The dentition of the people of Iron Age Non Ban Jak

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Natasha J. Heap (B.A.)

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Statement on the contribution of others

This thesis includes previously published and unpublished data collected by others such as Associate Professor Kate Domett (James Cook University), Professor Hallie Buckley (University of Otago), Professor Sian Halcrow (University of Otago), and Associate Professor Nancy Tayles (University of Otago). I was responsible for the analysis and interpretation of the data for the final synthesis of the results.

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Abstract

The Iron Age in mainland Southeast Asia was a time of significant climatic change. It is argued by many that as the climate dried the people changed their subsistence strategy to adapt to the new conditions. The aim of this research is to gain an understanding of the impact of this climatic change on the people of Non Ban Jak and the Upper Mun River Valley region through the lens of dental health.

The current hypothesis is the late Iron Age (1750-1350 BP) saw the health of the people of mainland Southeast Asia deteriorate as the inhabitants of the region experienced increasing stress due to climate change, the intensification of agriculture and an increase in population. This hypothesis was tested by macroscopic analysis of adult dentition at the late Iron Age site of Non Ban Jak in northeast Thailand for the prevalence of antemortem tooth loss, caries and advanced wear. Over the length of the settlement at Non Ban Jak the dental health of the population improved. The results from Non Ban Jak were compared with other sites in mainland Southeast Asia from the Neolithic (c.3700-3000 BP) through to the Iron Age (2250-1350 BP). It is apparent that there is no one, consistent trajectory in terms of dental health within the region

During the analysis of the permanent dentition, it was observed that there was a high prevalence of genetically missing teeth, agenesis, in the dentition from the people of Non Ban Jak. The results of the preliminary dental morphological analysis at Non Ban Jak were compared with two closely located Iron Age sites, Noen U-Loke and Ban Non Wat. Non Ban Jak had a high prevalence of dental agenesis, as did Noen U-Loke, however Ban Non Wat had no evidence of this condition. This is suggestive of a closer genetic connection between the settlements of Non Ban Jak and Noen U-Loke.

When considering the genetic and dental health results it is apparent that, aside from an abundance of biological factors, socio-environmental dynamics, such as the length of settlement occupation and the application of different strategies of adaptation, are contributing factors influencing dental health and overall health.

Keywords: bioarchaeology, dental anthropology, climate change, archaeology, mainland Southeast Asia, Iron Age, Thailand

บทคัดย่อ

สมัยเหล็กเป็นช่วงเวลาที่เกิดเปลี่ยนแปลงทางภูมิอากาศอย่างมีนัยสำคัญในภูมิภาคเอเชียตะวันออกเฉียงใต้ภาคพื้นแผ่นดินใหญ่
ข้อเสนอสำคัญคือสภาพอากาศที่แห้งแล้งขึ้นส่งผลให้มนุษย์เปลี่ยนแปลงวิถีการดำรงชีวิต
งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาถึงผลกระทบจากการเปลี่ยนแปลงสภาพอากาศที่ส่งผลภาวะสุขภาพของฟันตัวอย่างกลุ่มประชากรก่อนประวัติศาสตร์จากแหล่งโบราณคดีโนนบ้านจากและลุ่มแม่น้ำมูลตอนบน

สมมติฐานการศึกษาคือช่วงปลายสมัยเหล็ก อายุประมาณ 1,750-1,350 ปีมาแล้ว ประช่ากรในเอเชียตะวันออกเฉียงใต้ภาคพื้นแผ่นดินใหญ่
มีภาวะสุขภาพโดยรวมเสื่อมถอยลงเป็นผลจากการเปลี่ยนแปลงสภาพอากาศ การเกษตรกรรมแบบเข้มข้น และการเพิ่มขึ้นของประชากร
การทดสอบสมมติฐานด้วยการศึกษาอัตราความถี่หรือความชุกด้วยวิธีลักษณะทางมหภาคของฟันเช่นการสูญเสียฟันขณะมีชีวิต ฟันผุ
และการสึกของฟันในระดับรุนแรง
กลุ่มตัวอย่างประชากรผู้ใหญ่จากแหล่งโบราณคดีโนนบ้านจากพบว่าภาพรวมสุขภาพฟันโดยรวมของประชากรดีขึ้น
ไม่ปรากฏลักษณะใดเหมือนกับตัวอย่างประชากรยุคก่อนประวัติศาสตร์สมัยหินใหม่ถึงสมัยเหล็กกลุ่มอื่นในเอเชียตะวันออกเฉียงใต้ภาคพื้นแผ่นดินใหญ่

ข้อสังเกตสำคัญคือตัวอย่างประชากรจากโนนบ้านมีอัตราความชุกของการขาดหายของฟันจากลักษณะทางพันธุกรรมในระดับสูง
เมื่อเปรียบเทียบกับตัวอย่างประชากรสมัยเหล็กในบริเวณใกล้เคียงกันจำนวน 2 แหล่งที่เนินอุโลกและบ้านโนนวัด
พบว่ามีอัตราความชุกการพบลักษณะดังกล่าวสูงใกล้เคียงกับประชากรเนินอุโลก
ขณะที่ไม่ปรากฏลักษณะการขาดหายของฟันจากปัจจัยทางพันธุกรรมในบ้าน

โนนวัด
แสดงถึงความใกล้ชิดทางพันธุกรรมของประชากรสมัยเหล็กระหว่างโนนบ้านจ
ากกับที่เนินอุโลก

เมื่อพิจารณาจากลักษณะพันธุกรรมและสุขภาพฟัน
ปรากฏชัดเจนว่าความหลากหลายทางชีวภาพ
พลวัตทางสังคมและสิ่งแวดล้อมเช่นระยะเวลาการตั้งถิ่นฐาน
กลยุทธ์การปรับตัวให้เข้ากับสภาพแวดล้อม
เป็นปัจจัยสำคัญที่ส่งผลต่อสุขภาพฟันและภาวะสุขภาพโดยรวมของประชากร

คำสำคัญ: โบราณคดีเชิงชีววิทยา, ทันตมานุษยวิทยา
การเปลี่ยนแปลงภูมิอากาศ, โบราณคดี,
เอเชียตะวันออกเฉียงใต้ภาคพื้นแผ่นดินใหญ่, สมัยเหล็ก, ประเทศไทย

Contents

List of Tables

List of Figures

PART I

Chapter 1 Introduction

Over the past 20 years bioarchaeological studies on health and disease in mainland Southeast Asia, and in particular northeast Thailand, have increased, furthering the understanding of demography, diet, health and disease of the people who lived there. These studies have been conducted predominantly concerning the periods prior to the Iron Age. The archaeological evidence is thought by some to suggest that social structure became increasingly complex during the Iron Age (2350 – 1450 BP) in mainland Southeast Asia with the establishment of hierarchical and centralized societies and a widening exchange network (Higham et al., 2019), however this is not an unanimously held position within mainland Southeast Asia archaeology (White & Hamilton, 2021). During the Iron Age the region saw significant environmental change with increased aridity as the strength of the monsoonal rains declined (Higham, 2011). This led to land management change with forests cleared and villages constructing moats to manage water which facilitated the move from dry rice to wet rice agriculture (Higham et al., 2019). Iron working techniques were adopted which assisted with a further intensification of rice agriculture (Domett, 2001). The details of how and why these changes occurred, and their implications for communities in the region, are matters of continuing research interest. Until the excavations of Non Ban Jak in 2011– 2018, the human skeletal record of the late Iron Age in northeast Thailand was poorly preserved. The large number of well-preserved individuals excavated from Non Ban Jak (215 individuals) greatly assists the understanding of how the rapid environmental and social changes occurring in the late Iron Age impacted the people's health.

1.1 Background

Non Ban Jak, located on the Khorat Plateau in the Upper Mun Valley (Figure 1.1), was occupied during the Neolithic (3700-3000 BP), the Bronze Age (3000-2400 BP), Iron Age 4 (1750-1350 BP) and the early historic (1350-1150 BP) periods (Higham et al., 2019). Non Ban Jak is 10km west of Iron Age Noen U-Loke, which in turn is 2km southwest of Ban Non Wat, a large, multi-period site (Figure 1.2). The Iron Age material culture and the mortuary rituals at Non Ban Jak closely match those identified during the Iron Age phase 4 (IA4) at Noen U-Loke, the final of four mortuary periods encompassing the Iron Age (Higham, 2014; Higham et al., 2019). Ban Non Wat, in comparison, had a large number of burials belonging to Iron Age 1, an earlier period than the Non Ban Jak burials. By comparing the mortuary records of the sites of Non Ban Jak, Noen U-Loke and Ban Non Wat, a model of social change through the Iron Age has been proposed indicating a time of profound technological, cultural, and social stress (Higham et al., 2019).

Figure 1.1: Map of Thailand
Upper Mun River Valley is identified by the shaded area.

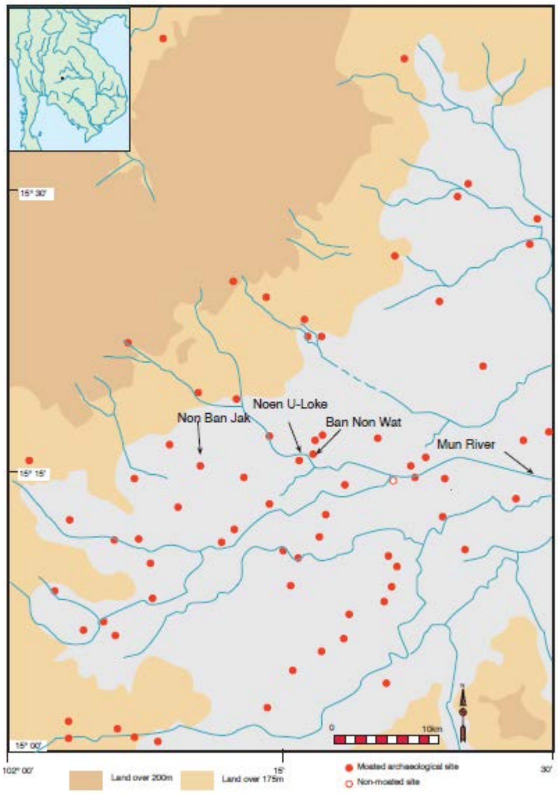

Figure 1.2: Upper Mun River Valley and the location of Non Ban Jak, Noen U-Loke and Ban Non Wat.
Adapted from Higham (2014).

The theoretical basis for this work follows Temple and Goodman (2014) requiring a strong biocultural understanding of factors affecting biological traits to ensure accurate interpretations of both regional and global events that have shaped human life in the past. In addition, Boyd and Chang (2010) suggest that to maintain an established lifestyle in the face of environmental change, people make a choice to either intensify the current agricultural practices or to change and adapt to the new environment. As the climate in northeast Thailand became drier, agriculture would have become more difficult. The choice people had in communities such as Ban Non Wat and Noen U-Loke, was to either leave the area or adapt their subsistence system. In choosing to adapt their subsistence system, from dry to wet rice agriculture, they “changed in order to remain the same” (Boyd & Chang, 2010, p. 285). Why did the people at Non Ban Jak choose to establish and intensify their settlement and agriculture at this time of climate change and variation? Did this population decision negatively impact the morbidity, mortality and dental health of the people of Non Ban Jak? This thesis advances the general database of knowledge of the health of Iron Age Thailand populations. It synthesises the data from Non Ban Jak with other nearby sites to determine broader influences on the quality of life or health impacts during this time of climate change.

Teeth are usually well preserved in the archaeological record. Their high component of inorganic material makes them the hardest, most chemically stable tissue in the human body (Hillson 1996). The teeth can provide information about genetic ancestry, diet, oral hygiene and dentistry practices, the level of biological stress experienced in childhood, repeated, possibly habitual activities, cultural behaviours and subsistence strategies of the population (Zakrzewski, 2012). The diagnosis, analysis, and interpretation of dental diseases in a palaeodemographic framework are integral when attempting to reconstruct past lifeways from human skeletal remains (Lukacs, 1989). Using a range of dental health observations and dental indicators of stress, health may be linked to socioeconomic variables and diet as the region went through significant climate and social change. Tooth morphology, by comparison, is more directly tied to underlying genetics and is less influenced by the external environment, sex and age compared to dental pathologies. Tooth morphology can be used to assess biological affinity and potentially differentiate between populations (Edgar, 2013; Hubbard et al., 2015; Rathmann et al., 2017; White et al., 2012). As such, the advantages in studying teeth lie not just in their preservability and observability, but also in their variability and heritability (Scott, 2008). An assessment of one dental morphological trait is included in this thesis to begin the dental morphological assessment of the population connections in the Upper Mun River Valley. A comparison of the dental health and population connections will enable a fuller picture of what was happening at Non Ban Jak and in the Upper Mun River Valley more broadly during the late Iron Age period to emerge. This thesis advances the general database of knowledge of the dental and overall health of Iron Age Thailand populations by synthesising the data from Non Ban Jak with other nearby sites to determine broader influences on the quality of life or health impacts during this time of climate change.

1.2 Research Approach

> "Human remains are the most tangible and direct forms of evidence for understanding how people lived in the past … "
>
> (Gowland & Knüsel, 2006b, p. ix).

Bioarchaeology is the contextual analysis of skeletal remains from archaeological sites (Buikstra, 1977; Larsen, 2015). Skeletal remains provide an independent archive that enables the examination of links between social standing in life and treatment in death (Budd et al., 2020). Their analysis can also provide insight into how individuals and populations adapted, or not, to change, be it cultural, socioeconomic or environmental (Roberts, 2010). As this work employs a critical biocultural interpretive framework (Goodman et al., 1988; Leatherman & Goodman, 2020; Temple & Goodman, 2014) it requires the integration of political-economic perspectives, alongside theoretical approaches from social theory, ethnography, human evolution, ecology and adaptability (Leatherman & Goodman, 2020). Inequalities in human health have been the main focus of the biocultural approach, but more recent work has called for an increased integration of social and biological aspects of the human experience to address other aspects including conflict and violence, environmental degradation and climate change (Leatherman & Goodman, 2020). Through the integration of historical, archaeological, biological and ethnographic data, bioarchaeology helps understand how people in the past lived.

The central focus of this thesis is the dental health of the adult individuals who lived at Non Ban Jak during the late Iron Age to early historic period. The increasing amount of biological and archaeological evidence from the region has revealed dental health changes in response to the possibly shifting political structures and changing environment (Domett, 2001; Halcrow & Tayles, 2011; Halcrow et al., 2016; Newton et al., 2013; Oxenham et al., 2006; Tayles et al., 2000). Prehistoric communities in mainland Southeast Asia do not consistently show a decline in health during the adoption of agriculture (Domett & Tayles, 2007; Douglas & Pietrusewsky, 2007; Halcrow et al., 2013; Tayles et al., 2000), which has been considered an atypical response compared to other global regions (Dhavale et al., 2017; Douglas, 2006; Halcrow et al., 2016; Pietrusewsky & Douglas, 2001). In mainland Southeast Asia, the maintenance of a broad-spectrum diet with added wild food, alongside rice, may have helped communities maintain a healthy, varied diet (Dhavale et al., 2017; Domett & Tayles, 2006; Tayles et al., 2000).

However, a recent model predicted that the period of intensive wet rice agriculture and climate change during the mid-late Iron Age period in the Upper Mun River Valley did result in large scale *negative* impacts on human health (King et al., 2017). There are hints that people experienced an increase in biological stress during this time, with the first evidence of the infectious diseases leprosy and tuberculosis (Buckley et al., 2020; Tayles & Buckley, 2004) and high infant mortality (Buckley et al., 2020; Tayles & Halcrow, 2015). The analysis of the dental health of the people of Non Ban Jak will contribute to the understanding of health impacts during this time of social and environmental change. Given the close location of Non Ban Jak to the Iron Age sites of Ban Non Wat and Noen U-Loke (Figure 1.2), the dental health of the people from Non Ban Jak can be compared with those from these settlements to document a comparison of chronological change in a relatively consistent environment.

A secondary focus of this thesis is a preliminary investigation into population connections within the Upper Mun River Valley during the Iron Age utilising dental morphology. Dental morphological traits include the size, shape and number of teeth (Scott, 2008). It is reasonable to suggest that Non Ban Jak interacted with other closely located settlements through trade, social or familial connections. Genetic connections can be investigated utilising the analysis of dental morphological traits (Edgar, 2013; Edgar et al., 2016; Pilloud et al., 2016). In this thesis, the dental morphological analysis was limited to the number of teeth, in particular the prevalence of genetically absent teeth known as agenesis.

1.3 Measures of Oral Health

Health is a term requiring clarification. The colloquially understood or assumed meaning of health is as a holistic concept encompassing all elements that contribute to quality of life. It is a construct of biological, social and cultural factors (Marklein et al., 2016). Yet this meaning of health is difficult to quantify (Reitsema & McIlvaine, 2014) particularly when attempting to apply the World Health Organisation's (WHO) definition of health, "a state of complete physical, mental and social wellbeing and not merely the absence of disease…" (WHO, 2020) to skeletal remains. The measurement of health utilising the WHO's definition has been critiqued in bioarchaeology due in part to its inability to measure the qualities of lifestyle and well-being from the skeleton (Pilloud & Fancher, 2019; Reitsema & McIlvaine, 2014).

Similarly, in the bioarchaeological literature there is no consensus regarding the concept of oral health. A contributing factor being the disconnect between how the term is defined in the clinical compared to the bioarchaeological literature (Pilloud & Fancher, 2019). The World Dental Federation's (FDI) definition of oral health includes the "ability to speak, smile, smell, taste, touch, chew, swallow and convey a range of emotions through facial expressions with confidence and without pain, discomfort and disease in the craniofacial complex" (Glick et al., 2016). As the bioarcheologist cannot question nor observe their patient in life, many of the elements of the FDI definition are unable to be determined through an analysis of skeletal remains, just like the unknowable aspects of the WHO's definition of health above. Any question related to 'health' cannot be adequately answered by the bones and teeth alone, so perhaps the questions need to be reframed. Instead of searching for evidence, or explanations of oral health, the discussions should be framed around what pathological conditions or evidence of disease can be observed in the oral cavity, adjusting the focus away from 'health' and its unknowable aspects such as mental wellbeing, as suggested by Pilloud and Fancher (2019).

Disease is a much easier concept to deal with bioarchaeologically, as a disease is a pathological process that can be identified by signs, symptoms and lesions (Tilley, 2015). To quantify the oral health status of past populations and individuals bioarchaeologists typically assess the prevalence of dental pathology and disease such as dental caries and antemortem tooth loss. Dental pathologies are typically analysed as components of a dental pathology profile (DPP) (Lukacs, 1989). Whilst the DPP was initially concerned with the differentiation of subsistence strategies evidenced by dental pathologies it continues to be used as a method of standardisation of data collection and analysis to improve comparability between studies. The DPP has been used by many researchers in mainland Southeast Asia to investigate changes in oral health (for example Domett, 2001; Domett & Tayles, 2006; Newton et al., 2013; Oxenham et al., 2002; Oxenham et al., 2006). Likewise, the DPP methodology is used in this thesis for regional consistency. Not all pathologies listed in the DPP first proposed by Lukacs (1989) were analysed for this thesis. The data collection was limited to the macroscopic examination and analysis of advanced wear, carious lesions (caries) and antemortem tooth loss, focusing on the extent that these oral lesions impacted the population at Non Ban Jak. Advanced wear is a degenerative condition, whilst caries has been classed as an infectious condition. Antemortem tooth loss may be a consequence of pulp exposure from advanced wear, caries or periodontal disease (not considered in this thesis), highlighting the interrelatedness of dental pathologies. Section 3.2 provides further detail of the aetiology of the pathologies analysed.

1.4 Biocultural Approach to Oral Health

A bioarchaeological analysis of dental health should be more than a collation of statistics listing different pathologies (Tilley, 2015) as the dentition can reveal biocultural adaptations that are unable to be gleaned from the archaeological record (Lukacs, 2017b). Indications of dental pathologies and general stress need to be interpreted using a biocultural approach. The biocultural interpretation of oral health is supported by developments in epidemiological models of oral health that recognise that oral pathologies are the result of social, cultural and environmental factors, at both the individual and societal level, combined with the biological processes within the oral cavity (Peres et al., 2019; Singh et al., 2013; Watt & Sheiham, 2012). Dental pathologies also need to be considered as part of a continuum and not in isolation, in terms of both the length of the life course and the interrelationship between pathologies (Glick et al., 2016; Heilmann et al., 2015; Hillson, 2008b). Dental pathologies typically increase with age with older individuals having an increased prevalence, and as mentioned above, the progression of a pathology, such as caries, can lead to another, such as antemortem tooth loss after the carious lesion grew to expose the dentine causing infection and subsequent tooth loss. The bidirectionality of oral health, such that general health can impact oral health, and oral health can in turn impact general health, also needs to be considered (Batchelor, 2015; Heilmann et al., 2015) as it is closely related to unequal health outcomes within populations.

1.4.1 Inequality in Health

The burden created by disease is not evenly distributed amongst a population but varies among individuals of different age, sex, and socioeconomic group (Lukacs, 2017a) and associated social conditions (Levin & Browner, 2005; Watt & Sheiham, 2012). Today, as in the past, oral health conditions disproportionately affect the impoverished and socioeconomically disadvantaged members of society with oral diseases a clinical marker for disadvantage (DeWitte et al., 2016; Heilmann et al., 2015; Peres et al., 2019; Watt & Sheiham, 2012). Whilst there is no definition of poverty that is applicable to every society and population worldwide there *is* a social gradient of health. The poorest in any society have worse health than those in the middle or higher income demographics (Marmot & Bell, 2011). As such, oral disease and other health outcomes are socially patterned across the social hierarchy (Watt & Sheiham, 2012). Socioeconomic status is strongly linked to diet and nutrition which are in turn linked to health, further contributing to health differences along socioeconomic lines with poverty associated with poorer diet and nutrition. For example, malnutrition intensifies the severity of oral infections (Moynihan & Petersen, 2004) as it impairs the body's defences and tropical infectious diseases, like malaria, are more affected by socioeconomic factors than climate (Lindahl & Grace, 2015).

Growing levels of social inequality (Wells & Stock, 2020) and poorer health in prehistory have been associated with the transition to agriculture. A causative and dichotomised relationship between the intensification of agriculture and a decrease in oral health has often been reported (Cohen, 2007; Lukacs, 1989). Until recently it was almost taken as a given that the intensification of agricultural had a universal negative impact on people's health worldwide (Marklein et al., 2019), even as some argued that cross regional studies were less valid than those within a single geographic area (Cohen, 2007). No evidence of a health deterioration with agriculture has been observed in mainland Southeast Asia (Tayles et al., 2009a; Tayles et al., 2000). Whilst it has been suggested that the oral health profile in this region is more complex than described for other regions (Oxenham et al., 2006), the lack of dental health deterioration in this region is perhaps simply because there was no *single*, global agricultural transformation. When agriculture developed it did so in a variety of ways and times worldwide so its impact on human biology generally, and human health more narrowly, was heterogeneous (DeWitte et al., 2016; Wells & Stock, 2020). Each region and location was affected by its own unique circumstances (Hutchinson et al., 2007) and the results interpreted as such.

1.5 Bioarchaeology of Climate Change

Climate change and its associated impact on our species is well recognised in modern times and the discipline of bioarchaeology is well placed to be able to offer explanations, possibilities, and an overview of what can be expected in terms of both cultural and biological adaption due to the changes (Barnes et al., 2013; Robbins Schug, 2021a,2021b; Robbins Schug et al., 2019). Much of the work to date has focused on the risks to economies, physical property and existing ecosystems (McMichael, 2012), but it has also been linked with poorer health outcomes (McMichael, 2012; Zuckerman & Dafoe, 2021). The Iron Age was a time of great change in the Upper Mun River Valley, both socioeconomic and environmental (Evans et al., 2016; Higham, 2014; Higham, 2016; Higham et al., 2019) and community health may have been impacted.

The climate is an extrinsic force impacting social, historical and cultural circumstances affecting different societies in different ways (Robbins Schug et al., 2019). The climate is one of the many variables influencing human behaviour; the local ecology and subsistence so needs to be considered in any analysis of oral health (Marklein et al., 2019; Wells & Stock, 2020). Given it is but *one* piece of the biocultural-social-environmental puzzle it is not possible to assign all changes in the environment, landscape, and society to climate change (Barnes et al., 2013). Neither climate reductionism, where climate is seen as the universal predictor, nor climate indeterminism, where climate is not utilised in any explanatory capacity (Hulme, 2011), are beneficial in attempting to illuminate the human story.

Humans have been adapting to changes in the climate since the beginning of our species (Zuckerman & Dafoe, 2021). The analysis of bioarchaeological data allows for the interpretation of both short term strategies and the longer term responses of humans to climate change (Robbins Schug, 2021a). It has been argued that the recognition of the impact of climate change on societies in the past is a recent development in the field of bioarchaeology due, in part, to "early simplistic uni-causal models of culture change that led to a necessary backlash against determinist thinking" (Roberts, 2021, p. 19). But this position ignores the long history of archaeology and the study of ancient sites and landscapes, their relationships to each other and the changes that have been made in response to a changing climate (Barnes et al., 2013). Utilising a comparative cross cultural approach to long term processes, bioarchaeology provides a lens with which to focus on climate variation and the diversity of the human response and resilience demonstrated amidst the ever changing society and culture (Robbins Schug et al., 2019).

Bioarchaeology has increasingly recognised climate and environmental change as important factors to consider in the interpretation of skeletal and biological data (Barnes et al., 2013; Boyd & Chang, 2010; Buckley et al., 2010; Castillo et al., 2018; Gregoricka, 2016; Harrod & Martin, 2014; King et al., 2017; Kramer & Hackman, 2020; Lukacs & Walimbe, 1998; Robbins Schug, 2021b; Wohlfarth et al., 2016). Much work has focused on climate change and its relationship to interpersonal violence, dietary change and migration (Robbins Schug et al., 2019). Recent work has questioned the long standing adaptationist narrative that a changing and warming climate leads to increased competition for resources inevitably leading to interpersonal violence (Robbins Schug et al., 2019). Detailed, locally contextualised data can illustrate societal and cultural factors influencing health outcomes within a community over time in response to, or affected by, the changing climate (Robbins Schug et al., 2019). There are challenges though in demonstrating causality between the human behaviour and indications and environmental changes (Davis, 2020). Correlation does not necessarily equal causation (Davis, 2020). The temporal coincidence between the two events cannot be the only evidence used in establishing the basis. It is an assumption in this thesis that no phenomenon ever has a single cause (Davis, 2020) but climate changes are one factor to be considered.

The climate was changing in late Iron Age Thailand. The monsoon rains weakened leading to more arid conditions (Castillo et al., 2018). Forests were cleared to make way for increased agriculture and water supply and control was needed. Moats were constructed around settlements to control and store the much-needed water for agriculture (O'Reilly, 2014). Forest clearing, moat construction and agriculture require group organisation. It has been suggested that this was the catalyst for the start of social differentiation and stratification and the establishment of a clear social hierarchy (Higham et al., 2019). Although this is not the universally held position within mainland Southeast Asian archaeology (Carter, 2021; Eyre, 2010; White & Eyre, 2011; White & Hamilton, 2021). The Iron Age settlement at Non Ban Jak was established during this time of climate and possible social change. Recently, King et al. (2017) proposed a bioarchaeological model to explain the changes in socioeconomic and social complexity and the associated impact on population and individual health in the late Iron Age. To date this model is yet to be thoroughly tested by comparing closely located, temporally and geographically, sites.

1.6 Aim, Objectives and Research Questions

1.6.1 Aim

> "adaption is the change by which organisms surmount the challenges to life"
> (Lasker, 1969, p. 1481).

Mainland Southeast Asia witnessed significant climate and socioeconomic change during the Iron Age. The summer monsoon weakened, leading to a drier climate. It is argued that the people changed the subsistence strategy to adapt to this drying environment. The aim of this research is to gain an understanding of the impact of this climate change on the people of the Upper Mun River Valley region broadly and the people of Non Ban Jak specifically, through the lens of dental health. It will contribute to the literature surrounding the impact of climate change, whether the people were able to adapt to the changing climate and if the climate change led to significant health and socioeconomic change.

1.6.2 Objectives and supporting research questions

Three main objectives guide the research:

1. Analyse the dental health of the people of Non Ban Jak to establish a dental pathology profile to investigate differences in dental health between sex, occupation mound and mortuary phase and whether this was impacted by the changing climate. The analysis will answer such questions as:

- Were the dental health outcomes the same for both sexes across the settlement? Between the occupation mounds? Between the mortuary phases?
- Did the changing climate lead to worse dental health outcomes?
- What impact, if any, did the changing climate have on the fertility of the population?

2. Investigate any differences in the dental health in terms of the changing environment and socioeconomic times – temporally and spatially – in the wider Upper Mun River Valley by comparing the results from the analysis of Non Ban Jak to those from the nearby sites of Noen U-Loke and Ban Non Wat. The comparison of the results will provide evidence to support a model of social change in mainland Southeast Asia;
3. Investigate any population connections for the people of Non Ban Jak to other people in Iron Age mainland Southeast Asia as evidenced by both dental health and dental agenesis.

1.7 Significance

Mainland Southeast Asia is home to numerous skeletal assemblages dating from the Neolithic to the Iron Age that have been the focus of detailed analyses of health and disease (for example see the works of Domett (2001); Domett et al. (2013); Domett et al. (2011); Domett and O'Reilly (2009); Domett and Tayles (2006); Domett and Tayles (2007); Clark et al. (2014); Halcrow et al. (2016); Halcrow et al. (2013); Halcrow and Tayles (2008); Nelsen et al. (2001); Matsumura and Oxenham (2014); Oxenham and Domett (2010); Oxenham et al. (2002); Oxenham et al. (2006); Vlok et al. (2021); Willis and Oxenham (2013a,2013b); Ikehara-Quebral et al. (2017); Pietrusewsky (2010); Pietrusewsky and Douglas (2001); Tayles (1996); Tayles and Buckley (2004); Tayles et al. (2009a); Tayles et al. (2000); Tayles et al.

(2007)). The region is also one of the world's most biologically and culturally diverse (Oxenham & Buckley, 2015). Despite the substantial amount of research that has been undertaken to date, the Southeast Asian region is still relatively ignored in world prehistory (see for instance general 'world' history books such as Chazan (2021); Heldaas Seland (2021) and Durrani and Fagan (2021)).

The people of Iron Age mainland Southeast Asia were confronted with a changing climate. How did the people manage this change? Were the people able to adapt to these changes? What, if any, social changes did this lead to? Did the changes negatively impact on their health? The answers to these questions will reveal the ways in which the people from long ago managed environmental change, which will have relevance to us today as we are confronted with significant new environmental changes. Truly, we "… cannot escape our connections to the past, and indeed there may be the germs of useful advice in the stories told by these long gone people" (Buckley & Oxenham, 2015, p. 2). As such the site of Non Ban Jak presents a unique opportunity to marry the health and the environmental and climate data to investigate consequences and connections.

Whilst there are numerous previous works incorporating analyses of the dental health of the people from prehistoric mainland Southeast Asia the large number of well-preserved skeletal remains at Non Ban Jak form a significant data set from a so far under-represented time period in mainland Southeast Asia being the late Iron Age to early historic period. Previous work on dental health from the Iron Age in mainland Southeast Asia being limited to Shkrum (2014) (unpublished and limited in the number of Iron Age individuals included); Tayles et al. (2007); Oxenham et al. (2006); Newton et al. (2013); Ikehara-Quebral et al. (2017) and Kirkland (2010) (unpublished and dental health results are very limited). The results of the analysis will provide a glimpse into the consequences of social and climatic changes on the dental health at Non Ban Jak during this time period. Given the location of

Non Ban Jak, and the number of other closely located settlement sites the results of the analysis at Non Ban Jak will also enable a comparison to other dental health data, both geographically and temporally, within the region. Non Ban Jak is narrowly and securely dated (Higham et al., 2014) thus presenting a unique opportunity to marry the health and the environmental and climate data to investigate any connections.

The comparison of the dental health outcomes, along with the analysis of the dental morphological trait of genetically absent teeth will provide further information regarding population connections, such as genetic, social, and economic, that were occurring in the Upper Mun River Valley during the Iron Age. This study informs researchers specialising in Southeast Asian archaeology and bioarchaeology, those investigating both dental and general health changes associated with socioeconomic change, and those researchers interested in the past impacts of climate change and associated changes to health.

1.8 Thesis Structure

This thesis is divided into four parts.

Part I contains chapters 1 and 2. Chapter 2 provides the context for the project beginning with the cultural and geographic context of Non Ban Jak. The chronology of mainland Southeast Asia is discussed and the arguments surrounding indications for social change occurring at this time. The comparative sites of Noen U-Loke and Ban Non Wat are also discussed.

Part II contains chapters 3, 4 and 5. Chapter 3 introduces dental health and the concept of the Dental Pathology Profile. A description of the materials used, including the demographic details of both Non Ban Jak and the comparative sites, along with the dental census of Non Ban Jak are provided. Chapter 3 continues by providing a discussion of the dental pathologies to be analysed. This is followed by Chapter 4, an explanation of the methods of analysis used and the results of each pathology: advanced wear, caries and antemortem tooth loss.

Chapter 5 provides a discussion of the dental health results from Non Ban Jak in regards to differences in sex, occupation mound and mortuary phase. Subsistence change is touched on before a comparison of the results from Non Ban Jak to previously published data from Noen U-Loke and Ban Non Wat.

Part III contains Chapter 6. This section discusses population connections in the region. An overview of dental agenesis is provided followed by an explanation of the methods used and the results of the analysis. These results are then discussed in terms of population history and connections in the region.

Part IV contains Chapter 7, the thesis conclusion where the aims, objectives and outcomes of the research questions are summarised. This is followed by the Afterword containing a discussion on ways of public engagement with the results of bioarchaeological research and an attempt at a fictive narrative based on the research in this thesis.

1.9 Limitations

Due to travel restrictions imposed by the Covid-19 pandemic I was unable to travel to Thailand to record the data from the skeletal remains. Sex and age at death of the individuals have been established previously by Buckley et al. (2020) and their results are utilised throughout this thesis. Dental pathological data was confined to that previously recorded from the macroscopic analysis completed by Associate Professor Kate Domett. I re-recorded the data utilising laboratory photographs of the dentition taken by Associate Professor Domett. The previously recorded data was compared with my analysis. No inconsistencies were found.

The dental pathologies analysed in this thesis are limited to antemortem tooth loss, caries and advanced wear as these were the conditions recorded by Associate Professor Domett. Other pathologies in a dental pathology profile such as periapical infection and periodontal disease were not able to be included in the analysis. It is hoped that at a future date, when international travel is possible, the dentitions will be able to be re-analysed and the results of the analysis be combined with this work.

The dental morphological analysis was limited to an assessment of congenitally absent dentition with the genetic absence of teeth known as agenesis. This was again due to the lack of travel possible and the availability of data that had been collected. It is hoped that at a future date a full dental morphological trait analysis can be completed and the results combined with this work.

Chapter 2 Biocultural Context of Non Ban Jak

2.1 Introduction

This chapter provides the background context for this project beginning with the cultural and geographic context of Non Ban Jak. The chronology of the Iron Age in the Upper Mun River Valley is discussed, as are the indications for the social change occurring at the time with evidence from Non Ban Jak, Ban Non Wat and Noen U-Loke. Lastly the use of mortuary ritual to determine differences in life courses or status, often classed as 'wealth', is discussed, and how it can be combined with the biological data to suggest a fuller picture of the lives of people in the past.

2.2 Geographic and Cultural Context of Non Ban Jak

Non Ban Jak is located on the Khorat Plateau in the Upper Mun River Valley of northeast Thailand (Figure 1.1 and 1.2) in Amphoe Non Sung, Nakhon Ratchasima Province (Higham et al., 2014). The Khorat Plateau has been called a peripheral zone in relation to the cultures of both central and northern Thailand (Murphy, 2016, p. 367). It is an area that encompasses a distinct geographic region that developed its own aesthetic and religious culture by blending the traits of their eastern and western neighbours (Murphy, 2010; Ball, 2020). The Upper Mun River Valley is also in a strategically important position. It controls the eastern side of the pass over the Phetchabun Range linking the region to central Thailand (Higham, 2015). The Mun River flows east through the valley and joins the Mekong River. This positions the area on a prime trading and exchange route.

Non Ban Jak is a large, doubled moated site, oval in shape, 360 metres long and 170 metres wide, with two distinct mounds, east and west (Higham et al., 2014) (Figure 2.1). The site was occupied during the Neolithic (3700-3000 BP), the Bronze Age (3000-2400 BP), Iron Age 4 (1750-1350 BP) and the early Historic (1350-1150 BP) periods (Higham et al., 2014; Higham et al., 2019). The majority of the mortuary evidence dates to the Iron Age 4 period named after the fourth Iron Age period (IA4) at Noen U-Loke, the final of four mortuary periods encompassing the Iron Age in this region (Higham et al 2014; Higham et al 2019).

The use of iron began in Southeast Asia approximately 2500 years ago (Higham, 2011; Higham, 2016) and whilst it is debated whether the introduction of iron led to the associated sociopolitical changes in mainland Southeast Asia that occurred in other regions globally (Eyre, 2010), the term 'Iron Age' is still used by many within mainland Southeast Asian archaeology to signify the technological, sociopolitical and environmental landscape changes occurring at this time, even as it is becoming increasingly apparent that the traditional three age system (Neolithic, Bronze and Iron Age) and its application within mainland Southeast Asian archaeology requires reassessment (White, 2017). The term will continue to be used in this thesis for continuity with previous studies.

During the Iron Age period significant climate and environmental change led to land management change with villagers constructing moats enabling a shift in subsistence strategy from dry to wet rice agriculture (Castillo et al., 2018; O'Reilly, 2014; Scott & O'Reilly, 2015). The moats, at one time thought to be defensive in nature (Higham, 1998) were likely established to control the water supply as the area became more arid (O'Reilly, 2014; Scott & O'Reilly, 2015). The construction of moats surrounding settlements signifies a potential change in the social organisation of the region. Moat construction would have been a labour-intensive undertaking, requiring planning, cooperation and organisation. It has been suggested that the amount of labour required implies a person, or persons, in charge, organising the resources and labour required for construction (O'Reilly, 2014). A leader. For there to be a leader there needs to be followers. This argument then continues that the moats, therefore, provide evidence of the social stratification within the settlements (O'Reilly, 2014). However social and group stratification does not necessarily follow from group organisation or cooperation (Graeber & Wengrow, 2021), so whilst it is possible this was the start of social stratification in the region, at this stage we do not know for sure. The construction of the moats, however, did change the local environment of the settlements and has been associated with a potential increase in disease vectors in the associated settlements impacting on population health (King et al 2017). The region was experiencing a time of *great* change and this may have impacted community health.

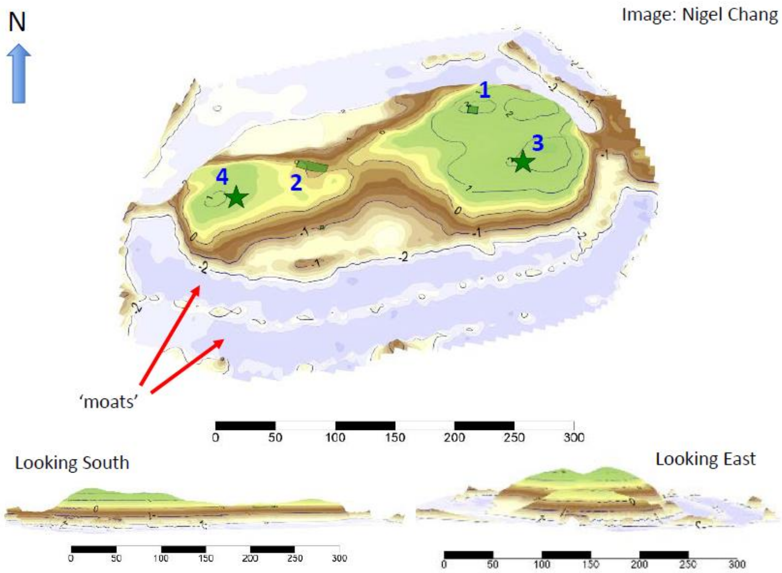

Figure 2.1: Image highlighting the two mounds and two moats of Non Ban Jak
Image courtesy of Dr Nigel Chang, used with permission
Key: 1 & 2: location of the two excavation squares during the 2011-2014 excavations; 3 & 4: location of the two excavation squares for subsequent seasons, ending in 2018

The Iron Age burials at Non Ban Jak, divided into four phases, span the Iron Age 4 (IA4) period at the nearby site of Noen U-Loke (Higham et al., 2019) (Section 2.3). During the first mortuary phase at Non Ban Jak the mortuary offerings were sparse in number, and comparatively impoverished, limited in types and forms and no iron artefacts were included, in juxtaposition to the wealth seen in contemporary graves at Noen U-Loke. It was hypothesised that this group of individuals buried on the western mound at Non Ban Jak represent the site's initial, and impoverished, Iron Age settlers (Higham et al., 2014). Whilst there is evidence of a Neolithic occupation layer, no subsequent occupation in the Bronze or Early Iron Ages have been identified (Higham & Kijngam, 2020). Bronze Age ceramics, never complete nor undisturbed in situ, were found on the western occupation mound and are possibly suggestive of disturbed Bronze Age occupation nearby (Chang, 2018). Only small differences exist between the grave goods of the first (MP1) and second (MP2) Iron Age mortuary phases and no burial superimposition was found between MP1 and MP2, suggesting MP1 and MP2 represent one continuous mortuary phase (Higham & Kijngam, 2020). Ward (2019) refers to this as the 'early phase'. Likewise the third (MP3) and fourth (MP4) mortuary phases seem to represent a single mortuary phase and Ward (2019) refers to this as the 'late phase'. Ward's early and late mortuary phases will be the main grouping used in this thesis.

During MP3, the start of the late phase at Non Ban Jak, the first evidence for residential burial is found (Higham et al., 2014). It had been suggested that residential burial was a new practice for Iron Age mainland Southeast Asia but it may have been a more widespread practice than first thought (Carter, 2021). Residential burial has been associated with the connection of the ancestors with the living (Adams & King, 2011), the generation of social memory (Hodder & Cessford, 2004; McAnany, 2011), commemoration, group membership in death, and reinforcement of household membership and kin-based place-making (Cradic, 2018; Laneri, 2011; McAnany, 2011) and reinforcing inherited rights regarding property, wealth and status (Higham et al., 2014). Residential burials would have been more accessible to the residents of the home on a daily basis (Cradic, 2018) and also signify that the funeral ritual moved from a public spectacle to a more private practice (Nishimura, 2015). Whilst the meaning of residential burial is debated, it has been argued that *changes* in funerary customs are a clear indication of changes in the social fabric of a society (Brandt et al., 2015; Hill, 2013; Laneri, 2011). If the mortuary practice changed at Non Ban Jak to incorporate residential burial it possibly denotes a change to the settlement's social fabric. A population moving from burial rights being a public spectacle to a more intimate, private practice may suggest a change in the social organisation or priorities. Although we also do not know what kind of ritual, spectacle, or process was involved. An internment within a house may still have required a large public participation outside. The recent work of Carter (2021) also calls into the question the idea that residential burial was a novel device of the Iron Age in mainland Southeast Asia. One of the objectives of this thesis is to investigate if such social change is evident in the dental health.

2.3 Comparative Sites – Ban Non Wat and Noen U-Loke

The settlement of Non Ban Jak is 10km west of Iron Age Noen U-Loke, which in turn is 2km southwest of Ban Non Wat, a large, multi-period site (Figure 1.2). It has been hypothesised that during the Iron Age occupation sequences at all three sites, environmental and social changes generated social inequality (Higham et al., 2019). These changes are argued to be evidenced in mortuary ritual, agricultural processes, material culture, site layout and construction. The catalyst for change has been posited as due to the sharp drop in the intensity of the summer monsoon which resulted in periods of aridity. A model for late and rapid social change in the Iron Age in northeast Thailand has been proposed which relies on geoarchaeological, palaeobotanical, mortuary and artefactual evidence (Higham et al., 2019). Social inequity, if present, may be apparent in the dental health of the individuals from the three sites, potentially providing further evidence for the hypothesis proposed by Higham et al. (2019).

Whilst the three sites are closely located geographically, they have different occupation sequences (Figure 2.2). The site of Ban Non Wat has the longest occupation sequence, from the Neolithic until the Iron Age (IA), including evidence of the first three Iron Age phases. A large number of burials were dated IA1 and IA2 (Higham, 2014; Higham et al., 2019). In comparison, Noen U-Loke encompasses the entire Iron Age (IA) in four phases, referred to as IA1-4 (Higham et al., 2019). The richest burials at Noen U-Loke in terms of mortuary wealth date from IA3, 1650-1550 BP, with the mortuary wealth diminishing in IA4. Non Ban Jak has mortuary evidence from IA4 only, with four burial sub-phases listed as IA4A-D (or MP1-4). The differences in occupation sequences allows for an analysis of regional change over time.

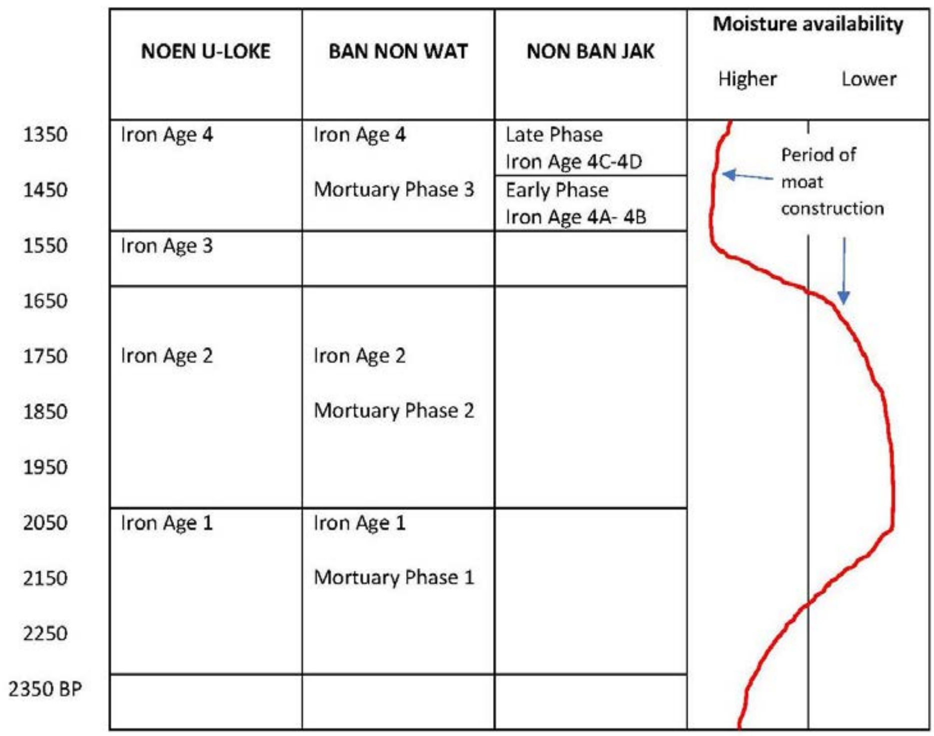

Figure 2.2: Relative chronologies of Noen U-Loke, Ban Non Wat and Non Ban Jak during the Iron Age, together with estimated rain fall.
Adapted from Higham et al. (2019)

During IA1 at Ban Non Wat the people (125 burials (Higham, 2011)) were buried in a cemetery space that extended towards the east from the previously used area of Late Bronze Age graves (Higham, 2014). Many of the mortuary offerings, including the form of the pottery vessels, continued, unchanged from the previous phases (Higham, 2011,2014) and there does not appear to be any differences in regards to mortuary wealth in the burials (Higham, 2011). This time also saw the appearance of the first iron offerings; large socketed spears, bimetallic spears with a bronze socket and iron blade, tool kits of knives, awls and hoes, and bangles (Higham, 2014), as well as rare items of glass, carnelian and agate jewellery (Higham, 2014). Glass in Southeast Asia is seen as a marker for the commencement of maritime exchange with India and Myanmar (Higham, 2011). However, more recent work has suggested that there was more than one exchange route between the regions of South and Southeast Asia (Carter, 2015; Carter, 2016). Taiwan exported nephrite (jade) blanks to the Philippines, Vietnam and Thailand where local artisans manufactured it into items for the local market (Carter, 2016). A maritime exchange network linked China with India, via mainland Southeast Asia, with evidence of stone and glass beads exchanged in Vietnam, Thailand, Cambodia and Myanmar, which continued west to the Mediterranean (Higham, 2014), where beads from the Mediterranean, Middle East and China were exchanged alongside those from areas of Asia (Carter, 2016).

There are similarities and differences between the IA1 phases at Ban Non Wat and Noen U-Loke. Large pottery vessels containing complete fish skeletons and joints of pork (pigs) were commonly included within the burials at both sites (Higham, 2011). Water-buffalo and cattle bones were found at Ban Non Wat, but not at Noen U-Loke. Iron spears and bangles were present at both sites with thin-bladed knives, awls, and other small tools recovered at Ban Non Wat (Higham, 2011). Only six IA1 burials were found at Noen U-Loke, however, these were found with heavy iron spears, iron ornaments and hoes, and at this stage at Noen U-Loke, there was no exotic stone or glass jewellery (Higham, 2014) unlike at Ban Non Wat. Differentiation of mortuary goods at Noen U-Loke was evident at this time with one group buried with iron torcs, tiger- and pig-canine pendants and shell ear ornaments (Higham, 2014). One individual is suspected to have suffered from leprosy (Tayles & Buckley, 2004), the first evidence of this disease in mainland Southeast Asia.

The dead were interred in different ways throughout the Iron Age at Noen U-Loke. During IA1 there were a few scattered burials. The organisation changed at the start of IA2, with two tight clusters of graves (Higham, 2011). One cluster included glass beads, an agate pendant, some shell beads and bronze finger rings as grave goods (Higham, 2011). The other cluster of graves were filled with rice (Higham, 2014). The cluster of rice-filled graves also saw the inclusion of long, faceted carnelian beads (Higham, 2011). The rice burial cluster also contained strings of glass beads, agate beads and pendants, as well as bronze toe and finger rings (Higham, 2011). During this phase there were no iron offerings and few pottery vessels, however, it was the rice-filled graves that possibly signified an increased level of mortuary wealth. Rice-filled burials continued into IA3 and there was a stark increase in the mortuary wealth of some individuals (Higham et al., 2019). The first evidence of gold and silver grave offerings appears (Higham, 2011). Whilst Sarjeant (2006) suggested the cessation of the inclusion of ceramic vessels with the burials during MP3 at Noen U-Loke coincided with either a lack of available access to these resources, or a lack of wealth during this phase, other items linked to prestige, trade, and status were included within the burials, such as carnelian, glass and shell beads, and rice-filled burials. During this time there were four distinct clusters of burials, of which three clusters contained one or two particularly wealthy individuals, including some wealthy infants (Higham, 2014). The groups were so tightly nucleated that it suggests that it is highly likely that they are of related individuals (Higham, 2011). One cluster was evidently different than the other three, as they were buried not with bronze, glass and agate, but with a disproportionate number of spindle whorls (Higham, 2014). The burial clusters at Noen U-Loke are perhaps similar to the two distinct occupation and associated mortuary mounds at Non Ban Jak with the eastern mound having buildings with thicker walls, and the western mound burials having larger numbers of grave goods. Both settlements suggest differentiation of mortuary treatment for certain individuals and groups which in turn are suggestive of potential differences in social class.

During IA4 at Noen U-Loke, graves were more dispersed, far less nucleated (Higham, 2011), and organised in rows, although there is some evidence of grouping (Higham, 2011). In all phases the dead were interred in an extended supine position, although there were rare exceptions to this with two individuals found prone, one with suspected leprosy (Tayles & Buckley, 2004) and one with an arrowhead lodged in his back (Higham et al., 2019). There were no more rice burials evident, but the distinctive Phimai Black pottery was still found (Higham, 2011). There were smaller amounts of grave goods, and changes in the offerings, both in the style of the ceramics and range and number of iron implements, with iron sickles now included. It is possible that residential burial occurred at Noen U-Loke, as it did at Non Ban Jak (Section 2.4), however the structural remains of the rooms have not survived in as much detail at this site compared to Non Ban Jak (Higham et al., 2019). The clay floorings in both locations do indicate the same construction technique in IA4. It is of note that until recently no evidence of residential burial had been identified at Ban Non Wat, a significant difference in the development of the mortuary ritual in the area. Although a recent re-visiting of the evidence from Ban Non Wat may alter the current interpretation (Carter, 2021).

The comparison of the contemporaneous Iron Age period of the settlements of Noen U-Loke, Ban Non Wat and Non Ban Jak have “the potential to refine our understanding of social change by producing regionally specific models and enable a more detailed understanding of the advent of social complexity in the area” (Higham et al., 2019, p. 2). The comparison of mortuary evidence from the three settlements reveals both similarities and differences. Non Ban Jak's mortuary evidence is most similar to the temporal evidence from Noen U-Loke. Of note is the apparent social groupings identified by burial location and mortuary goods at both Non Ban Jak and Noen U-Loke, which as yet has not been identified at Ban Non Wat. Perhaps this means that these two settlements were more similar in other ways as well – in terms of lifeways and response to the environmental change. Or perhaps not. The analysis and comparison of the dental health outcomes from the individuals and each settlement will provide a further layer of data to enhance our understanding of the impact of the changes occurring in the societies during the late Iron Age.

2.4 Mortuary Ritual, Wealth and the Life Course

Do more grave goods equate to greater wealth and status? Wealth is a difficult concept to define and measure and is dependent on cultural context (Smith, 1987). The interpretation of grave goods, the material culture from mortuary contexts, is multifaceted. The approach of simply equating the number of grave goods as representative of social status to study inequity has been heavily critiqued (Goldstein, 2006; Gowland & Knüsel, 2006a; Härke, 2002; Langdon, 2005; Parker Pearson, 1999; Scopacasa, 2014). Yet others suggest that variation in grave wealth in mortuary contexts *within* a site reveals social differentiation and, if present, is an indicator of non-egalitarian society (White & Eyre, 2011). Wealth and status have been previously measured in mainland Southeast Asia through a comparison of the quantity of grave goods (Fochesato et al., 2021; Higham, 2016; Higham et al., 2019; O'Reilly, 2003,2014; Rispoli et al., 2013; Tayles, 1996; Ward et al., 2019). Whilst it can be argued that this method lacks contextual information and is simplistic and unsophisticated (Cekalovic, 2014), it can provide a comparative framework free from interpretative bias that can be used to compare individuals buried at a similar time (Cekalovic, 2014). The method assumes burial ritual is static, which over generations they are not, but when comparing sites of the same temporal and geographic location it can be an *aid* to the analysis. It is important to remember though that "individuals and communities did not always find it necessary, or important, to express community level aspects of social and political order in their funerary rituals and grave offerings" (Oxenham, 2015, p. 1222).

Graves can have both a practical purpose, being the disposal of the dead, and ritual or symbolic meanings (Ekengren, 2013; Parker Pearson, 1999). Items interred with the dead may relate to social or political identity, social relationships, self-aggrandising behaviours, economic considerations and ideological or religious ritual (Ekengren, 2013; Härke, 2014; Parker Pearson, 1999). The items may also be reflective of the social identity of the mourners (Gowland, 2006; Gowland & Knüsel, 2006b; Härke, 2014) and their differing relationships to the deceased (Parker Pearson, 1999). They are deliberate inclusions, chosen by the *living*. Mortuary items included also potentially change across the life course as the social identity of people change as they age, as does the social identity of the principal mourners (Gowland, 2006). Mortuary contexts, including burial treatment and grave goods, reveal an aspect of a person's identity that has been performed and is the expression of select and idealised aspects of the deceased's identity and role in society (Quinn & Beck, 2016). The idealised aspects may be different to the lived identity of the person, aspects of which are preserved in the osteological record of diet, disease, workload and biological kinship (Quinn & Beck, 2016). A bioarchaeological investigation is uniquely placed to be able to identify any similarities or differences between the lived and performed social contexts which are an important source of information regarding both social organisation and inequality in the past (Quinn & Beck, 2016) and as such grave goods are not the only indicator of status available to the bioarchaeologist. Differences in social status have been linked to differences in health

(Armelagos et al., 2005), including dental health (Miliauskienė & Jankauskas, 2015). The combined analysis of mortuary ritual with osteological indications of disease can identify agreement, or not, between the lived experience of the individual, evidenced in the bones, and the idealised experience, evidenced by the grave goods.

PART II

Chapter 3 Dental Health

3.1 Introduction

Oral diseases are acknowledged to be among the most prevalent diseases globally. Today, despite being preventable they are prevalent throughout the entire life course, result in serious health and economic burdens, and greatly reduce the quality of life of both the affected individual and, in turn, the society (Peres et al., 2019). It is logical to assume that the burden of dental disease was similar on those who lived in the past.

The dentition of past people can reveal information both as a measure of health of an individual over their lifetime and an overall indication of general population health (Crittenden et al., 2017; Steckel, 2003). High levels of oral pathologies are an indication of an overall poor health status with an increased disease load and mortality (Humphrey et al., 2014). There are direct links between oral health and dental health, for example there is evidence for poor oral hygiene and periodontal disease being factors in pneumonia; periodontal disease adversely affecting diabetes outcomes (Heilmann et al., 2015); antemortem tooth loss compromising chewing ability leading to poor health and nutrition (Russell et al., 2013); malnutrition intensifying the severity of oral infections (Moynihan & Petersen, 2004); and caries affecting nutrition, growth and weight gain in children as toothache and infection impact eating and sleeping habits, dietary intake, and metabolic function (Sheiham, 2005). Poorer oral health, and a larger number of missing teeth, is also linked to increased mortality in older individuals (Hämäläinen et al., 2003; Paganini-Hill et al., 2011). The connection between dental and overall health is clear.

Despite ongoing discussions around whether questions pertaining to 'health' and all its aspects can be answered by studying the bones and teeth alone (Section 1.3), the terms health, dental health and oral health continue to be used within the bioarchaeological literature. Although all aspects of health cannot be determined from skeletal remains of individuals, the term ‘health’ is a powerful aid to understanding the impact that a multitude of dental pathologies can have on an individual and in making inferences between evidence of disease and potential life and health outcomes. As such this work shall use the term ‘dental health’ without apology.

3.2 Dental Pathology Profile Overview

The prevalence and distribution of dental disease when analysed by age, sex, and social group can yield valuable information regarding diet (what is eaten), nutrition (physiological adequacy of the diet) and subsistence (method of procuring the diet) (Lukacs, 1989). Dental health is affected by many factors and responds to the way in which people interact with the environment, so provides a record of how resources where utilised and potentially how people were affected by socio-political transformation (Newton et al., 2013). Evidence from the dentition can reveal biological adaptation, or maladaptation.

As explained in Section 1.4 dental pathologies should be considered as part of a continuum and not in isolation in terms of both the length of the life course and the interrelationship between pathologies (Glick et al., 2016; Heilmann et al., 2015; Hillson, 2008b). It is also important to ensure that data collection is conducted using a standardised methodology to ensure the comparability of dental pathology data sets. This is the reasoning behind the Dental Pathology Profile (DPP) proposed by Lukacs (1989), later revised by Littleton and Frohlich (1993), and modified by Oxenham et al. (2002). The DPP of a particular skeletal series is the prevalence with which each disease or condition occurs, and the relative incidence of one disease to another. The initial focus of the DPP was for the precise reconstructions of dietary patterns for people whose diet and subsistence patterns were known (hunter-gatherer; transitional mixed; or agriculture) and the reduction in inter-observer error by enhancing the precision with which comparative studies can be made (Lukacs, 1989, p. 276).

Dental pathologies can inform on more than subsistence pattern and the framework provided by the DPP provides for the standardised collection of data, increasing the comparability between studies. It also provides a solid data set to allow for more sophisticated interpretations within the biocultural framework. Many researchers have utilised the DPP in the exploration of changes of dental disease and health within Southeast Asia (Domett, 2001; Domett & Tayles, 2006; Douglas, 2006; Newton, 2014; Newton et al., 2013; Oxenham et al., 2006; Shkrum, 2014). The aetiology of pathological conditions of the dentition are interrelated, and as such it is logical and beneficial to examine the relationship and potential influence of each condition on the others. For consistency and to allow for the easier comparison of results, an abbreviated DPP will be utilised in this thesis, however the results will not solely be interpreted in regard to simple dietary reconstruction but will also focus on the influence these dental diseases potentially had on the oral health, general health and possible overall wellbeing (see below for further discussion).

Whilst Lukacs (1989) suggested recording 12 conditions for the DPP other researchers have used a differing numbers of conditions to establish the dental profiles for analysis and comparison; Oxenham et al. (2002) utilised eight, Eshed et al. (2006) six, Littleton and Frohlich (1993) recorded six. The data collection for this thesis was impacted by travel restrictions due to the Covid 19 pandemic (Section 1.9). As such the dental profile of Non Ban Jak is restricted to the analysis of caries, antemortem tooth loss, and advanced wear. The results of these pathologies can be compared with previous works in the region of mainland Southeast Asia. Subsistence strategy is strongly associated with oral pathology

(Eshed et al., 2006), however the usefulness of oral pathology does not end there, which will be included in the discussion below.

3.3 Dental Pathologies

This section provides a review of the literature surrounding the three pathological dental conditions to be analysed at Non Ban Jak – advanced wear, caries and antemortem tooth loss (AMTL).

3.3.1 Advanced Wear

Tooth wear is the cumulative loss of enamel and dentin. As the natural result of usage, it is an irreversible function of age (Hattab & Yassin, 2000) and teeth continue to wear throughout life (d'Incau et al., 2012; Richter & Eliasson, 2017). Dental wear can be a function of diet, masticatory forces, the non-masticatory use of teeth (Mahajan, 2019) or the result of bruxism (Hillson, 1996), although the influence of bruxism has been possibly overstated (Johansson et al., 2012). The analysis of tooth wear can be utilised to assist our understanding of the diet and also the life processes of people in the past (Mahajan, 2019; Molnar, 2011). The destruction of the dental hard tissues due to wear is a biological and physiological process (d'Incau et al., 2012; Lukacs, 1989). It is not a pathological process *per se*, but the flow on effects can lead to other pathologies affecting the teeth. The exposure of the dentine can lead to pathological processes and to the destruction of the tooth crown, causing the loss of teeth due to the effects of such excessive wear and potential pulp infections. Tooth wear can also disrupt the microbiotic community or biofilm of the mouth (Griffin, 2014). A biofilm is a community of bacteria in which different species can adapt and become dominant in response to a changing environment (Griffin, 2014; Hillson, 2008b). Disruptions to the oral environment can lead to the proliferation and rising dominance of pathogenic organisms which can then enter the tooth pulp due to the dentine being exposed due to wear.

Wear Mechanisms

Dental wear results from three mechanisms: (1) attrition – tooth-on-tooth contact either proximally or occlusally, (2) abrasion from the friction of foreign substances on the enamel, and (3) erosion – the chemical dissolution of enamel (d'Incau et al., 2012; Griffin, 2014; Hattab & Yassin, 2000; Kaidonis, 2008; Lee et al., 2012). The different forms of tooth wear often occur at the same time (Kaidonis, 2008; Richter & Eliasson, 2017; Robb et al., 1991) and thus the cause of the wear can be difficult to determine (Hattab & Yassin, 2000), especially when all forms of wear are dependent, primarily, on two major variables, the diet and the age of the individual (d'Incau et al., 2012; Griffin, 2014).

Erosion

Dental erosion is the chemically induced loss of dental hard tissue, enamel and dentine, by acids (d'Incau et al., 2012; Hattab & Yassin, 2000). The acids are introduced either extrinsically by fruits, fruit juices, soft drinks, other acidic food and drinks such as beer and wine, and vinegar (Coupal & Sołtysiak, 2017; Moynihan, 2005), or intrinsically, from the regurgitation of gastric acids (Lee et al., 2012). No bacteria is involved (Lee et al., 2012). Erosion softens the dental hard tissues which increases the susceptibility of the teeth to both abrasion and attrition (Richter & Eliasson, 2017). It is unusual to see wear classified as caused by erosion in archaeological samples, although it is reasonable to expect some evidence of erosion (Ogden, 2008). After the advent of agriculture fermented foods and drinks, which are acidic, became increasingly common (Coupal & Sołtysiak, 2017; Kaidonis, 2008). Recently, Richter and Eliasson (2017) argued the wear in a sample of Viking Age Icelanders demonstrated a remarkable similarity with the erosion seen in the dentition of modern young Icelanders caused by their excessive consumption of acidic drinks such as soft drinks, fruit juices and sports drinks. Whilst extensive tooth wear is seen in most ancient populations in the archaeological or palaeopathological literature, it is most often explained as the result of coarse dietary factors with acid erosion not considered to be contributory, likely or possible (Richter & Eliasson, 2017). Utilising both the skeletal evidence and historical evidence from the Vikings, Richter and Eliasson (2017) propose a plausible explanation that the acidic beverage made with whey, 'skyr', consumed by the population two to three times per day resulted in the erosion of the dental hard tissues, and acted in combination with the attrition caused by the coarse diet of dried foods. Although not the only one to investigate dental erosion in archaeological material (see for example Deter, 2009; Kieser et al., 2001; Tomczyk & Zalewska, 2015), this study highlights the importance of both a thorough knowledge of the tooth wear processes and their interactions to establish the cause of tooth wear combined with a thorough knowledge and application of all the available archaeological and cultural evidence to allow for a nuanced, biocultural interpretation of oral lesions.

The identification of erosion in archaeological material is challenging as there are currently no easy to apply, standard methodologies available for use with such material (Tomczyk & Zalewska, 2015). One such method proposed by Bell et al. (1998) requires the preparation of dental casts, which are then sliced, to allow for the measurement of the depth:breadth ratio of the occlusal surface loss. It has been shown that erosive wear results in deeper 'scooped out' dentine than abrasive wear. However, this method is not used extensively possibly given the requirement of casts.

Abrasion

Abrasion is the "loss of tooth substance through mechanical means, independent of occlusal contact" (Lee et al., 2012, p. 219) from a foreign substance or object repeatedly contacting the tooth (Hattab & Yassin, 2000). Abrasion can be due to habitual or occupational use, such as incisal notching caused by pipe smoking (Fidalgo et al., 2019; Lee et al., 2012), or the use of 'teeth as tools' or as a 'third hand' (Molnar, 2011). Shapes of such wear include notches, grooves, chipping, scratches on labial surfaces, pits, striations and polished enamel (Fidalgo et al., 2019). The extra masticatory use of teeth has been linked with particular dental wear patterns and tooth trauma such as chipping and associated pathologies including periapical lesions (Molnar, 2011) which can provide further evidence in relation to behavioural patterns and cultural practices of the past (Estalrrich & Rosas, 2015; Molnar, 2011). An analysis of abrasion wear patterns by population, sex and age may provide evidence of differences between these groups in labour habits and cultural practices (Fidalgo et al., 2019; Molnar, 2011) such as the evidence of distinct differences in the prevalence and patterning of dental filing from northwest Iron Age Cambodia compared to southern Cambodia and northeast Thailand (Domett et al., 2013).

Attrition

The clinical definition of attrition is the gradual loss of hard tooth substance from occlusal contacts with opposing dentition (Hattab & Yassin, 2000; Lee et al., 2012) from both proximal or occlusal inter-dental friction (d'Incau et al., 2012). Proximal contact is linked to the forces required for mastication, which are cumulative (d'Incau et al., 2012). Mastication forces can affect the dentition with either lateral and/or posterior-anterior movement (d'Incau et al., 2012). Interproximal wear begins in childhood and is age progressive (Zakrzewski, 2012). Interproximal wear often presents with the mesial tooth surface concave, whilst the distal surface remains convex (d’Incau et al., 2012). Occlusal attrition has been reported as mainly due to clenching, swallowing and bruxism (Grippo et al., 2004).

Attrition begins with the cusp tips being worn away, leading to a gradual reduction in cusp height and eventually causes the occlusal surfaces to flatten (Lee et al., 2012; Zakrzewski, 2012). The gradual loss of enamel and dentine does not normally result in dental sensitivity due to secondary dentine formation (Hattab & Yassin, 2000). Severe attrition leads to dentine exposure (Lee et al., 2012). Dentine exposure begins on the occlusal surfaces and generally progresses from one tooth to the next, in the order of tooth eruption beginning with the first adult molar (Zakrzewski, 2012). Attrition will usually produce equal and matching wear facets on opposing teeth (Lee et al., 2012) and can be accelerated by extrinsic factors such as chewing tobacco, traumatic occlusion, a coarse diet and malocclusion (Hattab & Yassin, 2000; Lee et al., 2012).

What Can Tooth Wear Tell Us?

Dental wear depends on masticatory function, diet, food processing techniques, order of tooth eruption, age, tooth forms, sex, and hardness and thickness of enamel (Zakrzewski, 2012). As the two major variables are diet and age (Griffin, 2014), dental wear is used to inform on both in a bioarchaeological analysis.

In populations that exhibit a high level of dental wear it can be used to facilitate estimating age at death of the skeletal remains (Mays, 2010). Whilst dental wear is influenced by a multitude of factors such as activity, diet, disease and genetics, the fact that dental wear is age dependent means that it is a particularly useful tool for establishing age at death differences of specific populations (Cave & Oxenham, 2016). Differences in populations such as subsistence strategies and cultural practices can limit the efficacy of a singular dental wear analysis system across multiple populations, with better outcomes resulting from a population specific seriated approach (Cave & Oxenham, 2016).

People that eat a more abrasive diet will show wear more rapidly than those people with softer, more processed diets (Griffin, 2014). Subsistence strategy has also been found to affect the pattern of wear on the teeth (Griffin, 2014). Dental wear has been used as a proxy for identifying subsistence strategy, with hunter-gatherer diets regarded as being more abrasive showing wear as flattening across the occlusal surface (Smith, 1984) whereas agriculturalists, regarded as having softer, more processed diets, produce a scooped out appearance of the occlusal surface (Griffin, 2014). However, the reality is not that straightforward.

The regurgitation of gastric juices, either in vomiting or reflux, cannot be discounted as a contributing factor to erosion of the teeth either (Robb et al., 1991). The effect of erosion needs to be considered in a multifactorial approach to tooth wear analysis (Ogden, 2008), as erosion softens the dental hard tissues making them more vulnerable to both attrition and abrasion.

Differences in wear according to sex and age may be evidence of sex and age related dietary changes throughout the life course (Trombley et al., 2019). The higher prevalence of wear on the posterior teeth of older females compared to older males in a sample has been suggested to indicate that older females had to rely on coarse, starchy cultigens later in life (Trombley et al., 2019). Such a simplistic diet-focused explanation does not consider the influence physiological differences due to biological sex and pregnancy have on both the oral microbiome and health of females, which has begun to be explored in regards to caries (see for example Ferraro & Vieira, 2010; Lukacs & Largaespada, 2006; Shaffer et al., 2015). Given the interrelated nature of dental pathologies this physiological impact needs to be considered in all dental pathologies and conditions.

Refer to Section 4.1 for an explanation of the methods used in the analysis of advanced wear in this thesis, and the results of the analysis.

3.3.2 Caries

The inclusion of the prevalence of caries is an important facet of the DPP for an individual and a population (Lukacs, 1989). This section will examine what caries are, how they are formed, what influences their formation, and what information their analysis can provide.

The term dental caries is descriptive of the disease process and not just the cavity formed in the tooth during the final stage of the process (Liebe-Harkort et al., 2010). The cavity, also called a carious lesion, is a manifestation of the disease process and a symptom of the disease (Fontana et al., 2010). Initial carious lesions appear as white or opaque areas or brown discoloured spots on the tooth enamel (Hillson, 2008b; Liebe-Harkort et al., 2010). The lesions are initially non-cavitated and may remain this way for years before progressing to cavitation (Fejerskov, 2004).

Pathogenesis of Caries

Caries is the progressive demineralisation of the tooth enamel, dentine and cement caused by localised fermentation of food sugars by the bacteria found in dental plaque (Hillson, 2005,2008b; Hujoel & Lingström, 2017; Lukacs, 1989; Peres et al., 2019). Dental plaque is a biofilm (previously mentioned in Section 3.3.1) containing a diverse number of oral micro-organisms (Kumar, 2017; Marsh, 2010; Scannapieco, 2013) and is a community of bacteria formed by the residential flora in the oral cavity living in an organised colony (Marsh, 2010; Scannapieco, 2013). The fermentation of sugars results in the formation of organic acids which demineralise the teeth (Featherstone, 2004; Fejerskov, 2004; Hillson, 2005). The balance of the microbiome is affected by the individual's diet (Kumar, 2017). An imbalance leads to the disruption of the physiological equilibrium between tooth mineral and the biofilm (Costalonga & Herzberg, 2014; Fejerskov, 2004; Kumar, 2017). Caries is the result of an overall imbalance of low and neutral pH episodes in the oral environment during the day and is the accumulative effect of pH environment changes of the dental plaque on the teeth (Hillson, 2008a).

Dental caries has been classed as an infectious disease due to the action of pathogenic microorganisms, the acidogenic bacteria, in the formation of the lesions (Humphrey et al., 2014; Klein et al., 2004; Lukacs, 1989). However, it is endogenous bacteria that affects the individual, not exogenous (Fejerskov, 2004), colonising the mouth within minutes of birth and co-evolving with the individual, adapting through tooth loss, changing oral hygiene practices and differing food habits (Kumar, 2017). Despite this it has been argued that caries is an infectious disease that can be spread from one infected person to an uninfected one (Humphrey et al., 2014). The transmission of cariogenic bacteria from mother to child has been reported (Klein et al., 2004; Weintraub et al., 2010) and argued as evidence for the infectious nature of caries, although a direct relationship between maternal and child bacterial transmission is not assured with additional variables such as feeding practices, time in day-care, time spent with other children, and the number of erupted teeth having an influence (Baca et al., 2012; Damle et al., 2016; Klein et al., 2004). Further, it has been reported that of the 52 distinct bacteria genotypes found among a group of children, only 16 were in common with the mothers (Klein et al., 2004) which implies that the transmission of bacteria from mother to child is not assured. High levels of cariogenic bacteria in a mother can result in higher caries rates in her children (Chaffee et al., 2014; Silk et al., 2008; Weintraub et al., 2010) which could suggest a genetic and transmissible link rather than diet-related causation.

However, what was not considered was the similar, if not identical, diet family members consume which will impact caries formation. Sheiham and James (2015) argue the identification of caries as an infectious transmissible disease demonstrates a misunderstanding of the aetiology of the disease. Only the addition of sugar to the microorganisms in the mouth responsible for caries stimulates their growth and adhesive qualities and the production of acid which in turn leads to the production of the caries. Caries is first and foremost a diet *mediated* disease.

Sugars, in particular sucrose, contribute to an increase in caries rates (Costalonga & Herzberg, 2014; Hujoel & Lingström, 2017; Moynihan, 2005; Moynihan & Kelly, 2014; Sheiham & James, 2015; Watt et al., 2019), with Hujoel and Lingström (2017, p. S81) calling it an "inconvertible truth" that sugar causes decay in the dental enamel. Hillson (2008b) has argued that it is possible for caries to develop in individuals that never eat sugar, and starches, whilst of low cariogenicity compared to sugars, can still create caries. More recent studies have found no association between starch consumption and caries rates *per se* (Halvorsrud et al., 2019) and starch has cariogenic potential only when accompanied by sucrose (Moynihan, 2005; Sheiham & James, 2015). Caries is a diet-mediated disease with a single, specific cause, free sugars (Costalonga & Herzberg, 2014; Sheiham & James, 2015). Free sugars encompass "all mono and disaccharides added to food by manufacturer, cook or consumer, plus the sugars naturally present in honey, syrups and fruit juices and concentrates" (WHO, 2015, p. 4). In a seeming contradiction, Geber and Murphy (2018), expecting to find good oral health in their sample of nineteenth century Irish Famine victims given the low cariogenic staple diet of the famine of potato and milk, reported a crude caries rate of 80% among adult dentition which they used as evidence of diet being an unlikely cause of dental decay. Crucially, their study did not examine what impact a famine diet had on creating imbalance in the microbiome, nor did they investigate the impact of famine on the immune system and immune response of individuals (Słotwińska & Słotwiński, 2014a,2014b). As such the contribution of the famine diet to the caries rate in this study cannot be fully discounted, a factor that has been attributed to caries rates in other studies (Walter et al., 2015). Further, malnutrition in childhood impacts general adult health (Heilmann et al., 2015) and can result in an increased prevalence of caries in adulthood (Heilmann et al., 2015; Psoter et al., 2005; Psoter et al., 2008; Shearer et al., 2011). The famine diet led to malnourished children and adults, and it is the impact of this malnourishment that potentially contributed to the high rate of caries.

Caries rates have been associated with not only diet but also with subsistence strategies (for example: Lanfranco & Eggers, 2010; Littleton & Frohlich, 1993; Temple & Larsen, 2007). However, during the last years of the twentieth century caries rates showed a sustained decline that cannot be explained clinically by fluoridated drinking water or toothpaste, and the consumption of fermentable carbohydrates has not decreased (Hillson, 2008a) nor have subsistence strategies changed markedly. The decrease in caries rate was paralleled by a general improvement in overall health (Hillson, 2008a). The implication being that caries is not simply a proxy for diet and/or subsistence strategy. If caries does not simply equate with diet today, it is unlikely it was only related to diet and subsistence strategies in the past. So whilst it is a diet mediated disease (Paglia, 2016; Sheiham & James, 2015), caries rates should not be used as a simple, black and white checklist of sorts, with the rate of caries within a population being the sole evidence of their mode of subsistence. Linear, causal relationships between dental markers and particular life conditions should not be accepted (Turner, 1979) and such evidence should not be used as a single diagnostic tool for diet and subsistence strategies (Marklein et al., 2019).

There is evidence of a strong heritability component to carious lesions, and, that regardless of diet, certain populations are more susceptible to carious lesions (Marklein et al., 2019). In the present day, oral health conditions, including caries, have been found to disproportionately affect impoverished and socioeconomically disadvantaged members of society. Oral diseases are used as a clinical marker for disadvantage (Foley & Akers, 2019; Peres et al., 2019). Factors of heritability and socioeconomic status can be related to diet and overall health, which in turn affects the oral microbiome. Families, parents and children generally eat the same diet, so heritability factors could also be diet mediated. Populations potentially also follow very similar dietary patterns. Lastly socioeconomic factors also impact on a person's or family's or a population's access to food and nutrition and their behaviours, again directly affecting the oral microbiome and overall health, potentially affecting the prevalence of dental caries (Heilmann et al., 2015; Lynch et al., 1997; Shearer et al., 2011). The intergenerational effects of health reveal that a mother's dental health impacts that of their children, even when their children are adults (Heilmann et al., 2015; Shearer et al., 2011) which can be explained by both heritability but also socioeconomic factors.

Caries has been labelled a multifactorial disease (Bratthall & Hänsel Petersson, 2005; Fejerskov, 2004; Ferraro & Vieira, 2010; Weber et al., 2018) as the disease process involves carbohydrates, the frequency of their consumption, oral micro-organisms, acids, differential properties of different teeth (discussed below), salivary flow (discussed below), and the impact of fluoride. However, these are not causal factors. They are factors that modify the speed at which the cariogenic properties of sugar affect the dentition (Sheiham & James, 2015). Caries is a complex disease with multiple factors able to vary the speed of its development, but it has a singular causative factor, dietary sugar (Paglia, 2016; Sheiham & James, 2015). The development of caries is influenced by many factors including the nature of the dental tissue and tooth surfaces, the dental biofilm, the amount of saliva in the mouth, an individual's diet, age and sex (Hillson, 2008a; Lukacs & Largaespada, 2006; Moynihan & Kelly, 2014). These will be explored below.

Factors influencing caries development

Dental Tissues and Tooth Surface

Teeth are most susceptible to caries when they first erupt because newly formed dental enamel is not completely mineralised (Hillson, 2008a). Newly erupted enamel is crystallographically immature and it is the calcium and phosphate ions in the saliva that aid in the post eruptive maturation, increasing the hardness and decreasing the permeability of the enamel surface which improves caries resistance (Lukacs & Largaespada, 2006; Lynch, 2013). Any defects in the enamel surface can lead to an increase in the surface permeability which in turn can lead to an increase in caries prevalence (Hillson, 2008a).

Caries have been observed to affect the dentition in a symmetrical fashion (Darby et al., 2012; Hillson, 2008b) but there are considerable differences in how caries affect the upper and the lower teeth, and the different classes of teeth, the incisors, canines, premolars and molars (Hillson, 2008a). The microflora of the mouth is not uniform and varies dependent on the location within the mouth (Lanfranco & Eggers, 2010) which can potentially influence cariogenicity. The pH of dental plaque also varies within the mouth being more neutral-acidic in fissures and interproximal surfaces, and more neutral-alkaline at the gingival-sulci (Lanfranco & Eggers, 2010). In the secondary teeth, the posterior teeth are more affected by caries than the anterior teeth (Tomczyk et al., 2013), with the upper molars most affected, followed by the lower molars, and then the upper canines and incisors, followed by the lower canines and incisors (Broadbent et al., 2013; Hillson, 2005; Sheiham & James, 2015). Molars are also the most commonly affected teeth in the primary dentition (Hillson, 2005). Caries are more commonly found on the occlusal surface of the dentition, being especially prevalent in the fissures and pits of the occlusal surfaces of the posterior teeth, and also on the interproximal tooth surfaces as these areas are prone to plaque formation and low saliva flow (Costalonga & Herzberg, 2014; Tomczyk et al., 2013).

Dental Biofilm

Different species of bacteria in the biofilm rise to dominance depending on the internal environment (Hillson, 2008a) which is affected by diet (Kumar, 2017). Microorganisms associated with caries lesion formation, including *Streptococcus mutans*, *Lactobacillus spp.* and low-pH non-*mutans streptococci*, are all tolerant of low pH conditions, which are the perfect environment for fermenting dietary carbohydrates (Marsh, 2010). Historically, *Streptococcus mutans* has most often been associated with caries. More recent studies have found no obvious single pathogen as the instigator for caries, but rather an imbalance among the microbiome (Costalonga & Herzberg, 2014). A plaque deposit can become potentially cariogenic when enough carbohydrate is regularly supplied to provide an advantage to the low pH loving bacteria who then multiply and dominate the plaque biofilm, producing more enamel demineralising organic acids (Costalonga & Herzberg, 2014).

Saliva

Saliva has an important, multifaceted role in oral health. Saliva protects by helping to remove cariogenic substances from the mouth, diluting, neutralising and buffering the organic acids formed by the biofilm organisms, reducing the demineralisation rate and enhancing remineralisation by providing calcium, phosphate and fluoride to the biofilm near the tooth surface (Hara & Zero, 2010; Lingström & Moynihan, 2003; Shaffer et al., 2015; Słotwińska & Słotwiński, 2014a). Saliva has a direct impact on the health of the oral cavity and is an important factor affecting caries rates (Fontana et al., 2010; Hara & Zero, 2010; Lingström & Moynihan, 2003).

Salvia production and its antibacterial and protective qualities are reduced during times of malnutrition (Psoter et al., 2005; Psoter et al., 2008; Słotwińska & Słotwiński, 2014a). The effect on saliva production and the knock-on effect to dental health has been shown to continue through childhood into the affected person's adolescence and potentially beyond (Psoter et al., 2005; Psoter et al., 2008).

Sex differences in hormonal composition affect the flow rate of saliva which can impact oral health (Ferraro & Vieira, 2010). Females have a lower flow rate of saliva throughout all life stages which decreases the amount of protection it can provide, potentially leading to increased caries rates (Ferraro & Vieira, 2010; Lukacs & Largaespada, 2006). As such, salvia and biological sex are interrelated regarding overall dental health, and caries formation specifically.

Sex

Females generally have more carious teeth than males in any given sample which is thought to be due to a range of factors including saliva flow, dietary differences, and hormonal changes throughout life including pregnancy (Da-Gloria & Larsen, 2014; Hillson, 2001,2008b; Kolpan & Bartelink, 2019; Shaffer et al., 2015; Temple, 2011; Walter et al., 2015). Until relatively recently, sex differences in caries prevalence were more widely accepted by clinical investigators of oral health than by bioarchaeologists (Lukacs, 2011b; Lukacs & Largaespada, 2006). The traditional explanation for sex differences in caries prevalence rates typically involved arguments for the earlier eruption of the dentition in females (Ferraro & Vieira, 2010; Shaffer et al., 2015), sex based division of labour, food access, time devoted to food preparation, and tasting dishes during food preparation (Douglas & Pietrusewsky, 2007; Temple, 2011; Temple & Larsen, 2007). Da-Gloria and Larsen (2014) argued that differences in dietary habits as a result of a sex based division of labour and food consumption were responsible for the “unexpected” high caries rates of females. They continued by suggesting that the elevated caries rates could not be due to females eating honey though as “honey collection is typically a male activity since it required athletic ability to either climb trees or to collect the material as fast as possible” (p. 21). Instead, the high caries rate was supposedly due to females “frequently snacking on fruits and eating tubers during the day” (p. 22). The WHO (2003) found no relationship between the eating of starches (tubers are a starch) and caries rates and they found insufficient evidence for an increased risk of caries from eating whole fresh fruit. Such explanations of sex based divisions of labour and diet have been widely and uncritically accepted (Lukacs & Largaespada, 2006) and are perhaps closely related to researcher’s pre-existing (and at times subconscious) biased views that the past should be interpreted utilising nineteenth century societal ideals (Moen, 2019). A growing body of clinical research has shown both physiological sex differences and pregnancy have an important impact on both the oral microbiome and health of females (Ferraro & Vieira, 2010; Lukacs & Largaespada, 2006; Shaffer et al., 2015; Watson et al., 2010).

Whilst behavioural and dietary sex-based differentiation is still the dominant narrative in regard to caries rates in bioarchaeological studies, the impact of hormonal and reproductive factors are becoming acknowledged, albeit often in a minor role (Temple, 2011; Willis & Oxenham, 2013b). Hormonal fluctuations occur *throughou*t the female life course and are not solely related to pregnancy and reproduction (Shaffer et al., 2015). Females are subject to a lifetime of hormonal shifts due to puberty, menses, pregnancy and menopause which contribute to changes in the micro-bacterial and biochemical environment of the mouth (Marklein et al., 2019). The detrimental effects of oestrogen fluctuations on the oral health of women and the increased predisposition of females for carious lesions has been shown in the clinical literature (Lukacs & Largaespada, 2006; Marcuschamer et al., 2009; Nirola et al., 2018).

An adoption of broader perspectives in interpreting sex differences in dental caries prevalence is required, including an increased attention on population demography and female reproduction in the aetiology of dental caries. It has been hypothesised that the cumulative impact in societies with high birth rates will demonstrate significant sex-based differences in oral health (Lukacs & Largaespada, 2006; Willis & Oxenham, 2013a). A further complication is that sex-based caries differences may also be due to differences in the frailty of the individuals affected, which implies differences in overall health and associated contributing factors, and not simply an indication of sex-based hormonal differences (Walter et al., 2015). As such, considered and nuanced interpretations are required for the sex disaggregated caries prevalence within populations.

Age

Caries is a progressive disease affecting more older than younger individuals (Hillson, 2008b; Preshaw et al., 2017; Sheiham & James, 2015) and as such is an age mediated disease (Heilmann et al., 2015). The prevalence of caries in the primary dentition is generally small (Stránská et al., 2014) and as such it is not often reported in the bioarchaeological literature. Although some studies do compare both primary and secondary dentition caries rates (for example Halcrow et al., 2013), finding that the primary teeth had more caries than the secondary, explained by differences in diet.

As a person ages, their immune function changes (immune senescence) resulting in older people being more susceptible to infections, such as caries (Preshaw et al., 2017). Immune function is further affected by diet, nutritional status, medical status and stress levels which can change as a person ages (Preshaw et al., 2017), indicating the bidirectional nature of oral and general health, with general health affecting oral health, and *vice versa* (Batchelor, 2015). Any analysis and comparison of caries prevalence needs to take into consideration the age of the individuals.

Progressive stages of lesion formation

The negative effects of caries and lesion formation are cumulative (Lamster et al., 2016; Peres et al., 2019; WHO, 2015). The first stage of lesion formation is the presence of a white spot on the tooth surface, which is an early sign of demineralisation (Peres et al., 2019). In the early stages this demineralisation can be reversed by the uptake of calcium, phosphate or fluoride (Waldron, 2009). If the demineralisation continues the lesion will become cavitated. At this stage the lesion can cause pain and discomfort to the affected individual. If the cavitation continues it can spread to the dental pulp, potentially causing an infection that can lead to tooth loss (Peres et al., 2019).

Location of Lesions

There are different types of caries and the lesions can be divided into categories related to their size and area of initiation (Hillson, 2008b). The different categories of lesions have contrasting aetiologies, developing in different ways, and show different trends with age (Hillson, 2005,2008b; Liebe-Harkort et al., 2011). Different categories of caries should be recorded separately (Section 4.2.1). The two main forms of carious lesions are coronal caries and root surface caries (Hillson, 2008b).

Coronal lesions form in the enamel surface of the crown, or in the dentine exposed by wear (Hillson, 2008b). From its original site, a coronal lesion may progress from a white or brown spot on the enamel which gradually grows with the surface becoming rough, and it eventually becomes a cavity, which in turn may eventually penetrate both the dentine and secondary dentine, exposing the pulp to potential infection (Bjørndal et al., 2019). Such progression can take years (Hillson, 2008a,2008b). Root surface lesions begin along the cemento-enamel junction (CEJ) at the base of the crown or on the cement of the root as it becomes exposed in older people as the alveolar bone recedes with age or due to periodontal disease (Hillson, 2008b). Root surface lesions have been associated with older age, but a more recent study found that neither coronal nor root surface lesions are age dependent, but coronal lesions are more common (Lamster et al., 2016). Both lesion types, coronal and root, involve subsurface demineralisation however the appearance, development and progression of the lesions is different (Liebe-Harkort et al., 2011) which is suggestive of the need to record the type of lesion separately.

Review of Recording Methods

The way in which dental caries are recorded effects the way results are interpreted (Hillson, 2001; Wesolowski, 2006). In the clinical literature as many as 29 different methods are used (Khattak et al., 2019). The lack of standardisation limits the comparability between studies (Ismail et al., 2007). The World Health Organisation (WHO) recommends the use of the Decayed Missing Filled (DMF) index in oral health assessment surveys (WHO, 2013). However, the DMF index is not appropriate for use in bioarchaeological settings as it is limited to the presence or absence of carious lesions, does not allow for the recording of the disease in the early stages, and variation in lesion size cannot be recorded (Liebe-Harkort et al., 2010). The pattern of the progression of dental disease within a population can be indicative of the nature of diet, subsistence methods and everyday tasks. Recording systems need to be able to illustrate differences and variations. Hillson (2001) recommends an extremely thorough and complex recording system, but due to its complexity it is not used by many researchers. In an effort to maintain thoroughness but decrease complexity, Liebe-Harkort (2012) proposed a system combining the palaeopathological system of Hillson

(2001) with the clinical system of visual identification of Ekstrand et al. (1997) to enable a thorough analysis of both lesion site and severity.

The lack of a standardised process of analysis and descriptive terminology is problematic (Liebe-Harkort, 2012). In the clinical literature dental caries is diagnosed by the presence of a "white spot", whereas in bioarchaeology carious lesions are routinely defined as "focal areas of necrotic cavitation of enamel and dentin" (Lukacs, 2008, pp. 901-902). These differences in caries identification and diagnosis makes comparisons of caries rates in past and present populations difficult. Wesolowski (2006) has also highlighted the problem of comparing studies of dental caries finding that the majority of papers reviewed contained inadequate information regarding lesion diagnostics and characteristics, age, and sex of sample, and calls for the standardisation of methods and the inclusion of explicit descriptions of the analytical procedures used.

Refer to section 4.2 for a description of the methods used in the analysis of carious lesions in this thesis, and the results of the analysis.

3.3.3 Antemortem Tooth Loss

Antemortem tooth loss (AMTL) is the premature loss of the tooth. This could be due to a number of pathological causes, such as caries (Section 3.3.2), or advanced wear (Section 3.3.1) (Hillson, 2005; Matalova et al., 2008; Russell et al., 2013; Trombley et al., 2019). Such pathological conditions can lead to pulp chamber exposure allowing bacteria to enter the periapical tissues leading to infection which can lead to the loss of the tooth. As such, tooth loss is often the endpoint of dental disease (Peres et al., 2019). However, in archaeological remains the cause of the tooth loss will not always be able to be identified. What can be agreed upon is that AMTL can be considered a multifactorial pathology given the various contributing factors (Lukacs, 2007).

Lukacs (2007) cites four primary contributing factors to premature loss of teeth: (1) variations in dietary consistency; (2) nutritional deficiency diseases; (3) cultural or ritual ablation; (4) trauma. It is important to understand the co-relationship between different pathologies. Establishing the primary cause of the AMTL can provide information about the masticatory stress and dental health of skeletal populations when considering the Dental Pathology Profile (DPP) (Lukacs, 1989). For example, some AMTL may be the result of caries. As such when considering the prevalence of caries within a population the prevalence of AMTL should also be considered as it is often the end result of gross caries and subsequent infection. Whilst some researchers attempt to quantify the under estimation of caries by applying different 'correction factors' (Duyar & Erdal, 2003; Erdal & Duyar, 1999; Lukacs, 1995), still others argue that such a manufactured correction introduces a level of fictionality to the data, introducing untestable assumptions (Hillson, 2001; Oxenham et al., 2006; Wasterlain et al., 2009) and are best avoided. Such corrections have also been avoided when analysing individuals from populations with known patterns of tooth ablation (Temple & Larsen, 2007).

It is the alveolar bone that supports the teeth and the muscles of both mastication and facial expression, however, once a tooth is lost the alveolar bone begins a process of resorption and remodelling (Alikhani et al., 2016) resulting in a loss of alveolar height (Mays, 2017). This remodelling of the bone follows a series of predictable events beginning with the formation of a blood clot which is replaced by a provisional connective tissue matrix. This, in turn, is followed by the formation of trabecular bone then lamellar bone, after which a bridge of cortical bone forms closing the socket (De Groote & Humphrey, 2016). The speed of resorption is greatest in the first three to 12 months post tooth loss (Alikhani et al., 2016;

Kingsmill, 1999). However, the rate of bone loss has been found to vary depending on which tooth is lost. For instance, alveolar bone loss can continue and be detected in the mandible up to 25 years after the loss of the tooth, whilst bone loss in the maxilla is replaced much quicker (Kingsmill, 1999). Given that alveolar bone remodelling follows a predicable series of events after tooth loss, the height of the alveolar bone could potentially be used to establish the time since tooth loss, given the inverse relationship between the height of the bone and the time since loss (Mays, 2017). A method of comparing estimated age at death with the extent of alveolar remodelling was used by De Groote and Humphrey (2016) to try and establish when the tooth loss occurred, in this case they were looking at non-pathological tooth loss (see section below on ablation). However, any differences in remodelling due to tooth loss at different ages becomes less visible with time and once remodelling is complete no differences will be visible making this technique of limited use.

AMTL can be used as a measure of overall oral health. Tooth loss has a direct association with both oral function and oral health. It also potentially impacts overall health as AMTL can lead to compromised chewing ability which in turn can lead to poor diet and improper nutrient access (Russell et al., 2013) and inadequate nutrition. As mentioned above, the somewhat unambiguous identification of AMTL, being that it is recorded only when the tooth socket shows evidence of alveolar bone resorption (Lorentz, 2014) makes it easy to record and compare within population groups. However a tooth lost shortly before death may be misidentified as post mortem loss due to no evidence of resorption of the alveolus (Lukacs, 1989).

AMTL can occur symmetrically due to the natural, common feature of symmetry within biological systems (Darby et al., 2012; Mombelli & Meier, 2001). AMTL due to periodontal disease is also usually symmetrical (Hillson, 2005). Periodontal disease itself often presents symmetrically among dentition (Darby et al., 2012) and, as AMTL is the end result of a pathological processes, if the periodontal disease affected the teeth symmetrically then it stands to reason that the teeth will potentially be lost symmetrically. Caries has also been suggested to affect the dentition in a symmetrical manner (Darby et al., 2012; Mombelli & Meier, 2001) as previously mentioned, and likewise if caries was the cause of the tooth loss it stands to reason that this loss would also be symmetrical.

Age and sex have been found to be contributing factors to AMTL. AMTL is age dependent, with increasing rates of AMTL found in older individuals (Geber & Murphy, 2018). This is not surprising given tooth loss is the end result of the effects on the teeth of various pathologies, such as caries and wear. As the prevalence of pathology increases with increasing age it stands to reason that AMTL will also increase with increasing age. AMTL is also reported to be related to sex, with females more affected than males (Geber & Murphy, 2018; Pietruseswsky et al., 2017; Russell et al., 2013). As sex influences other dental pathologies, such as caries (Section 3.3.2) it is logical to expect that sex based differences will result in differences in tooth loss, retention and edentulism (Geber & Murphy, 2018; Russell et al., 2013).

Dental pathology and subsistence patterns have been linked in bioarchaeological research for some time, most prolifically in regard to the prevalence of caries being equated with particular population subsistence strategies (Section 3.3.2). Studies have also shown that the rate of AMTL increased with the intensification of agriculture (Littleton & Frohlich, 1993; Lukacs, 2007). As such it is possible that different AMTL patterns and frequencies within populations with distinctive subsistence strategies can provide insights into the specific aetiology of tooth loss within populations (Lukacs, 2007). However, as discussed previously (Section 3.2), subsistence strategies are more complex than simply the dichotomy of hunter-gather or agriculturalist, and the idea that the multifactorial processes resulting in differing dental pathologies can be used as a simple identifier for a particular subsistence strategy is over simplified and leads to rudimentary interpretations of the life course of the populations under study.

Ablation

Non-pathological antemortem tooth loss is called ablation. This is different to agenesis which is the congenital absence of teeth (Chapter 6). Ablation is the intentional, culturally motivated, antemortem removal of a tooth or teeth and is commonly grouped with other forms of deliberate dental modification such as chipping, filing and inlays (Ikehara-Quebral et al., 2017; Russell et al., 2013; Willman et al., 2016). Ablation has been recorded on every continent, there is evidence of the practice from Neolithic to modern times, and it is thought to reflect social status, group identity, or reflect certain rites of passage (Kinaston et al., 2020; Palefsky, 2019; Russell et al., 2013).

Given the multifactorial nature of AMTL, a differential diagnosis of AMTL is imperative to the study of ablation (Willman et al., 2016). The differences between intentional and pathological tooth loss is generally not obvious in dry bone (Domett, 2001), and it can be difficult to determine whether a tooth has been ablated or lost due to other reasons (Russell et al., 2013). The identification of intentional dental ablation requires three factors: 1) the differentiation between antemortem and post-mortem loss based on alveolar remodelling; 2) the absence of pathology in adjacent teeth and alveolar bone; and 3) symmetry or near symmetry of tooth loss (Newton & Domett, 2017; Stojanowski et al., 2014). Other authors add that the patterning and frequency of the antemortem tooth loss despite otherwise good oral health in an individual is a further indication of ablation (Ikehara-Quebral et al., 2017; Pietrusewsky & Douglas, 1993). The case for intentional removal can be made stronger if there is evidence of sufficient space between remaining teeth and interproximal wear facets on adjacent teeth which would be absent if the missing tooth was a result of dental agenesis (Chapter 6). The reason for tooth loss must be carefully considered so as not to misidentify pathology related tooth loss (such as those due to caries, periodontal disease, excessive wear) as intentional ablation (Stojanowski et al., 2014). Whilst there is no direct evidence of a negative impact on dental health due to ablation (Newton & Domett, 2017; Willman et al., 2016), it has been reported that it can have a significant effect on the remaining dentition in regards to occlusion, wear patterns and even the emergence of the teeth (De Groote & Humphrey, 2016; Humphrey & Bocaege, 2008; Humphrey et al., 2014).

Ablation is a form of dental modification. Modification of the dentition is a form of human body modification. Intentional dental modification can be placed into two categories: therapeutic or cultural (Stojanowski et al., 2014). Therapeutic modification refers to intentional dental care with the overall aim to restore oral health. Archaeological evidence for therapeutic modification includes drilling, filing, corrective prosthetics and tooth extraction, whereas cultural modification, whilst still intentional, is motivated by sociocultural and/or aesthetic norms (Stojanowski et al., 2014). In bioarchaeological research, body modification has gained increasing emphasis as a way of determining aspects of both individual and group social identities (Knudson & Stojanowski, 2008; Stojanowski et al., 2014; Temple et al., 2010). Dental modification can potentially provide a way to identify groups or individuals within groups. Dental modification is also suggested to be a marker of different rites of passage such as puberty, marriage or as part of mourning rituals (Kangxin & Nakahashi, 1996; Kinaston et al., 2020; Newton & Domett, 2017; Pietrusewsky & Douglas, 1993; Temple et al., 2010). What cannot be disputed is the impact that the ablation of teeth, in particular the incisors, has on the appearance of the treated individual. It is not something that would be easily hidden. It is something that would have been immediately apparent to others in the same group or in different communities (Humphrey & Bocaege, 2008; Temple, 2018). It is also possible that the removal of the teeth would have impacted upon speech patterns and even pronunciation (Stojanowski et al., 2014). Possible links have been found between dental modification and burial patterns, suggestive of links between families (Tayles, 1996; Temple et al., 2010). It is likely that cultural practices such as ablation could provide a way to identify group status that are otherwise unable to be identified through a comparison of burial treatment (Newton & Domett, 2017). The age at which the tooth ablation occurred will have a bearing on its cultural meaning, such as being related to particular rites of passage, and will also impact the subsequent movement of the remaining teeth and remodelling of the facial bones (De Groote & Humphrey, 2016). As such it is important to record and compare the pattern of missing teeth, wear of the remaining teeth, and the prevalence of both in relation to age at death and sex to determine any links (Humphrey & Bocaege, 2008; Tayles, 1996).

Refer to Section 4.2 for a description of the methods used in the analysis of AMTL in this thesis, and the results of the analysis.

3.4 Materials

This section provides an overview of the material used for the analysis of the dental health at Non Ban Jak. The first section contains information surrounding the demographic analysis of Non Ban Jak. This is followed by the dental census.

3.4.1 Demography of Non Ban Jak

Bioarchaeological assemblages are subject to numerous biases – both intrinsic and extrinsic (Waldron, 2007). Intrinsically, any skeletal assemblage is made up of non-survivors and, by extension, may not accurately reflect the living of the past (Wood et al., 1992). Extrinsically, any assemblage is subject to the biases of the proportion of the dead buried at the site, the number lost to poor preservation and site destruction, the proportion discovered, excavated, recovered and finally examined (Waldron, 2007). The biases acting on an assemblage can inform whether the assemblage is a representative sample of a population and, as such, whether interpretations from the data can be considered reliable (Waldron, 2007). Therefore, it is important to incorporate the demographic profile of any site into a nuanced interpretation of the data.

This thesis is concerned with an analysis of dental pathologies which are age mediated and, as such, the results may be affected by the demographic distribution of the sample. Age at death profiles for the individuals at Non Ban Jak can illustrate what, if any, mortality differences are evident between the different groups at Non Ban Jak and also what, if any, changes to fertility occurred over time at the site. Such an assessment will then be compared with the findings of the dental health analysis to further inform the understanding of social and health differences among the people of Non Ban Jak.

The analysis of age at death profiles can determine whether a sample is representative of a population as age at death distributions follow patterns in relation to a group's social, and economic status, mortality and survivorship, disease exposure, physiological stress, environmental adaption and societal roles (Lewis, 2007; Volk & Atkinson, 2013; Ward, 2019; Wood et al., 1992). Age and sex estimates used are those provided by members of the Non Ban Jak bioarchaeology research team as published in Buckley et al. (2020) who classified the adults using the relative age groups as per Buikstra and Ubelaker (1994). In this work the age ranges published in Buckley et al. (2020) have been rationalised as follows: Young and Young-Mid adults are grouped as Young Adults; Mid and Mid-Old adults are grouped as Mid Adults; and Old adults remain as Old Adults. Subsequent aDNA analysis has provided the sex information for four individuals whose sex could previously not be determined from the skeletal remains (Burials 3, 139, 150, 68; all nonadults) (H. McColl and

E. Willerslev personal communication). Other aDNA results support the sex estimates made as published in Buckley et al. (2020).

The excavated sample of Non Ban Jak

At Non Ban Jak, 195 individuals have been identified from 199 burials. Adults (considered to be those 20 years of age and older) comprise 35.9% (70/195) (Table 3.1 and Figure 3.1). The 20 individuals (Burials 200-219) excavated during 2018 are not included here. Nonadult individuals have not been sexed in accordance with standard practice. Within the adult individuals excavated, 40.0% were classed as female, 38.6% male, the difference was statistically insignificant (p-value >0.9999), and 21.4% of the individuals could not be assigned a sex (Table 3.2).

Table 3.1: Non Ban Jak age at death distribution

Age	n	%
0-4.9 years*	109	55.9
5-14.9 years	4	2.0
15-19.9 years	12	6.2
Young adult	15	7.7
Mid adult	22	11.3
Old adult	22	11.3
Unknown adult	11	5.6
TOTAL	**195**	**100**

*includes prenatal and perinatal individuals
Note: Young adult; Middle adult; Old adult as per Buikstra and Ubelaker (1994)

Table 3.2: Non Ban Jak adult age at death and sex distribution

Adult Age	Females		Males		Indet. Sex		Total Adults		X²	p value
	n	%	n	%	n	%	n	%		
Young	7	10.0	6	8.6	2	2.9	15	21.43		
Middle	11	15.7	10	14.3	1	1.4	22	31.43		
Old	8	11.4	10	14.3	4	5.7	22	31.43	2.492	0.2877
Unknown	2	2.9	1	1.4	8	11.4	11	15.70		
TOTAL	28	40.0	27	38.6	15	21.4	70	100.0		
Sex diff FET *p*-value			>0.9999							

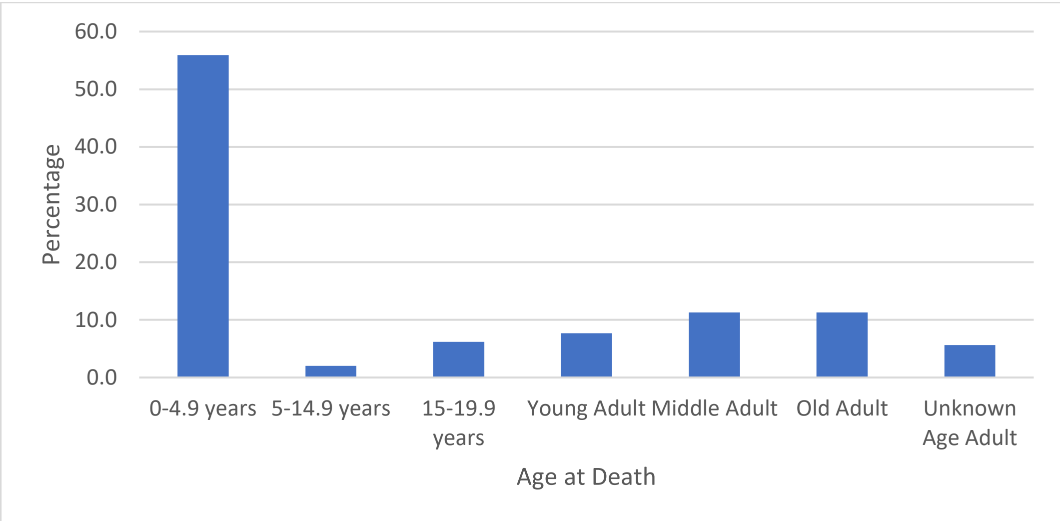

Figure 3.1: Age at death distribution for Non Ban Jak

The east occupation mound had 54 individuals (27.7%) whilst the west mound had 141 (72.3%) of the individuals. The analysis of the age at death distribution for the two mounds revealed no statistically significant difference (*p*-value = 0.6148) (Table 3.3 and Figure 3.2).

Table 3.3 Chi-square test of association between the different age categories and occupation mounds at Non Ban Jak

Age Range	**East Mound**		**West Mound**		**X^2**	***p*-value**
	n	**%**	**n**	**%**		
0-4.9 years	36	18.5	73	37.4		
5-14.9 years	1	0.5	3	1.5		
15-19.9 years	4	2.1	8	4.1	3.557	0.6148
Young adult	4	2.1	11	5.6		
Mid adult	3	1.5	19	9.7		
Old adult	6	3.1	16	8.2		
TOTAL	54	27.7	141	72.3		

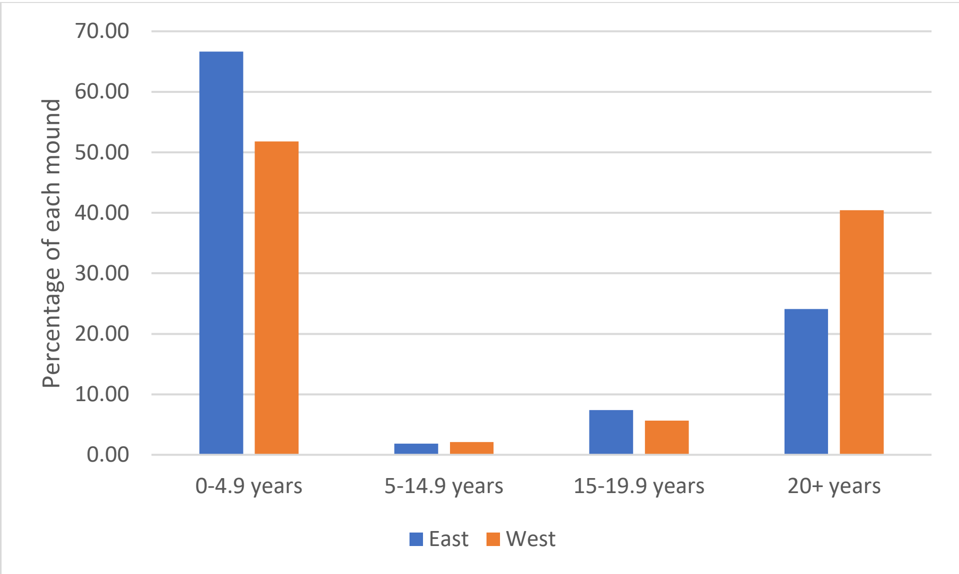

Figure 3.2: Age at death distribution at Non Ban Jak per occupation mound

Table 3.4: Non Ban Jak age distribution East v West mound, and early and late mortuary phase

	0-4.9* years		**5-14.9 years**		**15-19.9 years**		**20+ years**		**Young adult**		**Mid adult**		**Old adult**		**Unknown adult**		**TOTAL**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
East Mound	36	18.5	1	0.5	4	2.1	13	6.7	4	2.1	3	1.54	6	3.1	0	0	54	27.7
Early	30	15.4	0	0	2	1.02	8	4.1	2	1.0	2	1.0	4	2.1	0	0	40	20.5
Late	6	3.1	1	0.5	2	1.02	5	2.6	2	1.0	1	0.5	2	1.0	0	0	14	7.2
West Mound	73	37.4	3	1.5	8	4.1	57	29.2	11	5.6	19	9.7	16	8.2	11	5.6	141	72.3
Early	44	22.3	3	1.54	3	1.5	30	15.4	4	2.05	12	6.15	7	3.6	7	3.6	80	41.0
Late	29	14.9	0	0	5	2.6	27	13.8	7	3.6	7	3.6	9	4.6	4	2.1	61	31.3
TOTAL	**109**	**55.9**	**4**	**2.1**	**12**	**6.1**	**70**	**35.9**	**15**	**7.7**	**22**	**11.3**	**22**	**11.3**	**11**	**5.6**	**195**	**100**

*includes prenatal and perinatal individuals; 20+ years age group includes Young adult, Mid adult, Old adult and Unknown adult and is included to enable ease of comparison to some previous studies

Table 3.5: FET of significance between age at death and mortuary phases at Non Ban Jak

Age Range	**East Early Phase**	**West Early Phase**	***p*-value FET**	**East Late Phase**	**West Late Phase**	***p*-value FET**	**Total Early Phase**	**Total Late Phase**	***p*-value FET**
0-4.9 years	30	44	0.0460*	6	29	0.7764	74	35	0.0537
5-14.9 years	0	3	0.5499	1	0	0.1867	3	1	>0.9999
15-19.9 years	2	3	>0.9999	2	5	0.6084	5	7	0.2190
Young adult	2	4	>0.9999	2	7	0.6717	6	9	0.0976
Mid adult	2	12	0.1379	1	7	>0.9999	14	8	>0.9999
Old adult	4	7	>0.9999	2	9	>0.9999	11	11	0.2526
Unknown adult	0	7	0.0938	0	4	>0.9999	7	4	>0.9999
TOTAL	40	80		14	61		120	75	

*denotes statistical significance

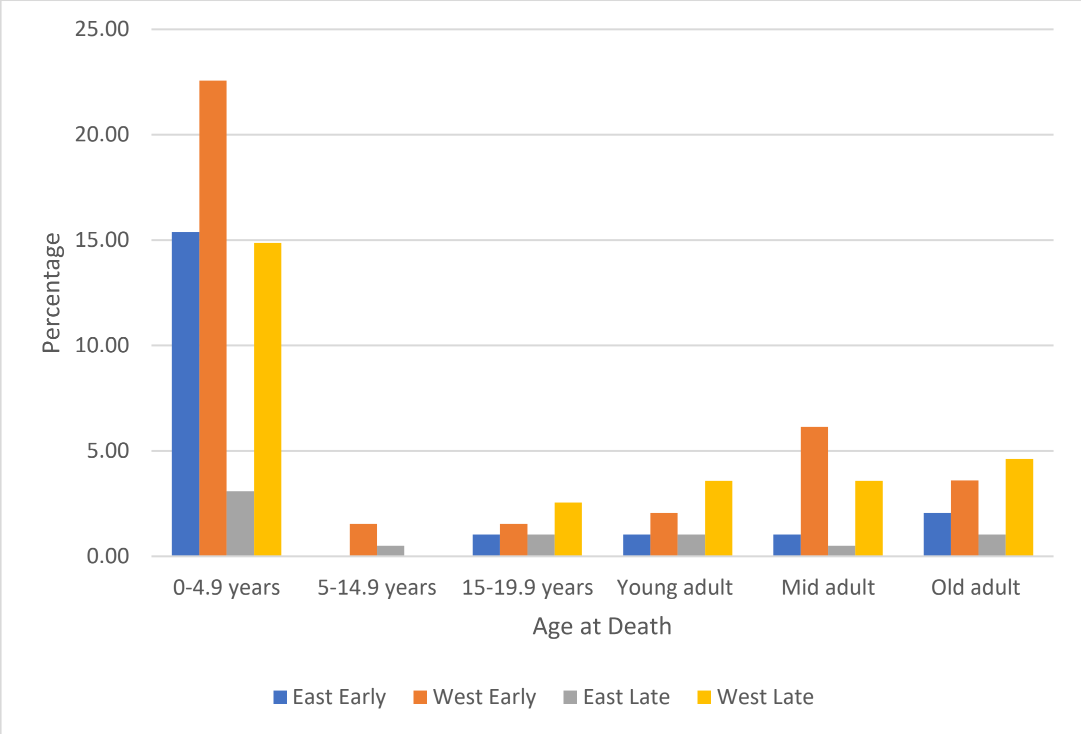

Figure 3.3: Age at death distribution at Non Ban Jak by mortuary phase and occupation mound

The age at death distribution for the early and the late mortuary phases reveals the number of burials in the early phase was statistically significantly different (*p*-value <0.0001) to those in the late phase (Table 3.6; Figure 3.4). However, when the phases were analysed by age groups there were no statistically significant differences in the number of early to the late phase burials (Table 3.6). This, combined with the age distribution analysis of the two mounds by mortuary phase (Table 3.4; Table 3.5; Figure 3.4), shows that despite the large differences in raw numbers of burials in the east and west mounds, the age distribution in both mounds and mortuary phases are very similar, suggestive of being equally representative samples at both locations.

Table 3.6: Non Ban Jak age distribution Early vs Late Mortuary Phase by individual

Mortuary Phase	**0-4.9^ years**		**5-14.9 years**		**15-19.9 years**		**Young adult**		**Mid adult**		**Old adult**		**Unknown adult**		**TOTAL**		***p*-value**
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**FET**
Early	74	38.0	3	1.5	5	2.6	6	3.1	14	7.2	11	5.6	7	3.6	120	61.5	<0.0001*
Late	35	18.0	1	0.5	7	3.6	9	4.6	8	4.1	11	5.6	4	2.1	75	38.5	
p-value FET age groups compared	0.0537		>0.9999		0.2190		0.0976		>0.9999		0.2526		>0.9999				
TOTAL	109	55.9	4	2.1	12	6.2	15	7.7	22	11.3	22	11.3	11	5.6	195	100	

^includes prenatal and perinatal individuals; *denotes statistical significance

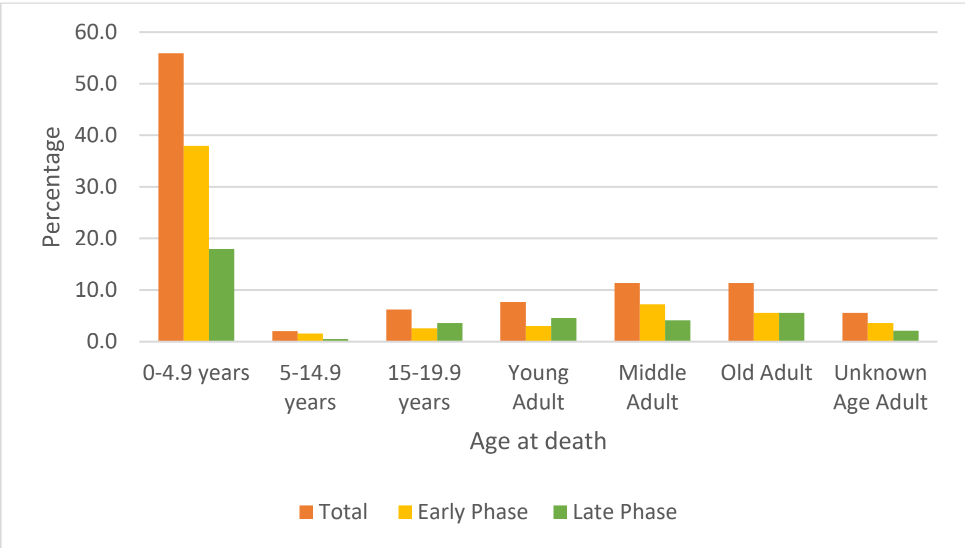

Figure 3.4: Age at death distribution at Non Ban Jak per mortuary phase

What is apparent, by a comparison of the age distributions of the early and late mortuary phases, is that a higher proportion of 0-4.9 year-old and 5-14.9 year-old nonadults were dying in the early phase compared to the late phase, although not statistically significant (Table 3.6; Figure 3.4). Further, this finding correlates with the change in female fertility and the RNPI changes from the early to the late mortuary phase, discussed further below.

Age Distribution of other Iron Age Sites

To allow for the comparison of the dental health profiles, the age distribution for the Iron Age sites of Non Ban Jak, Noen U-Loke and Ban Non Wat have been compared (Table 3.7 and Figure 3.5).

Table 3.7: Age Distribution for the Iron Age periods at Non Ban Jak, Noen U-Loke and Ban Non Wat

Location	**Period**	**0-4.9^ years**		**5-14.9 years**		**15-19.9 years**		**Young adult**		**Mid adult**		**Old adult**		**Unknown adult**		**TOTAL**	
		n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
NBJ*	**Iron Age 4**	**108**	**55.4**	**5**	**2.6**	**12**	**6.2**	**15**	**7.7**	**22**	**11.3**	**22**	**11.3**	**11**	**5.9**	**195**	**100**
Female								7	3.6	11	5.6	8	4.1	2	1.0	28	14.4
Male								6	3.1	10	5.1	10	5.1	1	0.5	27	13.8
Indet.								2	1.0	1	0.5	4	2.1	8	4.1	140	71.8
NUL[a]	**Iron Age 1 - 4**	**46**	**38.7**	**6**	**5.0**	**4**	**3.4**	**24**	**20.2**	**14**	**11.8**	**12**	**10.1**	**13**	**10.9**	**120^**	**100**
Female								8	6.7	7	5.9	6	5.0	0	0.0	21	17.7
Male								13	10.9	5	4.2	4	3.4	3	2.5	25	21.0
Indet.								4	3.4	3	2.5	1	0.8	9	7.6	74	61.7
BNW[b]	**Iron Age 1, 2 & 4**	**52**	**21.8**	**17**	**7.1**	**12**	**5.0**	**37**	**15.5**	**35**	**14.6**	**43**	**18.0**	**43**	**18.0**	**239**	**100**
Female								14	15.9	11	4.6	14	5.9	2	0.8	41	17.1
Male								12	5.0	16	6.7	18	7.5	6	2.5	52	21.8
Indet.								11	4.6	8	3.3	11	4.6	35	14.6	146	61.1

NBJ: Non Ban Jak; NUL: Noen U-Loke; BNW: Ban Non Wat; Nonadults are not sexed; Indet: Indeterminate sex
[*] Nonadult data as per Buckley et al. (2020)
[a]Tayles et al. (2007) and Domett and Tayles (2007)
^one nonadult age could not be determined but added to the total number of individuals
[b]Tayles, Halcrow and Domett – unpublished data/pers. comm.

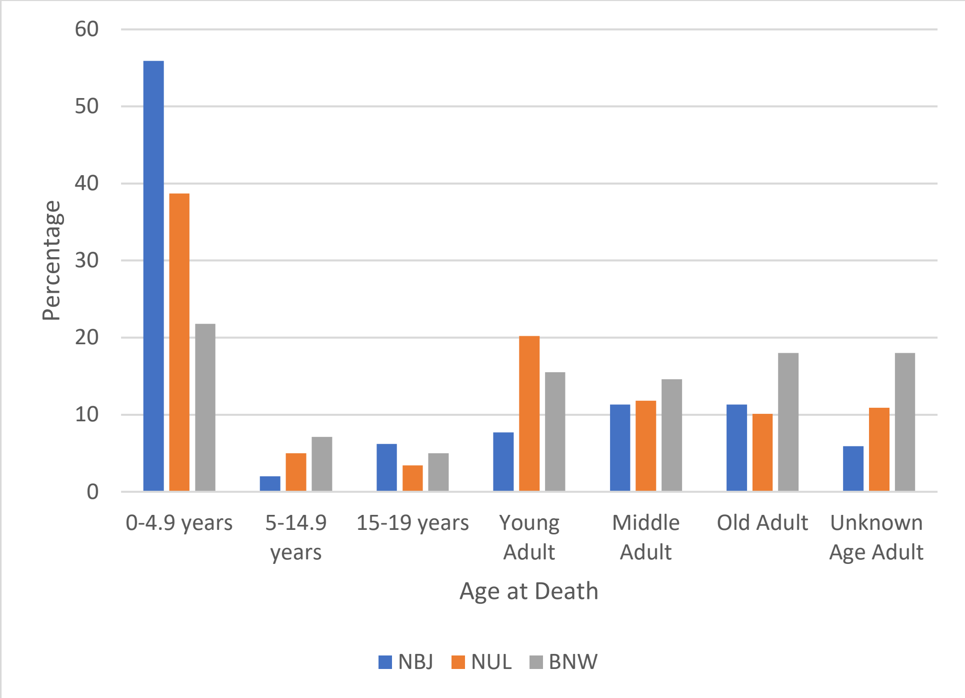

Figure 3.5: Age distribution of sites in Iron Age periods at Non Ban Jak, Noen U-Loke and Ban Non Wat
NBJ: Non Ban Jak; NUL: Noen U-Loke; BNW: Ban Non Wat

Non Ban Jak has the highest prevalence of age at death of 0-4.9 year olds. Noen U-Loke has the highest prevalence of young adult deaths, whereas Ban Non Wat has the highest in the middle and old adult categories.

Fertility – high or low?

Non Ban Jak is a site of high nonadult mortality, having the highest in the region (Buckley et al., 2020). This may be indicative of either a high level of fertility and/or ill health of the population (Buckley et al., 2020). Given the connection between nonadult mortality, maternal health (including dental health) and fertility, an analysis of fertility at Non Ban Jak is warranted.

The D0-14/D ratio developed by McFadden and Oxenham (2017) estimates total fertility rates. It utilises raw age at death data derived from the skeletal samples to avoid the necessity of modelling age-specific mortality rates. In turn, this ratio can be used to establish the rate of natural population increase (RNPI) (McFadden & Oxenham, 2018b). Changes in population size can provide information on both the health of the population and the population's response to change (McFadden & Oxenham, 2018b). The D0-14/D ratio for Non Ban Jak, calculated using the method in McFadden and Oxenham (2017), is 0.58. This ratio was used to determine the rate of natural population increase (RNPI) without migration, providing a rate of 4.22% (McFadden & Oxenham, 2018b). The fertility rate was 6.70 (McFadden & Oxenham, 2017) (Table 3.8). Total fertility rate is the average number of children born to each woman over her life, assuming she survived until the end of her reproductive age span (United Nations, 2017).

Table 3.8: D0-14/D ratio and rate of natural increase and maternal mortality rate for the Iron Age periods at Non Ban Jak, Ban Non Wat and Noen U-Loke

Site Iron Age	D0-14/D Ratio[a]	Fertility Rate[a]	RNPI[b] %	MMR
NBJ	0.58	6.70	4.22	299
BNW	0.29*	4.47^	1.26*	415[d]
NUL	0.44*	5.63^	2.83*	158[c]

NBJ: Non Ban Jak; BNW: Ban Non Wat; NUL: Noen U-Loke; MMR: Maternal Mortality Rate
[a] As described in McFadden and Oxenham (2017)
[b] As described in McFadden and Oxenham (2018b)
*Data taken from McFadden and Oxenham (2018a); (McFadden & Oxenham, 2018b)
^ calculated using the equation from McFadden and Oxenham (2017)
[C] as per van Tiel and McFadden (2021)
[d] Calculated with unpublished BNW Iron Age at death distribution figures from Tayles and Domett (personal communication)

The calculated RNPI for Non Ban Jak of 4.22% is the second highest for prehistoric mainland Southeast Asia so far recorded. Only the Neolithic site of Man Bac in Vietnam has a higher RNPI of 4.32% (McFadden & Oxenham, 2018a). The next highest after Non Ban Jak is also from a Neolithic site, Khok Phanom Di, with RNPI of 4.01% (McFadden &

Oxenham, 2018a). Whilst the determination of ‘high’, ‘moderate’ or ‘low’ fertility is dependent upon the population under study, Preston et al. (1989) suggest an average of 1.64 is ‘low’, 3.59 is ‘moderate’ and 6.15 is ‘high’. The United Nations (2017) describes a fertility level under replacement level, a fertility rate of 2.1, as low. After the end of the Neolithic period, population growth in the region decreased and remained below 2.00% up until the Iron Age. At this time Iron Age Noen U-Loke has a 2.83% RNPI, in excess of Iron Age Ban Non Wat’s of 1.26% (McFadden & Oxenham, 2018a). The high RNPI (4.22%) for Non Ban Jak is outside the identified trend consistent with the archaeological narrative for mainland Southeast Asia (McFadden & Oxenham, 2018a). In accordance with the argument that this “skeletally based method is capable of detecting interregional, short-term population changes within communities” (McFadden & Oxenham, 2018a, p. 99), it appears that something different was happening at Non Ban Jak to the rest of the region. A RNPI of 0.04% results in exponential population growth (McFadden & Oxenham, 2018a), so a population growth of 4.22% at Non Ban Jak could not possibly have occurred over thousands of years, so it is feasible to suggest that this growth rate represents the growth rate for a short period of time, such as decades or one to two centuries (McFadden & Oxenham, 2018a; Milner et al., 2019). Non Ban Jak was a site occupied for a shorter period of time in the Iron Age than other nearby sites and this is potentially impacting the results of the RNPI calculation. However, this community-level indication of growth can allow an investigation into both the population’s response to change and the localised conditions potentially impacting the population dynamics. Non Ban Jak’s rate of population increase will be discussed further and contextualised with the dental health evidence in this thesis.

The RNPI calculated for the different mounds and mortuary phases at Non Ban Jak (Table 3.9) reveal that both the total east mound rate (5.28%) and the early east mound rate (5.94%) are higher than the total west mound rate (3.81%) and the early west mound rate

(3.42%). The total early mortuary phase has a higher rate (4.85%) than the late mortuary phase (3.22%). Over time the RNPI has decreased. The demography of a population is influenced and affected by fertility, infant mortality and maternal mortality (McFadden et al., 2020). In a population high fertility can contribute to high maternal mortality and high infant mortality, whilst high maternal mortality can lead to low fertility. These results will be contextualised within the results of the dental health analysis.

Table 3.9: D0-14/D ratio and rate of natural increase at Non Ban Jak comparing mounds and mortuary phases

Mound & Mortuary Phase	Individuals 0-14/D	D0-14/D Ratio[a]	Fertility Rate[a]	RNPI (%)[b]	MMR^
East Total	37/54	0.685	7.52	5.28	590
Early	30/40	0.750	8.03	5.94	
Late	7/14	0.500	6.09	3.42	
West Total	76/141	0.539	6.39	3.81	242
Early	47/80	0.588	6.77	4.31	
Late	29/61	0.475	5.90	3.17	
Total Early	77/120	0.642	7.19	4.85	1128
Total Late	36/75	0.480	5.94	3.22	110

[a] McFadden and Oxenham (2017)
[b] McFadden and Oxenham (2018b)
RNPI – Rate of Natural Population Increase
MMR: Maternal Mortality Rate
^ Stabilised Maternal Mortality Rate calculated as per McFadden et al. (2020)

Overall, Non Ban Jak has a maternal mortality rate (MMR) of 299 using the stabilised formula (Table 3.8), compared to Ban Non Wat with a MMR of 415 and Noen U-Loke 158. MMR of 0-323 is low, 323-605 is moderate and over 605 is high (McFadden et al., 2020). The early mortuary phase has an extremely high MMR (1128) and the late mortuary period has a low MMR (111). This implies a marked decrease in the maternal mortality during the late phase. The early mortuary phase also has a higher rate of fertility than the late mortuary phase (Table 3.9). The maternal mortality rate is high in the early phase when the RNPI is high, as is the fertility. At Non Ban Jak the maternal mortality is higher during times of increased fertility.

The east mound, for the entire Iron Age occupation, has a stabilised MMR of 590, which is moderate. The west mound, for the entire Iron Age occupation, has a low MMR of 242. In conjunction with its higher MMR, the east mound also had a higher fertility rate than the west mound. Potentially this difference in maternal mortality will be reflected in the female dental health of the site. These maternal mortality indications will be contextualised within the discussion of the dental health results in Section 5.1.

3.4.2 Dental Census of Non Ban Jak

A total of 70 individuals with permanent teeth from Non Ban Jak have formed the basis for the analysis of dental health. There were 24 females, 28 males, and 18 individuals of indeterminate sex (Table 3.10). Five of these individuals were younger than 15 years but had permanent teeth available for analysis.

Table 3.10: Non Ban Jak individuals with permanent teeth: age at death and sex distribution

Age	**Female**		**Male**		**Indet. sex**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**
<15 years	-	-	-	-	5	7.1	5	7.1
Young adult	6	8.6	8	11.4	9	12.9	23	32.9
Mid adult	10	14.3	10	14.3	0	0.0	20	28.6
Old adult	7	10.0	10	14.3	4	5.7	21	30.0
Unknown	1	1.4	0	0	0	0	1	1.4
Total	24	34.3	28	40.0	18	25.7	70	100.0
Sex diff. FET *p*-value	0.6000							

Indet. sex: indeterminate sex
Note: Relative age categories as described in Section 3.4.1

All age categories of adults were represented. The difference in the ratio of male to female adult individuals was not statistically significant (FET p-value = 0.6000).

Every tooth position that was able to be observed (refer Section 1.9 for explanation of how the dentition were observed) was recorded using the coding system in Table 3.11. For example, an intact, whole tooth present was recorded as a code '1'. Recognising the difference between an ablated tooth, one lost pathologically or one congenitally absent (agenesis) is not as straightforward. Further reference will be made to this issue in the sections that analyse antemortem tooth loss (Section 4.3) and agenesis (Chapter 6).

Table 3.11: Coding scheme for recording the presence and absence of teeth

Code	**Name**	**Description**
0	Post-mortem loss	Socket remaining
1	Present	*In situ* or loose
2	Post-mortem broken	All or part of crown remaining
3	Post-mortem loss	Root only remaining
4	Antemortem loss	Pathological
5	Antemortem loss	Ablation
6	Erupting	
7	Unerupted	
8	Agenesis	
9	Unknown	

The dental census determined that there were 1579 tooth positions, of which 581 were female, 709 were male, and 289 were of indeterminate sex (Table 3.12). The difference between the number of male and female tooth positions in the sample was statistically significant (FET p-value <0.0001). There were 1249 intact permanent teeth in the sample.

Sex

There were more teeth from males (709) than from females (581) in the total sample (Table 3.12) and the difference was statistically significant (*p*-value<0.0001). When sex and age group were considered, there was no statistical differences in the number of teeth when comparing males and females in the young and mid age groups (Table 3.12).

Age Groups

The cohort with permanent teeth/tooth positions was divided into four age groups: young, mid, old, and unknown age. At the individual level there were five adolescents of indeterminate sex, 23 young adults (8 male; 6 female and 0 indeterminate sex), 20 mid aged (10 male; 10 female), 21 old (10 male; 7 female and 4 of indeterminate sex) and one of unknown age. The young adults were the most numerous (32.9%), followed by the old adults (30.0%) and the mid adults (28.6%). The ratio of young to mid to old adults (individuals) was 1.2:1.0:1.1.

The highest number of teeth came from young adults (647), followed by mid (469) and then old (446). The difference between the number of teeth from young adults and mid adults was statistically significant (*p*-value <0.0001); between teeth from young adults and teeth from old adults was also statistically significant (*p*-value <0.0001); whilst the difference between the number of teeth between the mid adults and the old adults was not statistically significant (*p*-value = 0.3882).

Occupation Mound

There were two occupation mounds at Non Ban Jak, an east and a west. There were more individuals with permanent teeth excavated from the west mound (51) compared to the east mound (19), which is a ratio of west to east of 2.7:1.0. Sex distribution of individuals from the east mound was 6 male, 4 female and 9 individuals of indeterminate sex, which is a ratio of male to female of 1.5:1.0. Whereas the western mound comprised 23 male, 19 female and 9 indeterminate sex individuals which is a male to female ratio of 1.2:1.0.

Table 3.12: Non Ban Jak permanent teeth position distribution by age at death and sex, by tooth

Adult age	**Female**		**Male**		**Sex diff. by age *p*-value**	**Indet. sex**		**Total**			**Age group *p*-value**
	n	**%**	**n**	**%**	**FET**	**n**	**%**	**n**	**%**		**FET**
Young	182	28.1	189	29.2	0.0730	276	42.7	647	41.0	Young v Mid	<0.0001*
Mid	207	44.1	262	55.9	0.6419	0	0	469	29.7		
Old	175	39.2	258	57.8	0.0179*	13	2.9	446	28.2	Mid v Old	0.3882
Unknown	17	100	-	-		-	-	17	1.1		
										Young v Old	<0.0001*
Total	581	36.8	709	44.9	<0.0001*	289	19.4	1579	100		

n: number of tooth positions
*denotes statistical significance (p-value <0.05)

The highest number of tooth positions were from the western mound (1187) with only a small number from the east (392) (Table 3.13), which gives a west mound:east mound ratio of 3.0:1.0 (Figure 3.6). Whilst differences in the number of teeth in the western mound compared to the eastern are statistically significant (Table 3.13), this is somewhat expected given 72.3% of the individuals were found on the western mound (Table 3.4).

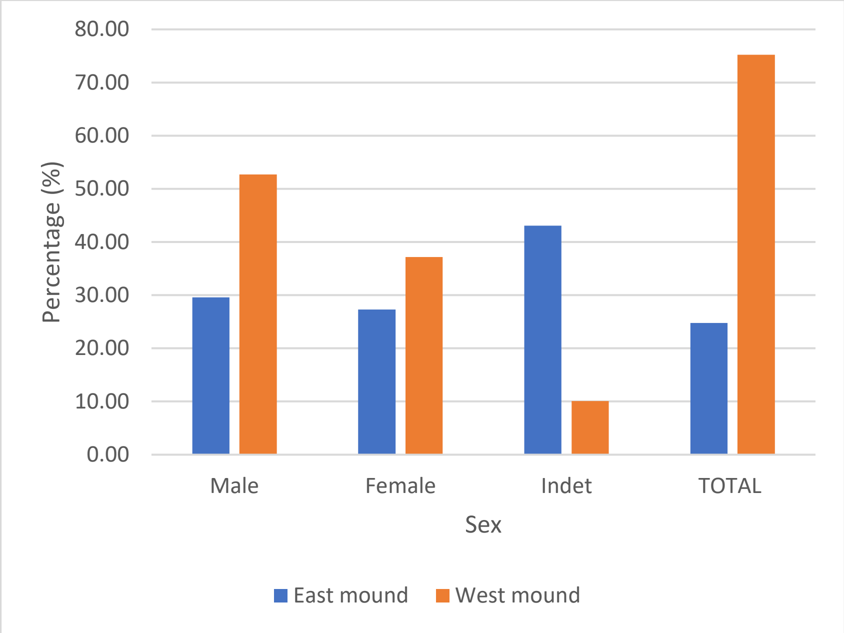

Figure 3.6: Non Ban Jak tooth positions by mound and sex

Table 3.13: Non Ban Jak permanent teeth position distribution by occupation mound by tooth

Occupation Mound	**Male**		**Female**		**Sex diff. *p*-value**	**Indet. Sex**		**Total**		**Occupation mound diff *p*-value**
	n	**%**	**n**	**%**	**FET**	**n**	**%**	**n/N**	**%**	**FET**
East	116	29.6	107	27.3	0.5266	169	43.1	392/1579	24.8	<0.0001*
West	593	49.9	474	39.9	<0.0001*	120	10.1	1187/1579	75.2	
Total	709	44.9	581	36.7		289	18.3	1579	100	
Mound and sex diff. *p*-value	**FET**	<0.0001*	**FET**	<0.0001*		**FET**	<0.0001*			

n: number of teeth
*denotes statistical significance (*p*-value <0.05)

Mortuary Phase

The mortuary phases have been separated into an early and a late phase. There was a statistically significant difference (*p*-value <0.0001) in the number of tooth positions assessable in the early (705) and late (874) phases, and between males and females in the late phase (Table 3.14 and Figure 3.7).

Table 3.14: Non Ban Jak permanent teeth distribution by mortuary phase by tooth

Mortuary Phase	**Male**		**Female**		**Sex diff. *p*-value**	**Indet. Sex**		**Total**		**Mortuary Phase diff *p*-value**
	n	**%**	**n**	**%**	**FET**	**n**	**%**	**n**	**%**	**FET**
Early	283	40.1	292	41.4	0.6646	130	18.4	705	44.6	<0.0001*
Late	426	48.7	289	33.6	<0.0001*	159	18.2	874	55.4	
	709	44.9	581	36.8				1579	100.0	
Total MP and sex diff. *p*-value **FET**	<0.0001*		0.1886			0.0838				

n: number of teeth
*denotes statistical significance (*p*-value <0.05)

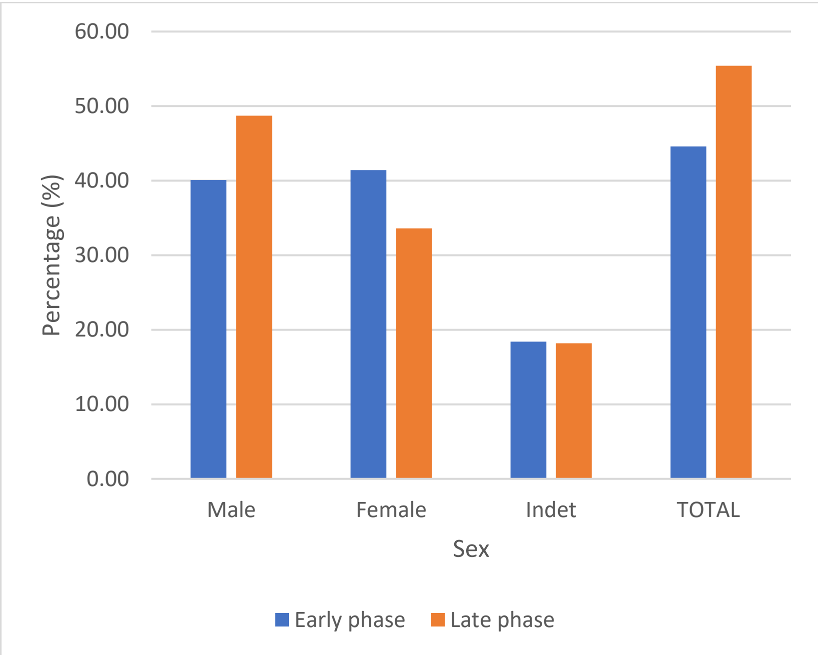

Figure 3.7: Non Ban Jak tooth position prevalence by mortuary phase and sex

Chapter 4 Methods and Results

This chapter describes the methods used in the dental health analysis conducted on the skeletal sample from Non Ban Jak and documents the results of the analysis. Advanced wear, caries and antemortem tooth loss were analysed. The chapter ends with a summary of the results. The results will be discussed in Chapter 5.

Statistical analysis was conducted using Prism 9 software. Two-sided Fisher's Exact Tests (FET) with a significance value of $p<0.05$, were conducted, unless otherwise stated. However, it is acknowledged that data interpretation is more than simply *p*-values (Amrhein et al., 2019; Wasserstein et al., 2019) and as such, the dental pathology discussion (Chapter 5) will contextualise the results further than is described in this chapter.

4.1 Advanced Wear

4.1.1 Methods

Advanced wear in the permanent dentition was recorded utilising the methods of Smith (1984) for incisors, canines and premolars, and Scott (1979) for the molars. Figures 4.1 and 4.2 provide an example of advanced wear on the dentition at Non Ban Jak.

Incisors, canines, and premolars with grades 6 to 8 on the Smith (1984) scale were deemed to have advanced wear. For the molar teeth, scores for each quadrant were given in accordance with Scott (1979), with the quadrant scores then averaged to produce a wear score for each tooth with average grades 7 to 10 signifying advanced wear.

In this analysis the anterior teeth are classed as the incisors and the canines. The posterior teeth are the premolars and molars.

Figure 4.1: Maxilla from Non Ban Jak (Burial 20; Old adult; Male) exhibiting advanced wear

4.1.2 Advanced Wear Results

A total of 1237 permanent teeth were analysed with 15.5% (192/1237) determined to have advanced wear (Table 4.1 and Figure 4.3).

Figure 4.2: Mandible from Non Ban Jak (Burial 171; Mid adult; Male) with teeth 47 (right second molar), 48 (right third molar), 37 (left second molar) and 38 (left third molar) exhibiting advanced wear

Table 4.1: Proportion of advanced wear by tooth among the Non Ban Jak sample – all permanent teeth

Age Group	Male		Female		Sex diff *p*-value	Indet. Sex		Total	
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**
Young	0/193	0	0/131	0	-	0/191	0	0/515	0
Mid	34/205	16.6	13/153	8.5	0.0271*	0/0	0	47/358	13.1
Old	87/215	40.5	53/134	39.6	0.9108	3/12	25.0	143/361	39.6
Unknown	0/0	0	2/3	66.7	>0.9999	0/0	0	2/3	66.7
TOTAL	121/613	19.7	68/421	16.2	0.1638	3/203	1.5	192/1237	15.5

n, number of teeth with advanced wear; N, number of observed teeth
Note: comparisons between young and old age groups are not valid as dental wear was used in many cases to assist in the determination of age at death, comparisons between male and female within each age group are valid
*statistically significant *p*-value <0.05.

The prevalence of advanced wear was 19.7% for male teeth (121/613), 16.2% (68/421) for female teeth and 1.5% (3/203) for indeterminate sex (Table 4.1). The difference between the male and female prevalence was not statistically significant (*p*-value = 0.1638).

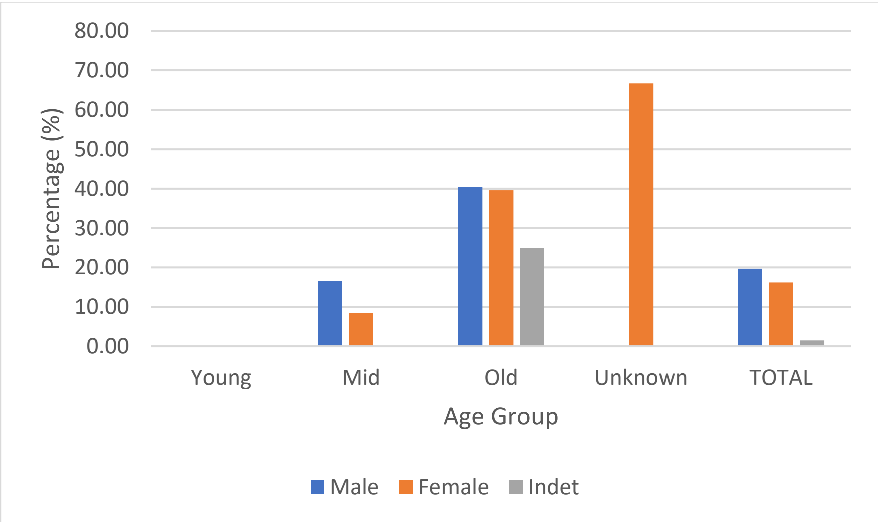

Figure 4.3: Prevalence of advanced wear by sex and age group at Non Ban Jak

Occupation Mound Differences

The teeth from the individuals of east mound had a higher prevalence of advanced wear (17.6%, 54/307) compared to those from the west mound (14.8%, 138/930), a statistically insignificant (*p*-value = 0.2752) difference (Table 4.2 and Figure 4.4). There were sex-based differences across the occupation mounds (Table 4.3). The teeth of females on the east mound had a statistically significantly (*p*-value = 0.0002) higher prevalence of advanced wear (29.5%) than on the west mound (12.3%). The teeth of males also had a statistically significantly (*p*-value = 0.0380) higher prevalence of advanced wear on the east mound (28.6%) compared to the west mound (18.3%) (Table 4.3).

The prevalence rate for advanced wear of the anterior teeth in the east mound was 24.3% compared to 15.4% from the west mound (statistically significant, *p*-value = 0.0455). The posterior teeth from the east mound exhibited a slightly lower prevalence of advanced wear (13.5%) than those from the west mound (14.5%), however this difference was not statistically significant (*p*-value = 0.8135) (Table 4.2).

Table 4.2: Advanced wear in teeth by occupation mound and tooth position at Non Ban Jak

	Anterior Teeth			**Posterior Teeth**			**TOTAL**		
Occupation Mound	**n/N**	**%**	***p*-value FET**	**n/N**	**%**	***p*-value FET**	**n/N**	**%**	***p*-value FET**
East	28/115	24.3	0.0455*	26/192	13.5	0.8135	54/307	17.6	0.2752
West	49/318	15.4		89/612	14.5		138/930	14.8	
TOTAL	77/433	17.8		115/804	14.3		192/1237	15.5	

n, number of teeth with advanced wear
N, number of teeth assessed
* statistically significant *p*-value <0.05

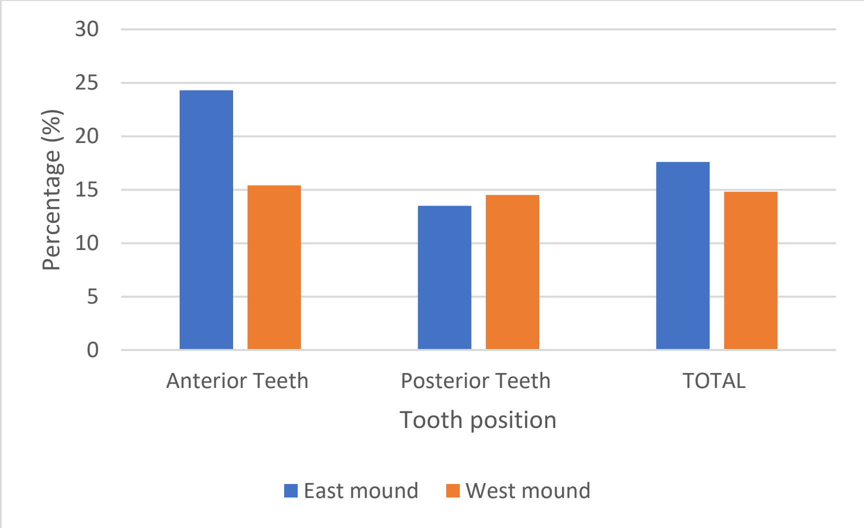

Figure 4.4: Prevalence of advanced wear by occupation mound and tooth position at Non Ban Jak

Table 4.3: Prevalence of advanced wear, combined teeth, by mound and sex at Non Ban Jak

Mound		n/N	%	Male v Female *intra*-mound FET *p*-value	Male v Female *inter*-mound FET *p*-value
East		**54/307**	**17.6**		East Female v West Female
	Female	28/95	29.5	>0.9999	0.0002*
	Male	24/84	28.6		
	Indet	2/128	1.6		
West		**138/930**	**14.8**		East Male v West Male
	Female	40/326	12.3	0.0211*	0.0380*
	Male	97/529	18.3		
	Indet	1/75	1.3		
TOTAL		**192/1237**	**15.5**		
	Female	68/421	16.2	0.1638	
	Male	121/613	19.7		
	Indet	3/203	1.5		

n, number of teeth with advanced wear
N, number of teeth assessed
* statistically significant *p*-value <0.05

Mortuary Phase Differences

The prevalence of teeth with advanced wear was greater during the early mortuary phase (17.1%) compared to the late phase (14.5%) (Table 4.4). The difference was found to be not statistically significant (*p*-value = 0.2309). The teeth from male individuals had a higher prevalence (61/243; 25.1%) of advanced wear than teeth from females (23/171, 13.5%) in the early mortuary phase, which was statistically significant (*p*-value = 0.0042). However, this was reversed in the late mortuary phase when female teeth had a higher prevalence of advanced wear (45/250, 18.0%) compared to the male teeth (60/370, 16.2%) and this was not statistically significant (*p*-value = 0.5861) (Figure 4.5).

For male teeth, the prevalence rate decreased from the early mortuary phase, 25.1% to 16.2% in the late mortuary phase. This difference was statistically significant (*p*-value = 0.0093). For female teeth, the prevalence rate increased from 13.5% in the early phase to 18.0% in the late phase, which was not statistically significant (*p*-value = 0.2276) (Table 4.4).

Table 4.4: Proportion of advanced wear by tooth among the sample by mortuary phase and sex at Non Ban Jak

Mortuary Phase	**Male**		**Female**		**Sex diff. *p*-value**	**Indet Sex**		**Total**		**Mortuary Phase diff. *p*-value**
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**
Early	61/243	25.1	23/171	13.5	0.0042*	2/90	2.2	86/504	17.1	0.2309
Late	60/370	16.2	45/250	18.0	0.5861	1/113	0.9	106/733	14.5	
Mortuary Phase diff. *p*-value	FET	0.0093*	FET	0.2276		FET	0.5854			

n, number of teeth with advanced wear; N, number of observed teeth
Note: comparisons between young and old age groups are not valid as dental wear was used in many cases to assist in the determination of age at death
* statistically significant *p*-value <0.05

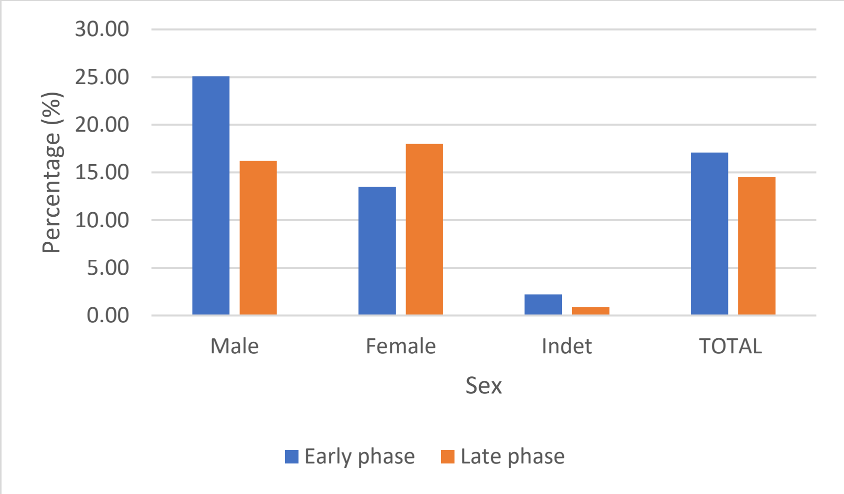

Figure 4.5: Prevalence of advanced wear by mortuary phase and sex at Non Ban Jak

Tooth Type and Arch Differences

Advanced wear was found in 17.8% of anterior teeth (77/433) (Table 4.5). The difference in prevalence of advanced wear in the anterior teeth between the male (21.3%) and female (21.1%) teeth was not statistically significant (*p*-value = 0.1178) (Figure 4.6).

The maxillary anterior teeth had a prevalence of advanced wear of 21.6% (47/218), whereas the mandibular anterior teeth had a prevalence of advanced wear of 14.0% (30/215) (Table 4.6). This difference was statistically significant (*p*-value = 0.0443).

Prevalence of advanced wear for the posterior teeth was 14.3% (115/804) (Table 4.7). Male posterior teeth with advanced wear had a prevalence rate of 19.0% (77/406). Female posterior teeth had an advanced wear prevalence rate of 13.5% (37/274). The difference between male and female posterior teeth with advanced wear was not statistically significant (*p*-value = 0.0749) (Figure 4.6). When the posterior teeth were considered by arch, the maxillary posterior teeth had a prevalence of advanced wear of 11.7% (47/402), whereas the mandibular posterior teeth had a prevalence of advanced wear of 16.9% (68/402) (Table 4.7). This difference was statistically significant (*p*-value = 0.0436).

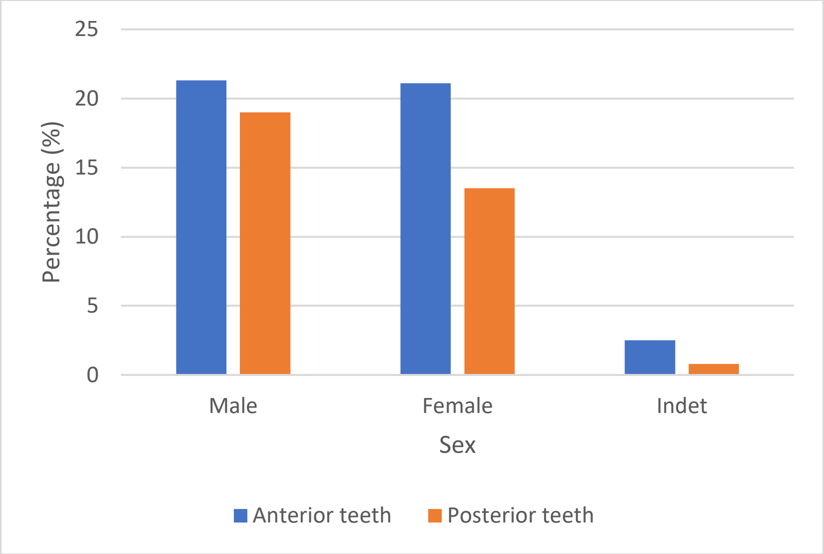

Figure 4.6: Prevalence of advanced wear in anterior and posterior teeth by sex at Non Ban Jak

Table 4.5: Proportion of advanced wear by tooth at Non Ban Jak – anterior and posterior teeth

	Anterior Teeth										**Posterior Teeth**								
Age Group	**Male**		**Female**		**Sex diff. *p*-value**	**Indet. Sex**		**Total Anterior**		**Male**		**Female**		**Sex diff. *p*-value**	**Indet. Sex**		**Total Posterior**	
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**
Young	0/69	0	0/48	0	-	0/73	0	0/190	0	0/124	0	0/83	0	-	0/118	0	0/325	0
Mid	14/61	23.0	9/49	18.4	0.6407	0/0	0	23/110	20.9	20/144	13.9	4/104	3.8	0.0086*	0/0	0	24/248	9.7
Old	30/77	39.0	20/48	41.7	0.8516	2/6	33.3	52/131	39.7	57/138	41.3	33/86	38.4	0.6770	1/6	16.7	91/230	39.6
Unknown	0/0	0	2/2	100	>0.9999	0/0	0	2/79	2.5	0/0	0	0/1	0	>0.9999	0/0	0	0/1	0
Total	44/207	21.3	31/147	21.1		2/79	2.5	77/433	17.8	77/406	19.0	37/274	13.5		1/124	0.8	115/804	14.3
					Difference in Anterior and Posterior teeth *p*-value			FET	0.1178									

n, number of teeth with advanced wear; N, number of observed teeth; *denotes a statistically significant *p*-value <0.05
Note: comparisons between young and old age groups are not valid as dental wear was used in many cases to assist in the determination of age at death

Table 4.6: Proportion of advanced wear by tooth at Non Ban Jak – anterior teeth by arch

	Anterior Teeth - Maxilla									**Anterior Teeth – Mandible**								
Age Group	**Male**		**Female**		**Sex diff. *p*-value**	**Indet. Sex**		**Total Anterior Maxilla**		**Male**		**Female**		**Sex diff. *p*-value**	**Indet, Sex**		**Total Anterior Mandible**	
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**
Young	0/34	0	0/22	0	-	0/33	0	0/89	0	0/35	0	0/26	0	-	0/40	0	0/101	0
Mid	11/35	31.4	8/26	30.8	>0.9999	0/0	0	19/61	31.1	3/26	11.5	1/23	4.3	0.6119	0/0	0	4/49	8.2
Old	15/43	34.9	11/21	52.4	0.2782	1/3	33.3	27/67	40.3	15/34	44.1	9/27	33.3	0.4385	1/3	33.3	25/64	39.1
Unknown	0/0	0	1/1	100	-	0/0	0	1/1	100	0/0	0	1/1	100	-	0/0	0	1/1	100
Total	26/112	23.2	20/70	28.6	0.4840	1/36	2.8	47/218	21.6	18/95	18.9	11/77	14.3	0.5396	1/43	2.3	30/215	14.0
					Diff. in anterior maxilla v mandible *p*-value			FET	0.0443*									

n, number of teeth with advanced wear; N, number of observed teeth; *denotes a statistically significant *p*-value <0.05
Note: comparisons between young and old age groups are not valid as dental wear was used in many cases to assist in the determination of age at death

Table 4.7: Proportion of advanced wear by tooth at Non Ban Jak – posterior teeth by arch

	Posterior Teeth - Maxilla									**Posterior Teeth – Mandible**								
Age Group	**Male**		**Female**		**Sex diff. *p*-value**	**Indet. Sex**		**Total Posterior Maxilla**		**Male**		**Female**		**Sex diff. *p*-value**	**Indet, Sex**		**Total Posterior Mandible**	
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**
Young	0/61	0	0/44	0	-	0/60	0	0/165	0	0/63	0	0/39	0	-	0/58	0	0/160	0
Mid	10/78	12.8	0/39	0	0.0295*	0/0	0	10/117	8.5	10/66	15.2	4/65	6.2	0.1557	0/0	0	14/131	10.7
Old	23/73	31.5	13/42	31.0	>0.9999	1/4	25.0	37/119	31.1	34/65	52.3	20/44	45.5	0.5596	0/2	0	54/111	48.6
Unknown	0/0	0	0/1	0	-	0/0	0	0/1	0	0/0	0	0/0	0	-	0/0	0	0/0	0
TOTAL	33/212	15.6	13/126	10.3	0.1925	1/64	1.6	47/402	11.7	44/194	22.7	24/148	16.2	0.0431*	0/60	0	68/402	16.9
					Diff. in posterior maxilla v mandible *p*-value			FET	0.0436*									

n, number of teeth with advanced wear; N, number of observed teeth; *denotes a statistically significant *p*-value <0.05
Note: comparisons between young and old age groups are not valid as dental wear was used in many cases to assist in the determination of age at death

Advanced Wear Results Summary

Overall, advanced wear was present in 15.5% (192/1237) of teeth. Teeth from male individuals had a statistically insignificantly (*p*-value = 0.1638) higher prevalence of advanced wear (19.7%) than teeth from the female individuals (16.2%). The anterior teeth had a higher prevalence of advanced wear (17.8%) than the posterior teeth (14.3%), however this was not statistically significant (*p*-value = 0.1178).

Dental remains from the early mortuary phase (17.1%) had a higher prevalence of teeth with advanced wear than the late mortuary phase (14.5%) although this was not statistically significant (*p*-value = 0.2752). Male teeth had a higher prevalence of advanced wear in the early mortuary phase compared to the late phase. This pattern was reversed for female teeth, which had a higher prevalence of teeth with advanced wear in the late mortuary phase compared to the early.

In the early mortuary phase, males had a statistically significantly (*p*-value = 0.0042) higher prevalence (25.1%) of advanced wear than females (13.5%). This pattern was reversed in the late phase when females had a statistically insignificantly (*p*-value = 0.5861) higher prevalence of advanced wear (18.0%) than males (16.2%).

Teeth from the east mound (17.6%) had a statistically insignificantly (*p*-value = 0.2752) higher prevalence of advanced wear than those from the west mound (14.8%).

4.2 Caries

4.2.1 Methods

Every observable permanent tooth (from adults and subadults) was assessed for the presence or absence of carious lesions. The lesions were identified by the demineralisation of enamel or root surfaces. The location of each lesion was also recorded (Table 4.8).

Table 4.8: Codes for classification of carious lesions (Adapted from Hillson (1996))

Code	Meaning
0	No caries
1	Pit/Fissure – located in the molar buccal and lingual pits and grooves
2	Interproximal – located at the point of contact between two adjacent teeth
3	Smooth surface – located on the smooth buccal or lingual surfaces
4	Cervical (CEJ) – located at the cementum-enamel junction
5	Root – located on the root below the CEJ
6	Massive – involving the crown of the tooth to an extent that obscures the site of the original caries
7	Occlusal – located on the occlusal fissures of premolars and molars

The recording method was that utilised by Associate Professor Domett who collected the data during the field seasons at Non Ban Jak. The method has been utilised in other works from the region (Domett, 2001; Domett & Tayles, 2006; Domett & Tayles, 2007) providing a level of standardisation and ease of comparison.

The observed caries rate, the proportion of the number of carious teeth over the total number of teeth observed, is reported using the tooth count method to enable comparisons with other previously published studies. All teeth observed with caries only ever had one lesion per tooth.

4.2.2 Caries Results

A total of 1186 permanent teeth were observed in the analysis and a total of 57 teeth were affected by caries (57/1186, 4.8%) (Table 4.9). Figure 4.7 provides an example. Female teeth had a higher prevalence rate of caries (26/414, 6.3%) than do male teeth (29/586, 4.9%). This difference was not statistically significant (*p*-value = 0.3991) (Table 4.9 and Figure 4.8).

Figure 4.7: Mandible from Burial 171 (Mid adult; Male) with evidence of carious lesion, grade 7, on tooth 44 (right first premolar)

Table 4.9: Proportion of caries by tooth at Non Ban Jak – all teeth

Age Group	**Male**		**Female**		**Sex diff *p*-value**	**Indet. Sex**		**Total**		**Total age group diff. *p*-value**	
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**	
Young	1/195	0.5	3/130	2.3	0.3058	0/176	0	4/501	1.0	Young v Mid	<0.0001*
Mid	13/210	6.2	6/144	4.2	0.4780	0/0	0	19/354	5.4	Young v Old	<0.0001*
Old	15/181	8.3	15/136	11.0	0.4421	2/10	20.0	32/327	9.8	Mid v Old	0.0297*
Unknown	0/0	0	2/4	50.0	-	0/0	0	2/4	50.0		
Total	29/586	4.9	26/414	6.3	0.3991	2/186	1.1	57/1186	4.8		

n, number of teeth with carious lesions; N, number of observed teeth
*statistically significant *p*-value <0.05.

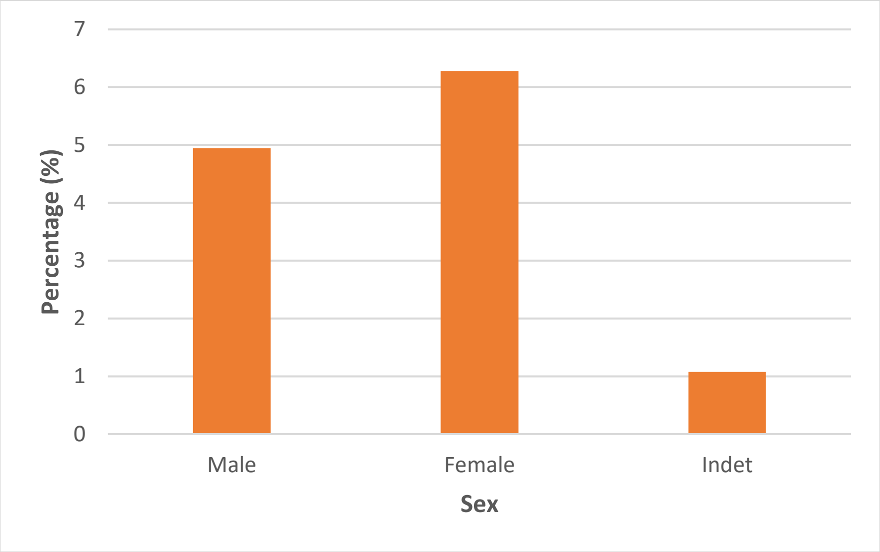

Figure 4.8: Caries prevalence for male, female and indeterminate sex, by tooth, at Non Ban Jak

Age Group differences

The prevalence of caries increased with age among the total sample (Table 4.9), with the youngest age group having the lowest prevalence (1.0%), followed by the mid adults (5.4%), then older adults (9.8%). This pattern was repeated when the age groups were analysed by sex (Table 4.9). Both male and female teeth in the youngest age group had low caries rates, with female teeth higher but not statistically significant (p-value = 0.3058). In the mid adult age group, caries prevalence increased in both male and female teeth, with the male teeth having the higher rate (statistically insignificant, p-value = 0.4780). In the oldest age group, again caries prevalence increased in both male and female teeth with female teeth having more caries compared with male teeth, the difference was not statistically significant (p-value = 0.4421).

Occupation Mound Differences

Overall, the difference in the caries prevalence rate from the two mounds was not statistically significant (*p*-value = 0.2123), however the teeth from the east mound had a slightly higher rate (6.3%) than the teeth from the west mound (4.3%) (Table 4.10). The higher prevalence rate for the east mound teeth remained when the data was analysed by sex for the males, with a statistically significant (p-value = 0.0008) higher prevalence rates of 3.5% in the west mound and 12.6% in the east. This trend was reversed with the females, with a prevalence of 6.5% in the west compared to 5.5% in the east, although this difference was not statistically significant (*p*-value > 0.9999) (Figure 4.9).

Table 4.10: Proportion of caries by tooth among the sample by occupation mound at Non Ban Jak

Occupation Mound	**Male**		**Female**		**Sex diff. *p*-value**	**Indet Sex**		**Total**		**Occupation Mound diff. *p*-value**
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**
East	12/95	12.6	5/91	5.5	0.1265	2/118	1.7	19/304	6.3	0.2123
West	17/491	3.5	21/323	6.5	0.0605	0/68	0.0	38/882	4.3	
Mound and sex diff. p-value	FET	0.0008*	FET	>0.9999		FET	0.5336			

n, number of teeth with carious lesions; N, number of observed teeth
* statistically significant *p*-value <0.05.

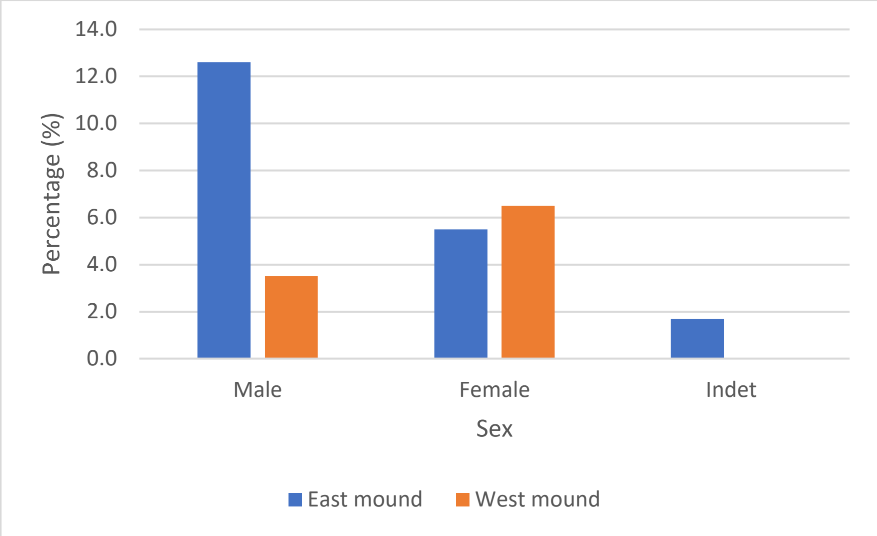

Figure 4.9: Proportion of caries by tooth per mound and sex at Non Ban Jak

Mortuary Phase Differences

There was a decline in the prevalence of caries from the early mortuary phase (8.3%; 42/509) to the late mortuary phase (2.2%; 15/671) which was statistically significant (*p*-value <0.0001) (Table 4.11).

Table 4.11: Proportion of caries by tooth among the sample by mortuary phase and sex at Non Ban Jak

Mortuary Phase	**Male**		**Female**		**Sex diff. *p*-value**	**Indet Sex**		**Total**		**Mortuary Phase diff. *p*-value**
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**
Early	25/254	9.8	15/176	8.5	0.7366	2/79	2.5	42/509	8.3	<0.0001*
Late	4/329	1.2	11/235	4.7	0.0156*	0/107	0.0	15/671	2.2	
Mortuary Phase diff. by sex *p*-value	FET	<0.0001*	FET	0.1509						

n, number of teeth with carious lesions; N, number of observed teeth
* statistically significant *p*-value <0.05.

Despite the female teeth prevalence rate almost halving from 8.5% to 4.7%, during the early to the late mortuary phase, this difference was not statistically significant (*p*-value = 0.1509). The male teeth prevalence rate, however, decreasing from 9.8% to only 1.2% in the late phase, was statistically significantly different (*p*-value <0.0001). Within the early phase, male and female teeth had a similar rate (8.5% and 9.8%, respectively) and both reduced in the late phase with female rate higher compared to the male in the late mortuary phase (4.7% and 1.2% respectively, *p*-value = 0.0156. (Figure 4.10).

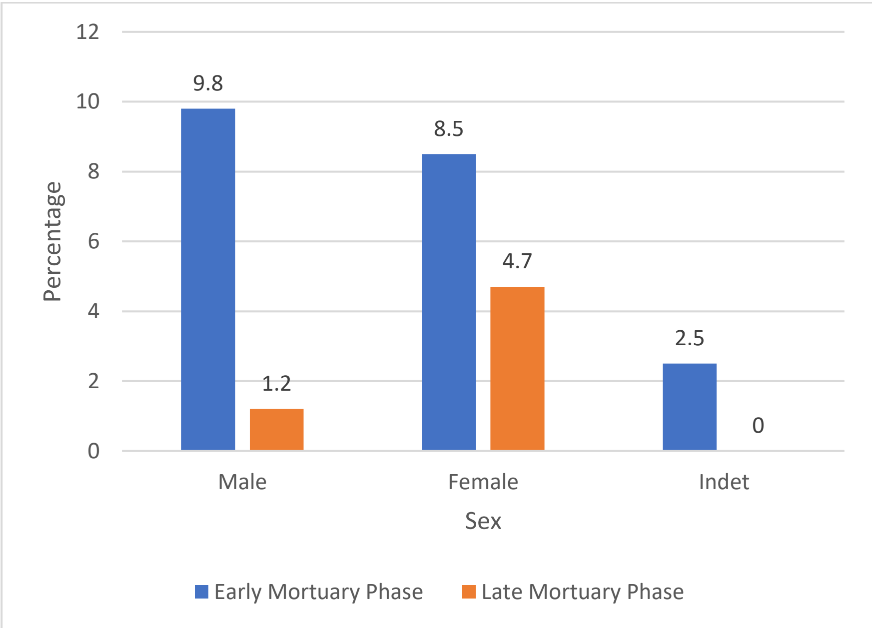

Figure 4.10: Caries prevalence by tooth per mortuary phase and sex at Non Ban Jak

Tooth Type and Arch Differences

The posterior teeth had a higher prevalence of caries (44/777, 5.7%) compared to the anterior teeth (13/406, 3.2%) (Table 4.12) although this was not statistically significant (*p*-value = 0.0638).

Table 4.12: Proportion of caries by tooth among the sample at Non Ban Jak – anterior and posterior teeth

Sex	Anterior Teeth n/N	Anterior Teeth %	Sex diff. *p*-value FET	Posterior Teeth n/N	Posterior Teeth %	Sex diff. *p*-value FET
Male	5/195	2.6	0.1632	24/388	6.2	0.8715
Female	8/142	5.6		18/269	6.7	
Indet	0/69	0		2/117	1.7	
Total	13/406	3.2		44/777	5.7	
Difference in Anterior and Posterior teeth *p*-value	**F**ET	0.0638				

n, number of teeth with carious lesions; N, number of observed teeth
* statistically significant *p*-value <0.05.

The most numerous type of carious lesion found was massive caries (24/57, 42.1%) (Table 4.13 and Figure 4.11). The majority of the massive caries (22/24, 91.7%) appear on the posterior teeth, with the majority being found in the maxilla (16/22, 72.7%). The second most common type of caries were on the occlusal surface of the dentition (12/57, 21.01%) (Figure 4.12). These two types of caries account for 63.1% (36/57) of all caries.

Figure 4.13 illustrates the variation in the distribution of caries type when considered by age. Only four caries were found in the teeth belonging to the young age group, two located on mandibular molars, one on a maxillary canine and one occlusal surface lesion located on a mandibular molar. The oldest age group had the most amount of each type of caries, except for root caries, which were not observed in this analysis, and smooth surface caries which were only observed in the young and mid aged individuals.

Table 4.13: Location of caries lesion by age at Non Ban Jak

	Location of Lesion													
Age Group	**Pit/Fissure**		**Inter-proximal**		**Smooth Surface**		**Cervical (CEJ)**		**Root**		**Massive**		**Occlusal**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Young	0	0	0	0	3	5.3	0	0	0	0	0	0	1	1.8
Mid	0	0	2	3.5	1	1.8	2	3.5	0	0	10	17.5	4	7.0
Old	4	7.0	4	7.0	0	0	5	8.8	0	0	12	21.1	7	12.3
Unknown	0	0	0	0	0	0	0	0	0	0	2	3.5	0	0
Total	4	7.0	6	10.5	4	7.0	7	12.3	0	0	24	42.1	12	21.1

n, number of teeth with type of carious lesion
Note: total number of teeth with carious lesions was 57.

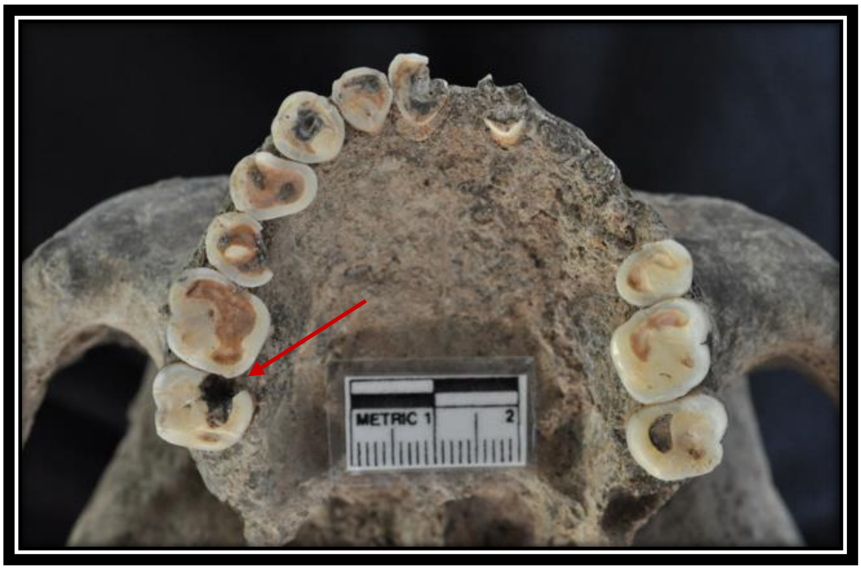

Figure 4.11: Burial 57 (Old adult; Female) with an example of massive caries (grade 6) on tooth 17 (right second molar)

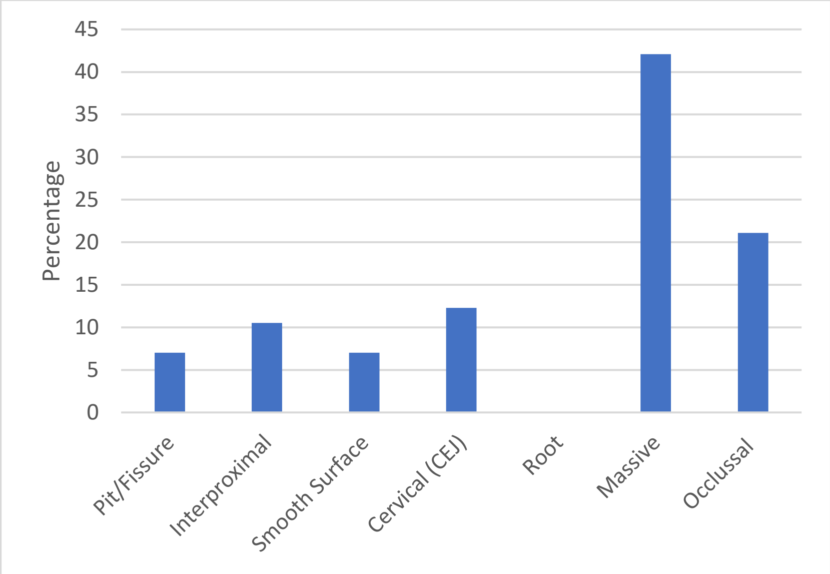

Figure 4.12: Location of caries as a percentage of all caries at Non Ban Jak

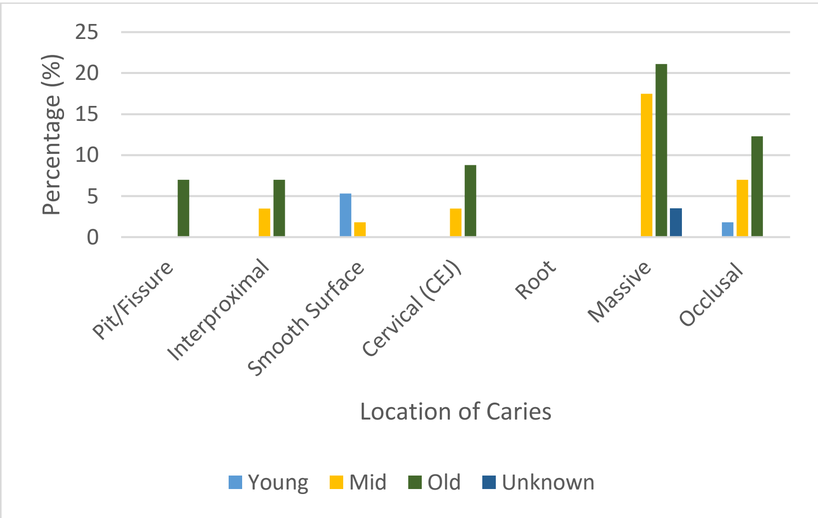

Figure 4.13: Location of carious lesion by age at Non Ban Jak

Caries Results Summary

The overall caries rate was 4.8% (57/1186). There were statistically significant differences in caries prevalence between the age groups, with the prevalence of caries increasing with age.

Overall, females had a higher prevalence rate (6.3%) than males (4.9%) although this was statistically insignificant (*p*-value = 0.3991). The highest prevalence was in the oldest age group for both female (11.0%) and male (8.3%) teeth although this difference was not statistically significant (*p*-value = 0.4421).

There was a statistically significant decline in the overall caries rate from the early mortuary phase (8.3%) to the late mortuary phase (2.2%) (*p*-value <0.0001). Whilst the prevalence rate for females almost halved from the early (8.5%) to the late (4.7%), it remained higher than that of the males in the late phase (1.2%).

The teeth from the east mound had a higher prevalence rate (6.3%) than the teeth from the west (4.3%), although this was statistically insignificant (*p*-value = 0.2123). Whilst this trend was true for males with a rate of 3.5% in the west compared to the higher 12.6% in the east, this pattern was reversed for females with a higher rate in the west (6.5%) compared to the east (5.5%).

The majority of carious lesions were either massive caries (42.1%) or occlusal surface caries (21.01%) in both males and females and the posterior teeth had a higher prevalence of caries (5.7%) compared to the anterior teeth (3.2%), however this was not statistically significant (*p*-value = 0.0638).

4.3 Antemortem Tooth Loss

4.3.1 Methods

Every dentition and each loose tooth were macroscopically analysed. The presence or absence of a tooth was recorded in accordance with the codes listed in Table 4.14.

Table 4.14: Dental presence and absence codes utilised in this study

Code	Meaning
0	Post-mortem loss, socket remaining
1	Present – *in situ* or loose
2	Postmortem broken – all or part of crown remaining
3	Postmortem loss – root only remaining
4	Antemortem loss – pathological
5	Antemortem loss – ablation
6	Erupting
7	Unerupted
8	Agenesis
9	unknown

To establish whether a tooth had been lost antemortem, every available tooth position was assessed for pathological loss (Figure 4.14 for an example of antemortem tooth loss). To establish the total number of tooth positions available for analysis, the number of positions/teeth in codes 0, 1, 2, 3, 4, 5, 6, 7, and 8 were totalled.

The differentiation between antemortem and post mortem tooth loss was based upon evidence of alveolar bone remodelling (Domett et al., 2013). Intentional ablation is considered as most likely if there is no evidence for disease in the adjacent teeth and alveolar bone, symmetry or near symmetry of loss should be evident and the pattern of loss repeated among individuals within the group (Domett et al., 2013; Merbs, 1968).

Figure 4.14: Burial 108 (Mid adult; Male) mandible with evidence of AMTL at tooth positions 31 (left central incisor), 32 (left lateral incisor), 33 (left first premolar), 41 (right central incisor), 42 (right lateral incisor) and 43 (right first premolar

4.3.2 Antemortem Tooth Loss Results

The number of total permanent tooth positions observed (code 0, 1, 2, 3, 4, 5, 6, 7 and 8) was 1579. It was determined that 54 teeth were missing as the result of antemortem tooth loss (AMTL), revealing an overall prevalence of 3.4% (54/1579) (Table 4.15). No teeth were determined to be lost antemortem by ablation due, in part, to the lack of symmetry visible in the tooth loss, and the lack of pattern of tooth loss repetition within the sample. Numerous examples of congenital absence have been identified at Non Ban Jak. Congenital absence is a separate condition to AMTL and as such the identified cases of agenesis are not included in the results for AMTL – for detail see Chapter 6 regarding tooth agenesis.

Differences in Sex

There was a higher prevalence of female teeth lost antemortem (5.8%, 32/549), compared to male teeth (2.8%, 21/741), and the difference was statistically significant (*p*-value = 0.0101) (Table 4.15).

Table 4.15: Proportion of AMTL by tooth among the sample at Non Ban Jak – all teeth

Age Group	**Male**		**Female**		**Sex diff *p*-value**	**Indet. Sex**		**Total**		**Age group diff. *p*-value**	
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**	
Young	2/221	0.9	3/150	2.0	0.3976	1/276	0.4	6/647	0.9	Young v Mid	0.0007*
Mid	11/262	4.2	8/207	3.9	>0.9999	0/0	0	19/469	4.1	Mid v Old	0.7338
Old	8/258	3.1	8/175	4.6	0.4462	0/13	0	16/446	3.6	Young v Old	0.0034*
Unknown	0/0	0	13/17	76.5	-	0/0	0	13/17	76.5		
Total	21/741	2.8	32/549	5.8	0.0101*	1/289	0.3	54/1579	3.4		

n, number of teeth with AMTL; N, number of observed tooth positions
* statistically significant *p*-value <0.05.

Age Group Differences

The prevalence of AMTL varied with age group (Table 4.15). The youngest age group had the lowest prevalence of 0.9% (6/647). The mid adult age group had the highest prevalence of 4.1% (19/469), statistically significantly higher than the youngest (*p*-value = 0.0007), but not statistically significantly higher than the oldest group (3.6%; 16/446; *p*-value = 0.7338). Further analysis of age group by sex was not undertaken given the small sample sizes.

Tooth Type and Arch

The prevalence of AMTL was higher in the anterior dentition (24/590, 4.1%) compared to the posterior teeth (30/989, 3.0%), however this was not statistically significant (*p*-value = 0.3164) (Table 4.16). The tooth most frequently lost was the mandibular right second molar (7/54, 13.0%). The second most numerous tooth type lost antemortem was the maxillary right lateral incisor (5/54, 6.3%).

Table 4.16: Proportion of AMTL by tooth among the sample at Non Ban Jak – anterior and posterior teeth

	Anterior Teeth			Posterior Teeth		
Sex	**n/N**	**%**	**Sex diff. *p*-value FET**	**n/N**	**%**	**Sex diff. *p*-value FET**
Male	16/273	5.9	0.2825	5/468	1.1	<0.0001*
Female	7/202	3.5		25/347	7.2	
Indet	1/115	0.9		1/174	0.6	
Total	24/590	4.1		30/989	3.0	
			Diff. Anterior v Posterior teeth *p*-value	FET	0.3164	

n, number of teeth with AMTL; N, number of observed tooth positions
* statistically significant *p*-value <0.05.

The highest prevalence of AMTL was in female posterior teeth (25/347, 7.2%), followed by male anterior teeth (16/273, 5.9%) (Table 4.16). The difference between male and female anterior teeth was statistically insignificant (*p*-value = 0.2825), with male teeth having a prevalence of 5.9% (16/273) and female teeth a prevalence of 3.5% (7/202).

There was a statistically significant difference (*p*-value <0.0001) between the prevalence of antemortem loss in the female posterior teeth (25/347, 7.2%) and the male posterior teeth (5/468, 1.1%).

Occupation Mound Differences

The prevalence of AMTL was analysed by mound. The prevalence rate in the east mound teeth was 1.5% (6/392), whilst in the west mound it was 4.0% (48/1187) (Table 4.17). This difference was statistically significant (*p*-value = 0.0158), however, given the small sample size of the east mound these results need to be interpreted with caution.

Table 4.17: Proportion of AMTL by tooth among the sample by occupation mound at Non Ban Jak

Occupation Mound	**Male**		**Female**		**Sex diff. *p*-value**	**Indet Sex**		**Total**		**Occupation Mound diff. *p*-value**
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**
East	5/116	4.3	1/107	0.9	0.2147	0/169	0	6/392	1.5	0.0158*
West	16/625	2.6	31/442	7.0	0.0007*	1/120	0.8	48/1187	4.0	
TOTAL	21/741	2.8	32/549	5.8	0.0101*	1/289	0.3	54/1579	3.4	
Mound diff. by sex *p*-value	FET	0.3541	FET	0.0109*						

n, number of teeth with AMTL; N, number of observed tooth positions
* statistically significant *p*-value <0.05.

Male teeth had a statistically insignificant (*p*-value = 0.2147) higher prevalence of AMTL (4.3%) than female teeth in the east mound (0.9%), a situation that was reversed in the teeth from the west mound with prevalence of 2.6% and 7.0% for male and female teeth, respectively, with the difference statistically significant (*p*-value = 0.0101).

Mortuary Phase Differences

The early phase had a higher prevalence of AMTL (41/705; 5.8%) than the late mortuary phase (13/874; 1.5%) (Table 4.18). This difference was statistically significant (*p*-value <0.0001). When analysed by sex, in the early mortuary phase 10.8% of female teeth (28/260) and 4.1% of male teeth (13/315) were missing due to antemortem loss, and this difference was statistically significant (*p*-value = 0.0030). In the late mortuary phase the prevalence of antemortem loss in the female teeth was 1.4% (4/289) and 1.9% for male teeth (8/426) and this difference was not statistically significant (*p*-value = 0.7703).

When comparing the effect of mortuary phase and sex, in the early phase female teeth had a prevalence of 10.8% (28/260) of AMTL which then reduced to 1.4% (4/289) in the late mortuary phase (Table 4.18). This difference was statistically significant (*p*-value <0.0001).

The prevalence of AMTL in the male teeth also decreased from 4.1% (13/315) in the early mortuary phase to 1.9% (8/426) in the late mortuary phase, the difference being not statistically significant (*p*-value = 0.0762).

Table 4.18: Proportion of AMTL by tooth among the sample by mortuary phase and sex at Non Ban Jak

Mortuary Phase	**Male**		**Female**		**Sex diff. *p*-value**	**Indet Sex**		**Total**		**Mortuary Phase diff. *p*-value**
	n/N	**%**	**n/N**	**%**	**FET**	**n/N**	**%**	**n/N**	**%**	**FET**
Early	13/315	4.1	28/260	10.8	0.0030*	0/130	0.0	41/705	5.8	<0.0001*
Late	8/426	1.9	4/289	1.4	0.7703	1/159	0.6	13/874	1.2	
Mortuary Phase diff. by sex *p*-value	FET	0.0762	FET	<0.0001*						

n, number of teeth with AMTL; N, number of observed tooth positions
* statistically significant *p*-value <0.05.

AMTL Results Summary

Overall, the prevalence of AMTL was higher in female teeth (5.8%) than in male teeth (2.8%) and this was statistically significant (*p*-value =0.0101). Female teeth had a higher prevalence of AMTL in the posterior teeth, whilst males had a higher prevalence in the anterior teeth.

More AMTL was present in the teeth from individuals on the west compared to the east mound and this was statistically significant.

The early mortuary phase teeth had more antemortem loss than late mortuary phase, and the difference is statistically significant (*p*-value <0.0001).

4.4 Dental Pathology Results Summary

The dental pathology profile at Non Ban Jak varied with sex, age, mortuary phase and mound.

Sex Differences

The results of the dental health analysis reveal that females had higher rates of caries and AMTL compared to males. Males had higher rates of advanced wear.

Age Differences

Teeth from old adults had the highest prevalence of caries. The teeth of the old adults had the highest prevalence of all types of caries: occlusal (12.3%), massive (21.1%), CEJ (8.8%), interproximal (7.0%) and pit/fissure (7.0%).

The teeth of the mid adults had the highest rate of AMTL (4.1%) although this was not statistically significant (p-value = 0.7338) compared to that of the old adults. Young adult teeth had the lowest prevalence of AMTL (0.9%).

Mortuary Phase Differences

The prevalence rate of caries (statistically significant p-value <0.0001), AMTL (statistically significant p-value <0.0001) and advanced wear (statistically insignificant p-value = 0.2309) all decreased from the early to the late mortuary phase.

Mound Differences

The east mound had higher rates of caries (not statistically significant p-value = 0.2123) and advanced wear (not statistically significant p-value = 0.2752) than in the west.

But the west mound had a statistically significantly (*p*-value = 0.0158) higher prevalence of AMTL than the east.

Chapter 5 Discussion

5.1 Discussion of Dental Health Results from Non Ban Jak

The late Iron Age in mainland Southeast Asia is presented as a period of significant climate, socioeconomic and cultural transformation (Higham, 2014; Higham, 2016; Newton et al., 2013; O'Reilly, 2014). A consideration of the dental health indications from Non Ban Jak is crucial to understanding this period.

5.1.1 Dental Pathology Profile of Non Ban Jak

As previously discussed (Section 3.2), numerous researchers in mainland Southeast Asia have utilised the framework of the Dental Pathology Profile (Domett, 2001; Domett & Tayles, 2006; Newton et al., 2013; Oxenham et al., 2006; Shkrum, 2014). The framework of the Dental Pathology Profile will be used here to assist in the contextualisation of the results of analysis. The analysis indicates that at Non Ban Jak females had poorer dental health than males; the people of the early mortuary phase had worse dental health than those in the late phase, and the people buried in the east mound had worse dental health than those buried in the west mound (Section 4.4). This information is presented in Table 5.1. The results of the analysis are also presented using the relative terms of ‘higher’ and ‘lower’, in Table 5.2, to assist with the visualisation of the results. Interpreting the dental health patterns in conjunction with previous research presents a varying picture of both the dental and overall health at the settlement.

Table 5.1: Dental Pathology Profile of Non Ban Jak, by tooth count

	Male		Female		Indet. Sex		Total	
Disease	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**	**n/N**	**%**
Caries	29/586	4.9	26/414	6.3	2/186	1.1	57/1186	4.8
AMTL	21/741	2.8	32/549	5.8	1/89	0.3	54/1579	3.4
Advanced wear	121/613	19.7	68/421	16.2	3/203	1.5	192/1237	15.5

5.1.2 Age Differences

At Non Ban Jak the older adults had worse dental health with higher rates of caries and AMTL than that of the younger adult age group. This result is not unexpected given the age mediated nature of dental diseases. Advanced wear was not considered by age given that tooth wear analysis was used to aid the identification of age at death in the population (Buckley et al., 2020). Seven locations of the carious lesions were analysed and the older adult teeth had the higher prevalence in six: pit/fissure, interproximal, CEJ, root, massive and occlusal. It was only smooth surface caries that affected the young and mid adults more, although the sample sizes are small, three teeth and one tooth respectively. Massive caries were the most prevalent (42.1%), with half of these occurring in the older adult age group which can again be explained by the age progressive nature of carious lesions. Caries of the occlusal surface were the next most prevalent lesions (21.1%) which again is not an unexpected result. Carious lesions most commonly form on the occlusal surfaces (Batchelor & Sheiham, 2004; Carvalho, 2014). The rate of occlusal caries also corresponds with the low cariogenicity of a rice diet (Tayles et al., 2000), as diets with higher cariogenicity are more likely to have great number of caries on locations other than the occlusal surfaces (Lanfranco & Eggers, 2010).

5.1.3 Sex Differences

Sex-based differences in dental health are well documented in living populations but have only been studied in past populations relatively recently (Section 3.3). Females have shown a higher burden of dental disease across a broad number of societies with different geographic locations, diets, subsistence patterns, and cultural values (Lukacs, 2017a). Sex-based differences in dental health have been identified at various prehistoric sites in mainland Southeast Asia (Domett, 2001; Domett et al., 2011; Domett & O'Reilly, 2009; Douglas, 1996; Ikehara-Quebral et al., 2017; Newton et al., 2013) as is evident at Non Ban Jak, where female dental health was poorer compared to that of males (Table 5.1 and 5.2). Female rates of caries and AMTL were higher than that of males, though males had a higher prevalence of advanced wear. Whilst the dental health of both sexes improved from the early to the late mortuary period, the dental health of females remained worse than that of the males in both phases.

Table 5.2: Representation of the Dental Pathology Profile at Non Ban Jak.

	Pathology / Condition		
	Caries	**AMTL**	**Advanced Wear**
Sex			
Female	Higher	Higher	Lower
Male	Lower	Lower	Higher
Mortuary Phase			
Early	Higher	Higher	Higher
Late	Lower	Lower	Lower
Occupation Mound			
East	Higher	Lower	Higher
West	Lower	Higher	Lower

Males showed higher rates of advanced wear than females across both occupation mounds. The difference between the teeth of males and females on the east mound was not statistically significant, but the difference was statistically significant on the west mound. Females and males on the eastern mound exhibited more advanced wear than females and males on the western mound, and this was statistically significant. Advanced wear has been suggested to be associated with unpolished rice consumption in mainland Southeast Asia (Frelat & Souday, 2015; Tayles et al., 2000). However, this does not explain the differences in rates across the mounds and by sex. Combined with the differences seen in both caries and AMTL (Table 5.1), this evidence is suggestive of differing lived experiences between the sexes across the occupation mounds.

What is often not considered is the contribution of erosion to dental wear. People in the past did not consume acidic soft drinks as people do today, but acidic drinks and food were consumed such as ‘skyr’ (Richter & Eliasson, 2017), beer, wine, other acidic beverages, fermented food stuffs, and fruit (Lussi et al., 2012) (Section 3.3.1). Fermented fish products are common in mainland Southeast Asian cuisine with the modern day countries of Laos, Myanmar, Vietnam and Thailand all utilising fermented fish products (Ruddle & Ishige, 2010). Fish, shellfish and crustaceans are processed with salt which causes fermentation and prevents putrefaction. The Khorat Plateau in northeast Thailand is known for an abundance of salt (Yankowski et al., 2015) and this was exploited on an industrial scale by the late Iron Age including at Non Ban Jak (Higham, 2016; Yankowski et al., 2015). The establishment of wet rice agriculture saw the creation and/or expansion of local hydrological systems including the moats surrounding the settlements providing increased habitat for fish and shellfish. It is reasonable to suggest that such fish would have been fermented and preserved with salt. The acidic nature of fermented foods potentially contributed to the erosion of the dental hard tissues of the inhabitants.

Reasons for sex-based differences in dental pathologies include the earlier eruption of teeth among females. Cultural and sex-based dietary differences influenced by activity and behaviour, such as the unequal allocation of food and resources, have also been suggested as causes of differences in dental health (Lukacs, 2017a). The presumption that females experienced unequal access to food resources either due to gendered roles or their marginalised position within a society in prehistory (Lukacs & Thompson, 2008) is long standing. Such "generalisations are neither constructive nor considerate towards the multifarious economic, cultural and social forces that shape human societies" (Vergidou et al., 2021, p. 2). Interpreting the past utilising nineteenth-century societal ideals biases the outcome of the analysis (Diaz-Andreu, 2005; Moen, 2019). The people in the past may have structured their world differently than our gendered dichotomy norm (Moen, 2019). Other factors, not only sex-based unequal access to resources, as mentioned above, must be considered regarding sex based dental health differences. Recently there has been a focus on alternate explanations focusing on female biology including the influence of reduced salivary flow in females, lifelong hormonal fluctuations associated with commencement and cessation of menses, pregnancy and post-partum changes (Section 3.3.2). Such influences are discussed further in the following sections.

5.1.4 Occupation Mound Differences

Non Ban Jak is a site with two distinct occupation mounds (Section 2.2). Individuals buried in the east mound had poorer dental health than those from the west. Rates of caries and advanced wear were higher in the east mound (Table 5.2). The east mound had a higher prevalence of advanced wear (17.6%) than the west (14.8%). The difference being statistically significant when considering tooth location. The east mound had a statistically significantly higher prevalence of advanced wear on the anterior teeth than the west mound, whilst the difference in the posterior teeth was not statistically significant. As mentioned above, when the advanced wear for the sexes was compared across the mounds, the east mound male and female teeth had higher rates of advanced wear than their counterparts on the west mound (Section 5.1.3). This difference could be indicative of the east mound individuals using their teeth as tools (Clement & Hillson, 2012; Douglas, 2006) more so than the western mound individuals. Anterior teeth in the maxilla had a statistically significantly higher prevalence of advanced wear than those in the mandible which is perhaps further evidence in support of the use of teeth as tools with the bite force of the maxilla during the extra-masticatory use causing more wear (Clement & Hillson, 2012). Differential access to salt/fermented foods which can cause erosion of the dental tissue between the east and west mound may have been another contributing factor.

The data disaggregated by sex shows the eastern mound females had a statistically significantly lower prevalence of caries than the western mound females. The eastern mound females had a statistically significantly lower prevalence of AMTL and a higher prevalence of advanced wear than the western mound females. Differences in fertility between the east and west mounds could explain these differences given the link between female dental health and fertility. The east mound had a higher fertility and rate of natural population increase (RNPI) (Table 3.9), an unexpected result given the now known relationship between poor female dental health and pregnancy (Ferraro & Vieira, 2010; Watson et al., 2010), but it is a reminder that fertility and dental health have a complicated relationship. It is also possible that the small sample size from the eastern mound is affecting the results. Males on the east mound also had a higher rate of advanced wear, higher rates of caries and higher rates of AMTL than those on the west mound. The male dental health is not directly affected by female fertility, however the differences are suggestive of a different lived experience potentially linked to occupation mound among the male individuals of the settlement. It is also possible that the results are affected by the small sample size of the eastern mound.

The mounds are unlikely to represent two different immigrant populations. Current isotopic evidence suggests very little migration of isotopically unique people occurred in Iron Age northeast Thailand (Bentley et al., 2009; Cox et al., 2011; King et al., 2015). The isotopic analysis at Non Ban Jak is yet to be completed. Once finalised it will be a welcome addition to the discussion surrounding migration, status and diet.

Are the occupation mounds indicative of different 'social classes'?

Evidence of social inequality in the archaeological record includes differences in mortuary wealth, land ownership and residential burial (Adams & King, 2011; Diaz-Andreu et al., 2005). However, such differences do *not* necessarily equate to social inequality. As it is not yet known what qualities were valued by the society at Non Ban Jak, such as wealth, beauty or power, it cannot be known whether this society was organised around these qualities in a hierarchical or egalitarian way. The dominant narrative in mainland Southeast Asian archaeology and bioarcheology has been that the Iron Age led to an increase in social stratification and inequality. This is perhaps due in part to the dominance of the culture-history theoretical approach taken by many researchers. Potential social differences between the mounds at Non Ban Jak were evident with western mound individuals buried with a larger number of iron sickles, and eastern mound being significantly higher with the houses constructed with thicker walls (Higham et al., 2014) leading to the interpretation that different social groups occupied the different mounds (Higham et al., 2014). The two groups are possibly evidence of different social rankings which could in turn imply the existence of a social hierarchy at Non Ban Jak (Higham et al., 2019). The increased labour requirement for the construction of the moats required for wet rice agriculture implies an increased level of social organisation, which is also suggestive of an increased level of social stratification (O'Reilly, 2014; Scott & O'Reilly, 2015). However, social differences and even social rankings can be found in a heterarchical society (Carter, 2021; Crumley, 1995).

Differences across the mounds continued with east mound individuals receiving significantly fewer grave goods, and they had shorter stature, both of which have been associated with lower status, than those on the western mound (Ward et al., 2019). Mortuary contexts reveal aspects of a person's identity that have been created by the mourners (Section 2.4) and can be the expression of selected or idealised aspects of the deceased's identity and role in society. The idealised mortuary version of the person may be different to the person's lived identity, aspects of which are preserved in the osteological record including indications of dental health and disease (Quinn & Beck, 2016). But no matter whether the mortuary treatment reflects an idealised or an accurate representation of the individual, it is plausible that any differences between individuals in the same settlement denote different lived experiences and potentially social groups in life. The lived experience at Non Ban Jak was investigated, in part, by Pedersen et al. (2019) who found a higher prevalence of traumatic injuries, interpreted as potentially related to agricultural work on the east mound, suggesting the burials on the east mound may have represented the agricultural working class.

Lower social status has been associated with poorer health (Armelagos et al., 2005). Physiological trade-offs between survival and health are intensified under conditions of social inequality as lower-status individuals are exposed to an increased risk of disease due to constant background stress, and insufficient nutrition (Dressler, 2010). Physiological evidence of status extends to the dental health (Miliauskienė & Jankauskas, 2015). The east mound individuals had worse dental health than those of the west. The prevalence of infectious disease was also different across the mounds. Preliminary palaeopathological examination at Non Ban Jak revealed the presence of two possible cases of leprosy and nine possible cases of tuberculosis, all except one found in the western mound (Buckley et al., 2020). The spread of infectious disease has been linked with increased outside contacts by a trading class, regarded as a different social class to that of the agricultural workers (Ward et al., 2019). However, the evaluation of the social status of individuals in a prehistoric population is complicated (Miliauskienė & Jankauskas, 2015). Whilst the combined evidence of differences in stature, nonspecific stress, quantity of mortuary goods, rates of trauma, infectious disease, and dental health and advanced wear prevalence differences across the mounds is suggestive of differentiation in lifeways across the two occupation mounds at this stage it cannot be determined if this is also representative of two different social classes across the occupation mounds as it is unknown whether such differences or possible social ranking is due to a hierarchical or heterarchical social structure at Non Ban Jak.

5.1.5 Mortuary Phase Differences

The late mortuary phase saw an improvement in dental health with rates of caries, advanced wear and AMTL decreasing from the early mortuary phase (Table 5.2) which may be evidence of decreasing levels of physiological stress. Stress is the nonspecific response of the body to external influences, altering the equilibrium of the body (Rochette & Vergely, 2017). The resulting biological trade-offs between survival and normal physiological function can lead to the development of nonspecific stress indicators on the skeleton. These stress indicators are termed ‘nonspecific’ as the same stressor can elicit different manifestations in different individuals, and conversely the same lesion can be the result of different stressors in different individuals (Selye, 1975). Markers of stress, such as linear enamel hypoplasia (LEH) and reduced stature, can provide insight into periods of stress caused by both environmental and social change. As previously reported the overall prevalence of LEH increased from the early to the late mortuary phase at Non Ban Jak (Ward et al., 2019). An increase in LEH could be indicative of a higher burden of growth disruption and nonspecific stress. Paradoxically, it could also be indicative of increased survivability and a decrease in frailty (Wood et al., 1992). As such, changes in LEH need to be interpreted in conjunction with other evidence of frailty and health. The improvement in dental health from the early to the late mortuary phase combined with increased evidence of LEH is suggestive that people survived stress insults for longer (Wood et al., 1992). The ability to withstand insult for a longer duration indicates lower underlying frailty which may correspond to an improvement in overall health, including dental health (Hillson, 2008a). The LEH evidence, combined with the dental health evidence, presents a strong case for improving health during the late phase. Is this due to improving conditions of the settlement?

When the Iron Age occupation began at Non Ban Jak, the first few years were potentially spent establishing a new settlement. Currently at Non Ban Jak there is evidence of a Neolithic occupation layer, but no subsequent occupation in the Bronze (despite one disturbed burial (Chang, 2018)) or Early Iron Ages have been identified (Higham & Kijngam, 2020). As such, the assumption for this thesis is the site was not densely occupied during the Bronze and Early Iron Ages, which accounts for the missing archaeological footprint of occupation during this time. Higham et al. (2014) observed that Non Ban Jak appeared to have been well planned with the layout of the buildings, roads and moats offered as evidence. Such an organised and planned appearance was vastly different to that of Ban Non Wat, a site of a much longer occupation sequence and which appears to have grown and changed organically. Whether planned or not, the activities at Non Ban Jak during this time of establishment would have potentially involved hard labour: reservoir construction to assist in the management of water due to the weakening monsoon rains, ploughing, planting and harvesting the new wetland rice crop. The initial period of occupation would have been a time of high workload and stress, potentially negatively impacting the people's health. The increased prevalence of dental pathology in the early mortuary phase (Table 5.2) supports such an interpretation. Overtime, once the new settlement had secured their water supply and the agricultural harvest cycles were established, the stress on the inhabitants lessened as food availability and surplus increased. Wet rice agriculture, when combined with ploughing, is a more labour intensive agricultural strategy compared to dry rice agriculture, but it is more productive (Castillo et al., 2018) potentially resulting in a greater surplus. An increased surplus could have led to a decrease in malnutrition due to the increased energy now available to the inhabitants. Malnutrition can manifest due to deficiency in protein, energy and/or micronutrients, and is associated with poor oral health (Sheetal et al., 2013) including increased caries prevalence (Psoter et al., 2005). Malnutrition can alter homeostasis, which impacts on disease progression, within the oral cavity due a reduction in the resistance of the microbial biofilm which reduces the capacity for tissue healing, all of which negatively impact oral health (Sheetal et al., 2013). The decrease in prevalence of caries and AMTL in the late mortuary phase, when considered within the context of a reduction in indications of frailty does imply an improvement of the availability of nutrition and required energy uptake. In further support, individuals from the late mortuary phase were provided with significantly more grave goods than those from the early mortuary phase (Ward et al., 2019). The increased mortuary wealth and improved health perhaps denoting a time of increased abundance at Non Ban Jak. Increases in nutrition can lead to improvements in population health which impacts maternal health, mortality and population fertility. An improvement in maternal health could, perhaps, be expected to lead to an increase in fertility. However, fertility and health have a complicated relationship. While better health and nutrition can lead to higher fertility (Panth et al., 2018), an increase in fertility can lead to a decline in female health, both overall and dental, due to the impact of hormonal fluctuations and other pregnancy related influences on female physiology (Wickrama & Lorenz, 2002). These outcomes can be further complicated by the impact of infant health, survivability, and mortality.

Human lactation can biologically prevent conception (Guz & Hobcraft, 1991; King, 2007; Todd & Lerch, 2021). The death of an infant causes the mother's lactation to cease enabling ovulation and potential conception. A high rate of infant death can lead to an increased number of pregnancies and births. As the number of births is the measure of fertility in a population, high rates of infant death can lead to high fertility. High fertility can lead to decreasing maternal health due to the physiological stress of multiple, closely spaced pregnancies, and an increase in frailty of mothers, infants and surviving children (King, 2003; Rousso et al., 2002). The survival of an infant into childhood can lengthen the period between births (Cleland, 2001) improving maternal health which has a direct and lasting impact on the future generation via the developmental origins of health and disease hypothesis (DOHaD) (Armelagos et al., 2009; Barker, 1990,2012; Bhutta et al., 2010; Brickley et al., 2020; Entringer et al., 2018; Gluckman et al., 2010; Gluckman et al., 2008; Gowland, 2015). Infants conceived 18-23 months after a live birth have the lowest risk of adverse perinatal outcomes (Rousso et al., 2002), with a reduced chance of maternal death and improved maternal and perinatal health outcomes and infant survival (Cleland et al., 2012) which leads to a smaller rate of population increase. Population health improvement can lead to a *decreasing* fertility rate. The improvement in dental health during Non Ban Jak's late phase may have resulted in a decrease in fertility as the health improvement led to better infant survivability, in turn leading to longer interbirth periods due to the birth control effects of lactation. The palaeodemographic evidence supports this (Section 3.4.1). The rate of natural population increase (RNPI) decreased (4.85% to 3.22%) and the fertility rate decreased (7.19% to 5.94%) (Table 3.9) in the late mortuary phase. Decreasing fertility implies less pregnancies and less physiological impact on health by pregnancy. The maternal mortality rate (MMR) decreased at Non Ban Jak to 110 (low) in the late mortuary phase, from 1128 (high) in the early phase (McFadden et al. (2020) define low and high MMR). A smaller number of pregnancies, combined with reduced maternal mortality, can impact the interbirth period. Whilst increased interbirth intervals have been found to improve maternal health and mortality and both perinatal and child survival (Cleland et al., 2012; King, 2007; King, 2003; Rousso et al., 2002), they are yet to be fully investigated in the archaeological record.

Improvement in the dental health of females and the improved health outcomes for infants and children are interdependent. The decrease in infant mortality resulted in longer interbirth intervals. The age at death distribution analysis for Non Ban Jak shows a trend for a higher proportion of the 0-4.9 year-olds and 5-14.9 year-olds dying in the early mortuary phase compared to the late mortuary phase (Figure 5.1), though not to a statistically significant level. The differences correlate with the decreases in fertility and RNPI evident from the early to the late mortuary phase.

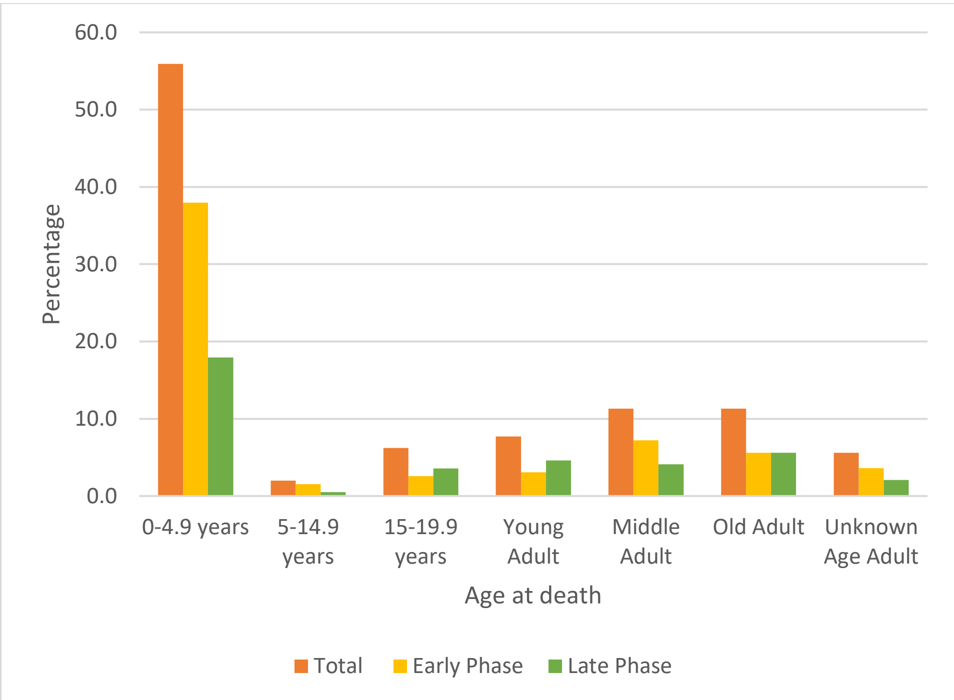

Figure 5.1: Age at death profile of the early and late mortuary phase at Non Ban Jak

Exploration of population fertility and associated health impacts have, until recently, concentrated on a child and/or infant-focused perspective of the mother-infant nexus (Gowland & Halcrow, 2020). The combination of health and fertility data from the females at Non Ban Jak allows a more maternal-centric approach to assist in the interpretation of the lifeways of the population. Improved maternal and infant health decreased the fertility of the population and is supported by the improved dental health of females at Non Ban Jak during the late mortuary phase. The improvement in dental health from the early mortuary phase to the late mortuary phase can be explained by the lessening of stress loads on the population as the rice harvest reliability improved as the settlement became established. The discussion will now focus on what impact, if any, the subsistence strategy of Non Ban Jak had on the dental health of the inhabitants.

5.1.6 Dental Pathologies and Subsistence

The Dental Pathology Profile has been used to suggest the subsistence strategy used by the population under study (Lukacs, 1989). Caries was regarded as rare until the adoption of agriculture with caries rates then generally increasing with the adoption and later intensification of agriculture (Hillson, 2008b; Larsen et al., 1991; Liebe-Harkort, 2012; Lukacs, 2008; Lukacs & Largaespada, 2006; Temple & Larsen, 2007). A combination of low caries and high rates of advanced wear were associated with hunter-gatherer diets, and high caries and low advanced wear with the diet of the agriculturalists (Lukacs, 1989). The simplistic relationship between caries and subsistence strategy has been critiqued (Lukacs, 2008; Lukacs & Largaespada, 2006; Tayles et al., 2009a; Tayles et al., 2000) (see Section 3.2 for further references). More recently, Marklein et al. (2019) emphasised the need to re-evaluate dental conditions and pathologies, questioning the direct causal relationship between subsistence choice and a population's dental lesion profile. Previous bioarchaeological investigations in mainland Southeast Asia have shown that the *cultivar* used in agriculture may have more of an influence on the rate of caries than the subsistence strategy utilised by the population (Tayles et al., 2000), as the expected increase in dental caries prevalence with the advent of agriculture has not been found among rice agriculturalists in the region (Domett, 2001; Newton et al., 2013; Oxenham et al., 2006; Tayles et al., 2009a; Tayles et al., 2000; Willis & Oxenham, 2013b). Rice is not as cariogenic as other carbohydrates (Sheiham, 2001; WHO, 2003) potentially impacting the rates of caries in Southeast Asia (Tayles et al., 2009b; Tayles et al., 2000).

The relative lateness of the intensification of agriculture in the region, occurring after the advent of iron, had been used to explain the lack of evidence of a decrease in oral health as mainly earlier sites had been examined (Oxenham et al., 2006). Prior to the excavation of Non Ban Jak the skeletal evidence for the Iron Age was small. The excavation of Non Ban Jak, commencing in 2011, has provided a rich source and a large amount of data with which to assist in developing understandings of the region. Non Ban Jak is a site of the late Iron Age to early historic periods, the time Oxenham et al. (2006) suggested an increase in caries could be expected due to agricultural intensification. The caries prevalence at Non Ban Jak is 4.8%, similar to other sites in the region, both temporally and spatially, and is *lower* than earlier sites (Table 5.4). As shown above, caries is impacted by more than simply subsistence strategy and cultivar used. The evidence at Non Ban Jak supports this. The subsistence strategy at Non Ban Jak from the beginning of the Iron Age was wet rice agriculture (Castillo et al., 2018). The multiple sources of evidence include iron sickles, the construction of mounds and moats (Higham et al., 2014; Higham & Kijngam, 2020; O'Reilly, 2014; Scott & O'Reilly, 2015), evidence of ploughing animals, and the analysis of rice grains (Castillo et al., 2018). There is no evidence that either the subsistence strategy or the cultivar changed throughout the Iron Age occupation. Despite this continuity, the caries prevalence changed significantly from the early (8.3%) to the late (2.2%) mortuary phases. The significant change in caries prevalence whilst both the subsistence strategy *and* the cultivar remained constant indicates there is more to caries than simply these two factors. The prevalence of advanced wear (decreased from 17.1% to 14.5%) and AMTL (decreased from 5.8% to 1.2%) also both decreased from the early to the late mortuary phase. Again, noting that neither the subsistence strategy nor cultivar changed over this time, the results reveal dental pathologies are not simply the result of subsistence strategy and/or cultivar.

The change to wet rice agriculture itself had the potential to cause significant repercussions on health due to the creation of new habitats for disease vectors. Increased stagnant water in the moats and irrigation system would have allowed for the colonisation of parasites and their vectors such as malarial mosquitoes (Halcrow et al., 2016; King et al., 2017). Castillo et al. (2018) identified the main species of algae in the moat system at Non Ban Jak as *chara zeylanica* (also called green musk chara). This species occurs in both shallow and deep water, including irrigated rice fields and irrigation channels (Pandey et al., 2005). The ability of malarial mosquito larvae to survive in an environment infested with *chara zeylanica* has been investigated with conflicting results (Barber, 1924; Consoli et al., 1989; Gonzalves & Vaidya, 1963; Sarkar et al., 2007). Malaria is but one possible disease, and other species of mosquitoes are vectors for other diseases. Stagnant water is also the known habitat of numerous other disease vectors and intermediary hosts such as snail, fish, flukes, helminth and protozoa (King et al., 2017). Human-parasite interaction could have increased at Non Ban Jak due to the increased proximity of living areas to the water storage in the moats and the increased chance of contamination with human waste deposits (Armelagos et al., 2005). Exposure to some parasites would have been common across the settlement, like parasites in food such as echinostomiasis, a food-borne intestinal zoonotic snail-mediated parasite (Fried et al., 2004; Graczyk & Fried, 1998) and other parasitic trematode infections. Infections due to parasitic helminths, soil transmitted parasites, could be expected across both mounds. Soil contamination is high in villages without designated latrines, and the latrine state of Iron Age settlements in mainland Southeast Asia is unknown at this stage. Parasitic helminth infection is also more common in those who do not wear shoes (Fried et al., 2004) and the shoe availability during Iron Age mainland Southeast Asia is unknown at this time. Individuals undertaking agricultural work would have suffered greater exposure to parasites due to the nature of their work within and around the moats (Ward et al., 2019). This is further circumstantial evidence for the individuals on the east mound, a possible agricultural 'class', being exposed to more physiological stress leading to their poorer dental health.

5.1.7 What's Happening at Non Ban Jak?

Biocultural interpretations need to be considered at a regional level (Buikstra, 1977). A biocultural model for health change in response to the socioeconomic and environmental change in the Upper Mun River Valley of northeast Thailand has been suggested (King et al., 2017). The model argues that the changes occurring in the late Iron Age in the region negatively impacted population health, on the whole, with the lower social position, defined as those with increased social inequality, affected more (King et al., 2017). Applying this model to Non Ban Jak supports the argument that the people on the western mound, with their better dental health, were of a higher social position than those of the eastern mound, an argument that can also be supported by the archaeological evidence and previous osteological evidence discussed above. However, the dental health of the entire settlement *improved* during the population sequence. The multiple processes and changes occurring in the Iron

Age, in particular socioeconomic and climate change, did not uniformly negatively impact health throughout the region, in contradiction to the King et al. (2017) model. Non Ban Jak was a newly established late Iron Age settlement founded during a time of significant environmental change. The environmental change necessitated the use of adaptive strategies by the population such as the intentional control of water and the establishment of a new agricultural strategy in wet rice agriculture. The change in agricultural strategy led to an increase in workload which led to an increase in stress and declining dental health. Over time the inhabitants adapted to their new home. Once water control was established and the rice harvest cycles became more reliable, the stress loads decreased, dental health improved, as did overall health. This led to a decrease in the fertility of the site.

The results of the dental health analysis at Non Ban Jak do not fit neatly into the recently proposed model of biocultural change (King et al., 2017). Is this evidence of limitations to the proposed model, or is there something 'different' about the settlement of Non Ban Jak that is affecting the outcome? Non Ban Jak is a site with a short Iron Age occupation, whereas the sites used by King et al. (2017) were multiperiod sites. The differences in the occupation sequences have potentially impacted the dental health results. To gain a comprehensive understanding of health outcomes of the people of the Upper Mun River Valley during the Iron Age the results from Non Ban Jak have been compared to those of other Iron Age settlements in the region, discussed in the next section.

5.2 Comparison within mainland Southeast Asia

This section focuses on the comparison of the dental health at Non Ban Jak within the context of regional sociopolitical, demographic and environmental changes occurring in the Upper Mun River Valley and more broadly in mainland Southeast Asia at this time.

Over the past two decades research into the dental health of prehistoric communities in mainland Southeast Asia has increased. Such studies have focused on the regional areas of northeast Thailand (Cekalovic, 2014; Domett, 2001; Domett & Tayles, 2006; Domett & Tayles, 2007; Douglas, 1996; Douglas, 2006; Douglas & Pietrusewsky, 2007; Higham et al., 1992; Nelsen et al., 2001; Pietrusewsky & Douglas, 2001; Shkrum, 2014; Tayles et al., 2007), central Thailand (Domett, 2001; Kirkland, 2010), Cambodia (Domett et al., 2013; Domett & O'Reilly, 2009; Ikehara-Quebral, 2010; Ikehara-Quebral et al., 2017; Newton et al., 2013), and Vietnam (Oxenham et al., 2002; Oxenham et al., 2006; Willis, 2015; Willis & Oxenham, 2013b). Previous reviews of the evidence of oral disease in prehistoric mainland Southeast Asia have been completed by such researchers as Oxenham et al. (2006), Newton et al. (2013) and Willis and Oxenham (2013b).

Prehistoric mainland Southeast Asia, including the modern countries of Thailand, Cambodia and Vietnam, has not shown a decline in oral health related to the intensification of agriculture unlike other geographic regions worldwide (Domett & Tayles, 2006; Newton et al., 2013; Oxenham et al., 2006; Pietrusewsky & Douglas, 2001; Tayles et al., 2009a). Health has been found to be stable with the intensification of agriculture (Newton et al., 2013). Table 5.3 illustrates the dental health profile over time of settlement sites throughout mainland Southeast Asia. The dental diseases listed are limited to caries, AMTL and advanced wear to facilitate comparison with the results from Non Ban Jak.

Table 5.3: Dental pathology results from mainland Southeast Asia – per tooth count

Assemblage	Modern Country	Date (years BP)	Caries %	AMTL %	Ad. Wear %	Caries		AMTL		Ad. wear		Source
						Male	Female	Male	Female	Male	Female	
Ban Non Wat	Thailand	3700-3000	12.5	8.7	30.7	10.6	13.1	3.1	10.4	34.2	26.7	Shkrum (2014)
Early Ban Chiang	Thailand	4100-2900*	6.2	6.6	14.5[#]	7.7	4.5	6.7	7.1	12.2[#]	18.2[#]	Douglas (1996)
Late Ban Chiang	Thailand	2900-1800*	7.7	6.9	16.9[#]	8.6	7.0	8.4	5.6	31.9[#]	4.8[#]	Oxenham et al. (2006); Douglas (1996)
Ban Non Wat	Thailand	3000-2750	8.3	7.6	21.4	6.4	12.0	6.0	10.8	22.4	23.3	Shkrum (2014)
Ban Na Di	Thailand	2550-2350	4.7	5.4	12.0	3.3	8.2	1.5	12.9	9.7	17.9	Domett (2001)
Ban Non Wat	Thailand	2750-2370	9.7	8.7	26.6	6.6	13.1	7.7	9.9	27.4	25.7	Shkrum (2014)
Ban Non Wat	Thailand	2350-1350	8.4	11.5	11.3	4.5	12.6	11.6	11.4	12.9	9.4	Shkrum (2014)
Promtin Tai	Thailand	1600-1400	0.5	0.00	6.8	^	^	^	^	^	^	Kirkland (2010)
Noen U-Loke	Thailand	2300-1700*	4.8	5.5	15.6	4.5	5.8	2.8	8.3	^	^	Tayles et al. (2007)
Ma. Ca Rivers	Vietnam	2300-1700*	2.8	2.9	^	1.6	4.8	2.0	3.0	^	^	Oxenham et al. (2006)
Red River	Vietnam	2300-1700*	1.4	3.6	^	0.0	1.8	2.5	5.6	^	^	Oxenham et al. (2006)
Phum Snay	Cambodia	2300-1750	11.2	2.6	5.6	4.5	10.4	1.9	2.2	11.6	7.0	Newton et al. (2013)
Angkor Borei	Cambodia	2150-1750	5.0	3.6	10.4	5.7	4.2	4.6	2.0	11.6	8.9	Ikehara-Quebral (2010)
Phum Sophy	Cambodia	1850-1350	9.1	0.7	10.2	7.2	10.3	0.5	1.3	15.9	11.4	Newton et al. (2013)
Non Ban Jak	Thailand	1500-1350	4.8	3.4	15.5	4.9	6.3	2.8	5.8	19.7	16.2	This study

*dates from Oxenham et al. (2006)
** date from Bellwood et al. (2011)
% values have been calculated from published data; ^cannot be determined from the published data; +Domett and Tayles (2007)
#Douglas (1996)

Advanced Wear in mainland Southeast Asia

The prevalence of advanced wear in mainland Southeast Asia does not show any temporal patterns (Newton et al., 2013) (Table 5.3 and Figure 5.2). Prevalence rates are highest in the Neolithic (Ban Non Wat 30.7%) with fluctuating rates in the Bronze and Iron Ages (Table 5.3). The Non Ban Jak rate of 15.5% is relatively high for the Iron Age. Tooth wear is affected by diet, food preparation methods and the use of teeth as tools. Communities with a heavy reliance on marine resources often show high rates of wear (Littleton & Frohlich, 1993) but this pattern has not been found in mainland Southeast Asia with coastal Khok Phanom Di having a low rate of advanced wear (Domett, 2001). Non Ban Jak and Noen U-Loke, both late Iron Age sites, and both located well inland on the Khorat Plateau away from marine resources, have the highest Iron Age rates of advanced wear (Table 5.3). It is evident that geographic location cannot solely predict a dental pathology profile (Newton et al., 2013). Sex based differences in advanced wear are apparent in the region as 10 of the 13 sites (76.9%), where the data could be disaggregated by sex, show that males had a higher prevalence of advanced wear (Table 5.3). Non Ban Jak follows this pattern (Section 4.1.2 for Results and Section 5.1 for Discussion). Whilst there is a known correlation with diet and advanced wear (Lukacs, 1989), other causes such as the use of teeth as tools can contribute to patterns of wear.

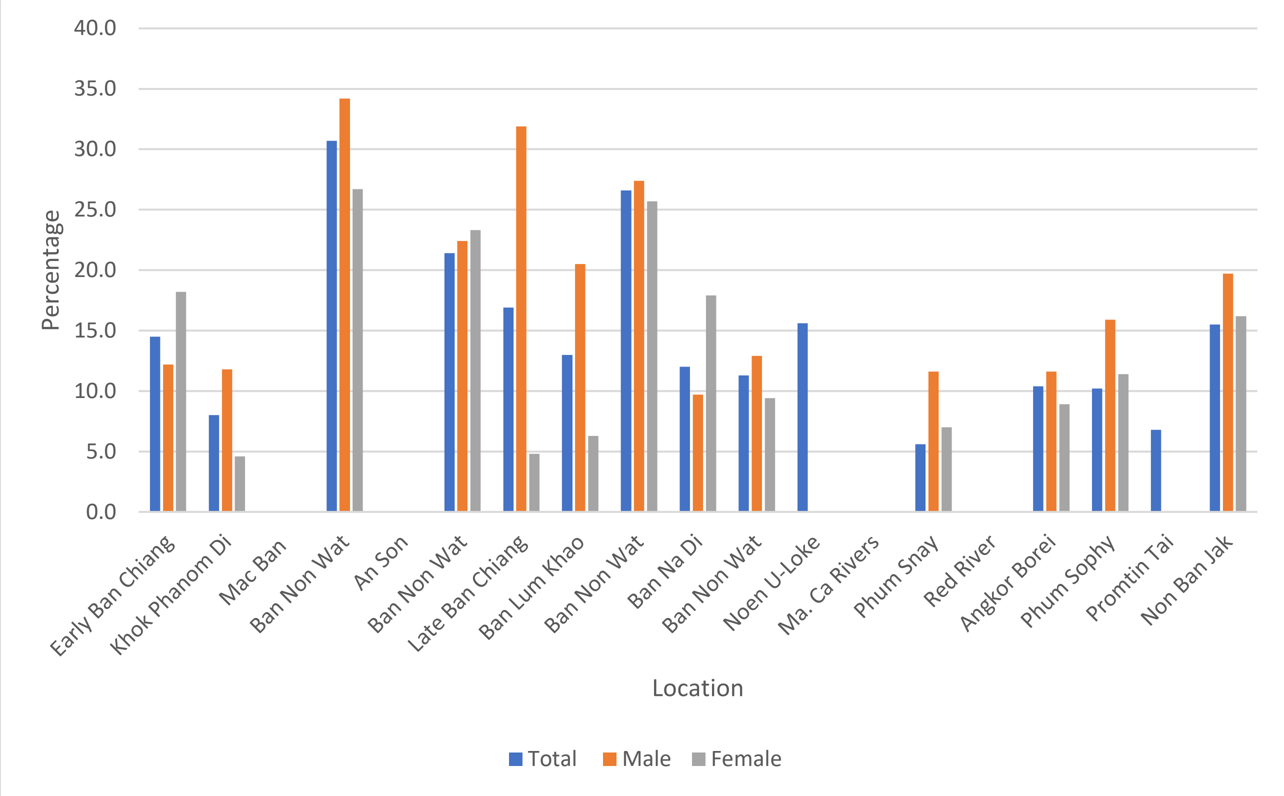

Figure 5.2: Percentage of teeth with advanced wear across Southeast Asia prehistoric sites (presented in chronological order)
Refer to Table 5.3 for dates and sources

Caries in mainland Southeast Asia

There is no clear patterning of caries rates across mainland Southeast Asia. Newton et al. (2013) report that the prevalence was variable in the Neolithic, low to moderate throughout the Bronze and early Iron Age, increasing in the late Iron Age. Carious lesions occur most frequently at Neolithic Ban Non Wat (12.5%) (Table 5.3 and Figure 5.3). The higher rates in the late Iron Age seem to be geographically dependent with sites in Cambodia having the highest prevalence (Table 5.3 and Figure 5.3). Late Iron Age sites in Vietnam and Thailand have similar low to moderate rates. The overall caries rate at Non Ban Jak (4.8%) is the same as at Noen U-Loke (4.8%). As noted by Newton et al. (2013) the results from the late Iron Age may be indicative of local factors causing variation. These differences illustrate the entirety of mainland Southeast Asia cannot be taken as a single, homogenous area and local factors impact on health, and must be considered in any analysis, as discussed further in Section 5.2.2 below.

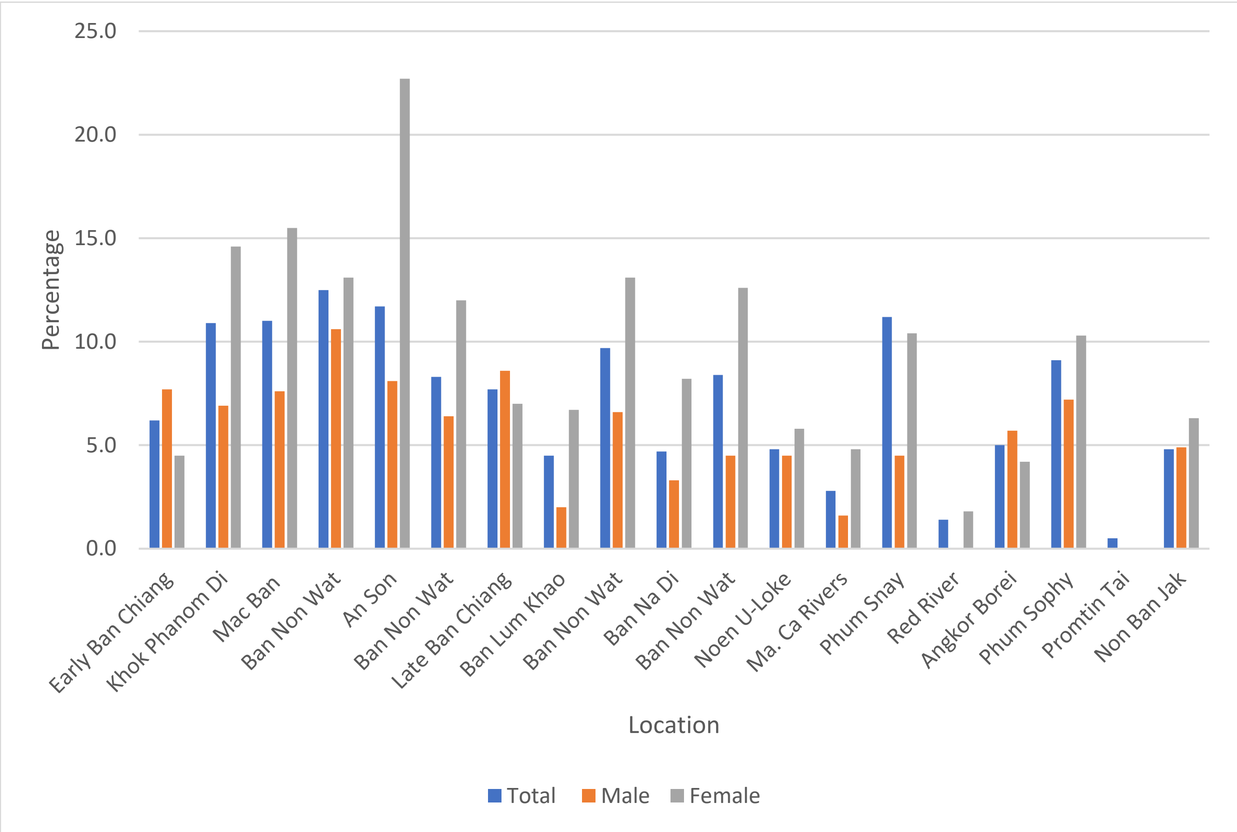

Figure 5.3: Percentage of teeth with caries across prehistoric Southeast Asian sites. Refer to Table 5.3 for dates and sources

As in other regions globally (Section 3.3.2), prehistoric mainland Southeast Asian females often show a higher prevalence of caries than males (Table 5.3 and Figure 5.3). Within this region sex based differences in caries frequencies have been explained by differences in diet and differences in sex based food acquisition (Oxenham et al., 2006; Tayles et al., 2000), earlier female tooth eruption, and hormonal fluctuations with pregnancy (Oxenham et al., 2006; Willis & Oxenham, 2013a), with only the later work of Newton et al. (2013) and Willis and Oxenham (2013b) raising the possibility of other hormonal fluctuations throughout the female life course as being a contributing factor. Sex-based differences are discussed further below.

Low rates of caries have historically been equated with hunter-gatherer or mixed economy groups with rates of caries increasing with agriculture (Lukacs, 1989), but as previously discussed (Section 5.1), the increase in caries with agriculture seems to be more dependent on the cultivar and not the subsistence strategy (Tayles et al., 2000). This is further evidence in support of variation caused by local factors. Throughout mainland Southeast Asia there is not a large increase in caries rates as agricultural practices intensify and Non Ban Jak follows this pattern. The impact of fertility rates on the dental health of individuals in mainland Southeast Asia has not, as yet, been investigated in detail. Whilst subsistence strategy and diet area contributing factors, there is more to dental health than these two factors alone. Section 5.2.2 explores this in further detail.

AMTL in mainland Southeast Asia

The prevalence of AMTL is mixed amongst the examples in Table 5.3. Rates of AMTL are higher in the earlier phases (Neolithic and Bronze Age) with Ban Non Wat (2350-1350 BP) having the highest rate (11.5%) and are lower in the later periods (Iron Age) (Newton et al., 2013) (Figure 5.4). Domett and Tayles (2006) suggest the dental health of people improved with their ability to exploit the environment; an idea revisited in Section 5.2.3. It is noticeable that the later Iron Age sites, including Non Ban Jak, have the lowest rate of AMTL. Sex differences are apparent in AMTL prevalence. Table 5.3 lists 18 samples where AMTL was analysed by sex, with females having a higher prevalence than males in 14 (77.8%).

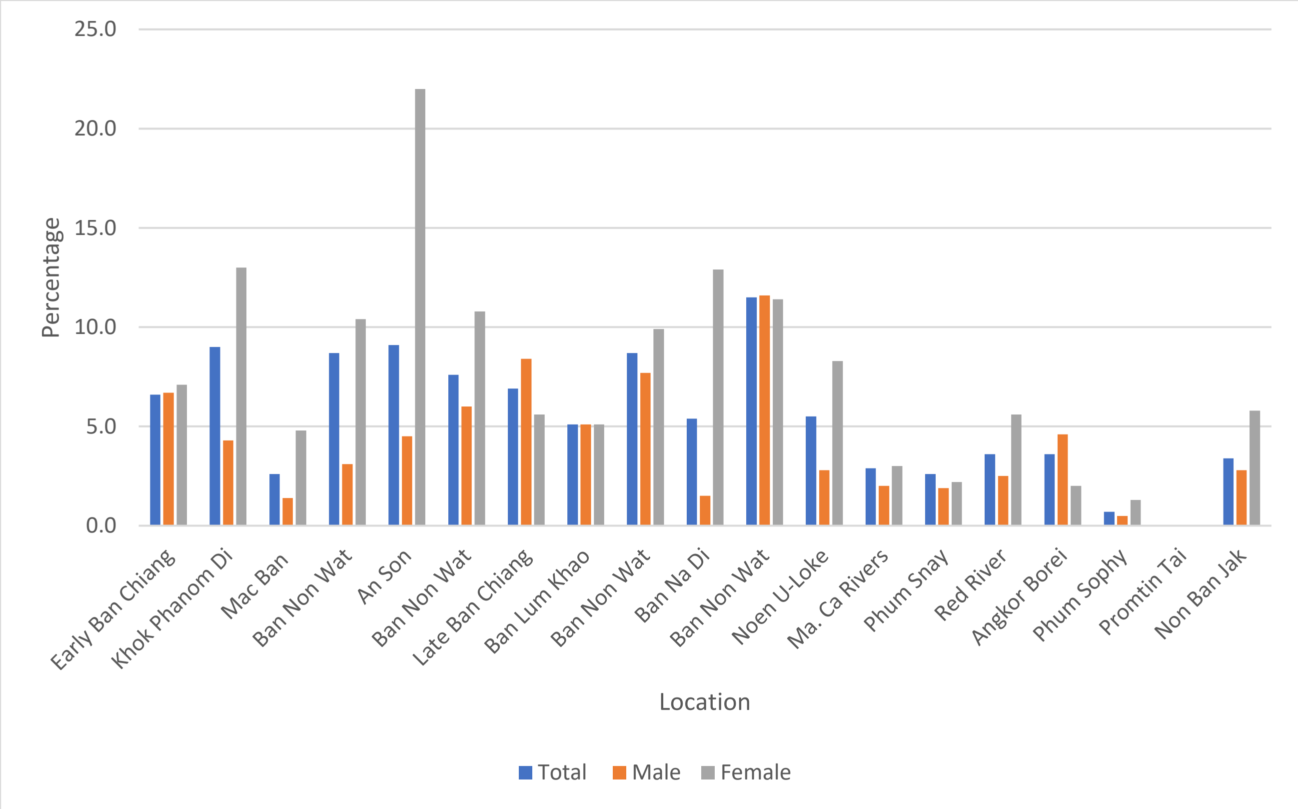

Figure 5.4: Percentage of AMTL across prehistoric Southeast Asian sites. Refer to Table 3.16 for dates and sources

Sex Based Differences

Sex differences in dental health can suggest sex based differences within communities (Newton et al., 2013). Previous research in the region has shown that the dental health of females follows the global trend with a higher prevalence of caries than males (Table 5.3). Females have a higher caries prevalence in 15 of the 18 sites (83.3%), 14 out of 18 (77.8%) for AMTL, but only three out of 13 (23.1%) for advanced wear (Table 5.3).

Sex-based dietary differences have been one of the loudest arguments used to explain differences in dental health in previous decades (Section 3.3.2). Dental health is more complicated than simply what someone ate (Marklein et al., 2019; Tayles et al., 2000). Whilst being aware of the long standing, biased assumption that females were marginalised and held a lesser position in society in prehistory (Section 3.3.1) leading to unequal access to resources, sex-based dietary differences have been isotopically identified in mainland Southeast Asia during the metal periods (King & Norr, 2006). Macroscopic dental evidence at Ban Chiang suggested sex-based differences in access to resources (Pietrusewsky & Douglas, 2001). Later isotopic work suggested dietary differences with statistically significant differences in stable isotopic variable between Bronze Age males and females and Iron Age males and females (King & Norr, 2006). However, the preliminary nature of this work, completed before a full isotopic assessment of the local flora and fauna had been completed, does suggest the results require a review. Isotopic evidence from Ban Non Wat revealed significant differences in mean carbon isotope ratios between the sexes during the Neolithic, Bronze Age 2 and 3 phases (King et al., 2013) implying a sex-based access to resources during these periods (Section 3.3). This sex-based difference was not supported by noticeable differences in the mortuary treatment at Ban Non Wat during Bronze Age 2. This was the only phase in which 'super burials' were uncovered which provided evidence for an extremely wealthy elite (Higham, 2011). These 'super burials' do not appear to be based on biological sex (King et al., 2013).

The Da But (c.6000 B.P) and Metal period (c.3000 – 1700 B.P) assemblages from prehistoric Viet Nam analysed by Oxenham (2006) revealed more caries and AMTL in the female individuals (statistically insignificant during Da But and statistically significant during the Metal period). The reasons for these differences are not discussed further than the observation that it is not an "uncommon finding" in bioarchaeological studies and such differences are often attributed to "differences in diet or eating behaviour" (Oxenham, 2006, p. 231). The Metal period males also showed more evidence of extra-masticatory wear facets on the dentition than the females suggestive of a difference in the level of involvement between the sexes in whatever the task was that created these facets. This is potential evidence of sex based differences in the lifeways of the people. Sex based differences have also been noticed in the Iron Age sites of Phum Snay and Phum Sophy in Cambodia (Newton et al., 2013). At both sites females had a higher prevalence of caries and AMTL whereas males had a higher prevalence of advanced wear which is again suggestive of differing lifeways between the sexes.

The limited isotopic evidence from the region, and other examples of macroscopic evidence, both discussed above, is supported by the evidence in Table 5.3 with clear sex-based differences in the rates of caries (discussed previously) and advanced wear, with ten out of 13 locations (76.9%) having males with the most advanced wear in the region. Non Ban Jak conforms with the regional norm of females having more caries and males having more advanced wear.

Mainland Southeast Asia Dental Health Summary

There is no evidence that the intensification of agriculture led to adverse dental health outcomes in mainland Southeast Asia (Clark et al., 2014; Ikehara-Quebral et al., 2017; Newton et al., 2013; Tayles et al., 2009a). The people of Southeast Asia had relatively good dental health from the Neolithic to the Iron Age. However, there is no one, consistent trajectory in terms of dental health in the region. Rather, it is apparent that the entirety of mainland Southeast Asia cannot be treated as a single, homogenous area in terms of dental health. Local conditions and environments induced variations in dental health (Ikehara-Quebral et al., 2017; Newton et al., 2013).

5.2.1 The Upper Mun River Valley

Narrowing the focus onto the Upper Mun River Valley, a comparison of the dental health results of the closely located Iron Age settlements of Ban Non Wat, Noen U-Loke and Non Ban Jak (Table 5.4) enables a more informed perspective of the social and environmental changes occurring in the region during the late Iron Age period (Halcrow & Tayles, 2011). The comparison of the settlements of Noen U-Loke, Ban Non Wat and Non Ban Jak have "the potential to refine our understanding of social change by producing regionally specific models and enable a more detailed understanding of the advent of social complexity in the area" (Higham et al., 2019, p. 2). There are limitations and difficulties with such comparisons (Wesolowski, 2006). The time frames of the settlements and the way in which data has previously been analysed must be considered. Ban Non Wat is a site with a long occupation sequence. The Ban Non Wat Iron Age dental sample, analysed by Shkrum (2014), covers the entire period (from 2530 – 1350 BP), some 1000 years. Any biological impacts from the social, economic, agricultural cultivation strategy change coupled with climate change may be obscured by the analysis treating the 1000-year sample as homogenous. Analysing the results in smaller time periods may illustrate trends within the data although the reduction in sample size could impact robust statistical analysis. Further, only a portion of the entire sample at Ban Non Wat has been analysed by Shkrum (2014). A subsample of 244 (118 female; 118 male; 8 indeterminate sex) individuals were chosen for analysis from the 630 individuals excavated, within which a smaller group of 37 female and 39 male individuals from the Iron Age were included. The majority of the Iron Age subset utilised dated to the earliest Iron Age period. Individuals chosen for the subset were those with firm age and sex estimations and the most complete and well-preserved dentition (Shkrum, 2014), introducing an additional layer of subjectivity and bias. Noen U-Loke is also a site with a long occupation period with the majority of burials dating to Iron Age 1 and 2

(Cekalovic, 2014). By comparison, Non Ban Jak is a later settlement with burials dating to the Iron Age 4 period. Whilst a comparative analysis will provide an interpretation of the dental health of the local region throughout the Iron Age, there are limitations.

Table 5.4: Dental pathological comparison for Ban Non Wat, Noen U-Loke and Non Ban Jak – tooth count method

Assemblage Iron Age	Caries			FET p value	AMTL			FET p value	Advanced wear			FET p value	Source
	Total	Male	Female		Total	Male	Female		Total	Male	Female		
Ban Non Wat	8.4 128/1530	4.5 36/797	12.6 92/733	<0.0001*	11.5 176/1530	11.6 94/813	11.4 82/717	>0.9999	11.3 160/1420	12.9 97/751	9.4 63/669	0.0434*	Shkrum (2014)
Noen U-Loke	4.8 46/956	4.5 19/422	5.8 22/382	0.4276	5.2 69/1334	2.8 16/569	8.3 46/557	<0.0001*	15.6 152/977	12.3 53/432	23.5 92/392	<0.0001*	Tayles et al. (2007)
Non Ban Jak	4.8 57/1186	4.9 29/586	6.3 26/414	0.3991	3.4 54/1579	2.8 21/741	5.8 32/549	0.0101*	15.5 192/1237	19.7 121/613	16.2 68/421	0.1638	This study

*denotes statistical significant
Red text highlights greater prevalence

The data from Ban Non Wat and Noen U-Loke are from similar time periods so it would be reasonable to expect these settlements to be under similar environmental and socioeconomic pressures, however this has not resulted in a similar dental health profile (Table 5.4). Noen U-Loke has a more similar dental health profile to Non Ban Jak; whilst Ban Non Wat is quite different to both Noen U-Loke and Non Ban Jak. Similarities in dental health may be the result of common economic, social and environmental pressures, and are also influenced by diversity in geographical, environmental and/or genetic factors (Vergidou et al., 2021). The question then is what is contributing to the differences in these three closely located sites?

An improvement in health over time for the people at Ban Non Wat and Noen U-Loke was reported by Cekalovic (2014) but included the caveat there were no marked changes at the transition of the Bronze to the early Iron Age at Ban Non Wat, which is in opposition to the other regionally based models of health variation through time (King et al., 2017; Willis & Oxenham, 2013b). There were significant health changes from the early to the mid Iron Age with the mid Iron Age people healthier than those from the other periods (Cekalovic, 2014). The length of establishment of the settlement appears to impact the health of the population. Individuals from Ban Non Wat had high levels of growth disruption during the late Bronze Age but there were no indications of this in the early Iron Age. Noen U-Loke was only established in the early Iron Age and there are high levels of growth disruption recorded at this time.

Ward et al. (2019, p. 286) report that the evidence of 'fluctuations' in oral health from Iron Age Ban Non Wat and Noen U-Loke, combined with increased levels of infant and maternal morbidity and mortality, suggest a deterioration in health during the late Iron Age, whereas Cekalovic (2014) argues the health at Noen U-Loke was poorer than that at Ban Non Wat. It should be noted that the excavation of Non Ban Jak did alter the regional time line – with the samples used by Cekalovic (2014) earlier in the Iron Age sequence than those from Non Ban Jak. Interpretations are bound to change with the increased understanding of the region. An increased reliance on wet rice agriculture, suggested reduced dietary diversity, and landscape modification are implicated as the chief drivers of the health deterioration at Noen U-Loke and Ban Non Wat (Ward et al., 2019, p. 286). The reported deterioration 'fits' with the model of poorer health in the late Iron Age proposed by King et al. (2017). However, at a broader regional level, no deterioration in dental health has been identified in the late Iron Age occupation at Non Ban Jak. The dental health *improved* from the early to the late mortuary phase (Section 4.4). Perhaps a crucial difference is that Non Ban Jak utilised wet rice agriculture from its beginning whereas the evidence at Ban Non Wat suggests a change from dry to wet rice cultivation (Castillo et al., 2018). Noen U-Loke also experienced a change from dry to wet rice agriculture (Castillo et al., 2018). Noen U-Loke and Ban Non Wat adapted to a new type of agriculture whereas it was the norm from the beginning at Non Ban Jak. The change in agricultural strategy at Noen U-Loke and Ban Non Wat can help explain the dental health fluctuations. At Noen U-Loke and Ban Non Wat the biological cost of adaption (Roberts, 2010) is evident, discussed further below.

5.2.2 Does demography help explain the difference in dental health?

Many earlier studies do not combine data from health, fertility and demography to explain and contextualise results in regards to health (French, 2018; McFadden, 2021). The age at death distributions of Iron Age Non Ban Jak, Ban Non Wat and Noen U-Loke are different (Figure 5.5). Non Ban Jak and Ban Non Wat are the most different from each other. Non Ban Jak has the highest prevalence of 0-4.9 year old age at death, whereas Ban Non Wat has the highest prevalence in the mid and old adult age at death bracket. The site of Noen U-Loke had the highest nonadult mortality in the region (44.2%) (Domett & Tayles, 2006) until the excavation of Non Ban Jak (64.1%) (Buckley et al., 2020).

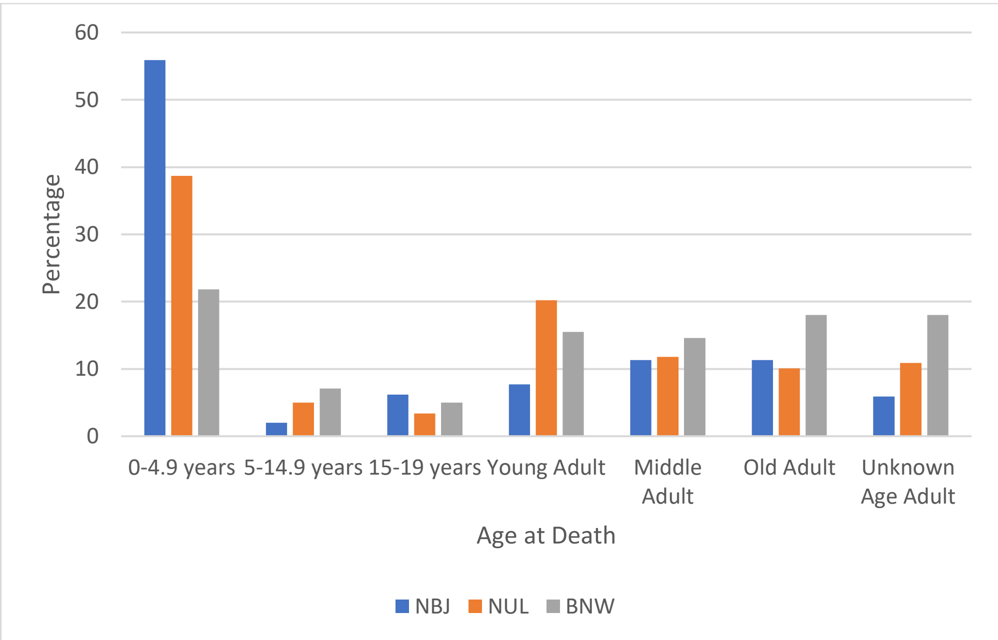

Figure 5.5: Age at death distribution at Iron Age Non Ban Jak, Noen U-Loke and Ban Non Wat

Non Ban Jak has the highest rate of natural population increase (RNPI) (4.22%) and the highest fertility rate (6.70%) (Table 5.5). Whereas the settlement with the highest maternal mortality, Ban Non Wat, had the lowest fertility rate and lowest RNPI (Table 5.5). Not all deaths in a population have the same impact on a society (French, 2018). A high rate of maternal death directly impacts both the RNPI and fertility rate as there are then less women of reproductive age available for subsequent births. Non Ban Jak shows the lowest maternal mortality and the highest RNPI and fertility rate. With less mothers dying it stands to reason that they would then be available for an increased number of subsequent births affecting the RNPI and the fertility rate.

Table 5.5: D0-14/D ratio and rate of natural increase and maternal mortality rate for the Iron Age periods of Non Ban Jak, Ban Non Wat and Noen U-Loke (reproduced from section 3.4.1)

Site Iron Age	D0-14/D Ratio[a]	Fertility Rate[a]	RNPI[b]	MMR
NBJ	0.58	6.70	4.22	299
BNW	0.29*	4.47^	1.26*	415[d]
NUL	0.44*	5.63^	2.83*	158[c]

NBJ: Non Ban Jak; BNW: Ban Non Wat; NUL: Noen U-Loke
[a] As described in McFadden and Oxenham (2017)
[b] As described in McFadden and Oxenham (2018b)
*Data taken from McFadden and Oxenham (2018a); (McFadden & Oxenham, 2018b)
^ calculated using the equation from McFadden and Oxenham (2017)
[C] as per van Tiel and McFadden (2021)
[d] Calculated with unpublished BNW Iron Age at death distribution figures from N. Tayles and K. Domett, (personal communication)

How do the dental health results 'fit' with the demographic results? Caries has an established connection with female fertility with previous work citing an increase in fertility connected with poorer dental health (Lukacs, 2008,2011a; Lukacs & Thompson, 2008; Russell et al., 2013). The site with the lowest RNPI, lowest fertility, and the highest maternal mortality, Ban Non Wat, also has the highest prevalence of caries among females (12.6%) (Table 5.4). Whereas the site with the highest fertility, implying the highest number of pregnancies, which entail increased hormonal fluctuations and other associated oral health impacts, Non Ban Jak, has a much lower females caries rate at 6.3%. At first this does not seem to make sense - given the hormonal changes associated with pregnancy and birth perhaps it would be expected that the sites with the higher fertility should have the poorest dental health. But interpretation of data is more than just statistics and numbers. Health and fertility data need to be considered with both the osteological paradox (Wood et al., 1992) and the bidirectionality of oral health (Batchelor, 2015) and the results regionally contextualised. The simplistic view, that agriculturally reliant populations simply offset poorer infant health with an increased birth rate and fertility (Page et al., 2016), needs reassessment, or at least further regional contextualisation. The rate of population increase at Ban Non Wat was below two (Table 5.5). This is below replacement level, which means that the population at Ban Non Wat was in *decline* during the Iron Age. A declining population is possible evidence of an increased level of frailty at Ban Non Wat compared to other sites with growing populations. It is possible that the females at Ban Non Wat were more frail, even before adding pregnancy into the mix, and, as such, their oral health reflects this. At Ban Non Wat, the females also have the highest rate of AMTL when comparing the three closely located sites. A higher rate of frailty can also help explain the high maternal mortality. The dental health of the females at Non Ban Jak shows that they were less frail than those at Ban Non Wat as their dental health was better even though the fertility rate was higher. Being less frail, they were better able to withstand the impact of the multiple pregnancies and as such Non Ban Jak had a much lower maternal mortality.

The differing levels of frailty in these closely located settlements can be explained in relation to their length of occupation and the climate change affected landscape. The next section will discuss the impact of this changing climate and the nature of the human response and propose an explanation of the effect on health.

5.2.3 Impact of Climate Change

Changes in climate are associated with socio-cultural change, alterations to agricultural production, infectious disease, epidemics and increased conflict (Zuckerman & Dafoe, 2021). The analysis of bioarchaeological data allows for the interpretation of both short and long term responses of humans to environmental change (Robbins Schug, 2021a). Even short term changes in climate can significantly impact the structure and health of societies (McMichael, 2012; Zuckerman & Dafoe, 2021).

Climate change has both direct and indirect effects on health (Helle & Helama, 2007). Climate change in the past, as today, altered seasonal weather patterns. Drying landscapes led to the adoption of new agricultural practices that enabled an intensification of agriculture (Wells & Stock, 2020). An intensification in agriculture has been equated with an increase in agricultural surplus leading to a time of abundance and improved health. The reliance on agriculture also resulted in people being more exposed to the seasonality of food supply (in some regions) and at risk of inadequate supply due to crop failure (Wells & Stock, 2020). Crop failure and famine being a direct impact of climate change on health, whereas the over reliance on a single crop leading to malnutrition is an indirect consequence.

Climate change has generally been associated with negative health outcomes in the past, due in part, to this aspect receiving the most research attention (McMichael, 2012; Zuckerman & Dafoe, 2021). An understanding of human resilience, adaption and the cumulative effects of climate change can be gained by observing the responses of people and the associated outcomes in the face of the changing environment (Zoéga & Murphy, 2021).

The three responses humans likely implement when faced with a changing climate, are (1) employ a strategy to mitigate or reduce the impact of the changing climate; (2) choose to migrate out of the impacted region in search of more abundant resources; and/or (3) attempt to eliminate competition (i.e. warfare) or to secure resources (i.e. raiding) from competing groups (Harrod & Martin, 2014). Not all resource stress results in conflict and violence as the human response to climate change is complex (Figure 5.7). Human resilience and adaptive strategies are associated with skeletal indications of physiological stress (Zuckerman & Dafoe, 2021). The comparison of skeletal health indications before and after climatic changes can provide a measure of the human adaptive (or maladaptive) response to climate change (Harrod & Martin, 2014).

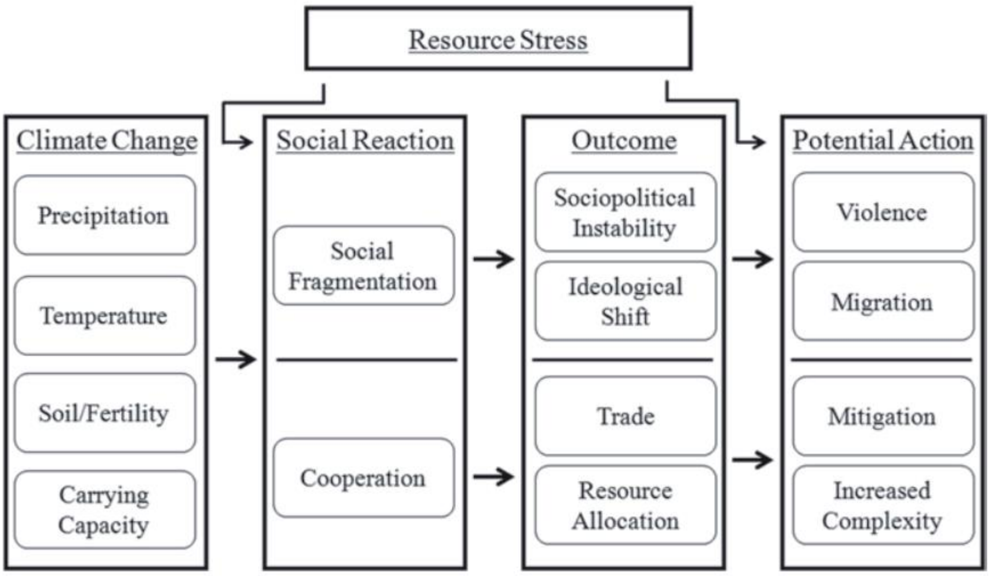

Figure 5.7: Model for how resource stress leads to different behaviours among cultures (Harrod & Martin, 2014, p. 25)

Current evidence indicates three environmental changes occurred in the Upper Mun River Valley during prehistory. During the Bronze Age into the early Iron Age (c. 4450 to 2150 BP) the forests of the Neolithic gradually changed to a more open landscape. This was followed by a period of rapid landscape change due to the agricultural management occurring during the mid to late Iron Age (2150 to 1450 BP). The agricultural landscapes were then replaced with dry woodlands and grassland during the post-Iron Age transition (1450 to 1350 BP) (Boyd & Chang, 2010). In many cases around the world the timing of climate, and any associated social change, cannot be determined with precision, which has led to the assumption of a time lag between the changing climate and any associated social response (Zuckerman & Dafoe, 2021). In mainland Southeast Asia the evidence of the changing climate is clear (Castillo et al., 2018) and corresponds to social change evidenced by the construction of moats around existing settlements and new, moated settlements in the region (O'Reilly, 2014; Scott & O'Reilly, 2015).

A model to explain the integration of changing human and environmental behaviour has been proposed by Boyd and Chang (2010). Whilst being cognisant that researchers do have a tendency to try and fit their findings, events, and artefacts into neat chronological boxes (Murphy, 2016), this model provides a framework for the interpretation of the changes in health, as demonstrated by the oral health, in the Upper Mun River Valley over time. The Neolithic can be defined as a period of 'Colonisation' (Boyd & Chang, 2010), where the people entered the environment and adapted to the conditions, bringing with them external adaptions, such as farming, technology and social structures. There is a biological cost with any adaption (Roberts, 2010). The dental health profile of the Upper Mun River Valley has one of high rates of caries, AMTL and advanced wear during this time (Table 5.3). The Bronze and early Iron Ages can be defined as a time of 'Stability' (Boyd & Chang, 2010). There was gradual change in social and environmental conditions but no major disruptions. The stability is reflected in the dental health profiles, with decreasing rates of caries, AMTL and advanced wear (Table 5.3). Domett and Tayles (2006) have suggested that the dental health improved as the people's ability to exploit the environment improved. Cekalovic (2014) hypothesised the reason for health improvement at Noen U-Loke from the early to the mid Iron Age was because it was a newly established site in the early Iron Age. The increased amount of physiological stress on the early inhabitants at Noen U-Loke was reflected in their poorer overall and dental health. As the settlement become more secure over time, the health of the people improved, a suggested explanation also for the site of Non Ban Jak (Section 5.1). A condition of 'Forced Adaptation' can be suggested to be necessary during the mid Iron Age which Boyd and Chang (2010) explain as a time of change driven by external environmental and social influences. The climate was drying as the monsoon weakened. Societies were becoming more outwardly connected with others in the region via trade and exchange, evidenced by the first regional cases of the infectious diseases leprosy and tuberculosis reported at Noen U-Loke (Tayles & Buckley, 2004). It is possible these diseases were more prevalent and appeared earlier and the evidence has been hidden through the, at times, poor preservation of skeletal remains from both the Iron and Bronze Age in this region. However, it seems significant that two possible cases of leprosy and nine possible cases of tuberculosis have also been identified at Non Ban Jak (Buckley et al., 2020). Interestingly, no examples of these infectious diseases have been reported at Ban Non Wat. At the same time societies were also becoming more centrally and locally focused. As Boyd and Chang (2010, p. 285) explain:

> "… the people of Ban Non Wat and Noen U-Loke could have opted to leave the area as agriculture became more difficult or they could have further adapted their subsistence system to the changed natural resources. What they chose to do was to attempt to maintain their current (rice-centred) lifestyle by an intensification of both physical and ritual practices. **They changed in order to remain the same**"

As the mid-Iron Age period ended, the environment was significantly drier. Moats to secure and control the water supply were being established around settlements to assist in rice agriculture (O'Reilly, 2014; Scott & O'Reilly, 2015). The existing settlements *changed* and *adapted* their agriculture strategy, moving from dry to wet rice agriculture, in order to continue to live in the area: changing to remain the same (Boyd & Chang, 2010). These societal changes led to a time of increased physiological stress, leading to fluctuating health and adverse dental health outcomes. The period of 'Forced Adaptation' led into the final two periods: the 'Tipping Point' and 'Resolution-New Equilibrium' equate to the late Iron Age to early Historic period following this model. It is at this time that the nearby settlement of Non Ban Jak was *established*, utilising the moated system of wet-rice agriculture from the outset. Whilst Noen U-Loke and Ban Non Wat were experiencing a time of change and 'Forced Adaptation' leading to the 'Tipping Point', Non Ban Jak was experiencing a time of 'Colonisation'. Non Ban Jak did not have to adapt to a changed agricultural process at this time, a point of difference to the nearby, longer established settlements of Ban Non Wat and Noen U-Loke. The Bronze and early Iron Age at Ban Non Wat and Noen U-Loke show *japonica*-type grains, whereas the late Iron Age has a significantly higher proportion of *indica* grains which is suggestive of the introduction of new, wet rice varieties (Castillo et al., 2018). The people of Non Ban Jak, in not having to alter or adapt their agricultural strategy, were not subject to the physiological cost of adaptation during the settlement sequence, unlike the settlements of Noen U-Loke and Ban Non Wat. Instead, they experienced health improvement through the evolution from 'Colonisation' to 'Stability', albeit at a heavily condensed time frame compared to at the wider, regional level. The dental health of the people at Non Ban Jak improved throughout the occupation sequence, whereas at Noen U-Loke and Ban Non Wat it fluctuates. Ban Non Wat and Noen U-Loke provide evidence of cultural resilience in the face of environmental change: "the ability to maintain livelihoods that satisfy both material and moral (normative) needs in the face of major stresses and shocks; environmental, political, economic, or otherwise" (Crane, 2010, p. 2). Resilience can be measured by utilising evidence of dietary behaviour, social traditions, mortuary practices, population size, stress, disease and violence (Temple, 2021). All of these aspects influence both overall and dental health. At its core is the concept of survival through flexibility (Temple, 2021). Ban Non Wat and Noen U-Loke, in changing to remain same (Boyd & Chang, 2010), show their resilience. Whilst at Non Ban Jak, the evidence shows the improvement of dental health as the population reaches ‘Stability’. All three settlements responded to change, but they were at different steps in their evolution which led to differences in health outcomes during the same temporal period.

PART III

Chapter 6 Population Connections

6.1 Introduction

The third objective of this thesis was to "investigate any population connections for the people of Non Ban Jak to other people in the Iron Age as evidenced by both dental health and dental agenesis" (Section 1.6.2). The dental health has been discussed above and will be revisited in the conclusion (Chapter 7). This section contains the overview, methods, results and analysis of the dental agenesis component of this thesis and has been prepared as a *standalone piece for journal submission*, thus there may be some repetition from previous chapters particularly regarding the context of Non Ban Jak.

6.2 Dental Agenesis at Non Ban Jak

The settlement of Non Ban Jak in the Upper Mun River Valley in northeast Thailand is recognised as being of high archaeological and bioarchaeological significance given its temporal and geographic location, and its well preserved skeletal remains and mortuary goods assemblage that cover a time of both rapid social and widespread environmental change (Evans et al., 2016; Higham, 2016; Higham et al., 2014; Higham et al., 2019). Among the large number of well-preserved skeletal remains at Non Ban Jak were an unusually large proportion of individuals with missing lateral incisors. This study investigates the cause of this phenomenon through a differential diagnosis and discusses the implications of this observation for our understanding of society at the time. Potential causes include dental ablation - the intentional removal of the teeth, a practice known to occur in prehistory in mainland Southeast Asia (Domett et al., 2013; Newton & Domett, 2017; Palefsky, 2019; Tayles, 1996; Willman et al., 2016); a pathological or traumatic aetiology; or agenesis.

Agenesis, the congenital absence of a tooth, has previously been recorded for a population in the Mun River Valley (Nelsen et al., 2001). As there is a significant genetic component to congenitally missing teeth the presence of this condition can help understand population relationships, promoting some interesting questions when considered alongside assemblages from the nearby sites of Ban Non Wat and Noen U-Loke.

The Iron Age of mainland Southeast Asia encompasses the period 2370 – 1450 BP and the region of the Mun River Valley has been an area of intensive archaeological study to elucidate the sociocultural changes through the Neolithic, Bronze Age and Iron Age. In particular, the sites of Ban Non Wat, Noen U-Loke and Non Ban Jak are connected by both chronology (Figure 6.1), geography (Figure 6.2 and 6.3) and material culture (Higham et al., 2019).

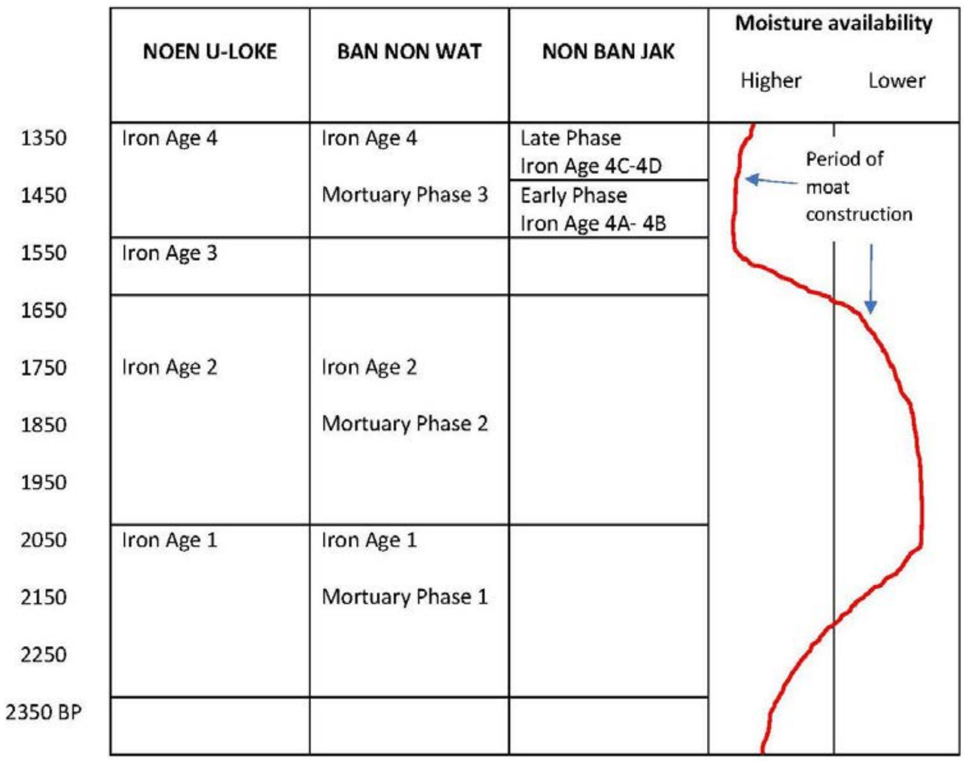

Figure 6.1: Relative chronologies of Noen U-Loke, Ban Non Wat and Non Ban Jak during the Iron Age, together with estimated rain fall
(Reproduced from Figure 2.2)
Early Phase: Early Mortuary Phase; Late Phase: Late Mortuary Phase
(adapted from Higham et al. (2019)

In Figure 6.1, Higham has integrated data from these three sites. Focusing on the Iron Age periods of each site (Figure 6.1), the Ban Non Wat evidence has been placed into three Iron Age (IA) Mortuary Phases (IA1-3) (Higham, 2014). However, at Noen U-Loke four Iron Age periods were identified covering broadly the same span of time as the three Ban Non Wat Iron Age Mortuary Phases. In this table, Higham indicates that there is little evidence for Iron Age 3 ritual and artefacts at Ban Non Wat. Potentially, Ban Non Wat was not occupied during this period, however, the more likely explanation is that well preserved burials corresponding to Noen U-Loke IA 3 lie in areas not yet excavated at Ban Non Wat (N. Chang personal communication). In contrast, the evidence from Non Ban Jak has been placed in four short mortuary phases that all occur within the Noen U-Loke IA 4 period. In this article these are grouped into early (4A & 4B) and late (4C & 4D) mortuary phases.

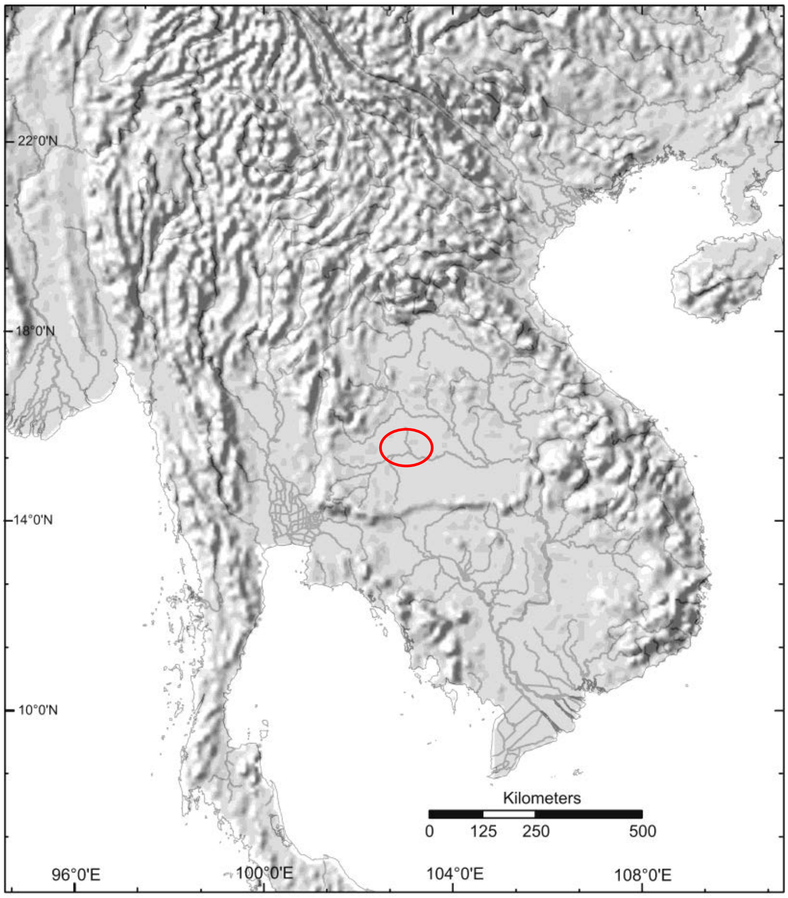

Figure 6.2: Map of Thailand
Red circle indicates approximate location of Ban Non Wat, Nan Ban Jak and Noen U-Loke.

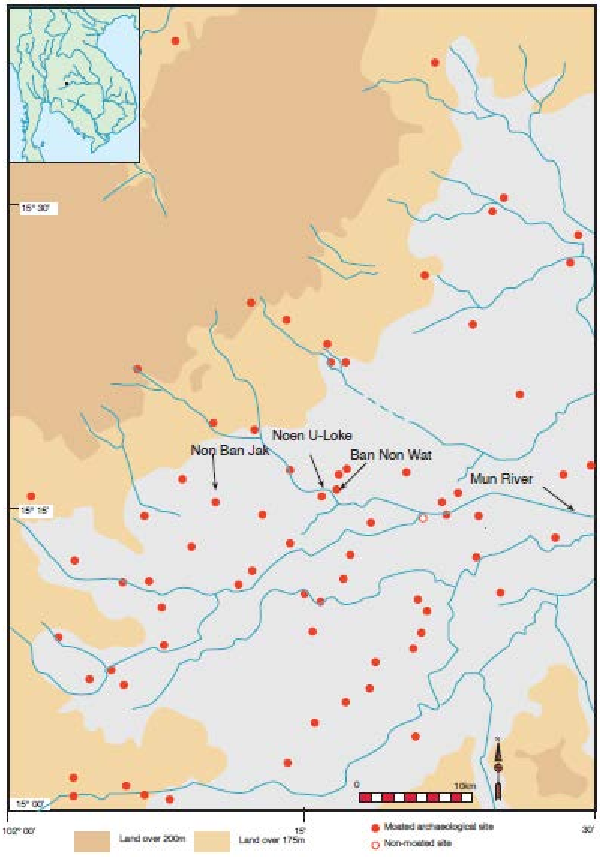

Figure 6.3: Upper Mun River Valley and the location of Non Ban Jak, Noen U-Loke and Ban Non Wat.
Adapted from Higham (2014)

During the occupation sequence at all three sites, environmental and social changes have been argued to have generated social inequality (Higham et al., 2019). These changes are evidenced in mortuary ritual, the suggested adoption of residential burial in the late Iron Age and the material culture evidence of the inclusion of large numbers of rare items within some burials denoting possible social elites (Higham et al., 2019); agriculture, the intensification of agriculture has been suggested for this period due to the introduction of iron ploughshares, sickles and other tools given the increase in the ability to improve agricultural land that these tools provided (Higham, 2015); material culture, and site construction. A posited catalyst for change is the sharp drop in the intensity of the summer monsoon which resulted in a period of aridity which, in turn, led to the establishment of moated settlement sites to allow for agricultural water management (Boyd & Chang, 2010) and the development of wet rice agriculture (Castillo et al., 2018; O'Reilly & Scott, 2015). As such, a model for late and rapid social change in the Iron Age in northeast Thailand has been proposed relying on the geoarchaeological, palaeobotanical, mortuary and artefactual evidence (Higham et al., 2019; King et al., 2017). According to this model, the reducing rainfall led to increased aridity prompting the construction of moats/water reservoirs around Iron Age settlements, allowing the control and targeted distribution of water (O'Reilly & Scott, 2015). The control of water increased the predictability of the harvest and allowed for the establishment of wet rice agriculture which in conjunction with the introduction of iron ploughs and the use of oxen increased the rice yield potentially providing for the growing population in the region (Castillo et al., 2018).

Archaeological Context

Non Ban Jak is one of the many large mounded and moated sites in the Upper Mun River Valley of the Khorat Plateau in northeast Thailand (Figure 6.3). It was excavated over six seasons from 2011 to 2018. It has been reported that the site is unusual in its double peaked occupation mound (Figure 6.4). However, it has been observed that the double mound structure is actually quite common in the area (N. Chang personal communication). The excavation strategy at Non Ban Jak has allowed a clear comparison between the two mounds.

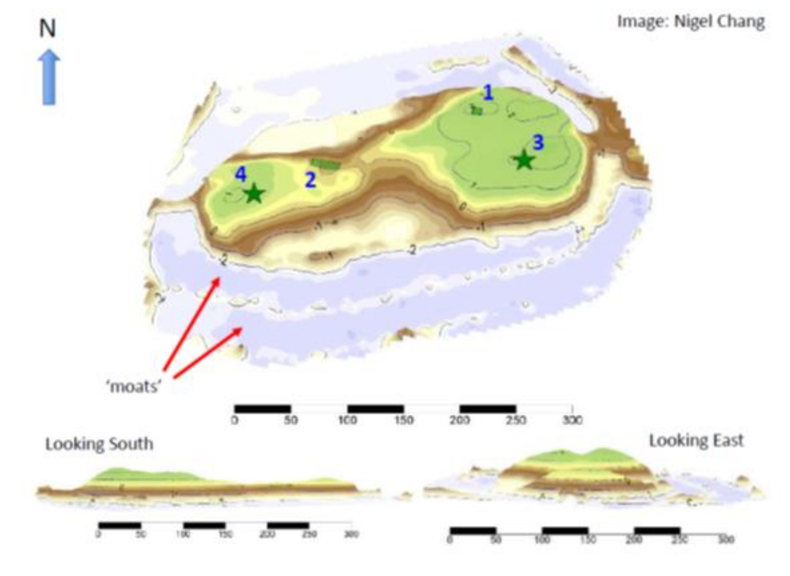

Figure 6.4: The site of Non Ban Jak illustrating the two mounds of occupation
Image by Dr Nigel Chang, used with permission
Key: 1 & 2: Excavation squares: 2011-14; 3 &4: excavation in subsequent seasons ending in 2018

6.1.1 Materials and Methods

Over the course of the six excavation seasons 199 burials were discovered at Non Ban Jak. These burials comprised 195 individuals (the analysis of the 20 burials from the 2018 season have yet to be analysed and are not included here). The burials date from 1650-1150 BP (Higham, 2015), which places Non Ban Jak in the late Iron Age (1650-1350 BP) and Pre-Angkorian periods (1350-1150 BP) (Higham, 2014).

The preservation of the skeletons was generally very good to excellent (Buckley et al., 2020). Age and sex estimations used were those previously published by Buckley et al. (2020) who utilised a multifactorial approach for adults. Standard measures used were observations of late fusing epiphyses (sternal clavicle and sacrum), pubic symphysis and auricular morphology and dental wear seriation (Buikstra & Ubelaker, 1994). The age of death of nonadults, defined as individuals less than 15 years of age at death, were estimated, where possible, using dental formation stages of Moorrees et al. (1963a); Moorrees et al.

(1963b). Other methods based on skeletal development and estimated size of skeletal elements were used (Scheuer & Black, 2000) when there was insufficient dental material. The adults were classified into relative age groups: AG1 - Young; AG2 - Middle; AG3 - Old (Buikstra & Ubelaker, 1994). Site occupation has been divided into an early phase (ca. 1650-1450 BP) and a late phase (ca.1450-1150 BP) based on radiocarbon dates, grave goods assemblages, burial superimposition and burial orientation which allows for the comparison over time (Ward et al., 2019).

There was a high proportion of nonadults within the excavated sample (125/195, 64.1%), with adults comprising 35.9% (70/195), with a near equal ratio of females to males, 40.0% and 38.5% respectively (Buckley et al., 2020). A subset of 64 individuals that had at least one anterior tooth position observable from the total sample of 70 adults was analysed.

Teeth are referred to utilising the FDI system (FDI, 1992). A differential diagnosis determined if the teeth were congenitally absent. There are a number of causes of missing teeth, including failure to erupt, congenital absence (agenesis), accidental loss, pathological loss and intentional removal (ablation). To determine the cause of the missing teeth a detailed macroscopic assessment of the surrounding alveolar bone and teeth must be conducted. The differentiation between antemortem and postmortem tooth loss was based upon evidence of alveolar bone remodelling (Domett et al., 2013). Intentional ablation was considered as most likely if there was no evidence for disease in the adjacent teeth and alveolar bone, symmetry or near symmetry of loss should be evident and the pattern of loss repeated among individuals within the group (Domett et al., 2013; Merbs, 1968). The presence of a diastema due to a congenitally absent tooth is likely to be closed by the rotation or movement of the adjacent teeth (Schuurs, 2013). Whereas a tooth intentionally ablated/culturally removed or lost during life for other reasons such as trauma, often results in the retention of the space in the dental arcade (Nelsen et al., 2001; Palefsky, 2019). As such a diagnosis of agenesis was considered to be most likely if there was insufficient space in the dental arch for the missing tooth, there was no indication of pathology in the adjacent alveolar bone, and there was a lack of symmetry of the patterning of lost teeth. Radiographs were not used in this analysis given the limitations of the fieldwork environment.

Whilst it does appear that Non Ban Jak presents a potentially biased sample with higher numbers of individuals from the west mound and from the late phase, the demographic analysis across the two mounds and across the mortuary periods has revealed no statistically significant differences in the age at death distributions (Section 3.4.1 and Table 3.4). However, when considered in wider context the results reported here lead to interesting implications for understanding population movement in Iron Age northeast Thailand.

Agenesis of the third molars is reportedly at 23% worldwide (Carter & Worthington, 2015), however, given this high prevalence it has been argued that third molar agenesis is an anatomical variant rather than a developmental anomaly (Moreno et al., 2019), and as such many studies exclude the prevalence of third molar agenesis from the results, as is done here. Analysis was conducted at the individual level to allow for comparisons with previous research in both the bioarchaeological and clinical literature. Statistical analysis was completed utilising Prism 9 software. Two-sided Fisher's Exact Test (FET), with significance value of $p<0.05$, were conducted, unless otherwise stated. However, it is acknowledged that data interpretation is more than simply *p*-values (Amrhein et al., 2019; Wasserstein et al., 2019) and as such the discussion (Section 6.2.3) will contextualise the results further.

6.2.2 Results

A total of 64 individuals (24 males, 20 females and 20 individuals of indeterminate sex), adults and nonadults, with at least one anterior tooth position (permanent canines and incisors) observable were included in this study.

A high rate of missing anterior teeth, in particular a large proportion of missing lateral incisors, was identified during the recording of the dentition for the analysis of pathology. 'Missing' teeth were defined by the absence of the tooth and the alveolus (Figure 6.5). A differential diagnosis was completed (as per Section 6.1.1) to determine the likely cause of the missing teeth considering ablation, both post- and antemortem loss and agenesis. It was determined that of the 64 individuals, 36 (56.3%) had at least one anterior tooth missing due to agenesis; 44.4% were male (16/36), 38.9% were female (14/36) and 16.7% were of indeterminate sex (6/36). The difference between the number of male and female individuals with agenesis was not statistically significant (FET, p-value = 0.8113).

Figure 6.5: Non Ban Jak Burial 34 (Mid adult; Female) with tooth 22 (left maxillary lateral incisor) congenitally absent

A total of 58 teeth were recorded as missing due to agenesis, with the most common tooth being the lateral incisor (55 teeth) and only two canines and one central incisor (Figure 6.6). The left anterior teeth (34/55, 61.8%) were more commonly affected than the right, (21/55, 38.2%), and the difference was statistically significant (FET, *p*-value = 0.0217). The number of anterior teeth missing from agenesis in the maxilla (n=28) and the mandible (n=27) was similar. The most common missing tooth was the left mandibular lateral incisor (19/58, 32.8%), followed by the maxillary left and right lateral incisors (15/58, 25.9%; 13/58, 22.4%, respectively).

Given this predominance of lateral incisors affected, a detailed study of the individuals with all four lateral incisor positions available for analysis is presented next.

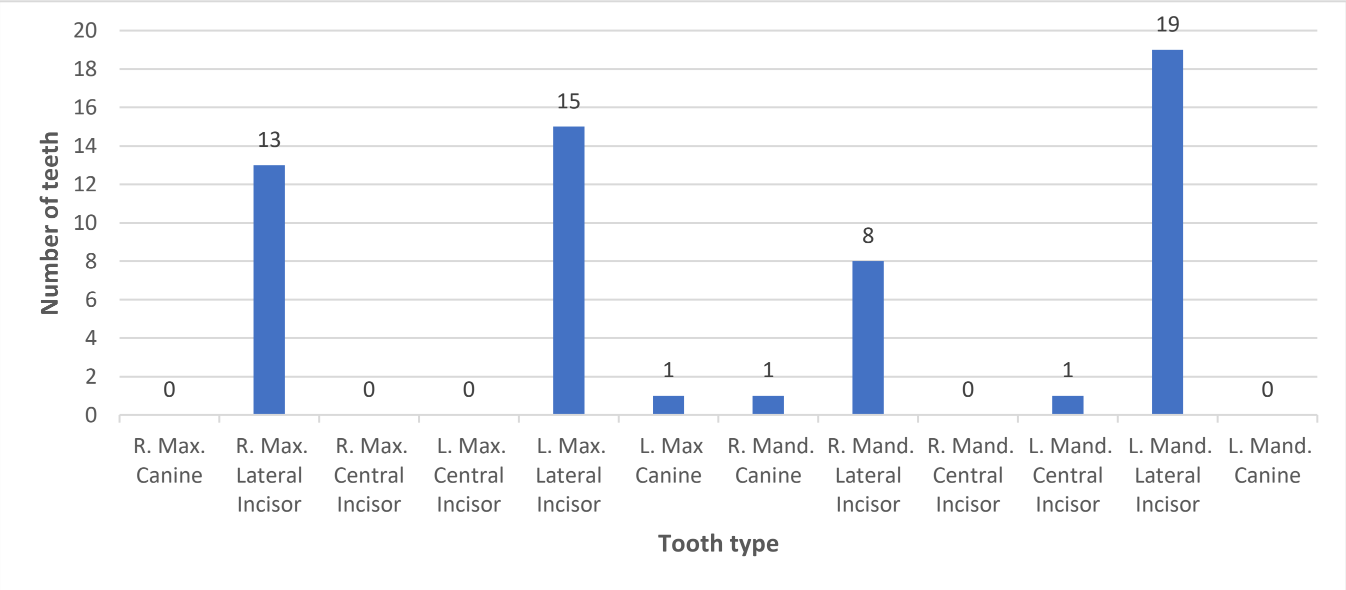

Figure 6.6: Tooth agenesis per tooth type in the total Non Ban Jak sample (58 teeth in 64 individuals)
Note: R., Right; L., Left; Max., Maxillary; Mand., Mandibular

Lateral Incisor Analysis

A subset of 34 individuals (14 male, 10 female, and 10 indeterminate sex) had all four lateral incisor teeth or tooth positions available for analysis. Within this subset, 25 individuals (25/34, 73.5%) had at least one missing lateral incisor (Table 6.1) and 43 teeth were missing from this sample due to agenesis (Figure 6.7). All but one female was affected (90%, 9/10), while 78.6% of males were affected (11/14); a further five individuals of indeterminate sex also had one or more teeth lost to agenesis. It was most common for both males, females and those of indeterminate sex to have two missing lateral incisors (16/34, 47.1%), followed by one tooth affected (8/34, 23.5%) (Figure 6.8). Only one person, a male, had three teeth affected (1/34, 2.9%). Despite the preponderance of two missing lateral incisors a diagnosis of ablation was discounted due to the lack of a diastema between the extant teeth as it is more likely that teeth lost during life will leave a diastema, whereas the diastema is more likely to be closed by the adjacent teeth if a tooth is congenitally absent.

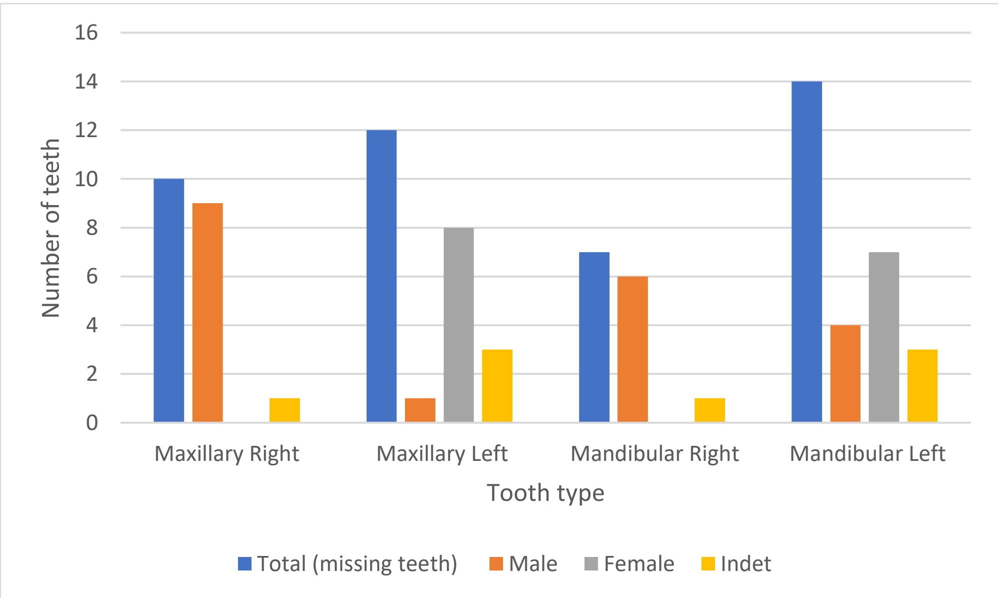

Figure 6.7: Lateral incisor agenesis prevalence from the subgroup of 34 individuals with all four lateral incisor positions available in the Non Ban Jak sample

Table 6.1: Percentage of individuals at Non Ban Jak with agenesis (in sample of only those with all 4 lateral incisors positions)

Number of Teeth Missing	**Male n/%**	**Female n/%**	**Indeterminate sex**	**Total n/%**
0 lateral incisors	3/8.8%	1/2.9%	5/14.7%	9/26.4%
1 lateral incisor	3/8.8%	3/8.8%	2/5.9%	8/23.5%
2 lateral incisors	7/20.6%	6/17.6	3/8.8%	16/47.1%
3 lateral incisors	1/2.9%	0/0.0%	0/0.0%	1/2.9%
% of individuals with agenesis by sex	**11/14 78.5**	**9/10 90.0%**	**5/10 50%**	**25/34 73.5%**
Total number of individuals observed (with 4 lateral incisors)	14	10	10	34

Note: FET *p*-value male vs female total agenesis = 0.6146

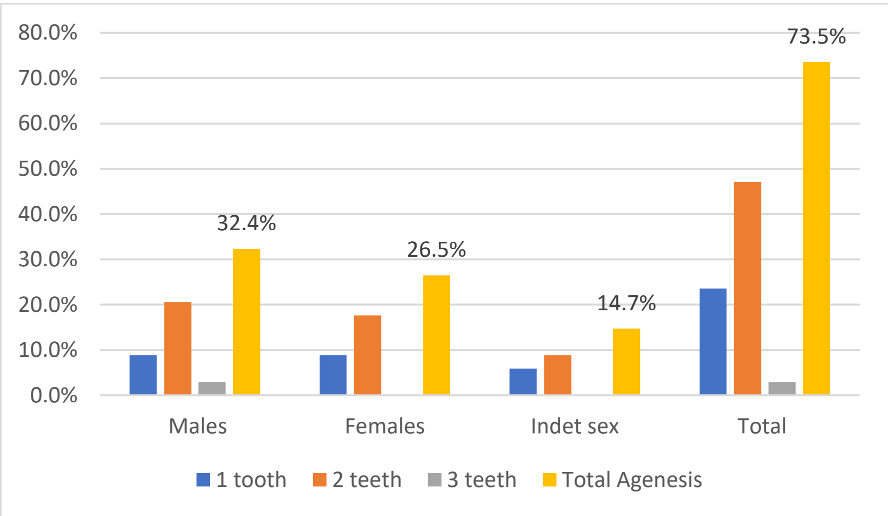

Figure 6.8: Percentage of individuals with agenesis at Non Ban Jak by sex and number of missing teeth

Patterns of Agenesis

The most frequent pattern of agenesis in individuals involved the left maxillary and left mandibular lateral incisors; this was evident in nine individuals (9/34, 36.0%; six females, one male and two of indeterminate sex) (Table 6.2). This patterning whilst symmetrical, being both missing teeth on the left side, it is not in a usual patterning for ablation (Nelsen et al., 2001). The next most frequent pattern was where both right lateral incisors were missing, with five individuals affected (5/34, 14.7%; all male). Five individuals had one lateral incisor missing in the maxilla only, where again females were only affected on the left and males on the right (though sample sizes are small). In the mandible, three individuals had one lateral incisor missing and all cases (one male, one female and one individual of indeterminate sex) were on the left side. No one individual had both left and right maxillary lateral incisors affected, which is further support against a diagnosis of ablation. One individual, a male, had both the left and right mandibular lateral incisors affected along with the maxillary right lateral incisor; this was the only case where three teeth were missing. Most cases presented unilaterally (22/25, 88.0%), with more cases on the left (14/22, 63.6%) compared to the right (8/22, 36.4%), though this side difference was not statistically significant (FET p-value = 0.1308). In the unilateral cases, no females were affected on the right side and fewer males were affected on the left side.

The most numerous missing tooth type was the mandibular left incisor, followed by the maxillary left incisor (Figure 6.7). In 23 individuals (nine female, 10 male and four of indeterminate sex), the maxillary lateral incisors were missing due to agenesis, a prevalence rate of 67.6%.

East and West Mound

In the subset of 34 individuals with all four lateral incisors positions available for analysis, 10/34 (29.4%) individuals were from the east mound and 24/34 (70.6%) from the west mound. Six of the east mound individuals have agenesis (60.0%, 6/10; two male, two female and two of indeterminate sex), whereas 79.2% (19/24; eight male, six female and five of indeterminate sex) of the individuals from the west mound have agenesis. The difference between the mounds was not statistically significant (FET, *p*-value = 0.3951).

Mortuary Phase

In the subset of 34 individuals with all four lateral incisor positions available for analysis, eleven individuals are from the early mortuary phase and nine of these individuals (9/11) have agenesis, 81.8%. Five were found on the eastern mound and four on the western, however the only individuals with agenesis from the initial mortuary phase were found on the western mound. Twenty-three individuals are from the late mortuary phase and sixteen have agenesis, 16/23, 69.9%. Of the late phase individuals with agenesis in this subsample, only one was from the eastern mound (burial 7, mortuary phase 3; 1/16, 6.3%). All other individuals from the late phase with agenesis were found buried in the western mound (15/16, 93.4%). The difference in the prevalence of agenesis between the early and the late mortuary phases was not statistically significant (FET, *p*-value = 0.6824).

Table 6.2: Patterns of missing teeth by tooth position and sex in the subsample of 34 adults at Non Ban Jak (14 Male, 10 Female, 10 Indeterminate) with all four lateral incisor tooth positions assessable, of which 25 had at least one lateral incisor missing

Pattern of missing teeth	**No. of missing incisors**	**Number of individuals with each pattern**			
		Male	**Female**	**Indet**	**TOTAL n/%**
Maxilla only					
Right only - 12	1	2	0	1	3/12.0%
Left only - 22	1	0	2	0	2/8.0%
Right and Left	2	0	0	0	0/0.0%
Total maxilla only		**2**	**2**	**1**	**5/20.0%**
Mandible only					
Right only - 42	1	0	0	0	0/0.0%
Left only - 32	1	1	1	1	3/12.0%
Right and Left	2	0	0	0	0/0.0%
Total Mandible only		**1**	**1**	**1**	**3/12.0%**
Maxilla and Mandible					
Right only 12+42	2	5	0	0	5/20.0%
Left only 22+32	2	1	6	2	9/36.0%
Maxilla L 22 + mandible R 42	2	0	0	1	1/4.0%
Maxilla R 12 + mandible L 32	2	1	0	0	1/4.0%
Maxilla R 12+ mandible R+L 42+32	3	1	0	0	1/4.0%
Total maxilla and mandible		**8**	**6**	**3**	**17/68.0%**
		Total no. of individuals*			**25**
Left side only (maxillary and/or mandible)	1 or 2	2	9	3	14
Right side only (maxillary and/or mandible)	1 or 2	7	0	1	8
Total unilaterally affected individuals		9	9	4	**22**
Total bilaterally affected individuals		2	0	1	**3**
		Total no. of individuals*			**25**

Note: Teeth are identified using the FDI two-digit system.
* Total number of individuals in the sample with at least one lateral incisor missing

6.2.3 Discussion

To summarise, the overall prevalence of agenesis at Non Ban Jak is high (56.3%), with males more affected than females. There was a higher prevalence in individuals on the west mound (70.6%) than the east (29.4%). The earliest burial of an individual with agenesis occurred during the initial mortuary phase on the western mound. The late mortuary phase had a higher prevalence of agenesis than the early mortuary phase.

The most prevalent missing tooth was the lateral incisor, with the left side more affected. Given the preponderance of missing lateral incisors, the analysis focused on a subset of individuals with all four lateral incisor positions available for analysis and within this subset an even higher prevalence rate of agenesis was found (73.5%).

The most frequent number of missing teeth per individual was two (47.1%), followed by one missing tooth (23.5%). Significantly, no one individual had four lateral incisors missing. In terms of patterning of the missing teeth, the most prevalent pattern involved the left maxillary and the left mandibular lateral incisors (26.5%). The patterning appears to be related to sex, with 6/9 individuals with this pattern female. The next most prevalent pattern was the right maxillary and right mandibular incisors missing, which affected five males.

No individual had both the left and right maxillary or the left and right mandibular lateral incisors missing, strengthening the argument that the teeth are congenitally missing and have not been ablated.

Sex Differences

Numerous studies report that agenesis is more common among females than males (Carter & Worthington, 2015; Gkantidis et al., 2017; Kanchanasevee et al., 2019; Khalaf et al., 2014; Polder et al., 2004; Shimizu & Maeda, 2009; Williams & Letra, 2018). The reason for the increased prevalence in females is not known. At Non Ban Jak, the initial investigation found that males were more frequently affected with 44.4% of the 36 individuals with agenesis male and 38.9% female (six individuals were of indeterminate sex). Noen U-Loke saw the same non-significant preponderance of males with agenesis over females (Nelsen et al., 2001). However, when the analysis turned to a detailed investigation of the 34 individuals (14 males, 10 females and 10 of indeterminate sex) who had all four lateral incisor positions available for analysis, 78.6% of the males were affected by agenesis, and females had the higher percentage with 90% (9/10) affected. This seems to imply a sex-based difference in the condition.

Sex based differences in the Non Ban Jak sample were also observed in the patterning of the lateral incisor missing, with females more likely to have left lateral incisors missing (15/43, 34.9%, eight maxillary left and seven mandibular left) than males (5/43, 11.6%, one maxillary left and four mandibular left). At Noen U-Loke, females also had more left lateral incisors missing due to agenesis and males had a higher prevalence on the right (Nelsen et al., 2001). The similarity in sex-based siding of the agenesis at both Non Ban Jak and Noen U-Loke raises the possibility of homogeneity in both the populations, discussed further below.

Tayles et al. (2007, p. 282) mention that there is "no documentation in the literature of a correlation between sex and laterality of agenesis". This position was also held by Küchler et al. (2008) and Gupta and Rauniyar (2019). Whilst there is no known biological reason why agenesis would appear more frequently on one side than the other, Rolling and Poulsen (2009) found sex based differences with agenesis of the left and right sides in their study, with females having agenesis of the right upper lateral incisor more than twice as often than the left, and males having agenesis of the right lower second premolar twice as frequently as the left. All other teeth had no sex-based difference in frequency in the study. As prevalence rates vary with geographic location it seems that so too does the side affected.

The differences in side preference with sex was offered as potential evidence of ablation at Noen U-Loke, along with the presence of spaces for the missing teeth in some cases (Tayles et al., 2007). At Non Ban Jak the side preference is repeated, however, there were no spaces available for the missing teeth. As such, ablation as the cause of the missing teeth was considered to be very unlikely at Non Ban Jak.

Patterns of Tooth Type and Arcade

Most common missing tooth type

Further complicating the story of agenesis is the fact that some teeth are more often affected than others (De Coster et al., 2009; Gkantidis et al., 2017; Matalova et al., 2008; Polder et al., 2004), with this variation seeming to be population dependant. In support of these findings a modern Thai study found that the mandibular right lateral incisor was the most affected, followed by mandibular left and right second premolars and the maxillary right lateral incisor (Kanchanasevee et al., 2019). Tantanapornkul (2015) found the most common missing tooth was the mandibular incisor, followed by the mandibular premolar, then the maxillary incisor. Although the sides of the missing teeth were not reported the affected teeth reported by Tantanapornkul (2015) are the same series of teeth as Kanchanasevee et al. (2019). Overall, missing teeth appear more commonly in the mandible than the maxilla. However, the omission of the recording of which incisor or premolar was missing prevents a more precise comparison. A third modern Thai study, Kositbowornchai et al. (2010), reports that the most common missing tooth was the mandibular incisor, followed by the maxillary incisor, then the mandibular second premolar, and finally the maxillary second premolar (all three of these Thai studies excluded the third molar from the analysis).

At Non Ban Jak the most commonly missing tooth was the left mandibular incisor followed by the maxillary left lateral incisor. This is the same as at Noen U-Loke (Nelsen et al., 2001). The most commonly missing tooth in these two Iron Age populations from northeast Thailand is the same as found in the modern Thai studies. Whilst the population history of modern Thailand is complicated and not necessarily linear, it seems significant that the most commonly missing tooth is the same amongst populations of nearby areas.

Bilateral v unilateral

Patterns of agenesis have been reported in the secondary dentition with unilateral agenesis previously reported as more common than bilateral (De Coster et al., 2009; Shimizu & Maeda, 2009). However, a recent meta-analysis has shown that bilateral agenesis is twice as prevalent as unilateral (Rakhshan, 2015). It is possible that such patterning is also population and geographically-dependant as a modern Thai study supports the original hypothesis of unilateral agenesis being more common (Kanchanasevee et al., 2019).

At Non Ban Jak the majority of cases presented unilaterally (88.0%) with more cases on the left (63.6%) compared to the right (36.4%) though this side difference was not statistically significant. In the unilateral cases, no females were affected on the right side and fewer males were affected on the left side. This is different to the finding at Noen U-Loke where both maxillary and mandibular lateral incisors were missing bilaterally in both jaws in 30% of individuals (6/20). Overall, at Noen U-Loke both jaws were affected almost equally, and almost half of the individuals had bilateral absence in one of both jaws (Tayles et al., 2007). At Non Ban Jak there was no individual that had both maxillary and mandibular lateral incisors missing, bilaterally in both jaws, further supporting the discounting of ablation causing the missing teeth.

Agenesis Prevalence

The prevalence of agenesis varies worldwide (De Coster et al., 2009) ranging from 1.6% to 26.4% of individuals, excluding third molars (De Coster et al., 2009; Kositbowornchai et al., 2010; Matalova et al., 2008; Polder et al., 2004; Yu et al., 2019). The reported regional prevalence of agenesis in modern populations in Africa is 13.4%, 7% in Europe, 6.3% in Asia and Australia, and 5.0% in North America (Khalaf et al., 2014). Modern clinical studies in Thailand have shown prevalence rates of 13.7% for lower northern

Thailand, Phitsanulok province (Tantanapornkul, 2015), 26.4% for northeastern Thailand, Khon Kaen province (Kositbowornchai et al., 2010), and 8.98% for central Thailand, Krung Them Maha Nakhon province /Bangkok Metropolis (Kanchanasevee et al., 2019) (Figure 6.9). All of these rates are higher than the average reported above for Asia which suggests a difference based on geographic area. The differences in prevalence of agenesis in the three modern Thai studies are suggestive of differences based around geographic areas (although it should be noted that Kanchanasevee et al. (2019) may represent a wider sub-set of the modern Thai population, with the other two studies more tightly geographically constrained).

Non Ban Jak's overall prevalence of agenesis (56.3% of individuals) is much higher than any reported clinical results from Thailand or Asia more broadly. The nearby site of Noen U-Loke also had an exceptionally high prevalence with 79% of individuals affected by agenesis (Nelsen et al., 2001), which is very similar to the rate of 70% for the subset reported here for Non Ban Jak. These are high rates and whilst it is acknowledged that sample size in bioarchaeological work is smaller than that in clinical work, it is of note that the modern literature also gives a significantly higher than average prevalence rate of agenesis from the northeast of Thailand of 26.4% (Kositbowornchai et al., 2010), which is suggestive of individuals from the northeast of Thailand having a genetic predisposition to tooth agenesis.

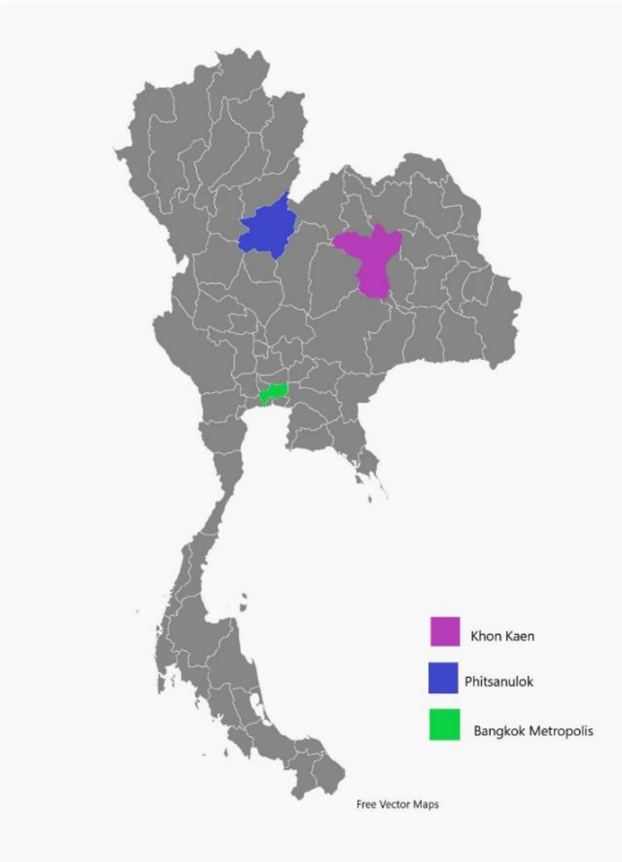

Figure 6.9: Map of Thailand highlighting the three Thai provinces referred to in the modern clinical studies of agenesis.

Any genetic predisposition though is challenged by the results from neighbouring Ban Non Wat. There is no evidence of agenesis in Ban Non Wat's prehistoric population (Shkrum, 2014). Looking more broadly across Thailand and Cambodia, the central Thai Iron Age sites of Ban Mai Chaimnogkol and Tha Kae also have no evidence of agenesis, although there is some evidence of intentional ablation at these sites (Palefsky, 2019). Iron Age Cambodia has been shown to have evidence of both ablation and dental filing, but no agenesis, for example Phum Sophy and Phum Snay in the northwest (Domett et al., 2013). Similarly, there is evidence of ablation, but not congenital absence in Koh Ta Meas, also in northwest Cambodia (Frelat & Souday, 2015). Prior to the Iron Age in Thailand there is evidence for tooth ablation and possibly agenesis from Khok Phanom Di, eastern Thailand at around 4000-3500 BP

(Tayles, 1996). High rates of agenesis throughout prehistoric mainland Southeast Asia are certainly not ubiquitous, making the examples of two closely located sites from the same time period with high rates even more interesting.

Pioneers from Noen U-Loke?

As previously mentioned, the earlier work by Nelsen et al. (2001) at Noen U-Loke, a site located close to Non Ban Jak, also revealed a population with a high prevalence of lateral incisor agenesis, in both the maxilla and mandible, with 79% of individuals affected. The similar distinct patterning of agenesis within these two closely located populations could be reflecting the genetic uniformity of the populations. In a small and relatively isolated gene pool agenesis can appear with greater frequency (Alt et al., 2013; Edgar et al., 2016; Nelsen et al., 2001).

It has been suggested the settlement of Non Ban Jak was established by a group of pioneers (Higham et al., 2014). Perhaps the agenesis at Non Ban Jak is linked to the pioneers coming from a site with agenesis such as Noen U-Loke. The timing of the mortuary phases support this as agenesis at Non Ban Jak first appears in the first mortuary phase and only on the western mound. No individuals from the first mortuary phase have been found with agenesis on the eastern mound.

In comparison, Palefsky (2019), in her work on the Iron Age populations from two sites in inland central Thailand, Ban Mai Chaimangkol and Tha Kae, found no evidence of agenesis. Perhaps further strengthening the argument of regional specificity and population homogeneity in the expression of agenesis in Non Ban Jak and Noen U-Loke. But again, the lack of evidence of agenesis from the settlement of Ban Non Wat seems significant.

The congenital absence of maxillary incisors is well-known in dental research (Pinho et al., 2010). As the frequency of expression is commonly low, coupled with a relatively limited range of interpopulation variability, it has been suggested that it does not make this trait suitable for estimating the extent of morphological affinities among human groups (Herrera-Atoche et al., 2019). However, this does not seem to be the case in the Mun River Valley in northeast Thailand where there is evidence of two populations with a high prevalence of congenital absence of maxillary incisors whilst a close, nearby settlement has no evidence. Recently, Alt et al. (2013) has used the presence of agenesis in a population in Jordan to suggest close genetic relationships within the population akin to endogamy. It is possible that the presence of agenesis at Non Ban Jak and Noen U-Loke is indicating the same close relationship between these settlements.

In areas of poor ancient DNA preservation, genetically determined anatomical traits provide valuable assistance when examining genetic kinship (Alt et al., 2013; Edgar, 2013). Populations with multiple origins, or with much mixing of people tend to have more variation in both common and rare tooth traits (Edgar et al., 2016). Traits that are rare in a general, well mixed population but then more common in another, may be indicative of a special case of genetic drift known as founder effect, which occurs when a small daughter population splits from a parent population forming a new community (Edgar et al., 2016) and also indicative of endogamy – the custom of marrying only within the limits of a local community, clan or tribe (Alt et al., 2013). The presence of a high proportion of the trait of lateral incisor agenesis in two closely located settlements and then non-existent in a third closely located settlement is suggestive of genetic ties between the populations. The timing of the occupation sequences at Noen U-Loke and Non Ban Jak and the presence of agenesis is suggestive that the settlement at Non Ban Jak was founded by a group from Noen U-Loke. The first individuals with agenesis at Non Ban Jak were buried during the first mortuary phase on the west mound.

Population Connections in the Region

The Khorat Plateau of northeast Thailand has been called a peripheral zone in relation to both the cultures of central and northern Thailand (Murphy, 2016, p. 367), and it has been identified as an area that encompasses a distinct geographic region that developed its own aesthetic and religious culture by blending the traits of their eastern and western neighbours (Murphy, 2010; Ball, 2020). Perhaps this cultural distinction extends to, and is able to be observed in, such biological traits as agenesis.

Ball (2019), focusing on pottery comparisons at Ban Non Wat and Non Ban Jak during the late Iron to proto-historic periods, has shown that the populations at these sites were not replaced by new Dvaravati people, but rather the people at these sites adapted the Dvaravati pottery technology to their own needs. There was a gradual change to the pottery over time rather than an influx of new peoples and ideas that overpowered or removed the existing people, ideas and technologies. As such, it is apparent that a new immigrant population of people did not suddenly appear at Non Ban Jak (nor at Ban Non Wat and by extension Noen U-Loke) during this period. However, it does seem apparent that two of the settlements, Non Ban Jak and Noen U-Loke, have closer genetic ties to each other than they do to Ban Non Wat.

The similarities between Noen U-Loke and Non Ban Jak are not limited to tooth agenesis. There are also similarities in mortuary ritual. At Noen U-Loke the way the dead were interred changed over the Iron Age (IA). From initially a few scattered burials, this changed to two tight clusters of graves (Higham, 2011) in IA2, with one cluster containing rice filled graves (Higham, 2014). This differentiation in ritual potentially denoting different statuses within the settlement. The rice filled burials continued into IA3 at Noen U-Loke which also saw a stark increase in mortuary wealth of some individuals (Higham et al., 2019).

At this time there were four distinct clusters of burials, of which three of the clusters contained one or two particularly wealthy individuals (Higham, 2014) with the groups so tightly nucleated that it has been suggested they are likely to be related individuals (Higham, 2011). One cluster was evidently poorer than the other three in which the dead in this cluster were buried not with bronze, glass and agate but with a disproportionate number of spindle whorls (Higham, 2014). At the cessation of the IA3/commencement of IA4 period, we see the first Iron Age mortuary evidence at Non Ban Jak. The burial clusters of IA3 Noen U-Loke, and associated evidence of differing status groups, are similar to the two distinct occupation and mortuary mounds at Non Ban Jak.

The mortuary rituals for all Iron Age burials at Non Ban Jak span the IA4 period at Noen U-Loke (Higham et al., 2019). At Non Ban Jak the early mortuary phase saw mortuary offerings that were sparse and impoverished compared to the wealth seen in the contemporary graves at Noen U-Loke, which is possibly suggestive that this group of individuals at Non Ban Jak represent the site's initial, and impoverished, settlers (Higham et al., 2014). Analysis by Ward (2019) found that burials in the late mortuary phase had twice the number of grave goods than the early mortuary phase. The west mound individuals had the highest mean number of items per person – although Ward's analysis considered only 34 individual burials, 30 individuals from the west mound and four from the east, which does skew the results and, as such, any comparison between the mounds must be done with caution. It is during the early phase at Non Ban Jak that there was also evidence of rice incorporated into burials (burials 12, 125, 139, 141, 190 and 199) with rice adhering to long bones and not associated with any vessels from the second half of the early mortuary phase (Higham & Kijngam, 2020). These burials were not filled with rice like at Noen U-Loke. Perhaps the early settlers at Non Ban Jak brought the practice of rice filled burials with them from Noen U-Loke, although in the early years of the settlement there was less of a surplus available for inclusion in burials. Rice filled burials have *not* been found at Ban Non Wat.

At Non Ban Jak the dead were interred in residential rooms during the late mortuary phase. Over time the houses became more substantial at Non Ban Jak (Higham & Kijngam, 2020). It has been suggested that residential burial occurred at Noen U-Loke however the structural remains of the rooms have not survived in as much detail compared to Non Ban Jak (Higham et al., 2019) although the clay floorings in both locations indicate the same construction technique.

Similarities in the mortuary practices of Non Ban Jak and Noen U-Loke continue with similar pottery vessels placed alongside or over the buried, identical iron sickles, knives and spears (Higham et al., 2019), and iron grave goods appearing at both locations at the same time – the end of the late mortuary phase. It is of interest that, as yet, no iron sickles have been found at Ban Non Wat, although its occupation sequences did not include IA4.

Spatial Segregation of Burials

The sites of Ban Non Wat and Noen U-Loke have been identified as being class societies (Cekalovic, 2014) and, whilst it has been observed that as a whole Non Ban Jak appears relatively impoverished in terms of grave goods compared to Noen U-Loke (Higham et al., 2019), differences in grave good quantities between the mounds and differences in evidence of non-specific stress at Non Ban Jak does suggest differences in social equality at this site (Ward, 2019). Further, Ward et al. (2019) showed that individuals from the west mound were interred with greater amounts of grave goods, had taller stature, a lower prevalence of linear enamel hypoplasia and a reduced nonadult mortality compared to the individuals from the east, all of which is suggestive of the west mound burials containing the less stressed portion of the community. Evidence of differences in the dental health adds further evidence in support of differences in social equality between the mounds (Section 5.1), with individuals on the west having better dental health. Adding to this differentiation, individuals with agenesis favour the western mound.

Iron sickles were an innovation of the late Iron Age and were found in the IA4 graves of Noen U-Loke and Non Ban Jak but they were not found in the earlier period of IA1-3 (Higham & Kijngam, 2020). These iron sickles in the mortuary goods were originally suggestive of being indicative of the occupation/work of the individual (Higham et al., 2014). However, at Non Ban Jak the iron sickles were predominantly found in the western mound (Higham & Kijngam, 2020), the mound with the most mortuary wealth. Perhaps, as suggested by Ward (2019) the iron sickles denote land ownership and thus wealth instead of an occupation. This is concordant with both the increased level of mortuary wealth found on the western mound and the incidence of residential burial there. Perhaps the first residents at Non Ban Jak claimed both the western mound and their land which led to a long standing increased amount of wealth shown in the mortuary goods on this side.

There is also a possible relationship between agenesis and the presence of iron sickles in the graves at Non Ban Jak. There were 17 burials with iron sickles, 15 of which were adults. All of the adults buried with sickles were found on the western mound, and 10/15 (66.7%) had agenesis. Further analysis of the burial locations considering both the presences of agenesis and location of the iron sickles is warranted.

6.2.4 Conclusion

The settlement of Non Ban Jak has an exceptionally high prevalence of dental agenesis, as does the neighbouring site of Noen U-Loke. Ban Non Wat, a neighbouring site to both Non Ban Jak and Noen U-Loke has no evidence of this genetic trait. Non Ban Jak and

Noen U-Loke share other similarities such as material culture and mortuary practices. Whereas Noen U-Loke had a long Iron Age occupation sequence, Non Ban Jak only has a short Iron Age occupation sequence and it has been suggested that this settlement was established by a group of pioneers (Higham et al., 2019), although other explanations are possible. The presence of agenesis in these two settlements is suggestive of closer genetic links between these sites than to other nearby locations without agenesis. The question must then turn to how do these results 'fit' within our understanding of population movement within mainland Southeast Asia, which whilst outside the remit of this thesis is worthy of further investigation.

PART IV

Chapter 7 Conclusion

This thesis was guided by the objectives and research questions identified in Section 1.6.2. These will be addressed in turn to illustrate an understanding of the impact of climate change on the people of Non Ban Jak specifically, and the Upper Mun River Valley region more broadly, through the lens of dental health.

7.1 Response to Objectives and supporting research questions

1. *Analyse the dental health of the people of Non Ban Jak to establish a dental pathology profile to investigate differences in dental health between sex, occupation mound and mortuary phase and whether this was impacted by the changing climate*
   - *Are the dental health outcomes the same for both sexes across the settlement? Between the occupation mounds? Between the mortuary phases*?

The analysis of the dentition has revealed that there is evidence for different dental pathology profiles between the sexes, occupation mounds and mortuary phases. Females had worse dental health than males, overall, in each mound, and during each mortuary phase.

Individuals from the east mound had worse dental health than those from the west mound. There is not a statistically significant difference in the age at death distributions for the two mounds (Table 3.4) which is suggestive that the individuals analysed are a representative sample of the population they came from. As dental health is a clinical marker for disadvantage (Peres et al., 2019), this finding supports the idea that the two mounds are representative of the individuals on each mound experiencing different lifeways. This cannot be taken as definitive proof that the mounds represent differing social statuses. As it is not yet known what key qualities were valued by this society (was it wealth, power, beauty, freedom, knowledge, or some other value?), it is not known whether Non Ban Jak was organised around these qualities in a hierarchical or egalitarian way (Graeber & Wengrow, 2021; O'Reilly, 2003). Different societies may have very different value systems to each other, and be very different to what we know of our own society, and what we *think* was of most value may not be the case (Graeber & Wengrow, 2021; O'Reilly, 2003). As a heterarchical society does not require the *absence* of any form of social ranking (Carter, 2021; Crumley, 1995; O'Reilly, 2003) or, by extension, the absence of any differences in lifeways, heterarchical social organisation at Non Ban Jak cannot be ruled out. Although it cannot be known whether there were different status groups within the society at Non Ban Jak organised around the occupation mounds, when the differences in dental health are combined with previous evidence in terms of trauma prevalence, number and type of mortuary goods, residential burial, stature and non-specific stress indications it is apparent that the people of the east mound experienced a different lifeway than those on the west.

The analysis at Non Ban Jak also revealed that individuals from the early mortuary phase had worse dental health than those from the late phase. The early mortuary phase corresponds with the time of initial Iron Age occupation at the site. The Iron Age settlement at Non Ban Jak is considered to be a newly established settlement as no archaeological evidence of Bronze Age occupation has been found at this stage. If there was a new community being established at Non Ban Jak that community would likely have had in mind a well-developed local model of what a moated site would look like. Unlike at Ban Non Wat, where the moated mound developed somewhat organically over millennia, the Non Ban Jak site may have been a more thought out and considered construction, with Higham et al. (2014) suggesting that the town lanes had evidently been planned, and moulded to follow a similar model to Ban Non Wat in a relatively short period of time. As such, the initial period of occupation would have been a busy time of moat building, settlement construction and the establishment of the agricultural harvesting cycles. The time was potentially one of high physiological stress and this is reflected in the poorer dental health of the settlement at this time, compared to later in the occupation sequence. It is significant that the dental health of the people at Non Ban Jak improved over the occupation sequence which corresponds to the work by Domett and Tayles (2006) who argue that over time people's ability to exploit resources improves. It also supports the idea that over time the settlement became more successful – as the agricultural harvest cycles became established, potentially food security improved, and physiological stress levels decreased, suggestive of a more comfortable and potentially 'wealthy' existence, possibly evidenced by the increased amount of mortuary wealth, and what Higham et al. (2014) have identified as the commencement of the practice of residential burial denoting land ownership (Higham et al., 2014). However, see Carter (2021) for the counter argument that residential burial was more widespread and had started earlier in mainland Southeast Asia than has been previously recognised. If this is the case the argument that property ownership signified by residential burial commenced in the Iron Age which in turn is used to signify social change, requires revisitation.

- *Did the changing climate lead to worse dental health outcomes?*

Climate change is often associated with poorer health outcomes, in part because that has been the focus of much of the research (McMichael, 2012; Zuckerman & Dafoe, 2021), but whilst the climate did change in the Upper Mun River Valley it is not possible, nor prudent, to apportion blame to changing health singularly to the changing climate. The change in climate during the Iron Age in the Upper Mun River Valley did necessitate the introduction of a different agricultural strategy and as such the lifeways of the people were impacted by the changing climate. Whilst the main subsistence strategy remained agriculture, the method changed from dry to wet rice agriculture. Whilst this occurred throughout the region, the results of the dental analysis at Non Ban Jak reveal differences when compared to the nearby sites of Noen U-Loke and Ban Non Wat. The settlement at Non Ban Jak had a shorter occupation sequence than Ban Non Wat and Noen U-Loke and it was established at the beginning of the late Iron Age (IA4) utilising the new wet rice agriculture subsistence mode. There was no adaptation needed by the people of Non Ban Jak to this new agricultural method throughout the settlement period, only the initial biological cost of adaptation that would have impacted the people as the commencement of occupation at this new settlement. This is a different situation to the nearby site of Ban Non Wat and Noen U-Loke and it is probable that this is reflected in the dental health results. These two settlements chose to implement adaptative strategies in order to remain in the region. In settlements that chose to remain where they were in the face of the changing climate, but needed to alter and intensify their agricultural practice, those that "changed to remain the same" (Boyd & Chang, 2010), such as Noen U-Loke and Ban Non Wat, there was fluctuating dental health (Cekalovic, 2014; Shkrum, 2014) possibly due to the impact of the biological costs of adaptation. However, Non Ban Jak was established with this new type of agriculture. The adaptive strategy chosen by the people of Non Ban Jak was to relocate and as such there is no evidence of the negative impact of the biological cost of adaptation *during* the settlement period. Instead, over time, at Non Ban Jak their dental health improved as their ability to manipulate and exploit the area increased. As such, whilst it was the changing climate that led to the need for adaptative agricultural strategies the evidence suggests that the current evolutionary step that each community found itself on, as described by Boyd and Chang (2010), albeit on a more heavily compressed timetable than their wider regionally based model, introduces differences in the dental health profile of the communities.

- *What impact, if any, did the changing climate have on the fertility of the population?*

The fertility at Non Ban Jak decreased over time. This reduction occurred as the settlement moved from a state of ‘Colonisation’ to ‘Stability’ as described by Boyd and Chang (2010), although at a more heavily compressed timetable when compared with the wider regional level model. It is possible that over time an increased level of abundance in terms of food and nutrition and a decreasing level of physiological stress as the people’s ability to exploit their surroundings increased, resulted in decreasing fertility. This can appear to be counter intuitive - the idea that healthier people have fewer babies - but it is simply the flip side of the argument that high fertility is the result of increased infant mortality. Increasing maternal health, due to the increased level of nutrition and decreased stress, can lead to a decline in maternal mortality, which could lead to decreased infant mortality, and an associated increase in birth interval and thus a lower level of fertility, along similar lines as the significant impact deliberate birth spacing has been shown to have on population fertility rates (Chamberlain, 2006). Relatedly, dental health was improving during the time of decreasing fertility at Non Ban Jak. A lower fertility level would result in less evidence of the negative impact of fluctuating hormones associated with pregnancy and birth on the dentition of females. This was particularly evident at Non Ban Jak in the female dental health as it improved from the early to the late phases as fertility decreased, yet remained worse than that of the males in each mortuary phase.

2. *Investigate any differences in the dental health in terms of the changing environment and socioeconomic times – temporally and spatially – in the wider Upper Mun River Valley by comparing the results from the analysis of Non Ban Jak to those from the nearby sites of Noen U-Loke and Ban Non Wat. The comparison of the results will provide evidence to support a model of social change in mainland Southeast Asia*

There is no definitive temporal trend in terms of dental health among all settlement sites within mainland Southeast Asia broadly, or the Upper Mun River Valley more specifically (Newton et al., 2013). Whilst generally dental health improved from the Neolithic to the early Iron Age, there are locations where this does not hold true. Further, the predicted worsening of dental health during the late Iron Age, as hypothesised by King et al. (2017), does not occur at Non Ban Jak. The dental health at Non Ban Jak *improved* over time, a contrasting result to both the Iron Age sites of Ban Non Wat and Noen U-Loke. At these sites the change in the climate led to establishing a new process of agriculture that the people needed to adapt to. The biological cost of adaptation is demonstrated at both Ban Non Wat and Noen U-Loke by increased stress indications and a fluctuating level of dental health (Cekalovic, 2014; Shkrum, 2014). The settlement of Non Ban Jak was established later, when the changed climate was known and had been planned for, with wet rice agriculture being utilised from the start. At Non Ban Jak, the dental health of the settlement improved over time. The climate did not change *during* the settlement and as such did not negatively impact on the dental health of the inhabitants.

When the dental pathology profiles of the three closely located settlements, Non Ban Jak, Noen U-Loke and Ban Non Wat, are compared, the dental pathology profile of Non Ban Jak is more similar to that of Noen U-Loke. Ban Non Wat's is quite different with higher rates of caries and antemortem tooth loss. It is of note that the temporal period Non Ban Jak and Noen U-Loke represent are closer to each other than Ban Non Wat. Further, Ban Non Wat is a site with a much longer settlement history. The trajectory of dental health in the region is not solely dependent on temporal or geographic factors. This thesis suggests it is the longevity of the settlement itself, along with the impact of the biological cost of any adaptation strategies needed by the people that are the key factors that influence the dental health of the people. It has also been observed that the settlement of Ban Non Wat was undergoing a decline during its final Iron Age occupation phases (N. Chang personal communication), evidenced in part by the demographic analysis of the three sites with Ban Non Wat having a low level of fertility, in fact below replacement level (Table 3.8), compared to the moderate-high levels at Noen U-Loke and Non Ban Jak. It is possible that the poorer level of dental health is a visible indication of this decline, although as previously noted the dental sample analysed from Iron Age Ban Non Wat is small. Further investigation during this phase is warranted.

As stated above, at first glance the model of socioeconomic change proposed by King et al (2017) does not fit the results at Non Ban Jak. When the work of Boyd and Chang (2010) is incorporated the reason for this becomes clear. People's health is not only impacted by socioeconomic and environmental change. It must also be recognised that settlement sites and their inhabitants undergo an evolution of sorts. The longer people are living somewhere the more they are able to successfully exploit their resources (Domett & Tayles, 2006). In addition, if people need to change their way of life during the course of the settlement, the biological costs of adaptation will be evident, written on their bones and teeth. It is accepted that the biological data from human remains needs to be integrated into the archaeological, geological, botanical and other evidence available at a regional level (Buikstra, 1977) to elucidate a nuanced understanding of the past lifeways (Roberts, 2010) and this work has shown, in agreement with previous work (Newton et al., 2013), that mainland Southeast Asia cannot be taken as a single, homogenous area in terms of dental health. It has already been established that dental health changed over time throughout the region (King et al., 2017;

Newton et al., 2013; Willis & Oxenham, 2013b). What also needs to be considered is not only the impact of multi period sites, but also the length of occupation at each settlement.

3. *Investigate any population connections for the people of Non Ban Jak to other people in Iron Age mainland Southeast Asia as evidenced by both dental health and dental agenesis*

The presence of a rare dental morphological trait shared between populations may be indicative of closer genetic connections (Alt et al., 2013) and potentially a special case of genetic drift known as the founder effect (Edgar et al., 2016). Populations with multiple origins, or with much mixing of people tend to have more variation in both common and rare tooth traits (Edgar et al., 2016). Non Ban Jak and Noen U-Loke both have a high prevalence of dental agenesis and both settlements have the same most commonly missing teeth, the left mandibular incisor and the left maxillary lateral incisor. Significantly, previous work at Ban Non Wat has not found any indication of this morphological trait. The presence of a high proportion of lateral incisor agenesis in two closely located settlements and then completely absent in a third closely located settlement is suggestive of genetic ties between the populations, and, just as importantly a genetic, and possibly cultural, block from the third settlement. The timing of the occupation sequences at Noen U-Loke and Non Ban Jak and the presence of agenesis is suggestive that the settlement at Non Ban Jak may have been founded by a group from Noen U-Loke or both of these settlements have the same genetic ancestry which is different to that at Ban Non Wat. There is a possibility that Non Ban Jak is a daughter population of Noen U-Loke. Though it is possible there may be other explanations. The first individuals with agenesis at Non Ban Jak were buried during the first mortuary phase on the western occupation mound. It also seems significant that the settlement of Ban

Non Wat was in decline at the time when Noen U-Loke was strongest and Non Ban Jak was emerging, which is a relationship that requires further investigation.

The most similar dental pathology profiles are those of Non Ban Jak and Noen U-Loke. Dental health is affected by many factors, such as diet, biological sex and genetics (Vergidou et al., 2021). It is of note that these two closely located sites, with the most similar dental pathology profiles are the two sites that have evidence of dental agenesis denoting a likely genetic connection. Whereas Ban Non Wat's dental pathology profile is much different and there is no evidence of agenesis. As such it is possible that genetic connections between Non Ban Jak and Noen U-Loke are an additional explanatory factor for the dental health results.

7.2 Future Directions

As mentioned in Section 1.7 this project was at the mercy of the Covid-19 pandemic, limiting travel and thus the ability to analyse the dentition of the people of Non Ban Jak in more detail. It is hoped that when international travel again becomes the norm, that the dentition can be reanalysed with additional pathologies added to the analysis. The deciduous dentition also requires analysis. The results of which will also be a welcome addition.

Whilst not the main focus of this thesis, the dental analysis of the large, multiperiod site of Ban Non Wat are yet to be published in full. This will be a large undertaking, however the results would add significantly to our understanding of the health changes of the people in large, multiperiod sites. Such additional analysis is warranted to enable further exploration of the suggestion that Ban Non Wat was in a period of decline whilst the nearby sites of Non Ban Jak and Noen U-Loke were getting stronger.

What is also needed for Southeast Asia is a large-scale, multiregional population level bioarchaeology analysis of health and disease for the region. In 2018 the Global Health History Project (Steckel et al., 2022) identified the commencement of an 'Asia Module' to the project and work has begun towards this. The currently observed variations among all sites and all periods within Asia broadly, and mainland Southeast Asia specifically, will make an analysis of the collated data challenging. Despite such difficulties it is possible that new connections or patterns of health and disease will become apparent during the analysis.

In terms of population connections between Non Ban Jak and other closely located sites, further analysis is warranted. The published results of the aDNA analysis at Non Ban Jak are eagerly anticipated. A more extensive dental morphological analysis comparing the sites of Non Ban Jak, Noen U-Loke and Ban Non Wat, given its success establishing inter-regional, inter-site and intra-cemetery connections (for example: Edgar et al., 2016; Gross & Edgar, 2019; Hubbard et al., 2015; Irish, 2013; Paul & Stojanowski, 2017; Pilloud et al., 2016) is another avenue requiring further exploration. Despite the work of Matsumura (1995,2007) and colleagues (Matsumura & Hudson, 2005; Matsumura et al., 2019; Matsumura & Oxenham, 2014), dental morphological differences remain an underutilised area in mainland Southeast Asia for both inter- and intra-site analysis. The utilisation of such work has the possibility of highlighting as yet unexplored population connections within the region, with the benefit of being a non-destructive technique.

7.3 Concluding Statement

The dental health of the people of Non Ban Jak was varied. Poorer health in the east mound compared to the west suggest differences in the lived experience between these occupation mounds. Differences in health outcomes in males and females may be indicative of different lived experiences between the sexes, and it also potentially, once again highlights the impact that the hormonal fluctuations during the life course of females have on dental health.

Whilst the results were varied it is of note the dental health of the people – in relation to sex, and mound - *improved* over time. This is in contravention to the previously published model of social and health change in the region (King et al., 2017) but once the impact of the changing climate and differences in length of settlement time are considered the picture of what is happening in the Upper Mun River Valley broadly, and at Non Ban Jak more specifically, becomes clearer. It has been known for some time that dental health is more than simply subsistence – and it is now clear that it is also affected by more than geographic and temporal factors on their own.

Afterword

What's Happening at Non Ban Jak - An imagined narrative

I am the first in my family to attempt a higher research degree. I am the only 'almost' archaeologist / bioarchaeologist in the family as well. Throughout the process of this research I have been often asked by both family and friends "what am I doing" and the soon to follow question "but why?" or "what is the point?". This has been dwelling in the far recesses of my mind during this whole process. And then I stumbled across the edited volume *Bioarchaeologists Speak Out* (Buikstra, 2019) and the section by Alexis Boutin on 'fictive narratives' (Boutin, 2019). This sent me on a path to find out more about humanistic approaches in bioarchaeology. There are two sides in the argument when it comes to such narratives in archaeology since the ground breaking work *What this Awl means* by Janet Spector (Spector, 1991). Those against the idea of an imagined narrative decry it is pretending to be facts when it is not leading to confusion in the lay person (Van Dyke & Bernbeck, 2015). However, the counter argument proposed by Stojanowski and Duncan (2015) reasons that bioarchaeology has an engagement problem impacting funding and research potential and:

> "…if we do not affirm the importance of humanistic outreach someone else with less expertise may, and probably will, fill the void. In the same way that it is preferable for Kathy Reichs to write fiction about forensic anthropology while carrying a responsible professional background, it is better for professional bioarchaeologists to help capture and shape public imagination about what we do." (p. 57)

It is also apparent that such narratives are not common in bioarchaeology (Boutin, 2019) despite the ability of such narratives to utilise the evidence from the human remains and their contexts to contextualise the story of both individuals and groups in the past and to bring to life similarities in the lived experiences of people in the past and the present (Stojanowski & Duncan, 2015). It is also a way that our professionally and experientially based interpretations of the data can serve to express and highlight. So, whilst not claiming to be a Kathy Reichs, I have decided to attempt a short, imagined narrative to help explain and contextualised these past years of research as a way to humanise the past and to make it more than simple orders of statistical significance as "we have much to gain through scholarly sensuous engagements with the past" (Van Dyke, 2015, p. 83).

This narrative is not exhaustive. It does not cover the entire occupation history of the settlement of Non Ban Jak. It is based upon my research and an interpretation of the archaeological and bioarchaeological evidence. The names of the people are fiction. Items of material culture referred to were found at Non Ban Jak. Symptoms of leprosy include a red rash on the skin, and, later, the nose collapsing, as there is evidence of possible leprosy at Non Ban Jak. Sindhu is the Sanskrit name for India. During this time there was increasing evidence of complex trade networks including with India and beyond. This is the imagined story of some of the people at Non Ban Jak living their lives during a time of climate change and increased interregional connections. A time perhaps that mirrors our own current lives as we are confronted with a changing climate. As stated in the first chapter of this thesis (section 1.7) truly, we "… cannot escape our connections to the past, and indeed there may be the germs of useful advice in the stories told by these long gone people" (Buckley & Oxenham, 2015, p. 2). However, this lofty ideal amounts to nothing if no one outside the academy engages with our work. We must make the past accessible to the present – offering interpretations but also high-lighting the ambiguities (Tringham, 2015).

Imagined Narrative

It was now May and it was unbearably hot and humid in the valley. April was usually the hottest month, but then the rains would come and bring cool relief to the settlement. But this year the rains had not come. The land was dry. The alleyways that wound their way around the houses on the two mounds of the settlement were thick with dust. Dust that was kicked up by the children running barefoot and laughing and playing between the houses avoiding the adults who would no doubt find them some boring job to do. The heat from the pottery kilns and the iron smelting made those areas on both mounds even hotter.

The rice crop had been harvested in the previous November. It was time to plant again. But without the rains there would be no water. There would be no planting. No harvest.

The people had celebrated the New Year Feast, Songkran, almost an entire moon cycle ago – and still the rains had not come. They had performed the rain making rites as they had done each year, and still the rains had not come. The people of Non Ban Jak continued their daily routines with the ever present oppressive humidity whilst waiting, longingly for the cooling life giving rains to commence. It hadn't always been this way. The stories handed down from the elders tells of a time when it rained year round and water was plentiful. The farming of rice had been easier. A smaller undertaking. It was the rain that would water the young plants in those days. There would be two rice crops each year – although each harvest was smaller. This was a time before the people had arrived at Non Ban Jak.

The rain could no longer be relied upon, year round. Now the rainy season was anxiously waited for so the life-giving water would flow into the two moats surrounding the *settlement, and remain there, ready to sustain the newer rice crop that would grow in the well-watered paddies outside the moats.*

Eyes continually searched the sky, particularly at meal times, hoping to see the first evidence of the build-up of clouds signalling that the rains were on their way. Hoping they would soon feel the relief of the first summer storm that would signal the start of the rainy season. Everyone in the settlement was tired of eating the preserved salted fish from the previous rainy season, when the fish and shellfish were plentiful in the water filled moats and caught and preserved for this dry season. There were no fish in the moats now. Only cracked plates of mud interspersed with swampy muddy puddles and clumps of rice stubble.

Whilst the paddies were dry the settlement's water buffalo had been resting. Corralled within the settlement to keep them safe from the wild animals of the nearby forest, and to stop them wandering off never to return. Once it rained they would be used to pull the heavy iron ploughs that were now needed to turn over the soil in the flooded rice paddies for planting. These beasts of burden were also waiting impatiently for the rains to start. To cool and clean their hot, dirty hides.

Today there was a sadness in the settlement. Today another child would be buried. Not yet two years old this child, Dara (meaning 'evening song'), a daughter, had become ill. With fear and dread her mother, Ya Chai (meaning 'sweetheart') realised she had a fever. The fever would not break. For 10 days the little girl had been ill, refusing to eat, barely drinking, becoming increasingly listless. After another long wakeful night trying to comfort Dara, Ya Chai had fallen into an exhausted sleep not long before sunrise. She was woken by the sound of the koels in the nearby forest trees, calling to rouse the world from its slumber with their melodious call. Ya Chai had awoken to find her daughter was dead. Dara had lost her battle with illness. Ya Chai had always loved the sounds of the koels, but not this morning. The death of a child was not an unusual occurrence in the settlement, and this was Ya Chai's *second child that had died before the age of two, but that didn't make the grief any less painful.*

That was two days ago. Today, Dara would be buried. To keep her close Dara would be buried within the family's small home. The white clay and laterite floor in the back room had already been scraped away and a hole dug into the ground. Dara had been wrapped in a shroud and placed between two jars, the types with the lustrous black finish. Ya Chai consoled herself with the thought that the jars would protect Dara in the earth. These jars had been first made in the valley and were now increasingly popular in both the entire plateau and in regions beyond. They could be traded for the shiny, colourful glass beads from areas further south, and for the colourful striped gemstones that came from even further away, across the seas. How they got to Non Ban Jak Ya Chai was not entirely sure. Only a few people from the village had seen the ocean. These few people had sailed the river southeast to trade and also for adventure. Ya Chai's brother Kasem (meaning 'happiness') had been one of them. He had come home after almost a year and half with tales of adventure and of seeing people with different looking eyes and hair and skin colour. And of seeing different boats. Boats that come from far away – from a place he had called Sindhu. But Kasem was dead now too. He had come home from his adventure with a strange rash on his body. Over time he lost feeling in his toes and fingers. And then his nose went flat. It was a such a strange illness. No one in the village had seen it before. But his fellow travellers said they had seen people with similar rashes on the coast where the large boats from Sindhu were. Kasem became too weak to work. And then too weak to walk. Then to speak and to eat. Nothing the wise healing women of the settlement did would help. He was ill for a long time. Then he had died too. One of his friends who had travelled with him also got the rash – but he died much faster than Kasem. Kasem was also buried within the home. Dara would be buried near her uncle.

To accompany Dara with her travel to the ancestors Ya Chai placed objects that she knew Dara liked; the heavy bronze bangles that Ya Chai wore on feast days she placed on Dara's legs pulling them up over her knees – like the way Dara would put them on herself in play; the shiny tektite that her grandmother had given her. Ya Chai placed a string of glass beads around Dara's neck – it was too long – but it was of Dara's favourite colours – red and blue. She also placed a small, lustrous black vessel filled with rice grains, decorated with circular burnished patterns. Running her fingers around on the streaks of the pot gave her comfort to feel the cool back smooth surface.

Yai Chai's family home was on the western mound of the settlement. There was a depression separating the western from the eastern sides and the whole area was surrounded by two moats. Ya Chai's family had been here for almost as long as the stories could remember. The family stories told that her grandmother's grandmother's grandmother had been born here. She was of the first generation to be born at Non Ban Jak after a group of settlers had left their homes at the nearby village of Noen U-Loke. The first houses at Non Ban Jak to be constructed, and the first burials, had taken place on this western mound area. Their family had always lived on this side of the settlement. Ya Chai wasn't sure why – she just knew it was so.

Despite the many years that had passed since the first settlers had arrived at the settlement the connection between Noen U-Loke and Non Ban Jak remained strong. Residents from Noen U-Loke would come to Non Ban Jak for feast days, other celebrations and funerals. And so too the people from Non Ban Jak would travel to Noen U-Loke. Kinship connections also remained strong between the settlements, with marriages often arranged between families from each settlement. Ya Chai's husband had come from Noen U-Loke. After their union he had come to live at Non Ban Jak with Ya Chai and her family. There was another nearby settlement too, Ban Non Wat. The people of Non Ban Jak rarely interacted *with these people. It was only a half day walk away yet the two settlements did not feast together. Nor did they share any kinship connections. Marriage unions between people from Non Ban Jak and Ban Non Wat were not allowed. Ya Chai did not know why – she just knew it was so.*

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References

Adams, R. L., & King, S. M. (2011). Residential Burial in Global Perspective. *Archaeological Papers of the American Anthropological Association*, *20*(1), 1-19. https://doi.org/10.1111/j.1551-8248.2011.01024.x.

Alikhani, M., Lopez, J. A., Alabdullah, H., Vongthongleur, T., Sangsuwon, C., Alikhani, M., Alansari, S., Oliveira, S. M., Nervina, J. M., & Teixeira, C. C. (2016). High-Frequency Acceleration: Therapeutic Tool to Preserve Bone following Tooth Extractions. *Journal of Dental Research*, *95*(3), 311-318. https://doi.org/10.1177/0022034515621495

Alt, K. W., Benz, M., Müller, W., Berner, M. E., Schultz, M., Schmidt-Schultz, T. H., Knipper, C., Gebel, H.-G. K., Nissen, H. J., & Vach, W. (2013). Earliest Evidence for Social Endogamy in the 9,000-Year-Old-Population of Basta, Jordan. *PloS one*, *8*(6). https://doi.org/http://dx.doi.org/10.1371/journal.pone.0065649

Amrhein, V., Greenland, S., & McShane, B. (2019). Retire statistical significance. *Nature*, *567*, 305-307.

Armelagos, G. J., Brown, P. J., & Turner, B. L. (2005). Evolutionary, historical and political economic perspectives on health and disease. *Social Science & Medicine*, *61*, 755-765. https://doi.org/10.1016/j.socscimed.2004.08.066

Armelagos, G. J., Goodman, A. H., Harper, K. N., & Blakely, M. L. (2009). Enamel Hypoplasia and Early Mortality: Bioarchaeological Support for the Barker Hypothesis. *Evolutionary Anthropology*, *18*, 261-271.

Baca, P., Castillo, A.-M., Liébana, M. J., Castillo, F., Martín-Platero, A., & Liébana, J. (2012). Horizontal transmission of Streptococcus mutans in schoolchildren. *Medicina Oral, Patologia Oral y Cirugia Bucal*, *17*(3), e495-e500. https://doi.org/10.4317/medoral.17592

Ball, H. M. (2019). *A Pottery Rim Form and Petrographic Analysis. Dvaravati in Northeast Thailand in the proto-historic period: Technologies and Culture Transfer from Central and North Thailand seen in the Archaeological Ceramics* [Honours, James Cook University]. Townsville

Barber, M. A. (1924). The Effect of Chara Robbinsii on Mosquito Larvae. *Public Health Reports (1896-1970)*, *39*(13), 611-615. http://www/jstor.org/stable/4577099

Barker, D. J. P. (1990). The fetal and infant origins of adult disease. *British Medical Journal*, *301*, 1111.

Barker, D. J. P. (2012). Developmental origins of chronic disease. *Public Health*, *126*(3), 185-189.

Barnes, J., Dove, M., Lahsen, M., Mathews, A., McElwee, P., McIntosh, R., Moore, F., O'Reilly, J., Orlove, B., Puri, R., Weiss, H., & Yager, K. (2013). Contribution of anthropology to the study of climate change. *Nature Climate Change*, *3*, 541-544. https://doi.org/10.1038/NCLIMATE1775

Batchelor, P. (2015). The changing epidemiology of oral diseases in the elderly, their growing importance for care and how they can be managed. *Age and ageing*, *44*(6), 1064-1070. https://doi.org/10.1093/ageing/afv148

Batchelor, P., & Sheiham, A. (2004). Grouping of tooth surfaces by susceptibility to caries: a study in 5-16 year-old children. *BMC Oral Health*, *4*(2). https://doi.org/https://doi.org/10.1186/1472-6831-4-2

Bell, E. J., Kaidonis, J., Townsend, G., & Richards, L. (1998). Comparison of exposed dentinal surfaces resulting from abrasion and erosion. *Australian Dental Journal*, *43*(5), 362-366. https://doi.org/10.1111/j.1834-7819.1998.tb00190.x

Bellwood, P., Oxenham, M., Hoang, B. C., Dzung, N. K., Willis, A., Sarjeant, C., Piper, P., Matsumura, H., Tanaka, K., Beavan-Athfield, N., Higham, T., Manh, N. Q., Kinh, D. N., Trung Kien, N. K., Huong, V. T., Bich, V. N., Quy, T. T. K., Thao, N. P., Campos, F., Sato, Y.-I., Cuong, N. L., & Amano, N. (2011). An Son and the Neolithic of Southern Vietnam. *Asian Perspectives*, *50*(1/2), 144-175.

Bentley, R. A., Cox, K. J., Tayles, N., Higham, C. F. W., Macpherson, C. G., Nowell, G., Cooper, M. J., & Hayes, T. E. F. (2009). Community diversity at Ban Lum Khao, Thailand: isotopic evidence from the skeletons. *Asian Perspectives*, *48*(1), 79-97. https://doi.org/http://dx.doi.org/10.1353/asi.0.0017

Bhutta, Z. A., Lassi, Z. S., Blanc, A., & Donnay, F. (2010). Linkages Among Reproductive Health, Maternal Health, and Perinatal Outcomes. *Seminars in Perinatology*, *34*(6), 434-445. https://doi.org/https://doi.org/10.1053/j.semperi.2010.09.002

Bjørndal, L., Simon, S., Tomson, P. L., & Duncan, H. F. (2019). Management of deep caries and the exposed pulp. *International Endodontic Journal*, *52*(7), 949-973. https://doi.org/10.1111/iej.13128

Boutin, A. (2019). Writing Bioarchaeological Stories to Right Past Wrongs. In J. E. Buikstra (Ed.), *Bioarchaeologists Speak Out: Deep Time Perspectives on Contemporary Issues* (pp. 283-303). Springer.

Boyd, W. E., & Chang, N. (2010). Integrating social and environmental change in prehistory: a discussion of the role of landscape as a heuristic in defining prehistoric possibilities in NE Thailand. In S. Haberle, J. Stevenson, & M. Prebble (Eds.), *Terra Australis: 21: Altered ecologies - fire, climate and human influence on terrestrial landscapes* (pp. 273-297). ANU E Press.

Brandt, J. R., Ingvaldsen, H., & Prusac, M. (Eds.). (2015). *Death and Changing Rituals: Function and Meaning in Ancient Funerary Practices*. Oxbow Books.

Bratthall, D., & Hänsel Petersson, G. (2005). Cariogram – a multifactorial risk assessment model for a multifactorial disease. *Community dentistry and oral epidemiology*, *33*(4), 256-264. https://doi.org/10.1111/j.1600-0528.2005.00233.x

Brickley, M. B., Kahlon, B., & D'Ortenzio, L. (2020). Using teeth as tools: Investigating the mother–infant dyad and developmental origins of health and disease hypothesis using vitamin D deficiency. *American Journal of Physical Anthropology*, *171*(2), 342-353. https://doi.org/10.1002/ajpa.23947

Broadbent, J. M., Page, L. A. F., Thomson, W. M., & Poulton, R. (2013). Permanent dentition caries through the first half of life. *British Dental Journal*, *215*(E12), 1-6.

Buckley, B. M., Anchukaitis, K. J., Penny, D., Fletcher, R., Cook, E. R., Sano, M., Nam, L. C., Wichienkeeo, A., Minh, T. T., & Hong, T. M. (2010). Climate as a contributing factor in the demise of Angkor, Cambodia. *Proceedings of the National Academy of Sciences*, *107*(15), 6748-6752. https://doi.org/10.1073/pnas.0910827107

Buckley, H., Domett, K., Halcrow, S., Pedersen, L., Ward, S., Ling, N., O'Reilly, D., & Shewan, L. (2020). An initial report on Health and Disease at Non Ban Jak. In C. F. W. Higham & A. Kijngam (Eds.), *The Excavation on Non Ban Jak* (pp. 463-486). Fine Arts Department: Thailand.

Buckley, H. R., & Oxenham, M. (2015). Bioarchaeology in Southeast Asia and the Pacific. In M. Oxenham & H. R. Buckley (Eds.), *The Routledge Handbook of Bioarchaeology in Southeast Asia and the Pacfic Islands* (pp. 1-6).

Budd, C., Bogucki, P., Lillie, M., Grygiel, R., Lorkiewicz, W., & Schulting, R. (2020). All things bright: copper grave goods and diet at the Neolithic site of Osłonki, Poland. *Antiquity*, *94*(376), 932-947. https://doi.org/10.15184/aqy.2020.102

Buikstra, J. E. (1977). Biocultural Dimensions of Archaeological Study: A Regional Perspective In R. L. Blakely (Ed.), *Biocultural Adaption in Prehistoric America* (pp. 67-84). University of Georgia Press.

Buikstra, J. E. (Ed.). (2019). *Bioarchaeologists Speak Out: Deep Time Perspectives on Contemporary Issues*. Springer.

Buikstra, J. E., & Ubelaker, D. H. (1994). *Standards for Data Collection from Human Skeletal Remains*. Arkansas Archaeological Survey.

Carter, A. (2015). Beads, Exchange Networks and Emerging Complexity: A Case Study from Cambodia and Thailand (500 BCE - CE 500). *Cambridge Archaeological Journal*, *25*(4), 733-757. https://doi.org/10.1017/S0959774315000207

Carter, A. (2021). Building from the Ground Up: The Archaeology of Residential Spaces and Communities in Southeast Asia. *Journal of Archaeological Research*. https://doi.org/10.1007/s10814-021-09170-4

Carter, A. K. (2016). The Production and Exchange of Glass and Stone Beads in Southeast Asia from 500 BCE to the early second millennium CE: An assessment of the work of Peter Francis in light of recent research. *Archaeological Research in Asia*, *6*, 16-29. https://doi.org/https://doi.org/10.1016/j.ara.2016.02.004

Carter, K., & Worthington, S. (2015). Morphologic and Demographic Predictors of Third Molar Agenesis: A Systematic Review and Meta-analysis. *Journal of Dental Research*, *94*(7), 886-894. https://doi.org/10.1177/0022034515581644

Carvalho, J. C. (2014). Caries Process on Occlusal Surfaces: Evolving Evidence and Understanding. *Caries Research*, *48*(4), 339-346. https://doi.org/10.1159/000356307

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*(365), 1274-1291. https://doi.org/http://dx.doi.org/10.15184/aqy.2018.198

Cave, C., & Oxenham, M. (2016). Identification of the Archaeological 'Invisible Elderly': An Approach Illustrated with an Anglo-Saxon Example. *International Journal of Osteoarchaeology*, *26*, 163-175. https://doi.org/10.1002/oa.2408

Cekalovic, H. (2014). *Health and Society in Southeast Asia: The Transition from the Late Bronze Age to Iron Age* [Doctor of Philosophy, James Cook University]. Townsville.

Chaffee, B. W., Gansky, S. A., Weintraub, J. A., Featherstone, J. D. B., & Ramos-Gomez, F. J. (2014). Maternal Oral Bacterial Levels Predict Early Childhood Caries Development. *Journal of Dental Research*, *93*(3), 238-244. https://doi.org/10.1177/0022034513517713

Chamberlain, A. (2006). *Demography in Archaeology* Cambridge University Press.

Chang, N. (2018). *Preliminary Report: Excavations at Non Ban Jak, Units E10 & E11 - the Western Mound*. J. C. University.

Chazan, M. (2021). *World Prehistory and Archaeology: Pathways through time* (5th ed.). Routledge.

Clark, A. L., Tayles, N., & Halcrow, S. (2014). Aspects of Health in Prehistoric Mainland Southeast Asia: Indicators of Stress in Response to the Intensification of Rice Agriculture. *American Journal of Physical Anthropology*, *153*, 484-495. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.22449

Cleland, J. (2001). The Effects of Improved Survival on Fertility: A Reassessment. *Population and Development Review*, *27*, 60-92.

Cleland, J., Conde-Agudelo, A., Peterson, H., Ross, J., & Tsui, A. (2012). Contraception and health. *The Lancet*, *380*, 149-156.

Clement, A. F., & Hillson, S. W. (2012). Intrapopulation variation in macro tooth wear patterns—a case study from Igloolik, Canada. *American Journal of Physical Anthropology*, *149*(4), 517-524. https://doi.org/https://doi.org/10.1002/ajpa.22153

Cohen, M. N. (2007). Introduction. In M. N. Cohen & G. M. M. Cane-Kramer (Eds.), *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification* (pp. 1-9). University Press of Florida.

Consoli, R. A. G. B., Mendes, N. M., Pereira, J. P., Santos, B. L., & Lamounier, M. A. (1989). Influence of several plant extracts on the oviposition behaviour of Andes fluviatilis (Lutz) (Diptera: Culicidae) in the laboratory. *Memórias do Instituto Oswaldo Cruz*, *84*(1). https://doi.org/10.1590/S0074-02761989000100009

Costalonga, M., & Herzberg, M. C. (2014). The oral microbiome and the immunobiology of periodontal disease and caries. *Immunology Letters*, *162*(2), 22-38. https://doi.org/10.1016/j.imlet.2014.08.017

Coupal, I., & Sołtysiak, A. (2017). Dental erosion in archaeological human remains: A critical review of literature and proposal of a differential diagnosis protocol. *Archives of Oral Biology*, *84*, 50-57. https://doi.org/https://doi.org/10.1016/j.archoralbio.2017.09.011

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. *Journal of Archaeological Science*, *38*(3), 665-671. https://doi.org/10.1016/j.jas.2010.10.018

Cradic, M. S. (2018). Residential Burial and Social Memory in the Middle Bronze Age Levant. *Near Eastern Archaeology*, *81*(3), 191-201.

Crane, T. A. (2010). Of Models and Meanings: Cultural Resilience in Social-Ecological Systems. *Ecology and Society*, *15*(4).

Crittenden, A. N., Sorrentino, J., Moonie, S. A., Peterson, M., Mabulla, A., & Ungar, P. S. (2017). Oral health in transition: The Hadza foragers of Tanzania. *PloS one*, *12*(3). https://doi.org/10.1371/journal.pone.0172197

Crumley, C. L. (1995). Heterarchy and the Analysis of Complex Societies. *Archaeological Papers of the American Anthropological Association*, *6*(1), 1-5. https://doi.org/10.1525/ap3a.1995.6.1.1

d'Incau, E., Couture, C., & Maureille, B. (2012). Human tooth wear in the past and the present: Tribological mechanisms, scoring systems, dental and skeletal compensations. *Archives of Oral Biology*, *57*(3), 214-229. https://doi.org/https://doi.org/10.1016/j.archoralbio.2011.08.021

Da-Gloria, P., & Larsen, C. S. (2014). Oral Health of the Paleoamericans of Lagoa Santa, Central Brazil. *American Journal of Physical Anthropology*, *154*, 11-26. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.22467

Damle, S. G., Yadav, R., Garg, S., Dhindsa, A., Beniwal, V., Loomba, A., & Chatterjee, S. (2016). Transmission of mutans streptococci in mother-child pairs. *Indian Journal of Medical Research*, *144*(2), 264-270. https://doi.org/10.4103/0971-5916.195042

Darby, I. B., Polster, A., Gan, J. S., Guo, Q., Henein, N., Heredia, A., Horina, H., Sanduja, D., & Radvar, M. (2012). Left-to-right distribution of periodontal disease. *International Journal of Dental Hygiene*, *10*(1), 74-79. https://doi.org/10.1111/j.1601-5037.2011.00509.x

Davis, D. S. (2020). Studying Human Responses to Environmental Change: Trends and Trajectories of Archaeological Research *Environmental Archaeology 25*(4), 367-380. https://doi.org/10.1080/14614103.2019.1639338

De Coster, P. J., Marks, L. A., Martens, L. C., & Huysseune, A. (2009). Dental agenesis: genetic and clinical perspectives. *Journal of Oral Pathology & Medicine*, *38*(1), 1-17. https://doi.org/10.1111/j.1600-0714.2008.00699.x

De Groote, I., & Humphrey, L. T. (2016). Characterizing evulsion in the Later Stone Age Maghreb: age, sex and effects on mastication. *Quaternary International*, *413*, 50-61. https://doi.org/10.1016/j.quaint.2015.08.082

Deter, C. A. (2009). Gradients of occlusal wear in hunter-gatherers and agriculturalists. *American Journal of Physical Anthropology*, *138*(3), 247-254. https://doi.org/10.1002/ajpa.20922

DeWitte, S. N., Hughes-Morey, G., Bekvalac, J., & Karsten, J. (2016). Wealth, health and frailty in industrial-era London. *Annals of Human Biology*, *43*(3), 241-254. https://doi.org/10.3109/03014460.2015.1020873

Dhavale, N., Halcrow, S. E., Buckley, H. R., Tayles, N., Domett, K. M., & Gray, A. R. (2017). Linear and appositional growth in infants and children from the prehistoric settlement of Ban Non Wat, Northeast Thailand: Evaluating biological responses to agricultural intensification in Southeast Asia. *Journal of Archaeological Science: Reports*, *11*, 435-446. https://doi.org/https://doi.org/10.1016/j.jasrep.2016.12.019

Diaz-Andreu, M. (2005). Gender identity. In M. Diaz-Andreu, S. Lucy, S. Babic, & D. N. Edwards (Eds.), *The Archaeology of Identity: Approaches to gender, age, status, ethnicity and religion* (pp. 13-42). Routledge.

Diaz-Andreu, M., Lucy, S., Babic, S., & Edwards, D. N. (Eds.). (2005). *The Archaeology of Identity: Approaches to gender, age, status, ethnicity and religion*. Routledge.

Domett, K. (2001). *Health in Late Prehistoric Thailand*. Archaeopress.

Domett, K., Newton, J., O'Reilly, D. J. W., Tayles, N., Shewan, L., & Bevan, N. (2013). Cultural Modification of the Dentition in Prehistoric Cambodia. *International Journal of Osteoarchaeology*, *23*, 274-286. https://doi.org/10.1002/oa.1245

Domett, K., O'Reilly, D. J. W., & Buckley, H. R. (2011). Bioarchaeological evidence for conflict in Iron Age north-west Cambodia *Antiquity*, *85*, 441-458.

Domett, K., & O’Reilly, D. J. W. (2009). Health in Pre-Angkorian Cambodia: A Bioarchaeological Analysis of the Skeletal Remains from Phum Snay. *Asian Perspectives*, *48*(1), 56-78.

Domett, K., & Tayles, N. (2006). Human biology from the Bronze Age to the Iron Age in the Mun River valley of northeast Thailand. In M. F. Oxenham & N. Tayles (Eds.), *Bioarchaeology of Southeast Asia* (pp. 220-240). Cambridge University Press.

Domett, K., & Tayles, N. (2007). Population health from the Bronze to the Iron Age in the Mun River Valley, Northeastern Thailand. In M. N. Cohen & G. M. M. Crane-Kramer (Eds.), *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification* (pp. 286-299). University Press of Florida.

Douglas, M. T. (1996). *Paleopathology in Human Skeletal Remains from the Pre-metal, Bronze and Iron Ages, Northeastern Thailand* [Doctor of Philosophy, University of Hawai'i]. Hawai'i.

Douglas, M. T. (2006). Subsistence change and dental health in the people of Non Nok Tha, northeast Thailand. In M. Oxenham & N. Tayles (Eds.), *Bioarchaeology of Southeast Asia* (pp. 191-219). Cambridge University Press.

Douglas, M. T., & Pietrusewsky, M. (2007). Biological Consequences of Sedentism: Agricultural Intensification in Northern Thailand. In M. N. Cohen & G. M. M. Crane-Kramer (Eds.), *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification* (pp. 300-319). University Press of Florida.

Dressler, W. W. (2010). Social Inequality and Health: A Commentary. *Medical Anthropology Quarterly*, *24*(4), 549-554. https://doi.org/10.1111/j.1548-1387.2010.01122.x

Durrani, N., & Fagan, B. M. (2021). *World Prehistory: The Basics*. Taylor and Francis. https://doi.org/10.4324/9781003177326

Duyar, İ., & Erdal, Y. S. (2003). A new approach for calibrating dental caries frequency on skeletal remains. *Homo - The Journal of Comparative Human Biology*, *54*(1), 57-70.

Edgar, H. J. H. (2013). Estimation of Ancestry using Dental Morphological Characteristics. *Journal of Forensic Sciences*, *58*(S1), S1-S8. https://doi.org/10.1111/j.1556-4029.2012.02295.x

Edgar, H. J. H., Willermet, C., Ragsdale, C. S., O'Donnell, A., & Daneshvari, S. (2016). Frequencies of Rare Incisor Variations Reflect Factors Influencing Precontact Population Relationships in Mexico and the American Southwest. *International Journal of Osteoarchaeology*, *26*(6), 987-1000. https://doi.org/10.1002/oa.2510

Ekengren, F. (2013). Contextualizing Grave Goods: Theoretical Perspectives and Methodological Implications. In S. Tarlow & L. Nilsson Stutz (Eds.), *The Archaeology of Death and Burial*. Oxford University Press.

Ekstrand, K. R., Ricketts, D. N. J., & Kidd, E. A. M. (1997). Reproducibility and Accuracy of Three Methods for Assessment of Demineralization Depth on the Occlusal Surface: An in vitro Examination. *Caries Research*, *31*(3), 224-231. https://doi.org/10.1159/000262404

Entringer, S., de Punder, K., Buss, C., & Wadhwa, P. D. (2018). The fetal programming of telomere biology hypothesis: an update. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1741), 20170151. https://doi.org/doi:10.1098/rstb.2017.0151

Erdal, Y. S., & Duyar, İ. (1999). A new correction procedure for calibrating dental caries frequency. *American Journal of Physical Anthropology*, *108*(2), 237-240.

Eshed, V., Gopher, A., & Hershkovitz, I. (2006). Tooth wear and dental pathology at the advent of agriculture: New evidence from the Levant. *American Journal of Physical Anthropology*, *130*(2), 145-159. https://doi.org/10.1002/ajpa.20362

Estalrrich, A., & Rosas, A. (2015). Division of labor by sex and age in Neandertals: an approach through the study of activity-related dental wear. *Journal of Human Evolution*, *80*, 51-63. https://doi.org/https://doi.org/10.1016/j.jhevol.2014.07.007

Evans, C., Chang, N., & Shimizu, N. (2016). Sites, survey, and ceramics: Settlement patterns of the first to ninth centuries CE in the Upper Mun River Valley, northeast Thailand. *Journal of Southeast Asian Studies*, *47*(3), 438-467. https://doi.org/10.1017/S0022463416000278

Eyre, C. O. (2010). Social Variation and Dynamics in Metal Age and Proto-historic Central Thailand: A Regional Perspective. *Asian Perspectives*, *49*(1), 43-84.

FDI. (1992). Commission on Oral Health Research and Epidemiology: A review of the developmental defects of enamel index (DDE Index). *International Dental Journal*, *42*, 411-426.

Featherstone, J. D. B. (2004). The Continuum of Dental Caries - Evidence for a Dynamic Disease Process. *Journal of Dental Research*, *83*, C39-C42.

Fejerskov, O. (2004). Changing Paradigms in Concepts on Dental Caries: Consequences for Oral Health Care. *Caries Research*, *38*, 182-191.

Ferraro, M., & Vieira, A. R. (2010). Explaining gender differences in caries: a multifactorial approach to a multifactorial disease. *International Journal of Dentistry*, *2010*, 649643-649645. https://doi.org/10.1155/2010/649643

Fidalgo, D., Silva, A. M., & Porfírio, E. (2019). Non-masticatory dental wear patterns in individuals exhumed from the Middle Bronze Age rock-cut tombs of Torre Velha 3 (Serpa, Portugal). *International Journal of Osteoarchaeology*, *30*(1), 13-23. https://doi.org/10.1002/oa.2825

Fochesato, M., Higham, C., Bogaard, A., & Castillo, C. C. (2021). Changing social inequality from first farmers to early states in Southeast Asia. *Proceedings of the National Academy of Sciences - PNAS*, *118*(47), 1. https://doi.org/10.1073/pnas.2113598118

Foley, M., & Akers, H. F. (2019). Does poverty cause dental caries? *Australian Dental Journal*, *64*(1), 96-102. https://doi.org/10.1111/adj.12666

Fontana, M., Young, D. A., Wolff, M. S., Pitts, N. B., & Longbottom, C. (2010). Defining Dental Caries for 2010 and Beyond. *Dental Clinics of North America*, *54*, 423-440. https://www.sciencedirect.com/science/article/abs/pii/S0011853210000340?via%3Dihub

Frelat, M. A., & Souday, C. (2015). The Bronze Age Necropolis of Koh Ta Meas: insights into the health of the earliest inhabitants of the Angkor region. *Bulletins et mémoires de la Société d'anthropologie de Paris*, *27*, 142-157.

French, J. C. (2018). Archaeological Demography as a Tool for the Study of Women and Gender in the Past. *Cambridge Archaeological Journal*, *29*(1), 141-157. https://doi.org/10.1017/S0959774318000380

Fried, B., Graczyk, T. K., & Tamang, L. (2004). Food-borne intestinal trematodiases in humans. *Parasitology Research*, *93*, 159-170. https://doi.org/10.1007/s00436-004-1112-x

Geber, J., & Murphy, E. (2018). Dental markers of poverty: Biocultural deliberations on oral health of the poor in mid-nineteenth-century Ireland. *American Journal of Physical Anthropology*, *167*, 840-855. https://doi.org/10.1002/ajpa.23717

Gkantidis, N., Katib, H., Oeschger, E., Karamolegkou, M., Topouzelis, N., & Kanavakis, G. (2017). Patterns of non-syndromic permanent tooth agenesis in a large orthodontic population. *Archives of Oral Biology*, *79*, 42-47. https://doi.org/10.1016/j.archoralbio.2017.02.020

Glick, M., Williams, D. M., Kleinman, D., Vujicic, M., Watt, R. G., & Weyant, R. J. (2016). A new definition for oral health developed by the FDI World Dental Federation opens the door to a universal definition of oral health. *The Journal of the American Dental Association*, *147*(12), 915-917. https://doi.org/10.1016/j.adaj.2016.10.001

Gluckman, P. D., Hanson, M. A., & Buklijas, T. (2010). A conceptual framework for the developmental origins of health and disease. *Journal of Developmental Origins of Health and Disease*, *1*(1), 6-18. https://doi.org/10.1017/S2040174409990171

Gluckman, P. D., Hanson, M. A., Cooper, C., & Thornburg, K. L. (2008). Effect of In Utero and Early-Life Conditions on Adult Health and Disease. *The New England Journal of Medicine*, *359*(1), 61-73. https://doi.org/10.1056/NEJMra0708473

Goldstein, L. (2006). Mortuary Analysis and Bioarchaeology In J. E. Buikstra & L. A. Beck (Eds.), *Bioarchaeology* (pp. 375-387). Routledge.

Gonzalves, E. A., & Vaidya, B. S. (1963). On the larvicidal properties of charophytes. *Hydrobiologia*, *21*(1-2), 188-192. https://doi.org/10.1007/BF00161383

Goodman, A. H., Thomas, R. B., Swedlund, A. C., & Armelagos, G. J. (1988). Biocultural Perspectives on Stress in Prehistoric, Historical, and Contemporary Population Research. *Yearbook of Physical Anthropology*, *31*, 169-202.

Gowland, R. L. (2006). Ageing the Past: Examining Age Identity from Funerary Evidence. In R. L. Gowland & C. Knüsel (Eds.), *Social Archaeology of Funerary Remains* (pp. 143-154). Oxbow Books.

Gowland, R. L. (2015). Entangled lives: Implications of the developmental origins of health and disease hypothesis for bioarchaeology and the life course. *American Journal of Physical Anthropology*, *158*(4), 530-540. https://doi.org/10.1002/ajpa.22820

Gowland, R. L., & Halcrow, S. (Eds.). (2020). *The Mother-Infant Nexus in Anthropology: Small Beginnings, Significant Outcomes*. Springer.

Gowland, R. L., & Knüsel, C. (2006a). Introduction In R. L. Gowland & C. Knüsel (Eds.), *Social Archaeology of Funerary Remains* (pp. ix-xiv). Oxbow Books.

Gowland, R. L., & Knüsel, C. (Eds.). (2006b). *Social Archaeology of Funerary Remains*. Oxbow Books.

Graczyk, T. K., & Fried, B. (1998). Echinostomiasis: a common but forgotten food-borne disease. *American Journal of Tropical Medicine*, *58*(4), 501-504.

Graeber, D., & Wengrow, D. (2021). *The Dawn of Everything. A New History of Humanity* Penguin Random House.

Gregoricka, L. A. (2016). Human response to climate change during the Umm an-Nar/Wadi Suq Transition in the United Arab Emirates. *International Journal of Osteoarchaeology*, *26*, 211-220. https://doi.org/10.1002/oa.2409

Griffin, M. C. (2014). Biocultural Implications of Oral Pathology in an Ancient Central California Population. *American Journal of Physical Anthropology*, *154*, 171-188.

Grippo, J. O., Simring, M., & Schreiner, S. (2004). Attrition, abrasion, corrosion and abfraction revisited: A new perspective on tooth surface lesions. *The Journal of the American Dental Association*, *135*(8), 1109-1118. https://doi.org/10.14219/jada.archive.2004.0369

Gross, J. M., & Edgar, H. J. H. (2019). Informativeness of dental morphology in ancestry estimation in African Americans. *American Journal of Physical Anthropology*, *168*(3), 521-529. https://doi.org/10.1002/ajpa.23768

Gupta, S., & Rauniyar, S. (2019). Prevalence and distribution of dental agenesis among orthodontic patients of Kathmandu, Nepal. *Archives of Medicine and Health Sciences*, *7*(2), 172-176. https://doi.org/10.4103/amhs.amhs_103_19

Guz, D., & Hobcraft, J. (1991). Breastfeeding and Fertility: A Comparative Analysis. *Population Studies*, *45*(1), 91-108.

Halcrow, S., Harris, N. J., Tayles, N., Ikehara-Quebral, R., & Pietrusewsky, M. (2013). From the Mouths of Babes: Dental Caries in Infants and Children and the Intensification of Agriculture in Mainlaind Southeast Asia. *American Journal of Physical Anthropology*, *150*, 409-420. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.22215

Halcrow, S., & Tayles, N. (2008). Stress near the start of life? Localised enamel hypoplasia of the primary canine in late prehistoric mainland Southeast Asia. *Journal of Archaeological Science*, *35*(8), 2215-2222. https://doi.org/10.1016/j.jas.2008.02.002

Halcrow, S., & Tayles, N. (2011). Human diversity in mainland Southeast Asia: the contribution of bioarcheology. In N. J. Enfield (Ed.), *Dynamics of human diversity* (pp. 47-61). Pacific Linguistics.

Halcrow, S. E., Tayles, N., & King, C. L. (2016). Infant and child health and disease with agricultural intensification in mainland Southeast Asia. In M. Oxenham & H. R. Buckley (Eds.), *The Routledge Handbook of Bioarchaeology and Southeast Asia and and the Pacific Islands* (pp. 158-186). Routledge.

Halvorsrud, K., Lewney, J., Craig, D., & Moynihan, P. J. (2019). Effects of Starch on Oral Health: Systematic Review to Inform WHO Guideline. *Journal of Dental Research*, *98*(1), 46-53. https://doi.org/10.1177/0022034518788283

Hämäläinen, P., Meurman, J. H., Keskinen, M., & Heikkinen, E. (2003). Relationship between dental health and 10-year mortality in a cohort of community-dwelling elderly people. *European Journal of Oral Sciences*, *111*(4), 291-296. https://doi.org/https://doi.org/10.1034/j.1600-0722.2003.00055.x

Hara, A. T., & Zero, D. T. (2010). The Caries Environment: Saliva, Pellicle, Diet, and Hard Tissue Ultrastructure. *Dental Clinics of North America*, *54*(3), 455-467. https://doi.org/https://doi.org/10.1016/j.cden.2010.03.008

Härke, H. (2002). Interdisciplinarity and the archaeological study of death. *Mortality*, *7*(3), 340-341. https://doi.org/10.1080/1357627021000025487

Härke, H. (2014). Grave goods in early medieval burials: messages and meanings. *Mortality*, *19*(1), 41-60. https://doi.org/10.1080/13576275.2013.870544

Harrod, R. P., & Martin, D. L. (2014). *Bioarcheology of Climate Change and Violence: Ethical Considerations*. Springer.

Hattab, F., & Yassin, O. (2000). Etiology and diagnosis of tooth wear: a literature review and presentation of selected cases. *International Journal of Prosthodontics*, *13*(2), 101-107.

Heilmann, A., Georgios, T., & Watt, R. G. (2015). Oral Health Over the Life Course. In C. Burton-Jeangros, S. Cullati, A. Sacker, & D. Blane (Eds.), *A Life Course Perspective on Health Trajectories and Transitions* (pp. 39-59). Springer https://doi.org/10.1007/978-3-319-20484-0_3

Heldaas Seland, E. (2021). *A Global History of the Ancient World: Asia, Europe and Africa Before Islam*. Taylor & Francis Group.

Helle, S., & Helama, S. (2007). Climatic Variability and the Population Dynamics of Historical Hunter-Gatherers: The Case of Sami in Northern Finland. *American Journal of Human Biology*, *19*, 844-853. https://doi.org/10.1002/ajhb.20650

Herrera-Atoche, J. R., Ríos-Muñoz, A. M., Sardaneta-Escudero, D. A., Colomé-Ruiz, G. E., & Cucina, A. (2019). Anatomical variations of maxillary incisors: A comparative analysis of archaeological and modern populations from the Yucatan peninsula. *HOMO - Journal of Comparative Human Biology*, 147/154.

Higham, C., Bannanurag, R., Mason, G., & Tayles, N. (1992). Human Biology, Environment and Ritual at Khok Phanom Di. *World Archaeology*, *24*(1), 35-54. http://www.jstor.org.elibrary.jcu.edu.au/stable/124896

Higham, C. F. W. (1998). The Transition from Prehistory to the Historic Period in the Upper Mun Valley. *International Journal of Historical Archaeology*, *2*(3), 235-260.

Higham, C. F. W. (2011). The Iron Age of the Mun Valley, Thailand. *The Antiquaries Journal*, *91*, 101-144. https://doi.org/10.1917/s0003581511000114

Higham, C. F. W. (2014). From the Iron Age to Angkor: new light on the origins of a state. *Antiquity*, *88*, 822-835. http://antiquity.ac.uk/ant/008/ant0880822.htm

Higham, C. F. W. (2015). From site formation to social structure in prehistoric Thailand. *The Journal of Field Archaeology*, *40*(4), 3830396. https://doi.org/10.1179/2042458214Y.0000000010

Higham, C. F. W. (2016). At the dawn of history: From Iron Age aggrandisers to Zhenla kings. *Journal of Southeast Asian Studies*, *47*(3), 418-437. https://doi.org/10.1017/S0022463416000266

Higham, C. F. W., Cameron, J., Chang, N., Castillo, C., O'Reilly, D. J. W., Petchey, F., & Shewan, L. (2014). The Excavation of Non Ban Jak, Northeast Thailand - a report on the first three seasons. *Journal of Indo-Pacific Archaeology*, *34*, 1-41.

Higham, C. F. W., & Kijngam, A. (Eds.). (2020). *The Excavation of Non Ban Jak* (Vol. VII). Fine Arts Department of Thailand

Higham, C. F. W., Manly, B. F. J., Thosarat, R., Buckley, H. R., Chang, N., Halcrow, S. E., Ward, S., O'Reilly, D. J. W., Shewan, L. G., & Domett, K. (2019). Environmental and social change in Northeast Thailand during the Iron Age. *Cambridge Archaeological Journal*, 1-21. https://doi.org/10.1017/50959774319000192

Hill, E. (2013). Death, Emotion, and the Household Among the Late Moche. In S. Tarlow & L. N. Stutz (Eds.), *The Oxford Handbook of the Archaeology of Death and Burial*. Oxford University Press.

Hillson, S. (1996). *Dental Anthropology*. Cambridge University Press.

Hillson, S. (2001). Recording Dental Caries in Archaeological Human Remains. *International Journal of Osteoarchaeology*, *11*, 249-289. https://doi.org/10.1002/oa.538

Hillson, S. (2005). *Teeth* (Second ed.). Cambridge University Press.

Hillson, S. (2008a). The current state of dental decay. In J. D. N. Irish, Greg. C. (Ed.), *Technique and Application ii Dental Anthropology* (pp. 111-135). Cambridge University Press.

Hillson, S. (2008b). Dental Pathology. In A. A. Katzenberg & S. R. Saunders (Eds.), *Biological Anthropology of the Human Skeleton* (Second ed., pp. 301-340). John Wiley & Sons.

Hodder, I., & Cessford, C. (2004). Daily practice and social memory at Catalhoyuk. *American Antiquity*, *69*, 17-40.

Hubbard, A. R., Guatelli-Steinberg, D., & Irish, J. D. (2015). Do Nuclear DNA and Dental Nonmetric Data Produce Similar Reconstructions of Regional Population History? An Example from Modern Coastal Kenya. *American Journal of Physical Anthropology*, *157*, 295-304. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.22714

Hujoel, P. P., & Lingström, P. (2017). Nutrition, dental caries and periodontal disease: a narrative review. *Journal of Clinical Periodontology*, *44*(S18). https://doi.org/10.1111/jcpe.12672

Hulme, M. (2011). Reducing the Future to Climate: A Story of Climate Determinism and Reductionism. *Osiris*, *26*, 245-266.

Humphrey, L. T., & Bocaege, E. (2008). Tooth Evulsion in the Maghreb: Chronological and Geographical Patterns. *African Archaeological Review*, *25*(109), 109-123. https://doi.org/10.1007/s10437-008-9022-4

Humphrey, L. T., De Groote, I., Morales, J., Barton, N., Collcutt, S., Ramsey, C. B., & Bouzouggar, A. (2014). Earliest evidence for caries and exploitation of starchy plant foods in Pleistocene hunter-gatherers from Morocco. *Proceedings of the National Academy of Sciences of the USA*, *111*, 954-959. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3903197/pdf/pnas.201318176.pdf

Hutchinson, D. L., Norr, L., & Teaford, M. F. (2007). Outer Coast Foragers and Inner Coast Farmers in Late Prehistoric North Carolina. In M. N. Cohen & G. M. M. Crane-Kramer (Eds.), *Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification* (pp. 52-64). University Press of Florida.

Ikehara-Quebral, R. (2010). *An assessment of health in early historic (200 B.C. to A.D. 200) inhabitants of Vat Komnou, Angkor Borei, Southern Cambodia: a Bioarchaeological Perspective* [Doctor of Philosophy, University of Hawai'i]. Hawai'i.

Ikehara-Quebral, R. M., Stark, M. T., Belcher, W., Vuthy, V., Krigbaum, J., Bentley, R. A., Douglas, M. T., & Pietrusewsky, M. (2017). Biocultural Practices during the Transition to History at the Vat Komnou Cemetery, Angkor Borei, Cambodia. *Asian Perspectives: The Journal of Archaeology for Asia and the Pacific*, *56*(2), 191. https://doi.org/10.1353/asi.2017.0008

Irish, J. D. (2013). Afridonty: the "Sub-Saharan African Dental Complex" revisited. In E. C. Scott & J. D. Irish (Eds.), *Anthropological Perspectives on Tooth Morphology: Genetics, Evolution, Variation* (pp. 278-295). Cambridge University Press. https://doi.org/10.1017/CBO9780511984464.012

Ismail, A. I., Sohn, W., Tellez, M., Amaya, A., Sen, A., Hasson, H., & Pitts, N. B. (2007). The International Caries Detection and Assessment System (ICDAS): an integrated system for measuring dental caries. *Community dentistry and oral epidemiology*, *35*(3), 170-178. https://doi.org/10.1111/j.1600-0528.2007.00347.x

Johansson, A.-K., Omar, R., Carlsson, G. E., & Johansson, A. (2012). Dental Erosion and Its Growing Importance in Clinical Practice: From Past to Present. *International Journal of Dentistry*, *2012*, 1-17. https://doi.org/10.1155/2012/632907

Kaidonis, J. A. (2008). Tooth wear: the view of the anthropologist. *Clinical Oral Investigations*, *12*, S21-S26. https://doi.org/10.1007/s00784-007-0154-8

Kanchanasevee, C., Theerapanon, T., Intarak, N., Pittayapat, P., & Porntaveetus, T. (2019). Prevalance and Pattern of Tooth Agenesis in Non-syndromic Thai Dental Patients. Proceedings of the RSU International Research Conference, Rangsit University.

Kangxin, H. A. N., & Nakahashi, T. (1996). A Comparative Study of Ritual Tooth Ablation in Ancient China and Japan. *Anthropological Science*, *104*(1), 43-64. https://doi.org/10.1537/ase.104.43

Khalaf, K., Miskelly, J., Voge, E., & Macfarlane, T. V. (2014). Prevalence of hypodontia and associated factors: a systematic review and meta-analysis. *Journal of Orthodontics*, *41*, 299-316. https://doi.org/10.1179/1465313314Y.0000000116

Khattak, M. I., Csikar, J., Vinall, K., & Douglas, G. (2019). The views and experiences of general dental practitioners (GDP's) in West Yorkshire who used the International Caries Detection and Assessment System (ICDAS) in research. *PloS one*, *14*(10), e0223376. https://doi.org/10.1371/journal.pone.0223376

Kieser, J. A., Dennison, K. J., Kaidonis, J. A., Huang, D., Herbison, P. G. P., & Tayles, N. G. (2001). Patterns of dental wear in the early Maori dentition. *International Journal of Osteoarchaeology*, *11*(3), 206-217. https://doi.org/10.1002/oa.534

Kinaston, R. L., Koesbardiati, T., Suriyanto, R. A., Buckley, H. R., Halcrow, S. E., Foster, A., Simanjuntak, T., Bedford, S., Murti, D. B., Putri, R. S., & Galipaud, J.-C. (2020). Ritual tooth ablation and the Austronesian expansion: Evidence from eastern Indonesia and the Pacific Islands. *The Journal of Island and Coastal Archaeology*, 1-32. https://doi.org/10.1080/15564894.2020.1754971

King, C. A., & Norr, L. (2006). Palaeodietary change among pre-state metal age societies in northeast Thailand: a study using bone stable isotopes. In M. Oxenham & N. Tayles (Eds.), *Bioarchaeology of Southeast Asia* (pp. 241-262). Cambridge University Press.

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. *Journal of Archaeological Science*, *40*(4), 1681-1688. https://doi.org/https://doi.org/10.1016/j.jas.2012.11.013

King, C. L., Halcrow, S. E., Tayles, N., & Shkrum, S. (2017). Considering the palaeoepidemiological implications of socioeconomic and environmental change in Southeast Asia. *Archaeological Research in Asia*, *11*, 27-37. https://doi.org/10.1016/j.ara.2017.05.003

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. *American Journal of Physical Anthropology*, *158*(1), 141-150. https://doi.org/10.1002/ajpa.22772

King, J. (2007). Contraception and Lactation. *Journal of Midwifery and Women's Health*, *52*(6), 614-620. https://doi.org/10.1016/j.jmwh.2007.08.012

King, J. C. (2003). The Risk of Maternal Nutritional Depletion and Poor Outcomes Increases in Early or Closely Spaced Pregnancies. *The Journal of Nutrition*, *133*(5), 1732S-1736S. https://doi.org/10.1093/jn/133.5.1732S

Kingsmill, V. J. (1999). Post-Extraction Remodeling of the Adult Mandible. *Critical Review in Oral Biology & Medicine*, *10*(3), 384-404.

Kirkland, S. (2010). *Dental Pathology at Promtin Tai: An Iron Age Cemetery from Central Thailand* [Master of Arts, North Carolina State University]. Raleigh.

Klein, M. I., Flório, F. M., Pereira, A. C., Höfling, J. F., & Gonçalves, R. B. (2004). Longitudinal study of transmission, diversity, and stability of Streptococcus mutans and Streptococcus sobrinus genotypes in Brazilian nursery children. *Journal of Clinical Microbiology*, *42*(10), 4620-4626. https://doi.org/10.1128/JCM.42.10.4620-4626.2004

Knudson, K. J., & Stojanowski, C. M. (2008). New Directions in Bioarchaeology: Recent Contributions to the Study of Human Social Identities. *Journal of Archaeological Research*, *16*(4), 397-432. https://doi.org/10.1007/s10814-008-9024-4

Kolpan, K. E., & Bartelink, E. J. (2019). Dental disease in prehistoric Central California: sex differences in early period Windmiller populations. *Archaeological and Anthropological Sciences*, *11*(6), 3001-3012. https://doi.org/10.1007/s12520-018-0728-1

Kositboworнchai, S., Keinprasit, C., & Poomat, N. (2010). Prevalence and distribution of dental anomalies in pretreatment orthodontic Thai patients. *Khonkean Dental Journal*, *13*(2), 92-100.

Kramer, K. L., & Hackman, J. (2020). Scaling climate change to human behaviour predicting good and bad years for Maya farmers. *American Journal of Human Biology*, *33*, 1-15. https://doi.org/10.1002/ajhb.23524

Küchler, E. C., Risso, P. A., Costa, M. d. C., Modesto, A., & Vieira, A. R. (2008). Studies of dental anomalies in a large group of school children. *Archives of Oral Biology*, *53*(10), 941-946. https://doi.org/https://doi.org/10.1016/j.archoralbio.2008.04.003

Kumar, P. S. (2017). From focal sepsis to periodontal medicine: a century of exploring the role of the oral microbiome in systemic disease. *The Journal of Physiology*, *595*(2), 465-476. https://doi.org/10.1113/JP272427

Lamster, I. B., Asadourian, L., Del Carmen, T., & Friedman, P. K. (2016). The aging mouth: differentiating normal aging from disease. *Periodontology 2000*, *72*(1), 96-107. https://doi.org/10.1111/prd.12131

Laneri, N. (2011). A Family Affair: The Use of Intramural Funerary Chambers in Mesopotamia during the Late Third and Early Second Millennia B.C.E. *Archeological papers of the American Anthropological Association*, *20*(1), 121-135. https://doi.org/10.1111/j.1551-8248.2011.01031.x

Lanfranco, L. P., & Eggers, S. (2010). The usefulness of caries frequency, depth, and location in determining cariogenicity and past subsistence: A test on early and later agriculturalists from the Peruvian coast. *American Journal of Physical Anthropology*, *143*(1), 75-91. https://doi.org/https://doi.org/10.1002/ajpa.21296

Langdon, S. (2005). *Views of wealth, a wealth of views: Grave goods in Iron Age Attica* Women and property in ancient Near Eastern and Mediterranean Societies, Centre for Hellenic Studies, Harvard University.

Larsen, C. S. (2015). *Bioarchaeology: Interpreting Behaviour from the Human Skeleton* (Second ed.). Cambridge University Press.

Larsen, C. S., Shavit, R., & Griffin, M. C. (1991). Dental caries evidence for dietary change: an archaeological context. In M. A. Kelley & C. S. Larsen (Eds.), *Advances in dental anthropology* (pp. 179-202). Wiley-Liss.

Lasker, G. W. (1969). Human Biological Adaptability. *Science*, *166*(3912), 1480-1486.

Leatherman, T., & Goodman, A. (2020). Building on the biocultural syntheses: 20 years and still expanding. *American Journal of Human Biology*, *32*(e23360), 1-14. https://doi.org/10.1002/ajhb.23360

Lee, A., He, L. H., Lyons, K., & Swain, M. V. (2012). Tooth wear and wear investigations in dentistry. *Journal of Oral Rehabilitation*, *39*(3), 217-225. https://doi.org/10.1111/j.1365-2842.2011.02257.x

Levin, B. W., & Browner, C. H. (2005). The social production of health: Critical contributions from evolutionary, biological, and cultural anthropology. *Social Science & Medicine*, *61*(4), 745-750. https://doi.org/10.1016/j.socscimed.2004.08.048

Lewis, M. E. (2007). *The Bioarchaeology of Children: Perspectives from Biological and Forensic Anthropology*. Cambridge University Press.

Liebe-Harkort, C. (2012). Exceptional rates of dental caries in a Scandinavian Early Iron Age population—A study of dental pathology at Alvastra, Östergötland, Sweden. *International Journal of Osteoarchaeology*, *22*(2), 168-184. https://doi.org/10.1002/oa.1194

Liebe-Harkort, C., Ástvaldsdóttir, Á., & Tranæus, S. (2010). Quantification of dental caries by osteologists and odontologists—a validity and reliability study. *International Journal of Osteoarchaeology*, *20*(5), 525-539. https://doi.org/10.1002/oa.1079

Liebe-Harkort, C., Ástvaldsdóttir, Á., & Tranæus, S. (2011). Visual and radiographic assessment of dental caries by osteologists: a validity and reliability study. *International Journal of Osteoarchaeology*, *21*(1), 55-65. https://doi.org/10.1002/oa.1107

Lindahl, J. F., & Grace, D. (2015). The consequences of human actions on risks for infectious diseases: a review. *Infection Ecology & Epidemiology*, *5*(1), 30048. https://doi.org/10.3402/iee.v5.30048

Lingström, P., & Moynihan, P. (2003). Nutrition, saliva, and oral health. *Nutrition*, *19*(6), 567-569. https://doi.org/http://dx.doi.org/10.1016/S0899-9007(03)00062-5

Littleton, J., & Frohlich, B. (1993). Fish-Eaters and Farmers: Dental Pathology in the Arabian Gulf. *American Journal of Physical Anthropology*, *92*, 427-447.

Lorentz, K. O. (2014). Ante-mortem Tooth Loss in Chalcolithic Populations of Cyprus: Comparisons between Cemetery and Settlement. In M. Michaelides (Ed.), *Medicine and Healing in the Ancient Mediterranean* (pp. 252-264). Oxbow Books.

Lukacs, J. (1989). Dental Paleopathology: Methods for Reconstructing Dietary Patterns. In M. Y. Iscan & K. A. R. Kennedy (Eds.), *Reconstructing Life from the Skeleton* (pp. 261-286). Wiley-Liss.

Lukacs, J. (1995). The 'caries correction factor': A new method of calibrating dental caries rates to compensate for antemortem loss of teeth. *International Journal of Osteoarchaeology*, *5*(2), 151-156. https://doi.org/10.1002/oa.1390050207

Lukacs, J. (2007). Dental trauma and antemortem tooth loss in prehistoric Canary Islanders: prevalence and contributing factors. *International Journal of Osteoarchaeology*, *17*(2), 157-173. https://doi.org/10.1002/oa.864

Lukacs, J. (2008). Fertility and Agriculture Accentuate Sex Differences in Dental Caries Rates. *Current Anthropology*, *49*(5), 901-914. https://doi.org/10.1086/592111

Lukacs, J. (2011a). Gender differences in oral health in South Asia: metadata imply multifactorial biological and cultural causes. *American Journal of Human Biology*, *23*(3), 398-411. https://doi.org/10.1002/ajhb.21164

Lukacs, J. (2011b). Sex differences in dental caries experience: clinical evidence, complex etiology. *Clin Oral Invest*, *15*, 649-656.

Lukacs, J. (2017a). Bioarchaeology of Oral Health: Sex and Gender Differences in Dental Disease. In S. C. Agarwal & J. K. Wesp (Eds.), *Exploring Sex and Gender in Bioarchaeology* (pp. 263-290). University of New Mexico Press.

Lukacs, J. (2017b). Dental adaptations of Bronze Age Harappans: Occlusal wear, crown size, and dental pathology. *International Journal of Paleopathology*, *18*, 69-81. https://doi.org/https://doi.org/10.1016/j.ijpp.2017.05.008

Lukacs, J., & Largaespada, L. L. (2006). Explaining sex differences in dental caries prevalence: Saliva, hormones, and "life-history" etiologies. *American Journal of Human Biology*, *18*(4), 540-555. https://doi.org/10.1002/ajhb.20530

Lukacs, J., & Thompson, L. (2008). Dental caries prevalence by sex in prehistory: magnitude and meaning. In J. D. Irish & G. C. Nelson (Eds.), *Technique and Application in Dental Anthropology* (pp. 136-177). Cambridge University Press.

Lukacs, J., & Walimbe, S. R. (1998). Physiological Stress in Prehistoric India: New Data on Localized Hypoplasia of Primary Canines Linked to Climate and Subsistence Change. *Journal of Archaeological Science*, *25*(6), 571-585. https://doi.org/10.1006/jasc.1997.0260

Lussi, A., Megert, B., Peter Shellis, R., & Wang, X. (2012). Analysis of the erosive effect of different dietary substances and medications. *British Journal of Nutrition*, *107*(2), 252-262. https://doi.org/10.1017/S0007114511002820

Lynch, J. W., Kaplan, G. A., & Salonen, J. T. (1997). Why do poor people behave poorly? Variation in adult health behaviours and psychosocial characteristics by stages of the socioeconomic lifecourse. *Social Science & Medicine (1982)*, *44*(6), 809-819. https://doi.org/10.1016/s0277-9536(96)00191-8

Lynch, R. J. M. (2013). The primary and mixed dentition, post-eruptive enamel maturation and dental caries: a review. *International Dental Journal*, *63*(s2), 3-13. https://doi.org/10.1111/idj.12076

Mahajan, S. (2019). Role of Human Tooth Wear Analysis in Archaeology: A Review. *Ancient Asia*, *10*. https://doi.org/10.5334/aa.181

Marcuschamer, E., Hawley, C. E., Speckman, I., Romero, R. M. D., & Molina, J. N. (2009). A lifetime of normal hormonal events and their impact on periodontal Health. *Perinatología y Reproduccíon Humana*, *23*(2), 53-64.

Marklein, K. E., Leahy, R. E., & Crews, D. E. (2016). In sickness and in death: Assessing frailty in human skeletal remains. *American Journal of Physical Anthropology*, *161*(2), 208-225. https://doi.org/10.1002/ajpa.23019

Marklein, K. M., Torres-Rouff, C., King, L. M., & Hubbe, M. (2019). The Precarious State of Subsistence. Reevaluating Dental Pathological Lesions Associated with Agriculture and Hunter-Gatherer Lifeways. *Current Anthropology*, *60*(3), 341-368.

Marmot, M., & Bell, R. (2011). Social Determinants and Dental Health. *Advances in Dental Research*, *23*(2), 201-206. https://doi.org/10.1177/0022034511402079

Marsh, P. D. (2010). Microbiology of Dental Plaque Biofilms and Their Role in Oral Health and Caries. *Dental Clinics of North America*, *54*, 441-454. https://doi.org/10.1016/j.cden.2010.03.002

Matalova, E., Fleischmannova, J., Sharpe, P. T., & Tucker, A. S. (2008). Tooth Agenesis: from Molecular Genetics to Molecular Dentistry. *Journal of Dental Research*, *87*(7), 617-623. https://doi.org/10.1177/154405910808700715

Matsumura, H. (1995). Dental Characteristics Affinities of the Prehistoric to Modern Japanese with the East Asians, American Natives and Australo-Melanesians. *Anthropological Science*, *103*(3), 235-261. https://doi.org/10.1537/ase.103.235

Matsumura, H. (2007). Non-metric dental trait variation among local sites and regional groups of the Neolithic Jomon period, Japan. *Anthropological Science*, *115*(1), 1-9. https://doi.org/10.1537/ase.051202

Matsumura, H., & Hudson, M. J. (2005). Dental Perspectives on the Population History of Southeast Asia. *American Journal of Physical Anthropology*, *127*, 182-209. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.20067

Matsumura, H., Hung, H.-C., Higham, C., Zhang, C., Yamagata, M., Nguyen, L. C., Li, Z., Fan, X.-C., Simanjuntak, T., Oktaviana, A. A., He, J.-N., Chen, C.-Y., Pan, C.-K., He, G., Sun, G.-P., Huang, W.-J., Li, X.-W., Wei, X.-T., Domett, K., Halcrow, S., Nguyen, K. D., Trinh, H. H., Bui, C. H., Nguyen, K. T. K., & Reinecke, A. (2019). Craniometrics Reveal "Two Layers" of Prehistoric Human Dispersal in Eastern Eurasia. *Scientific Reports*, *9*(1), 1-12. https://doi.org/10.1038/s41598-018-35426-z

Matsumura, H., & Oxenham, M. F. (2014). Demographic transitions and migration in prehistoric East/Southeast Asia through the lens of nonmetric dental traits. *American Journal of Physical Anthropology*, *155*(1), 45-65. https://doi.org/10.1002/ajpa.22537

Mays, S. (2010). *The archaeology of human bone*. Routledge.

Mays, S. (2017). A test of a skeletal ageing method based on resorption of the alveolar crest following tooth loss using a skeletal population of documented age at death. *American Journal of Physical Anthropology*, *163*(2), 242-251. https://doi.org/10.1002/ajpa.23202

McAnany, P. A. (2011). Practices of Place-Making, Ancestralizing, and Re-animation within Memory Communities. *Archaeological Papers of the American Anthropological Association*, *20*(1), 136-142. https://doi.org/https://doi.org/10.1111/j.1551-8248.2011.01032.x

McFadden, C. (2021). The past, present and future of skeletal analysis in palaeodemography. *Philosophical Transactions of the Royal Society B*, *376*. https://doi.org/10.1098/rstb.2019.0709

McFadden, C., & Oxenham, M. (2018a). Detection of temporospatially localized growth in ancient Southeast Asia using human skeletal remains. *Journal of Archaeological Science*, *98*, 93-101. https://doi.org/10.1016/j.jas.2018.08.010

McFadden, C., & Oxenham, M. (2018b). Rate of natural population increase as a paleodemographic measure of growth. *Journal of Archaeological Science: Reports*, *19*, 352-356. https://doi.org/10.1016/j.jasrep.2018.03.012

McFadden, C., & Oxenham, M. F. (2017). The D0-14/D ratio: A new paleodemographic index and equation for estimating total fertility rates. *American Journal of Physical Anthropology*, *165*(3), 471-479. https://doi.org/10.1002/ajpa.23365

McFadden, C., van Tiel, B., & Oxenham, M. (2020). A stabilized maternal mortality rate estimator for biased skeletal samples. *Anthropological Science*, *128*(3), 113-117. https://doi.org/10.1537/ase.2005051

McMichael, A. J. (2012). Insights from past millennia into climatic impacts on human health and survival *Proceedings of the National Academy of Sciences*, *109*(13), 4730-4737. https://doi.org/10.1071/pnas.1120177109

Merbs, C. F. (1968). Anterior Tooth Loss in Arctic Populations. *Southwestern Journal of Anthropology 24*(1), 20-32. https://www.jstor.org/stable/3629300

Miliauskienė, Ž., & Jankauskas, R. (2015). Social differences in oral health: Dental status of individuals buried in and around Trakai Church in Lithuania (16th -17th c.c.). *Anthropologischer Anzeiger*, *72*(1), 89-106. https://doi.org/10.1127/anthranz/2014/0407

Milner, G. R., Wood, J. R., & Boldsen, J. L. (2019). Paleodemography: Problems, Progress and Potential In A. A. Katzenberg & A. L. Grauer (Eds.), *Biological Anthropology of the Human Skeleton* (pp. 593-633). John Wiley & Sons.

Moen, M. (2019). Gender and Archaeology: Where Are We Now? *Archaeologies: Journal of the World Archaeological Congress*, *15*(2), 206-226. https://doi.org/10.1007/s11759-019-09371-w

Molnar, P. (2011). Extramasticatory dental wear reflecting habitual behavior and health in past populations. *Clinical Oral Investigations*, *15*(5), 681-689. https://doi.org/10.1007/s00784-010-0447-1

Mombelli, A., & Meier, C. (2001). On the symmetry of periodontal disease. *Journal of Clinical Periodontology*, *28*(8), 741-745. https://doi.org/10.1034/j.1600-051X.2001.280804.x

Moorrees, C. F., Fanning, E. A., & Hunt, E. E. (1963a). Age Variation of Formation Stages for Ten Permanent Teeth. *Journal of Dental Research*, *42*(6), 1490-1502. https://doi.org/10.1177/00220345630420062701

Moorrees, C. F., Fanning, E. A., & Hunt, E. E. (1963b). Formation and resorption of three deciduous teeth in children. *American Journal of Physical Anthropology*, *21*(2), 205-213. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.1330210212?sid=nlm%3Apubmed

Moreno, M. T., Diaz, A., Gonzalez, A., Manriquez Soto, G., & Toro-Ibacache, V. (2019). Is Third Molar Agenesis an Anomaly or Just a Sign of Variation? Prevalence and Manner of Presentation of this Condition in a Sample from the Metropolitan Region of Chile. *International Journal of Morphology*, *37*(4), 1382.

Moynihan, P. J. (2005). The role of diet and nutrition in the etiology and prevention of oral diseases. *Bulletin of the World Health Organisation*, *83*(9), 694-699.

Moynihan, P. J., & Kelly, S. A. M. (2014). Effect on Caries of Restricting Sugars Intake: Systematic Review to Inform WHO Guidelines. *Journal of Dental Research*, *93*(1), 8-18. https://doi.org/10.1177/0022034513508954

Moynihan, P. J., & Petersen, P. E. (2004). Diet, nutrition and the prevention of dental diseases. *Public Health Nutrition*, *7*(1a), 201-226. https://doi.org/10.1079/PHN2003589

Murphy, S. A. (2016). The case for proto-Dvaravati: A review of the art historical and archaeological evidence. *Journal of Southeast Asian Studies*, *47*(3), 366-392.

Nelsen, K., Tayles, N., & Domett, K. (2001). Missing lateral incisors in Iron Age South-East Asians as possible indicators of dental agenesis. *Archives of Oral Biology*, *46*(10), 963-971. https://doi.org/10.1016/S0003-9969(01)00051-6

Newton, J., & Domett, K. (2017). The Biocultural Context of Dental Modification in Prehistoric Southeast Asia. In B. S.E. & J. D. Irish (Eds.), *A World View of Bioculturally Modified Teeth* (pp. 159-181). The University Press of Florida.

Newton, J. S. (2014). *Health, diet and migration prior to the establishment of the pre-Angkorian civilization of Southeast Asia* [PhD Thesis, James Cook University]. Townsville. http://researchonline.jcu.edu.au/34721

Newton, J. S., Domett, K. M., O'Reilly, D. J. W., & Shewan, L. (2013). Dental Health in Iron Age Cambodia: Temporal variations with rice agriculture. *International Journal of Paleopathology*, *3*, 1-10.

Nirola, A., Batra, P., & Kaur, J. (2018). Ascendancy of sex hormones on periodontium during reproductive life cycle of women. *Journal of the International Clinical Dental Research Organization*, *10*(1), 3-11. https://doi.org/10.4103/jicdro.jicdro_29_17

Nishimura, Y. (2015). A Systematic Comparison of Material Culture Between Household Floors and Residential Burials in Late Third-Millennium B.C.E. Mesopotamia. *American Journal of Archaeology*, *119*(4), 419-440. https://doi.org/10.3764/aja.119.4.0419

O'Reilly, D. J. W. (2003). Further Evidence of Heterarchy in Bronze Age Thailand. *Current Anthropology*, *44*(2), 300-306. https://doi.org/10.1086/367973

O'Reilly, D. J. W. (2014). Increasing complexity and the political economy model: a consideration of Iron Age moated sites in Thailand. *Journal of Anthropological Archaeology*, *35*, 297-309. https://doi.org/10.1016/j.jaa.2014.06.007

O’Reilly, D. J. W., & Scott, G. (2015). Moated sites of the Iron Age in the Mun River Valley, Thailand: New discoveries using Google Earth. *Archaeological Research in Asia*, *3*, 9-18. https://doi.org/10.1016/j.ara.2015.06.001

Ogden, A. (2008). Advances in the Palaeopathology of Teeth and Jaws. In R. Pinhasi & S. Mays (Eds.), *Advances in Human Palaeopathology* (pp. 283-308). John Wiley & Sons, Ltd.

Oxenham, M. (2006). Biological Responses to Change in Prehistoric Viet Nam. *Asian Perspectives*, *45*(2), 212-239. https://doi.org/10.1353/asi.2006.0025

Oxenham, M. (2015). Mainland Southeast Asia: towards a new theoretical approach. *Antiquity*, *89*(347), 1221-1223. https://doi.org/10.15184/aqy.2015.106

Oxenham, M., & Buckley, H. R. (2015). Meta-themes in the bioarchaeology of the Asia-Pacfic region. In M. Oxenham & H. R. Buckley (Eds.), *The Routledge Handbook of Bioarchaeology in Southeast Asia and the Pacfic Islands* (pp. 655-662).

Oxenham, M., & Domett, K. (2010). Palaeohealth at Man Bac. In M. Oxenham, H. Matsumura, & N. K. Dung (Eds.), *Man Bac: the excavation of a neolithic site in Northen Vietnam*. ANU Press.

Oxenham, M., Nguyen, L. C., & Nguyen, K. T. (2002). Oral Health in Northern Vietnam: Neolithic through Metal Periods. *Indo-Pacific Prehistory Association Bulletin*, *22*, 121-134.

Oxenham, M. F., Nguyen, L. C., & Nguyen, K. T. (2006). The oral health consequences of the adoption and intensification of agriculture in Southeast Asia. In M. F. Oxenham & N. Tayles (Eds.), *Bioarchaeology of Southeast Asia* (pp. 263-289). Cambridge University Press.

Paganini-Hill, A., White, S. C., & Atchison, K. A. (2011). Dental Health Behaviors, Dentition, and Mortality in the Elderly: The Leisure World Cohort Study. *Journal of Aging Research*, *2011*, 156061. https://doi.org/10.4061/2011/156061

Page, A. E., Viguier, S., Dyble, M., Smith, D., Chaudhary, N., Salali, G. D., Thompson, J., Vinicius, L., Mace, R., & Migliano, A. B. (2016). Reproductive trade-offs in extant hunter-gatherers suggest adaptive mechanism for the Neolithic expansion *Proceedings of the National Academy of Sciences*, *113*(17), 4694-4699. https://doi.org/10.1073/pnas.1524031113

Paglia, L. (2016). Is dental caries a multifactorial disease? Likely not! *European Journal of Paediatric Dentistry*, *17*(1), 5.

Palefsky, G. (2019). Tooth ablation in Iron Age central Thailand: Evidence from the archaeological sites of Ban Mai Chaimongkol and Tha Kae. *International Journal of Osteoarchaeology*, *29*(5), 696-705. https://doi.org/10.1002/oa.2766

Pandey, D. K., Mishra, N., & P., S. (2005). Relative phytotoxicity of hydroquinone on rice (*Oryza sativa* L.) and associated aquatic weed green musk chara (*Chara zeylanica* Willd.). *Pesticide Biochemistry and Physiology*, *83*, 82-96. https://doi.org/10.1016/j.pestbp.2005.03.013

Panth, N., Gavarkovs, A., Tamez, M., & Mattei, J. (2018). The Influence of Diet on Fertility and the Implications for Public Health Nutrition in the United States. *Frontiers in public health*, *6*, 211-211. https://doi.org/10.3389/fpubh.2018.00211

Parker Pearson, M. (1999). *The Archaeology of Death and Burial*. Texas A & M University Press

Paul, K. S., & Stojanowski, C. M. (2017). Comparative performance of deciduous and permanent dental morphology in detecting biological relatives. *American Journal of Physical Anthropology*, *164*, 97-116. https://doi.org/10.1002/ajpa.23260

Pedersen, L. T., Domett, K., Chang, N., Halcrow, S., Buckley, H. R., Higham, C. F. W., O'Reilly, D. J. W., & Shewan, L. (2019). A Bioarchaeological Study of Trauma at Late Iron Age to Protohistoric Non Ban Jak, Northeast Thailand. *Asian Perspectives*, *58*(2), 220-249.

Peres, M. A., Macpherson, L. M. D., Weyant, R. J., Daly, B., Venturelli, R., Mathur, M. R., Listl, S., Celeste, R. K., Guarnizo-Herreño, C. C., Kearns, C., Benzian, H., Allison, P., & Watt, R. G. (2019). Oral diseases: a global public health challenge. *The Lancet*, *394*(10194), 249-260. https://doi.org/10.1016/S0140-6736(19)31146-8

Pietruseswsky, M., Toomay Douglas, M., & Ikehara-Quebral, R. (2017). Skeletal and Dental Health: the bioarchaeology of the human skeletons from Sigatoka Sand Dunes Sites, VL 16/1, Viti Levu, Fiji. *Journal of Pacific Archaeology*, *8*(2), 53-78.

Pietrusewsky, M. (2010). A multivariate analysis of measurements recorded in early and more modern crania from East Asia and Southeast Asia. *Quaternary International*, *211*(1), 42-54. https://doi.org/10.1016/j.quaint.2008.12.011

Pietrusewsky, M., & Douglas, M. T. (1993). Tooth Ablation in Old Hawai'i. *The Journal of the Polynesian Society*, *102*(3), 255-272.

Pietrusewsky, M., & Douglas, M. T. (2001). Intensification of agriculture at Ban Chiang: Is there evidence from the skeletons? *Asian Perspectives*, *40*(2), 157-178.

Pilloud, M., Edgar, H. J. H., George, R., & Scott, G. R. (2016). Dental Morphology in Biodistance Analysis. In M. Pilloud & J. T. Hefner (Eds.), *Biological Distance Analysis. Forensic and Bioarchaeological Perspectives* (pp. 109-133). Academic Press.

Pilloud, M. A., & Fancher, J. P. (2019). Outlining a Definition of Oral Health within the Study of Human Skeletal Remains. *Dental Anthropology*, *32*(02), 3-11.

Pinho, T., Maciel, P., Lemos, C., & Sousa, A. (2010). Familial Aggregation of Maxillary Lateral Incisor Agenesis. *Journal of Dental Research*, *89*(6), 621-625. https://doi.org/http://dx.doi.org/10.1177/0022034510364486

Polder, B. J., Van't Hof, M. A., Van der Linden, F. P. G. M., & Kuijpers-Jagtman, A. M. (2004). A meta-analysis of the prevalence of dental agenesis of permanent teeth. *Community dentistry and oral epidemiology*, *32*(3), 217-226. https://doi.org/10.1111/j.1600-0528.2004.00158.x

Preshaw, P. M., Henne, K., Taylor, J. J., Valentine, R. A., & Conrads, G. (2017). Age-related changes in immune function (immune senescence) in caries and periodontal diseases: a systematic review. *Journal of Clinical Periodontology*, *44*(S18), S153-S177. https://doi.org/10.1111/jcpe.12675

Preston, S. H., Himes, C., & Eggers, M. (1989). Demographic Conditions Responsible for Population Aging. *Demography*, *26*(4), 691-704. https://www.jstor.org/stable/2061266

Psoter, W., Reid, B. C., & Katz, R. V. (2005). Malnutrition and Dental Caries: A Review of the Literature. *Caries Research*, *39*(6), 441-447.

Psoter, W., Spielman, A. L., Gebrian, B., St. Jean, R., & Katz, R. V. (2008). Effect of childhood malnutrition on salivary flow and pH. *Archives of Oral Biology*, *53*(3), 231-237. https://doi.org/https://doi.org/10.1016/j.archoralbio.2007.09.007

Quinn, C. P., & Beck, J. (2016). Essential Tensions: A Framework for Exploring Inequality Through Mortuary Archaeology and Bioarchaeology. *Open Archaeology*, *2*, 18-41. https://doi.org/10.1515/opar-2016-0002

Rakhshan, V. (2015). Congenitally missing teeth (hypodontia): A review of the literature concerning the etiology, prevalence, risk factors, patterns and treatment. *Dental Research Journal*, *12*(1), 1-13. https://doi.org/10.4103/1735-3327.150286

Rathmann, H., Saltini Semerari, G., & Harvati, K. (2017). Evidence for Migration Influx into the Ancient Greek Colony of Metaponto: A Population Genetics Approach Using Dental Nonmetric Traits. *International Journal of Osteoarchaeology*, *27*, 453-464.

Reitsema, L. J., & McIlvaine, B. K. (2014). Reconciling "Stress" and "Health" in Physical Anthropology: What Can Bioarchaeologists Learn from Other Subdisciplines? *American Journal of Physical Anthropology*, *155*, 181-185. https://doi.org/10.1002/aja.22596

Richter, S., & Eliasson, T. S. (2017). Erosive and Mechanical Tooth Wear in Viking Age Icelanders. *Dentistry Journal*, *5*(3). https://doi.org/10.3390/dj5030024

Rispoli, F., Ciarla, R., & Pigott, V. C. (2013). Establishing the Prehistoric Cultural Sequence for the Lopburi Region, Central Thailand. *Journal of World Prehistory*, *26*, 101-171. https://doi.org/10.1007/s10963-013-9064-7

Robb, N. D., Cruwys, E., & Smith, B. G. N. (1991). Regurgitation erosion as a possible cause of tooth wear in ancient British populations. *Archives of Oral Biology*, *36*(8), 595-602. https://doi.org/10.1016/0003-9969(91)90110-G

Robbins Schug, G. (2021a). A Bioarchaeology of Climate and Environmental Change In G. R. Schug (Ed.), *The Routledge Handbook of the Bioarchaeology of Climate and Environmental Change*. Routledge.

Robbins Schug, G. (Ed.). (2021b). *The Routledge Handbook of the Bioarchaeology of Climate and Environmental Change*. Routledge.

Robbins Schug, G., Parnell, E. K., & Harrod, R. P. (2019). Changing the Climate: Bioarchaeology Responds to Determinist Thinking About Human-Environment Interactions in the Past In J. E. Buikstra (Ed.), *Bioarchaeologists Speak Out, Bioarchaeology and Social Theory* (pp. 133-159). Springer. https://doi.org/10.1007/978-3-319-93012-1_6

Roberts, C. (2010). Adaptation of populations to changing environments: Bioarchaeological perspectives on health for the past, present and future. *Bulletins et mémoires de la Société d'anthropologie de Paris*, *22*((1-2)), 38-46. https://doi.org/https://doi.org/10.1007/s13219-010-0008-9

Roberts, C. A. (2021). Exploring the Third Epidemiological Transition: Palaeopatholgy's contribution to understanding health and well-being today and for the future. In G. R. Schug (Ed.), *The Routledge Handbook of the Bioarchaeology of Climate and Environmental Change*. Routledge

Rochette, L., & Vergely, C. (2017). Hans Selye and the stress response: 80 years after his "letter" to the Editor of Nature. *Annales de Cardiologie et d'Angeiologie*, *66*(4), 181-183. https://doi.org/10.1016/j.ancard.2017.04.017

Rolling, S., & Poulsen, S. (2009). Agenesis of permanent teeth in 8138 Danish schoolchildren: prevalence and intra-oral distribution according to gender. *International Journal of Paediatric Dentistry*, *19*(3), 172-175. https://doi.org/https://doi.org/10.1111/j.1365-263X.2008.00958.x

Rousso, D., Panidis, D., Gkoutzioulis, F., Kourtis, A., Mavromatidis, G., & Kalahanis, I. (2002). Effect of the interval between pregnancies on the health of mother and child. *European Journal of Obstetrics & Gynecology and Reproductive Biology*, *105*, 4-6. https://doi.org/10.1016/S0301-2115(02)00077-5

Ruddle, K., & Ishige, N. (2010). On the Origins, Diffusion and Cultural Context of Fermented Fish Products in Southeast Asia In J. Farrer (Ed.), *Globalization, Food and Social Identities in the Pacific Region*. Sophia University Institute of Comparative Studies.

Russell, S. L., Gordon, S. D., Lukacs, J. R., & Kaste, L. M. (2013). Sex/Gender Differences in Tooth Loss and Edentulism. *Dental Clinics of North America*, *57*(2), 317-337. https://doi.org/10.1016/j.cden.2013.02.006

Sarjeant, C. (2006). *Iron Age Mortuary Goods: A Comparative Study Between Ban No Wat and Noen U-Loke, Northeast Thailand* [B.A. (Hons) thesis, University of Otago].

Sarkar, G. M., Bamerjee, R. D., Chatterjee, M. L., Dutta, S., & Ghosh, A. (2007). Antimicrobial and insecticidal activity of an aquatic alga *chara zeylanica* klein ex willd. *International Journal fo Environmental Studies*, *48*(1), 29-39. https://doi.org/10.1080/00207239508710974

Scannapieco, F. A. (2013). The oral microbiome: Its role in health and in oral and systemic infections. *Clinical Microbiology Newsletter*, *35*(20), 163-169. https://doi.org/10.1016/j.clinmicnews.2013.09.003

Scheuer, L., & Black, S. (2000). *Developmental Juvenile Osteology*. Academic Press.

Schuurs, A. H. B. (2013). *Pathology of the hard dental tissues*. Wiley-Blackwell. https://doi.org/10.1002/9781118702659

Scopacasa, R. (2014). Gender and Ritual in Ancient Italy: A Quantitative Approach to Grave Goods and Skeletal Data in Pre-Roman Samnium. *American Journal of Archaeology*, *118*(2), 241-266. https://doi.org/10.3764/aja.118.2.0241

Scott, E. C. (1979). Dental wear scoring technique. *American Journal of Physical Anthropology*, *51*(2), 213-217. https://doi.org/10.1002/ajpa.1330510208

Scott, G., & O'Reilly, D. J. W. (2015). Rainfall and circular moated sites in north-east Thailand. *Antiquity*, *89*(347), 1125-1138. https://doi.org/10.15184/aqy.2015.130

Scott, G. R. (2008). Dental Morphology. In M. A. Katzenberg & S. R. Saunders (Eds.), *Biological Anthropology of the Human Skeleton* (Second ed., pp. 265-298). John Wiley & Sons.

Selye, H. (1975). Confusion and controversy in the stress field. *Journal of Human Stress*, *1*(2), 37-44. https://doi.org/10.1080/0097840X.1975.9940406

Shaffer, J. R., Wang, X., McNeil, D. W., Weyant, R. J., Crout, R., & Marazita, M. L. (2015). Genetic Susceptibility to Dental Caries Differs between the Sexes: A Family-Based Study. *Caries Research*, *49*(2), 133-140. https://doi.org/10.1159/000369103

Shearer, D. M., Thomson, W. M., Broadbent, J. M., & Poulton, R. (2011). Maternal Oral Health Predicts Their Children's Caries Experience in Adulthood. *Journal of Dental Research*, *90*(5), 672-677. https://doi.org/10.1177/0022034510393349

Sheetal, A., Hiremath, V. K., Patil, A. G., Sajjansetty, S., & Kumar, S. R. (2013). Malnutrition and its oral outcome - a review. *Journal of clinical and diagnostic research*, *7*(1), 178-180. https://doi.org/10.7860/JCDR/2012/5104.2702

Sheiham, A. (2001). Dietary effects on dental diseases. *Public Health Nutrition*, *4*(2b), 569-591. https://doi.org/10.1079/PHN2001142

Sheiham, A. (2005). Oral health, general health and quality of life. *Bulletin of the World Health Organisation*, *83*(9), 644-645.

Sheiham, A., & James, W. P. T. (2015). Diet and Dental Caries: The Pivotal Role of Free Sugars Reemphasized. *Journal of Dental Research*, *94*(10), 1341-1347. https://doi.org/10.1177/0022034515590377

Shimizu, T., & Maeda, T. (2009). Prevalence and genetic basis of tooth agenesis. *Japanese Dental Science Review*, *45*, 52-58. https://doi.org/10.1016/j.jdsr.2008.12.001

Shkrum, S. A. (2014). *Oral Health and the Intensification of Agriculture at Ban Non Wat, Thailand* [Doctor of Philosophy, University of Otago]. Dunedin.

Silk, H., Douglass, A. B., Douglass, J. M., & Silk, L. (2008). Oral health during pregnancy. *American Family Physician*, *77*(8), 1139.

Singh, A., Rouxel, P., Watt, R. G., & Tsakos, G. (2013). Social inequalities in clustering of oral health related behaviors in a national sample of British adults. *Preventive Medicine*, *57*(2), 102-106. https://doi.org/https://doi.org/10.1016/j.ypmed.2013.04.018

Słotwińska, S. M., & Słotwiński, R. (2014a). Host response, malnutrition and oral diseases. Part 1. *Central-European Journal of Immunology*, *39*(4), 518-521. https://doi.org/10.5114/ceji.2014.47738

Słotwińska, S. M., & Słotwiński, R. (2014b). Host response, malnutrition and oral diseases. Part 2. *Central-European Journal of Immunology*, *39*(4), 522-524. https://doi.org/10.5114/ceji.2014.47739

Smith, H. B. (1984). Patterns of molar wear in hunter gatherers and agriculturalists. *American Journal of Physical Anthropology*, *63*, 39-56.

Smith, M. E. (1987). Household Possessions and Wealth in Agrarian States: Implications for Archaeology. *Journal of Anthropological Archaeology*, *6*, 297-335.

Spector, J. D. (1991). What this awl means: towards a feminist archaeology. In J. M. Gero & M. W. Conkey (Eds.), *Engendering Archaeology: women and prehistory* (pp. 388-406). Blackwell.

Steckel, R. H. (2003). What Can Be Learned from Skeletons that Might Interest Economists, Historians, and Other Social Scientists? *The American Economic Review*, *93*(2), 213-220. https://doi.org/10.1257/000282803321947074

Steckel, R. H., Larsen, C. S., Sciulli, P. W., & Walker, P. L. (2022). *Global History of Health Project*. The Ohio State University College of Arts and Sciences Retrieved 20 February 2022 from https://economics.osu.edu/global-history-health-project

Stojanowski, C. M., Carver, C. L., & Miller, K. A. (2014). Incisor avulsion, social identity and Saharan population history: New data from the Early Holocene southern Sahara. *Journal of Anthropological Archaeology*, *35*, 79-91. https://doi.org/10.1016/j.jaa.2014.04.007

Stojanowski, C. M., & Duncan, W. N. (2015). Engaging bodies in the public imagination: Bioarchaeology as social science, science, and humanities. *American Journal of Human Biology*, *27*(1), 51-60. https://doi.org/https://doi.org/10.1002/ajhb.22522

Stránská, P., Velemínský, P., & Poláček, L. (2014). The prevalence and distribution of dental caries in four early medieval non-adult populations of different socioeconomic status from Central Europe. *Archives of Oral Biology*, *60*(1), 62-76. https://doi.org/10.1016/j.archoralbio.2014.08.002

Tantanapornkul, W. (2015). Prevalence and distribution of dental anomalies in Thai orthodontic patients. *International Journal of Medical and Health Sciences*, *4*(2), 165-172.

Tayles, N. (1996). Tooth Ablation in Prehistoric Southeast Asia. *International Journal of Osteoarchaeology*, *6*(4), 333-345.

Tayles, N., & Buckley, H. R. (2004). Leprosy and Tuberculosis in Iron Age Southeast Asia. *American Journal of Physical Anthropology*, *125*, 239-256. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.10378

Tayles, N., Domett, K., & Halcrow, S. (2009a). Can Dental Caries be Interpretated as Evidence of Farming? The Asian Experience. *Comparative Dental Morphology*, *13*, 162-166.

Tayles, N., Domett, K., & Halcrow, S. (2009b). Can Dental Caries Be Interpreted as Evidence of Farming? The Asian Experience. In T. Koppe, G. Meyer, & K. Alt (Eds.), *Comparative Dental Morphology. Frontiers in Oral Biology* (Vol. 12, pp. 162-166). Karger.

Tayles, N., Domett, K., & Nelsen, K. (2000). Agriculture and Dental Caries? The Case of Rice in Prehistoric Southeast Asia. *World Archaeology*, *32*(1), 68-83.

Tayles, N., & Halcrow, S. (2015). Age at death estimation in a sample of prehistoric Southeast Asian adolescents and adults. In M. Oxenham & H. R. Buckley (Eds.), *The Routledge Handbook of Bioarchaeology in Southeast Asia and the Pacific Islands* (pp. 220-238). Routledge

Tayles, N., Halcrow, S. E., & Domett, K. (2007). The people of Noen U-Loke. In C. F. W. Higham & A. Kijngam (Eds.), *The Origins of the Civilization of Angkor Volume 2: the Excavation of Noen U-Loke and Non Muang Kao* (pp. 244-304). The Fine Arts Department of Thailand.

Temple, D. H. (2011). Variability in dental caries prevalence between male and female foragers from the Late/Final Jomon period: Implications for dietary behavior and reproductive ecology. *American Journal of Human Biology*, *23*(1), 107-117. https://doi.org/10.1002/ajhb.21113

Temple, D. H. (2018). From the Embodied to the Etheral: Tooth Extraction as a Reflection of Time, Agency, and the Persistence of Social Presence after Death in Late/Final Jomon Period Hunter-Gatherers from the Atsumi Peninsula, Japan. *Bioarchaeology International*, *2*(3), 182-195. https://doi.org/10.5744/bi.2018.1023

Temple, D. H. (2021). Live Through This: Developing a sustainable pathway for resilience theory in bioarchaeological research. In C. M. Cheverko, J. R. Prince-Buitenhuys, & M. Hubbe (Eds.), *Theoretical Approaches in Bioarchaeology* (pp. 113-130). Routledge.

Temple, D. H., & Goodman, A. H. (2014). Bioarchaeology has a "Health" problem: Conceptualizing "Stress" and "Health" in Bioarchaeological Research. *American Journal of Physical Anthropology*, *155*, 186-191.

Temple, D. H., Kusaka, S., & Sciulli, P. W. (2010). Patterns of Social Identity in Relation to Tooth Ablation Among Prehistoric Jomon Foragers from Yoshigo Site, Aichi Prefecture, Japan. *Internation Journal of Osteoarchaeology*, *21*, 323-335. https://doi.org/10.1002/oa.1146

Temple, D. H., & Larsen, C. S. (2007). Dental caries prevalence as evidence for agriculture and subsistence variation during the Yayoi period in prehistoric Japan: biocultural interpretations of an economy in transition. *American Journal of Physical Anthropology*, *134*(4), 501-512. https://onlinelibrary.wiley.com/doi/abs/10.1002/ajpa.20694

Tilley, L. (2015). *Theory and Practice in the Bioarchaeology of Care*. Springer. https://doi.org/10.1007/978-3-319-18860-7

Todd, N., & Lerch, M. (2021). Socioeconomic development predicts a weaker contraceptive effect of breastfeeding. *Proceedings of the National Academy of Sciences*, *118*(29), e2025348118. https://doi.org/10.1073/pnas.2025348118

Tomczyk, J., Szostek, K., Komarnitki, I., & Mańkowska-Pliszka, H. (2013). Dental caries and chemical analyses in reconstruction of diet, health and hygienic behaviour in the Middle Euphrates valley (Syria). *Archives of Oral Biology*, *58*(6), 740-751. https://doi.org/10.1016/j.archoralbio.2012.12.014

Tomczyk, J., & Zalewska, M. (2015). Mechanical and chemical dental wear in historical population from the Syrian lower Euphrates valley. *Archives of Oral Biology*, *62*, 49-57. https://doi.org/10.1016/j.archoralbio.2015.11.011

Tringham. (2015). Creating Narratives of the Past as Recombinant Histories In R. M. Van Dyke & R. Bernbeck (Eds.), *Subjects and Narratives in Archaeology* (pp. 27-54). University Press of Colorado.

Trombley, T. M., Agarwal, S. C., Beauchesne, P. D., & Goodson, C. (2019). Making sense of medieval mouths: Investigating sex differences of dental pathological lesions in a late medieval Italian community. *American Journal of Physical Anthropology*, *169*(2), 253-269. https://doi.org/10.1002/ajpa.23821

Turner, C. G. (1979). Dental Anthropological Indications of Agriculture Among the Jomon People of Central Japan. *American Journal of Physical Anthropology*, *51*, 619-636.

United Nations. (2017). *World Fertility Report 2015: Highlights*. UnitedNations.

Van Dyke, R. M. (2015). The Chacoan Past: Creative Representations and Sensory Engagements. In R. M. Van Dyke & R. Bernbeck (Eds.), *Subjects and Narratives in Archaeology* (pp. 83-100). University Press of Colorado.

Van Dyke, R. M., & Bernbeck, R. (Eds.). (2015). *Subjectives and Narratives in Archaeology* University Press of Colorado.

van Tiel, B., & McFadden, C. (2021). Assessing the maternal risks associated with short stature in ancient Southeast Asia. *Internation Journal of Osteoarchaeology*, 1-9. https://doi.org/10.1002/oa.3032

Vergidou, C., Karamitrou-Mentessidi, G., Voutsaki, S., & Nikita, E. (2021). Oral health and its implications on male-female dietary differences: A study from the Roman Province of Macedonia. *Journal of Archaeological Science: Reports*, *35*. https://doi.org/10.1016/j.jasrep.2020.102784

Vlok, M., Buckley, H. R., Miszkiewicz, J. J., Walker, M. M., Domett, K., Willis, A., Trinh, H. H., Minh, T. T., Nguyen, M. H. T., Nguyen, L. C., Matsumura, H., Wang, T., Nghia, H. T., & Oxenham, M. F. (2021). Forager and farmer evolutionary adaptations to malaria evidenced by 7000 years of thalassemia in Southeast Asia. *Scientific Reports*, *11*(1), 5677. https://doi.org/10.1038/s41598-021-83978-4

Volk, A. A., & Atkinson, J. A. (2013). Infant and child death in the human environment of evolutionary adaptation. *Evolution and Human Behaviour*, *34*, 182-192. https://doi.org/10.1016/j.evolhumbehav.2012.11.007

Waldron, T. (2007). *Palaeoepidemiology: The Meassure of Disease in the Human Past*. Left Coast Press, Inc.

Waldron, T. (2009). *Palaeopathology*. Cambridge University Press.

Walter, B. S., DeWitte, S. N., & Redfern, R. C. (2015). Sex differentials in caries frequencies in Medieval London. *Archives of Oral Biology*, *63*, 32-39. https://doi.org/10.1016/j.archoralbio.2015.11.024

Ward, S. (2019). *Health impacts of increasing social inequality in Late Prehistoric Northeast Thailand* [Doctor of Philosophy Thesis, University of Otago].

Ward, S., Halcrow, S., Buckley, H. R., Gray, A. R., Higham, C. F. W., Domett, K., O'Reilly, D. J. W., & Shewan, L. (2019). Social status and its relationship to non-specific stress at late Iron Age Non Ban Jak, Northeast Thailand. *Bioarchaeology International*, *3*(4), 283-304. https://doi.org/10.5744/BI.2019.1017

Wasserstein, R. L., Schirm, A. L., & Lazar, N. A. (2019). Moving to a World Beyond "p < 0.05". *The American Statistician*, *73*(sup1), 1-19. https://doi.org/10.1080/00031305.2019.1583913

Wasterlain, S. N., Hillson, S., & Cunha, E. (2009). Dental caries in a Portuguese identified skeletal sample from the late 19th and early 20th centuries. *American Journal of Physical Anthropology*, *140*(1), 64-79. https://doi.org/10.1002/ajpa.21036

Watson, J. T., Fields, M., & Martin, D. L. (2010). Introduction of agriculture and its effects on women's oral health. *American Journal of Human Biology*, *22*(1), 92-102. https://doi.org/10.1002/ajhb.20958

Watt, R. G., Daly, B., Allison, P., Macpherson, L. M. D., Venturelli, R., Listl, S., Weyant, R. J., Mathur, M. R., Guarnizo-Herreño, C. C., Celeste, R. K., Peres, M. A., Kearns, C., & Benzian, H. (2019). Ending the neglect of global oral health: time for radical action. *The Lancet*, *394*(10194), 261-272. https://doi.org/10.1016/S0140-6736(19)31133-X

Watt, R. G., & Sheiham, A. (2012). Integrating the common risk factor approach into a social determinants framework. *Community dentistry and oral epidemiology*, *40*(4), 289-296. https://doi.org/10.1111/j.1600-0528.2012.00680.x

Weber, M., Bogstad Søvik, J., Mulic, A., Deeley, K., Tveit, A. B., Forella, J., Shirey, N., & Vieira, A. R. (2018). Redefining the Phenotype of Dental Caries. *Caries Research*, *52*(4), 263-271. https://doi.org/10.1159/000481414

Weintraub, J. A., Prakash, P., Shain, S. G., Laccabue, M., & Gansky, S. A. (2010). Mothers' caries increases odds of children's caries. *Journal of Dental Research*, *89*(9), 954. https://doi.org/10.1177/0022034510372891

Wells, J. C. K., & Stock, J. T. (2020). Life History Transitions at the Origins of Agriculture: A Model for Understanding How Niche Construction Impacts Human Growth, Demography and Health. *Frontiers in Endocrinology*, *11*(325). https://doi.org/10.3389/fendo.2020.00325

Wesolowski, V. (2006). Caries prevalence in skeletal series - Is it possible to compare? *Memórias do Instituto Oswaldo Cruz*, *101*(s2).

White, J. C. (2017). Changing Paradigms in Southeast Asian Archaeology. *Journal of Indo-Pacific Archaeology*, *41*, 66-77. https://doi.org/10.7152/jipa.v41i0.15024

White, J. C., & Eyre, C. O. (2011). Residential Burial and the Metal Age of Thailand. *Archaeological Papers of the American Anthropological Association*, *20*(1), 59-78. https://doi.org/10.1111/j.1551-8248.2011.01028.x

White, J. C., & Hamilton, E. G. (2021). The metal age of Thailand and Ricardo's Law of Comparative Advantage. *Archaeological Research in Asia*. https://doi.org/10.1016/j.ara.2021.100305

White, T. D., Black, M. T., & Folkens, P. A. (2012). *Human Osteology* (Third ed.). Academic Press.

WHO. (2003). *Diet, nutrition and the prevention of chronic disease*. World Health Organisation https://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf;jsessionid=DA16743C9376BDC0D9E84C182DC1FDF5?sequence=1

WHO. (2013). *Oral Health Surveys - basic methods* (5th ed.). World Health Organisation. https://apps.who.int/iris/bitstream/handle/10665/97035/9789241548649_eng.pdf;jsessionid=6D0E099B605F0A9E3ED07BE15B0479F5?sequence=1

WHO. (2015). *Guideline: Sugars intake for adults and children* (W. H. Organisation, Ed.). http://who.int/nutrition/publications/guidelines/sugars_intake/en

WHO. (2020). *Basic Documents: forty-ninth edition* (49th ed.). World Health Organisation https://www.who.int/about/governance/constitution

Wickrama, K. A. S., & Lorenz, F. O. (2002). Women's Status, Fertility Decline, and Women's Health in Developing Countries: Direct and Indirect Influences of Social Status on Health. *Rural Sociology*, *67*(2), 255-277.

Williams, M. A., & Letra, A. (2018). The Changing Landscape in the Genetic Etiology of Human Tooth Agenesis. *Genes*, *9*(5), 255. https://doi.org/10.3390/genes9050255

Willis, A. (2015). *The Bioarchaeology of An Son and Hòa Diêm: Biosocial Insights into Prehistoric Southern Vietnam* [Doctor of Philosophy Thesis, Australian National University]. Canberra

Willis, A., & Oxenham, M. F. (2013a). A Case of Maternal and Perinatal Death in Neolithic Southern Vietnam, c. 2100-1050 BCE. *International Journal of Osteoarchaeology*, *23*(6).

Willis, A., & Oxenham, M. F. (2013b). The Neolithic Demographic Transition and Oral Health: The Southeast Asia Experience. *American Journal of Physical Anthropology*, *152*, 197-208. https://doi.org/10.1002/ajpa.22343

Willman, J. C., Shackelford, L., & Demeter, F. (2016). Incisor ablation among the late upper paleolithic people of Tam Hang (Northern Laos): Social identity, mortuary practice, and oral health. *American Journal of Physical Anthropology*, *160*(3), 519-528. https://doi.org/10.1002/ajpa.22988

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*(11), 1875-1886. https://doi.org/10.1177/0959683616645947

Wood, J. R., Milner, G. R., Harpending, H. C., & Weiss, K. M. (1992). The osteological paradox: problems inferring health from skeletal samples. *Current Anthropology*, *33*(4), 343-358.

Yankowski, A., Kerdsap, P., & Chang, N. (2015). "Please pass the salt" - An ethnoarchaeological study of salt and salt fermented fish production, use and trade in northeast Thailand. *Journal of Indo-Pacific Archaeology*, *37*, 4-13.

Yu, M., Wong, S. W., Han, D., & Cai, T. (2019). Genetic analysis: Wnt and other pathways in nonsyndromic tooth agenesis. *Oral Diseases*, *25*(3), 646-651. https://doi.org/10.1111/odi.12931

Zakrzewski, S. (2012). *Dental Morphology, Dental Health and its Social Implications* Prehistory of Northeastern Africa New Ideas and Discoveries. Studies in African Archaeology 11, Poznan Archaeological Museum.

Zoéga, G., & Murphy, K. A. (2021). Resources, stress, and response in late Viking Age Iceland. In G. R. Schug (Ed.), *The Routledge Handbook of the Bioarcheology of Climate and Environmental Change*. Routledge.

Zuckerman, M. K., & Dafoe, A. C. (2021). Disease in the context of climate change. In G. R. Schug (Ed.), *The Routledge Handbook of the Bioarchaeology of Climate and Environmental Change*. Routledge