diet coupled with either a C_4 crop such as millet or the use of terrestrial animals foraging on wild C_4 grasses. Contextualising this within the broader Southeast Asian context is necessary, and explored later below. There were no differences in diet among any of the individuals from Oakaie or Nyaung'gan, based on either $\delta^{13}C$ or $\delta^{18}O$, and nothing to suggest any change in adaptations over time, in either subsistence economy, or as a response to changes in the environment, although this was difficult to assess due to the lack of temporal resolution at the cemeteries. To examine any potential patterns over time through a clearer lens, the faunal data is explored in more detail below.

4.2 Is there any evidence at either Nyaung'gan or Oakaie for changes in animal husbandry over time?

The stable carbon isotope values of the Bovinae were higher than both the humans and the Suidae, however, the $\delta^{13}C$ values of the Suidae were also significantly higher than the humans. This suggests that the diet of the Suidae included more C_4 resources than that of the humans. The mean isotope value of the Suidae is similar to those from the Neolithic Chinese sites of Zhongba in Chongqing, southwestern China (Tian, et al., 2008) and Liangchengzhen in Shandong, eastern China (Lanehart, et al., 2011). Tian et al. (2008) suggested that at Zhongba the diet of the Suidae included a mix of human leftovers dominated by C_4 millet and supplemented with C_3 plants while the domesticated pigs and dogs from Liangchengzhen were argued to have been foddered on millet (Lanehart, et al., 2011). Alternatively, the suids at Oakaie and Nyaung'gan may have been allowed to roam freely, rather than being permanently corralled, foraging wild C_4 grasses in addition to the scraps fed to them by humans.

There was no evidence for a temporal change in the stable carbon isotope values of bovines at Oakaie 3 indicating there was no change in foddering or foraging practices over time. The difference between the $\delta^{13}C$ values of Bovinae at Nyaung'gan and the Oakaie sites may indicate a difference in foddering practices with more of a focus on C_4 at the latter, however, it is more likely due to the small sample size. The oxygen isotope values of the Bovinae were higher than both the humans and the Suidae, likely reflecting the fact they were grazing in more open, drier areas. While the values of the humans, suids and canid were more similar, suggesting, perhaps, they were consuming water derived from standing water e.g. wells.

The range of bovine values are on a scale equivalent to the yearly variation in the $\delta^{18}O$ values of monsoonal areas (IAEA/WMO, 2020). Perhaps most interesting is the wide range of $\delta^{18}O$ values observed in the Oakaie Bovinae. While this could be due to differences in water consumption between *Bos* and *Bubalus* it may also relate to time period. In the chronological sequence there was a difference in bovid $\delta^{18}O$ values between the Neolithic and Bronze Age layers at Oakaie 3. These differences could be linked to a change in animal management practices, but there were no obvious changes in the $\delta^{13}C$ values to indicate changes in foddering practices or foraging behaviours. Perhaps the simplest explanation for this pattern is environmental change, with lower $\delta^{18}O$ values in the Neolithic likely indicating relatively higher rainfall and/or lower temperatures (Dansgaard, 1964). If, as suggested above, Bovidae were being grazed in drier grasslands around the sites, we would expect them to be more sensitive barometers for rainfall changes than the Suidae who likely roamed around human occupation areas. Those bovines with lower carbon values therefore may represent a period of increased precipitation, perhaps associated with severe monsoonal cycles. Lake sediment records from both Northeast Thailand and southern China indicate the period around 1000BC, which marks the Neolithic-Bronze Age transition, at least in Thailand, was associated with heavy monsoonal activity in these regions (Wang, et al., 2005, Wohlfarth, et al., 2016, Wohlfarth, et al., 2012). Here, the difference in bovine $\delta^{18}O$ values through time may be echoing this trend in climate seen across Mainland Southeast Asia.

In Myanmar there are no specific regional or local palaeoclimatic reconstructions, however, the weakening of the Indian Summer Monsoon after ca. 4000BC, is consistent with the regional model based on palynology (Hope, et al., 2019) and sedimentology, mineralogy, and geochemistry (Hamilton, et al., 2019, Sebastian, et al., 2019). The lower $\delta^{18}O$ in the Neolithic are possibly associated with higher precipitation with the change over time reflecting the weakening of the monsoon associated with reduced mean moisture and cooler temperatures in the Late Holocene. Alternatively, the magnitude of variation in bovine $\delta^{18}O$ values echoes the differences we might expect at different points in the monsoon cycle (usually around 5-6‰ variation in any given area). It is possible that the variability in values may reflect differences in birth season e.g. enamel sampled from those with higher values represents the driest months of the year, and vice versa. If this is the case, the variation among the bovines hints that animal husbandry did not involve the manipulation of birth seasonality (in contrast to other regions, eg., Gron, et al., 2015).

A final possibility is that some of the bovines were not local to the site and came from regions that were climatically quite different. In this scenario those bovines lying close to the human values were likely born and raised locally, and those with higher $\delta^{18}O$ values may have been traded in from regions more climatically similar to other areas of Southeast Asia. To ascertain whether or not this is the case we would need more isotopic evidence ($^{87}Sr/^{86}Sr$), however, preliminary work in Thailand has suggested that Iron Age cattle were likely traded across the Southeast Asian Peninsula, and so it is not outside the realms of possibility that some bovines were non-local. Examining temporal changes to animal foddering/foraging strategy using $\delta^{13}C$ and water availability/usage using $\delta^{18}O$ has provided insight into ancient animal husbandry practices in Myanmar. As an integral part of the subsistence economy these fauna would have influenced the human $\delta^{13}C$ values. However, it remains unclear whether the high human values are the result of direct C_4 crop consumption such as millet, or consumption of terrestrial animals foraging on wild or cultivated fodder or C_4 grasses, contextualising this within the broader Southeast Asian context is necessary, and explored below.

4.3 Is there any evidence for differences among Nyaung'gan and Oakie and other sites in Mainland Southeast Asia and China?

The stable carbon isotope values of the individuals from the sites in Mainland Southeast Asia and the Chinese site of Zhongba provide a comparative reference for communities engaged in subsistence economies focused on either C_3 or C_4 crops, respectively (Figure 5). As Mainland Southeast Asia is largely a C_3 biome with very few staple C_4 cultigens, except for millet, Job's tears and possibly sorghum (Krigbaum, 2005) the subsistence economy for most prehistoric sites in Mainland Southeast Asia focused on a staple C_3 crop, rice, supplemented with riverine and terrestrial fauna (Castillo, et al., 2018, King, 2008, King, et al., 2013). This is reflected in $\delta^{13}C$ values in humans. On the other hand the subsistence economy for the Zhongba site was focused on both broomcorn and foxtail millet (Zhao and Flad, forthcoming cited in d'Alpoim Guedes et al., 2013), C_4 crops, supplemented with terrestrial fauna (Tian, et al., 2008). The $\delta^{13}C$ values of the individuals from the communities of Nyaung'gan and Oakaie overlap with some of the individuals from the Chinese sites of Mayutian in Yunnan and Liangchengzhen in Shandong. The Neolithic site of Mayutian located in the Yuanjiang region of the Red River in Yunnan engaged in a subsistence economy which included a mixture of C_3 and C_4 resources but it was not solely focused on either millet or rice as a domestic staple (Zhang, et al., 2014). Similarly, the late Neolithic site of Liangchengzhen in southeastern Shandong in China relied on the crops of both rice and millet and supplemented their subsistence economy with terrestrial domesticates and aquatic resources (Lanehart, et al., 2011). Mayutian, Zongba and Liangchengzhen provide an insight into mixed subsistence economies and the contribution of C_4 crops with Mayutian, the most geographically relevant, providing the most interesting analogy.

The individuals from the Myanmar sites also had significantly lower stable oxygen isotope values in comparison to the other Mainland Southeast Asian sites, despite the aridity of the CDZ. It is possible that these differences reflect temporal variation with many of the Mainland Southeast Asian sites dating to the later Bronze and Iron Age, arguably representing a period where there was a gradual drying of the region (Castillo, et al., 2018, Wohlfarth, et al., 2016).

Additionally, the oxygen isotope values align well with both archaeological and modern isotope data from Yunnan province in China (IAEA/WMO, 2020, Zhang, et al., 2014) and are most comparable with Mayutian in Yunnan, a region which forms a large part, ca. 1600km, of the modern northeastern border of Myanmar. This may reflect the similar climate of northern Myanmar to neighbouring Yunnan in both the past and today. However, given the nature of stable oxygen isotope data, and the lack of success, in previous studies, using $\delta^{18}O$ to differentiate communities living in different geographical locations in Southeast Asia (Bentley, et al., 2005, Bentley, et al., 2007, King, et al., 2015, Krigbaum, 2003) should be approached cautiously.

5. Conclusion

Understanding the origin, adoption and intensification of agricultural subsistence practices is a focal area of research among Southeast Asian scholars, but due to a paucity of palaeobotanical and archaeological data, Myanmar has remained enigmatic in terms of our understanding of the origins and transmission of agriculture. Using $\delta^{13}C$ we assessed whether there is evidence for consumption of either millet or rice, and whether, in the absence of any archaeobotanical data, it can be used as a proxy to understand the subsistence economies of individuals from the ancient communities of Oakaie and Nyaung'gan. Despite the lack of appropriate data to define the $\delta^{13}C$ values of endmembers, the carbon isotope data of the individuals from the communities of Nyaung'gan and Oakaie indicate that they consumed a mixed C_3/C_4 diet falling between the average value of pure C_3 consumers and pure C_4 consumers (Tykot, 2006).

The clear distinction between the carbon isotope values of the individuals from Nyaung'gan and Oakaie in comparison to the assemblages in Mainland Southeast Asia is intriguing. The isotopes were analysed from the carbonate from tooth enamel in all cases, and the assemblages in all regions are inland, with the exception of Khok Phanom Di, so the differences are not due to tissue analysed or a marine dietary input — the explanation lies elsewhere. This difference is perhaps not unexpected given Oakaie and Nyaung'gan are located in the CDZ of Myanmar and situated in the rainshadow of the Rakhine Mountains which, as discussed earlier, is currently mostly not suitable for growing rice. Nevertheless, the crop and cropping systems practiced in prehistory would have influenced the intensity and success in different areas but the local environment and how the communities managed that would have largely driven the ecological success in different areas (Fuller and Castillo, 2021). The similarity between the carbon isotope values of the communities of Nyaung'gan and Oakaie and the individuals from Mayutian in Yunnan, and the other Chinese sites, is equally intriguing and suggests significant differences in subsistence economy between Myanmar and contemporary sites elsewhere in Southeast Asia. Additionally, their values were higher than individuals from Promtin Thai in central Thailand who were arguably consuming a small amount of millet (Liu, 2018).

Dating to the transitionary period between the Neolithic and Bronze Age, these communities are potentially descendent from low density migrating communities of dry rice and millet farmers, which prior to and during this time, were on the move in search of new and appropriate farming land to settle (Fuller and Castillo, 2021). The data here show commonality with that observed at Yunnan, and could indicate a link to that region, which is consistent with the aDNA of two individuals from Oakaie suggesting an ancestral link with early Sino-Tibetan speaking people from East Asia (Lipson, et al., 2018).

Contextualising these findings in a broader Southeast Asian context has provided significant new knowledge about the subsistence economy of the communities of Oakaie and Nyaung'gan and their animal husbandry practices, but there are still questions remaining. Applying stable carbon isotope analysis to dentinal collagen of the teeth could clarify the contribution of terrestrial animal protein, freshwater resources or C_4 crops to their diet. In order to try and tease apart the underlying reason for the distinction between Myanmar and Mainland Southeast Asia, these observations require further investigation, on a broader scale, to evaluate the strength of the patterns observed in the preliminary data and to use that to drive and refocus specific questions to enable a better resolution to our understanding of the data.

Acknowledgements

The *Mission Archéologique Française au Myanmar* was a 2001-2020 collaboration between the *Centre National de la Recherche Scientifique* and the Department of Archaeology of the (then) Ministry of Culture. Sayar Myo Min Kyaw was MAFM co-director for the first season at Oakaie, which helped put us on track to be able to achieve this paper. The fieldwork for the present paper was supported by the Archaeological Consultative Commission of the French Ministry for Europe and Foreign Affairs for the 2013-2016 project cycle. The laboratory analyses were undertaken at the Max Planck Institute for the Science of Human History (now the Max Planck Institute of Geoanthropology). This research was supported by an Australian Research Council Discovery Early Career Researcher Award to AW (project ID DE210101383) funded by the Australian Government.

References

Albanese, J., 2003. A metric method for sex determination using the hipbone and the femur. J. Forensic Sci. 48, 263-273.

AlQahtani, S.J., Hector, M.P., Liversidge, H.M., 2010. Brief communication: The London atlas of human tooth development and eruption. Am. J. Phys. Anthropol. 142, 481-490.

Amano, N., Piper, P.J., Hung, H.-c., Bellwood, P., 2013. Introduced domestic animals in the Neolithic and Metal Age of the Philippines: Evidence from Nagsabaran, Northern Luzon. The Journal of Island and Coastal Archaeology 8, 317-335.

Ambrose, S.H., Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate, in: Lambert, J.B., Grupe, G. (Eds.). Prehistoric human bone: Archaeology at the molecular level. Springer-Verlag, Berlin, pp. 1-37.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data 5, 180214.

Bellwood, P., 2005. First farmers: The origins of agricultural societies, Blackwell publishers, Malden.

Bellwood, P., Oxenham, M.F., Bui, C.H., Nguyen, K.D., Willis, A., Sarjeant, C., Piper, P., Matsumura, H., Tanaka, K., Beavan-Athfield, N., Higham, T., Nguyen, Q.M., Dang, N.K., Nguyen, K.T.K., Vo, T.H., Van, N.B., Tran, T.K.Q., Nguyen, P.T., Campos, F., Sato, Y., Nguyen, L.C., Amano, N., 2011. An Son and the Neolithic of Southern Vietnam. Asian Persp 50, 144-174.

Bentley, R.A., Cox, K., Tayles, N., Higham, C., Macpherson, C., Nowell, G., Cooper, M., Hayes, T.E.F., 2009. Community diversity at Ban Lum Khao, Thailand: Isotopic evidence from the skeletons. Asian perspectives. 48, 79-97.

Bentley, R.A., Pietrusewsky, M., Douglas, M.T., Atkinson, T.C., 2005. Matrilocality during the prehistoric transition to agriculture in Thailand? Antiquity 79, 865-881.

Bentley, R.A., Tayles, N., Higham, C., Macpherson, C., Atkinson, Tim C., 2007. Shifting gender relations at Khok Phanom Di, Thailand: Isotopic evidence from the skeletons. Curr Anthrop 48, 301-314.

Berg, G.E., 2008. Pubic bone age estimation in adult women. J. Forensic Sci. 53, 569-577.

Bradley, D., 2011. Proto-Tibeto-Burman grain crops. Rice 4, 134-141.

Brooks, S., Suchey, J., 1990. Skeletal age determination based on the os pubis: A comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Hum Evol 5, 227-238.

Brůžek, J., 2002. A method for visual determination of sex, using the human hip bone. Am. J. Phys. Anthropol. 117, 157-168.

Buckberry, J.L., Chamberlain, A.T., 2002. Age estimation from the auricular surface of the ilium: A revised method. Am. J. Phys. Anthropol. 119, 231-239.

Buikstra, J.E., Ubelaker, D.H., 1994. Standards for data collection from human skeletal remains: Proceedings of a seminar at the Field Museum of Natural History, Arkansas Archeological Survey Fayetteville, Arkansas.

Castillo, C.C., Higham, C.F.W., Miller, K., Chang, N., Douka, K., Higham, T.F.G., Fuller, D.Q., 2018. Social responses to climate change in Iron Age north-east Thailand: New archaeobotanical evidence. Antiquity 92, 1274-1291.

Castillo, C.C., Tanaka, K., Sato, Y.-I., Ishikawa, R., Bellina, B., Higham, C., Chang, N., Mohanty, R., Kajale, M., Fuller, D.Q., 2016. Archaeogenetic study of prehistoric rice remains from Thailand and India: evidence of early japonica in South and Southeast Asia. Archaeological and Anthropological Sciences 8, 523-543.

Chi, Z., Hung, H.-c., 2012. Later hunter-gatherers in southern China, 18 000–3000 BC. Antiquity 86, 11-29.

Cohen, D.J., 2011. The beginnings of agriculture in China: A multiregional view. Curr Anthrop 52, S273-S293.

Cox, K.J., Bentley, R.A., Tayles, N., Buckley, H.R., Macpherson, C.G., Cooper, M.J., 2011. Intrinsic or extrinsic population growth in Iron Age northeast Thailand? The evidence from isotopic analysis. J Archaeol Sci 38, 665-671.

D'Arrigo, R., Ummenhofer, C.C., 2015. The climate of Myanmar: Evidence for effects of the Pacific Decadal Oscillation. IJCli 35, 634-640.

d'Alpoim Guedes, J., Alpoim, Jiang, M., He, K., Wu, X., Jiang, Z., 2013. Site of Baodun yields earliest evidence for the spread of rice and foxtail millet agriculture to south-west China. Antiquity 87, 758-771.

d'Alpoim Guedes, J., Hanson, S., Higham, C., Higham, T., Lertcharnrit, T., 2019. The wet and the dry, the wild and the cultivated: subsistence and risk management in ancient central Thailand. Archaeological and Anthropological Sciences 11, 6473–6484.

d'Alpoim Guedes, J., Hanson, S., Thanik, L., Weiss, A.D., Pigott, V.C., Higham, C.F.W., Higham, T.F.G., Weber, S.A., 2020. Three thousand years of farming strategies in central Thailand. Antiquity 94, 966-982.

Dal Martello, R., Min, R., Stevens, C., Higham, C., Higham, T., Qin, L., Fuller, D.Q., 2018. Early agriculture at the crossroads of China and Southeast Asia: Archaeobotanical evidence and radiocarbon dates from Baiyangcun, Yunnan. Journal of Archaeological Science: Reports 20, 711-721.

Dansgaard, W., 1964. Stable isotopes in precipitation. Tell 16, 436-468.

DeNiro, M.J., Epstein, S., 1976. You are what you eat (plus a few ‰): the carbon isotope cycle in food chains. Geological Society of America - Abstracts with Programs 8, 834-835.

Favereau, A., Pryce, T.O., Win, T.T., Champion, L., Win, T.T., Htwe, K.M.M., Mar, A.A., Pradier, B., Willis, A., 2018. Étude du mobilier céramique de deux cimetières de la fin du deuxième au début du premier millénaire avant notre ère en Haute Birmanie : technologie, typologie et chronologie. Bulletin de l'École française d'Extrême-Orient 104, 33-61.

Fuller, D.Q., Castillo, C.C., 2021. 4 The origins and spread of cereal agriculture in Mainland Southeast Asia, in: Sidwell, P., Jenny, M. (Eds.). The languages and linguistics of Mainland Southeast Asia: A comprehensive guide. De Gruyter, Berlin, pp. 45-59.

Fuller, D.Q., Qin, L., Zheng, Y., Zhao, Z., Chen, X., Hosoya, L.A., Sun, G.-P., 2009. The domestication process and domestication rate in rice: Spikelet bases from the Lower Yangtze. Science 323, 1607-1610.

Gron, K.J., Montgomery, J., Rowley-Conwy, P., 2015. Cattle management for dairying in Scandinavia's earliest Neolithic. PLoS One 10, e0131267.

Hamilton, R., Penny, D., Hua, Q., 2019. A 4700-year record of hydroclimate variability over the Asian monsoon intersection zone inferred from multi-proxy analysis of lake sediments. GPC 174, 92-104.

Herridge, D.F., Win, M.M., Nwe, K.M.M., Kyu, K.L., Win, S.S., Shwe, T., Min, Y.Y., Denton, M.D., Cornish, P.S., 2019. The cropping systems of the Central Dry Zone of Myanmar: Productivity constraints and possible solutions. Agricultural Systems 169, 31-40.

Hillson, S., 1986. Teeth, Cambridge University Press, Cambridge.

Hope, G., van der Kaars, S., Finn, J., Moe, K.z., 2019. Holocene environmental change at Inle Lake, Shan State, Myanmar, and its implications for the regional development of agriculture. Palaeogeogr., Palaeoclimatol., Palaeoecol. 523, 18-29.

IAEA/WMO, 2020. Global network of isotopes in precipitation. The GNIP Database, Accessible at: http://www.iaea.org/water.

Katzenberg, M.A., 2008. Stable isotope analysis: A tool for studying past diet, demography, and life history, in: Katzenberg, M.A., Saunders, S.R. (Eds.). Biological anthropology of the human skeleton, 2nd ed. John Wiley & Sons, New Jersey, pp. 413-441.

Katzenberg, M.A., Weber, A., 1999. Stable isotope ecology and palaeodiet in the Lake Baikal region of Siberia. J Archaeol Sci 26, 651-659.

Kim, S.-T., Coplen, T.B., Horita, J., 2015. Normalization of stable isotope data for carbonate minerals: Implementation of IUPAC guidelines. GeCoA 158, 276-289.

King, C.A., 2008. Stable isotopic analysis of carbon and nitrogen as an indicator of paleodietary change among pre-state metal age societies in Northeast Thailand, Archaeopress, Oxford.

King, C.L., Bentley, R.A., Higham, C., Tayles, N., Viðarsdóttir, U.S., Layton, R., Macpherson, C.G., Nowell, G., 2014. Economic change after the agricultural revolution in Southeast Asia? Antiquity 88, 112-125.

King, C.L., Bentley, R.A., Tayles, N., Viðarsdóttir, U.S., Nowell, G., Macpherson, C.G., 2013. Moving peoples, changing diets: Isotopic differences highlight migration and subsistence changes in the Upper Mun River Valley, Thailand. J Archaeol Sci 40, 1681-1688.

King, C.L., Tayles, N., Higham, C., Strand-Viđarsdóttir, U., Bentley, R.A., Macpherson, C.G., Nowell, G., 2015. Using isotopic evidence to assess the impact of migration and the two-layer hypothesis in prehistoric Northeast Thailand. Am. J. Phys. Anthropol. 158, 141-150.

Krigbaum, J., 2003. Neolithic subsistence patterns in northern Borneo reconstructed with stable carbon isotopes of enamel. J Anthrop Archaeol 22, 292-304.

Krigbaum, J., 2005. Reconstructing human subsistence in the West Mouth (Niah Cave, Sarawak) burial series using stable isotopes of carbon. Asian Persp 44, 73-89.

Lanehart, R.E., Tykot, R.H., Underhill, A.P., Luan, F., Yu, H., Fang, H., Fengshu, C., Feinman, G., Nicholas, L., 2011. Dietary adaptation during the Longshan period in China: stable isotope analyses at Liangchengzhen (southeastern Shandong). J Archaeol Sci 38, 2171-2181.

Larsen, C.S., 2015. Bioarchaeology: Interpreting behavior from the human skeleton, 2nd ed., Cambridge University Press, Cambridge.

Lee-Thorp, J.A., Sealy, J.C., Van Der Merwe, N.J., 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. J Archaeol Sci 16, 585-599.

Lee, H.-Y., Chung, S.-L., Yang, H.-M., 2016. Late Cenozoic volcanism in central Myanmar: Geochemical characteristics and geodynamic significance. Litho 245, 174-190.

Levin, N.E., Simpson, S.W., Quade, J., Cerling, T.E., Frost, S.R., 2008. Herbivore enamel carbon isotopic composition and the environmental context of Ardipithecus at Gona, Ethiopia, in: Quade, J., Wynn, J. (Eds.). The geology of early humans in the Horn of Africa. Geological Society of America Special Paper 446, Boulder, Colorado pp. 215-234.

Lipson, M., Cheronet, O., Mallick, S., Rohland, N., Oxenham, M., Pietrusewsky, M., Pryce, T.O., Willis, A., Matsumura, H., Buckley, H., Domett, K., Nguyen, G.H., Trinh, H.H., Kyaw, A.A., Win, T.T., Pradier, B., Broomandkhoshbacht, N., Candilio, F., Changmai, P., Fernandes, D., Ferry, M., Gamarra, B., Harney, E., Kampuansai, J., Kutanan, W., Michel, M., Novak, M., Oppenheimer, J., Sirak, K., Stewardson, K., Zhang, Z., Flegontov, P., Pinhasi, R., Reich, D., 2018. Ancient genomes document multiple waves of migration in Southeast Asian prehistory. Science 361, 92-95.

Liu, C.-H., 2018. Human foodways, metallurgy, and landscape modification of Iron Age central Thailand. Asian Persp 57, 83-104.

Liu, L., Chen, X., 2012. The archaeology of China : From the Late Paleolithic to the Early Bronze Age, Cambridge University Press, New York.

Lovejoy, C.O., Meindl, R.S., Pryzbeck, T.R., Mensforth, R.P., 1985. Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death. Am. J. Phys. Anthropol. 68, 15-28.

Matsuda, M., 2013. Upland farming systems coping with uncertain rainfall in the Central Dry Zone of Myanmar: How stable is indigenous multiple cropping under semi-arid conditions? Hum Ecol 41, 927-936.

Maury, R.C., Pubellier, M., Rangin, C., Wulput, L., Cotten, J., Socquet, A., Bellon, H., Guillaud, J.-P., Htun, H.M., 2004. Quaternary calc-alkaline and alkaline volcanism in an hyper-oblique convergence setting, central Myanmar and western Yunnan. Bull. Soc. Geol. Fr. 175, 461-472.

McColl, H., Racimo, F., Vinner, L., Demeter, F., Gakuhari, T., Moreno-Mayar, J.V., Driem, G.v., Wilken, U.G., Seguin-Orlando, A., Castro, C.d.l.F., Wasef, S., Shoocongdej, R., Souksavatdy, V., Sayavongkhamdy, T., Saidin, M.M., Allentoft, M.E., Sato, T., Malaspinas, A.-S., Aghakhanian, F.A., Korneliussen, T., Prohaska, A., Margaryan, A., Damgaard, P.d.B., Kaewsutthi, S., Lertrit, P., Nguyen, T.M.H., Hung, H.-c., Tran, T.M., Truong, H.N., Nguyen, G.H., Shahidan, S., Wiradnyana, K., Matsumae, H., Shigehara, N., Yoneda, M., Ishida, H., Masuyama, T., Yamada, Y., Tajima, A., Shibata, H., Toyoda, A., Hanihara, T., Nakagome, S., Deviese, T., Bacon, A.-M., Duringer, P., Ponche, J.-L., Shackelford, L., Patole-Edoumba, E., Nguyen, A.T., Bellina-Pryce, B., Galipaud, J.-C., Kinaston, R., Buckley, H., Pottier, C., Rasmussen, S., Higham, T., Foley, R.A., Lahr, M.M., Orlando, L., Sikora, M., Phipps, M.E., Oota, H., Higham, C., Lambert, D.M., Willerslev, E., 2018. The prehistoric peopling of Southeast Asia. Science 361, 88-92.

Miller, M., Christensen, G., Evans, H., 1964. Anatomy of the dog, Saunders Company, Philadelphia.

Ministry of Agriculture, L.a.I., 2016. Myanmar agriculture at a glance 2016.

Moore, E., Pauk, P., 2001. Nyaung-gan: A preliminary note on a Bronze Age cemetery near Mandalay, Myanmar (Burma). Asian Persp 40, 35-47.

Oxenham, M.F., Matsumura, H., Nguyen, K.D., 2011. Man Bac: The excavation of a Neolithic site in northern Vietnam. The biology, ANU E Press, Canberra.

Pales, L., Garcia, M., 1981. Atlas ostéologique: pour servir à l'identification des mammifères du Quaternaire. Les membres herbivores, Centre National de la Recherche Scientifique, Paris.

Perini, T.A., Oliveira, G.L.d., Ornellas, J.d.S., Oliveira, F.P.d., 2005. Technical error of measurement in anthropometry. Revista Brasileira de Medicina do Esporte 11, 81-85.

Phenice, T.W., 1969. A newly developed visual method of sexing the Os pubis. Am. J. Phys. Anthropol. 30, 297-301.

Piper, P.J., Campos, F.Z., Đặng, N.K., Amano, N., Oxenham, M., Bùi, C.H., Bellwood, P., Willis, A., 2014. Early evidence for pig and dog husbandry from the Neolithic site of An Sơn, southern Vietnam. Int J Osteoarchaeol 24, 68-78.

Pradier, P., Kyaw, A., Win, T., Willis, A., Favereau, A., Valentin, F., Pryce, T.O., 2019. Pratiques funéraires et dynamique spatiale à Oakaie 1 : une nécropole à la transition du Néolithique à l’âge du Bronze au Myanmar (Birmanie). Bulletin de la Société préhistorique française 116, 539-560.

Pryce, T.O., Htwe, K.M.M., Georgakopoulou, M., Martin, T., Vega, E., Rehren, T., Win, T.T., Win, T.T., Petchey, P., Innanchai, J., Pradier, B., 2018a. Metallurgical traditions and metal exchange networks in late prehistoric central Myanmar, c. 1000 BC to c. AD 500. Archaeological and Anthropological Sciences 10, 1087-1109.

Pryce, T.O., Kyaw, A.A., Kyaw, M.M., Win, T.T., Win, T.T., Win, K.H., Mon, M.M., Aye, M.M., Htay, S.H., Mar, A.A., Bellina, B., Bentley, R.A., Champion, L., Colonna, C., Cook, A.J., Favereau, A., Fuller, D.Q., Georjon, C., Higham, C., Htwe, K.M.M., Iizuka, Y., Innanchai, J., Le Meur, C., Peixoto, X., Petchey, P., Pinhasi, R., Pradier, B., Valentin, F., Willis, A., Zazzo, A., 2018b. A first absolute chronology for Late Neolithic to Early Bronze Age Myanmar: new AMS 14C dates from Nyaung'gan and Oakaie. Antiquity 92, 690-708.

Roberts, P., Louys, J., Zech, J., Shipton, C., Kealy, S., Carro, S.S., Hawkins, S., Boulanger, C., Marzo, S., Fiedler, B., Boivin, N., Mahirta, Aplin, K., O'Connor, S., 2020. Isotopic evidence for initial coastal colonization and subsequent diversification in the human occupation of Wallacea. Nat Commun 11, 2068.

Rowley-Conwy, P., Albarella, U., Dobney, K., 2012. Distinguishing wild boar from domestic pigs in prehistory: A review of approaches and recent results. Journal of World Prehistory 25, 1-44.

Scheuer, L., Black, S., 2000. Developmental juvenile osteology, Academic Press, London.

Schwarcz, H.P., Schoeninger, M.J., 2011. Stable isotopes of carbon and nitrogen as tracers of paleo-diet reconstruction, in: Baskaran, M. (Ed.). Handbook of environmental isotope geochemistry. Springer Verlag, Berlin, pp. 725-742.

Scott, E.C., 1979. Dental wear scoring technique. Am. J. Phys. Anthropol. 51, 213-217.

Sebastian, T., Nagender Nath, B., Venkateshwarlu, M., Miriyala, P., Prakash, A., Linsy, P., Kocherla, M., Kazip, A., Sijinkumar, A.V., 2019. Impact of the Indian Summer Monsoon variability on the source area weathering in the Indo-Burman ranges during the last 21 kyr – A sediment record from the Andaman Sea. Palaeogeogr., Palaeoclimatol., Palaeoecol. 516, 22-34.

Silva, F., Weisskopf, A., Castillo, C., Murphy, C., Kingwell-Banham, E., Qin, L., Fuller, D.Q., 2018. A tale of two rice varieties: Modelling the prehistoric dispersals of japonica and proto-indica rices. The Holocene 28, 1745-1758.

Stevens, C.J., Fuller, D.Q., 2017. The spread of agriculture in eastern Asia: Archaeological bases for hypothetical farmer/language dispersals. Language Dynamics and Change 7, 152-186.

Styring, A.K., Höhn, A., Linseele, V., Neumann, K., 2019. Direct evidence for agricultural intensification during the first two millennia AD in northeast Burkina Faso. J Archaeol Sci 108, 104976.

Tayles, N., Domett, K., Pauk, U.P., 2001. Bronze Age Myanmar (Burma): a report on the people from the cemetery of Nyaunggan, Upper Myanmar. Antiquity 75, 273-278.

Tian, X., Zhu, C., Xu, X., Ma, C., Sun, Z., Yin, Q., Zhu, Q., Shi, W., 2008. Reconstructing past subsistence patterns on Zhongba Site using stable carbon and oxygen isotopes of fossil tooth enamel. ChSBu 53, 87-94.

Tykot, R.H., 2006. Isotope analyses and the histories of maize, in: Staller, J.E., Tykot, R.H., Benz, B.F. (Eds.). Histories of maize in Mesoamerica. Multidisciplinary approaches. Routledge, pp. 131-142.

Tykot, R.H., Falabella, F., Planella, M.T., Aspillaga, E., Sanhueza, L., Becker, C., 2009. Stable isotopes and archaeology in central Chile: methodological insights and interpretative problems for dietary reconstruction. Int J Osteoarchaeol 19, 156-170.

Ubelaker, D.H., 1989. Human skeletal remains: excavation, analysis, interpretation, 2nd ed., Taraxacum, Washington, DC.

Vaiglova, P., Gardeisen, A., Buckley, M., Cavanagh, W., Renard, J., Lee-Thorp, J., Bogaard, A., 2020. Further insight into Neolithic agricultural management at Kouphovouno, southern Greece: expanding the isotopic approach. Archaeological and Anthropological Sciences 12, 43.

van der Merwe, N.J., Medina, E., 1991. The canopy effect, carbon isotope ratios and foodwebs in Amazonia. J Archaeol Sci 18, 249-259.

Ventresca Miller, A., Fernandes, R., Janzen, A., Nayak, A., Swift, J., Zech, J., Boivin, N., Roberts, P., 2018. Sampling and pretreatment of tooth enamel carbonate for stable carbon and oxygen isotope analysis. Journal of Visualized Experiments 138, 58002.

Walrath, D.E., Turner, P., Bruzek, J., 2004. Reliability test of the visual assessment of cranial traits for sex determination. Am. J. Phys. Anthropol. 125, 132-137.

Wang, Y., Cheng, H., Edwards, R.L., He, Y., Kong, X., An, Z., Wu, J., Kelly, M.J., Dykoski, C.A., Li, X., 2005. The Holocene Asian Monsoon: Links to solar changes and North Atlantic climate. Science 308, 854-857.

Weber, S., Lehman, H., Barela, T., Hawks, S., Harriman, D., 2010. Rice or millets: early farming strategies in prehistoric central Thailand. Archaeological and Anthropological Sciences 2, 79-88.

White, T.D., Folkens, P.A., 2005. The human bone manual, Academic Press.

Wohlfarth, B., Higham, C., Yamoah, K.A., Chabangborn, A., Chawchai, S., Smittenberg, R.H., 2016. Human adaptation to mid- to late-Holocene climate change in northeast Thailand. The Holocene 26, 1875-1886.

Wohlfarth, B., Klubseang, W., Inthongkaew, S., Fritz, S.C., Blaauw, M., Reimer, P.J., Chabangborn, A., Löwemark, L., Chawchai, S., 2012. Holocene environmental changes in northeast Thailand as reconstructed from a tropical wetland. GPC 92-93, 148-161.

Xu, H., Hong, Y., Hong, B., 2012. Decreasing Asian summer monsoon intensity after 1860 AD in the global warming epoch. ClDy 39, 2079-2088.

Zhang, X., Burton, J., Jin, Z., Xiao, M., Fan, A., Xu, J., 2014. Isotope studies of human remains from Mayutian, Yunnan Province, China. J Archaeol Sci 50, 414-419.

Zhao, Z., Flad, R., forthcoming. Report on flotation results from the Zhongba site in Chongqing, in: Li, S., von Falkenhausen, L. (Eds.). Salt archaeology in China, vol. 3. Science Press, Beijing.