Health, diet and migration prior to the establishment of the Pre-Angkorian civilisation of Southeast Asia

Thesis submitted by

Jennifer Sarah Newton

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Statement on the Contribution of Others

Nature of Assistance	Contribution
Supervision	Dr Kate Domett, Dr Nigel Chang, A/Prof. Sean Ulm
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Declaration on Ethics

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the National Statement on Ethics Conduct in Research Involving Humans (2007), the Joint NHMRC/AVCC Australian Code for the Responsible Conduct of Research (2007), and the James Cook University Code for the Responsible Conduct of Research (2009). The proposed research methodology received clearance from the James Cook University Human Research Ethics Committee.

Warning

This thesis contains images of human remains which may be offensive to some readers.

January 17, 2014.

Signature

Date

Jennifer Newton

Name

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Abstract

This project examines the health, diet and migratory patterns of prehistoric people of Southeast Asia prior to the establishment of the Angkorian Empire in the early 9th century during the state development known as Funan and Chenla. Until now, evidence suggests Southeast Asia *did not* follow the trend towards declining health experienced by the rest of the world during the rise of complex civilizations. The research sample included human skeletal remains from three prehistoric Southeast Asian sites. The remains selected from Ban Non Wat in northeastern Thailand spans the Neolithic to early Iron Age (~2500 – 500 BC) and includes new samples as well as previously published work. Also included is new data from two late Iron Age sites in northwestern Cambodia, Phum Snay (~500 BC – 500AD), and Phum Sophy (~AD 100 – 600). Previously published bioarchaeological work from other prehistoric sites encompassing the Neolithic to late Iron Age is used to identify general trends for Southeast Asia. This project hypothesized that the Neolithic to early Iron Age's stable environment and minimal sociocultural changes would not have negatively impacted the health of communities through these time periods. In contrast, the environmental and social changes throughout the Iron Age would impact diet and migratory patterns, causing a general decline of health into the late Iron Age.

Health was examined at all sites through the analyses of childhood stressors including cribra orbitalia, linear enamel hypoplasia, and stature, along with adult dental health. Through carbon isotope ($\delta^{13}C$) analysis of the dental enamel this study was able to identify childhood diet at Ban Non Wat. Unfortunately, isotope analyses were not available for Phum Snay and Phum Sophy, therefore only dental health was used to identify aspects of diet at these sites. Migration was studied using strontium isotopes from dental enamel for Ban Non Wat. Phum Snay and Phum Sophy migratory patterns were determined from biological markers, such as dental modification. Through the examination of these three lines of evidence, the data for each site was examined independently to explain health, diet and migration, then combined with previously published work to identify general trends through Southeast Asian prehistory.

The evidence from the examination of health suggests the people of Ban Non Wat were generally healthy. The results across Southeast Asia demonstrate improvement of health into the early Iron Age, supporting previously published work. However, when compared to the broader context of the Iron Age in prehistoric Southeast Asia, both Phum Snay and Phum Sophy suggest a trend of declining dental health during the late Iron Age. In particular, it appears female health may have

been more negatively impacted throughout the Iron Age, evident from increased stress and poorer dental health.

Analyses of $\delta^{13}C$ values at Ban Non Wat indicate a gradual change of diet composition during the Neolithic to early Iron Age with minor variation in the middle of the Bronze Age. This suggests a change to a diet comprised mainly of C_3 foods, with minimal impact from C_4. Other nearby sites in Thailand also display $\delta^{13}C$ values indicative of a mainly C_3 diet, but were significantly different to Ban Non Wat based on overall contribution of C_3/C_4. These differences are suggestive of groups in this region living as independent units into the early Iron Age. Phum Snay and Phum Sophy dental pathology profiles suggest a diet with a greater reliance on agricultural foods, following a trend from other Iron Age sites within Southeast Asia.

Migratory indicators through the use of of strontium isotopes at Ban Non Wat suggest migration from outside of the Mun River catchment sharply declined or ceased in the late Bronze Age, but may have continued into the Iron Age through short distance routes. Social and biological patterns from Phum Snay and Phum Sophy suggest extensive movement and/or trade with many groups near and far during the late Iron Age.

This study finds that the stability of the environment and smaller population sizes allowed the inhabitants of prehistoric Southeast Asian communities to utilize local resources and live generally well into the Iron Age with improving health. However, throughout the Iron Age a decline of health, in particular for females, corresponded with changes to diet, increased fertility and settlement sizes, which may have been at least partially caused by the environmental changes. Increased settlement size and extensive exchange routes during the late Iron Age may have linked emerging new diseases and increased health problems. This research suggests Southeast Asia *does* follow a similar trend of declining health as a result of diet changes, migratory patterns and environmental changes as other complex societies around the world have shown, but these changes occurred at a much later time period in Southeast Asia - in the late Iron Age.

Abbreviations

μl	Micro litre
%	Percent
‰	Percent per mil
$\delta^{13}C$	Carbon isotope
$\delta^{15}N$	Nitrogen isotope
$\delta^{18}O$	Oxygen isotope
AMTL	Antemortem tooth loss
BNW	Ban Non Wat
FET	Fisher's Exact Test
km	Kilometres
LEH	Linear enamel hypoplasia
MNI	Minimum number of individuals
MP	Mortuary Phase
N	Number
s.d.	Standard deviation

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Chapter 1 Introduction

1.1 Introduction

This study traces trajectories of health, diet and migration throughout communities in ancient northeast Thailand and northwest Cambodia to understand whether and how these patterns changed along with documented sociocultural and environmental changes.

Previous documented evidence from Southeast Asia suggests health improved during the shift to complex societies and states. However, this research suggests there was a decline of health evident in the late Iron Age. Through the analyses of numerous factors this study strives to understand the factors which may have negatively impacted human health through the examination of health trends in association with diet and migration changes throughout time. This study builds upon the premise of the Goodman et al. (1988) biocultural model which encompasses the biological and cultural responses to stress impacting human health.

Importantly, consideration will be given to what stresses communities suffered and how they attempted to resolve them in light of environmental change. A better understanding of population movements related to changing patterns of health also allows an investigation into the progress of disease in tropical climates.

This research acknowledges the primary sites used for this project are located in northeastern Thailand and northwestern Cambodia; however reference is made to other sites throughout mainland Southeast Asia. There is virtually no data from Laos and minimal from Burma. The evidence from Cambodia, Thailand and Vietnam is considered a representation of Southeast Asia to date. Specific reference is made to a particular region/country when available; otherwise the area will be referred to as Southeast Asia.

1.2 Bioarchaeology and the rise of complex societies worldwide

The rise of complex civilizations occurred at different times throughout prehistory in different locations around the world. It is through the examination of these complex societies that the lives of the prehistoric occupants can be exposed. How did these people live? Were they healthy? What did they eat? Through evidence from archaeological remains, the reconstruction of prehistoric health, diet and migration during the rise of complexity has been examined and is briefly reviewed below.

Complex societies around the world originated from hunter-gatherer groups who migrated between temporary residences (Bellwood, 2005). This type of lifestyle would have been ideal for small numbers of individuals travelling as a group utilizing the resources from hunting and gathering while en route from different locations. However, this lifestyle would have been dependant on the environment, impacting how the group lived and what foods they would have eaten during times of stress. Ginter (2011) noted instability of the environment may have forced groups to change subsistence patterns due to the gradual increases of population sizes that would have increased food demands. This is one factor which probably helps to explain why agriculture started to flourish for different communities around the world. A reliance on agricultural practices was probably beneficial for maintaining extra supplies of food during unreliable times (Cohen, 1989; Diamond, 2002; Rose et al., 1984). As people started to establish permanent residences, a stable solution for subsistence was required, such as farming, which could feed larger groups of people (Cohen, 1989; Diamond & Bellwood, 2003). However, a negative impact of agricultural reliance was a decrease in the variety of dietary resources and nutritional quality (Norr, 1984; Papathanasiou, 2011). "[T]he proportion of animal foods in the human diet is likely to have declined as human populations grew, large animals disappeared, and the declining efficiency of hunting forced people to devote more of their attention to other resources" which may have been nutrient and protein deficient, causing a decline of dietary quality (Cohen, 1989, p. 58). However, some groups were able to incorporate food items required for dietary balance and variety, perhaps through trade (Cohen, 1989).

An increase of population size may suggest more communities were living in close proximity to one another. The larger population densities appear to have allowed a number of infectious diseases to emerge and spread throughout human populations (Armelagos et al., 1991; Wolfe et al., 2007) due in part to increased contact with animals (Eshed & Galili, 2011; Jones et al., 2013) and to human waste and contaminated water, in comparison to hunter gatherer lifestyles which would not have these problems (Armelagos, 2004). Mobility through migration was also a means of transferring disease (Araujo et al., 2013), as well as increasing trade networks (Allison, 1984). These changes noted above correspond with a general worldwide decline of health.

Increased reliance on agriculture appears to have affected the sexes differently. In some locations around the world the impact of agriculture was worse for female health due to increased exposure to pathogens leading to a greater likelihood of infection (Larsen, 1984). Therefore, the increased reliance on agriculture appears to have allowed an introduction of many diseases. Evidence from changes to long bones and stress on joints differs between males and females during the changes to subsistence suggesting a sexual division of labour (Larsen & Ruff, 2011; Ruff et al., 1984; Stock et al., 2011). These sexual differences suggest a negative impact on female health, especially dental health. Lukacs (2008) and Watson et al. (2010) suggest dental health was negatively impacted due to physiological changes associated with pregnancy during times of increased fertility. However, sociocultural and dietary trends, for example sex-specific access to foods (Temple & Larsen, 2007; Walker & Erlandson, 1986), may have been additional factors negatively impacting dental health throughout time. Female deaths may have been associated with complications during pregnancy and at the time of birth (Eshed & Galili, 2011) and the reduced time between pregnancies (Diamond, 1987). Thus the mean age-at-death was lower for females than for males (Eshed et al., 2004; Wells, 1975).

Overall, the rise of different complex societies around the world show similar characteristics particularly during the transition from hunting and gathering to increased reliance on agriculture in terms of enlarged population size, social changes, dietary shifts, and a decline of health. "[I]t is clear that the adverse effect of agriculture on health was a very wide-ranging geographic phenomenon that extended well beyond the so-called Ancient World" (Steckel & Rose, 2002, p. 578). During times of agricultural dependence and increased population sizes a number of infectious diseases never before seen are evident on the skeletal remains (Rathbun, 1984). While there is the possibility a number of other infectious disease and bacteria were present during this time, not all diseases are evident from the skeletal remains (Cohen, 1989). "[S]keletal material alone generally reflects less than 20% of the diseases that plague human populations" (Allison, 1984, p. 515). It appears that diseases known to be present and survive in large populations were more evident during this time, compared to the times of hunter and gatherers (Cohen 1989). However, interestingly, the health during the rise of complex civilization in Southeast Asia appears to have improved.

1.3 Overview of bioarchaeology in prehistoric Southeast Asia

The Angkorian Empire ruled during the 9th to mid-15th centuries AD and spanned what is now modern-day Thailand, Cambodia, Vietnam, Myanmar, Malaysia and Laos (O'Reilly, 2007, p. 2). This overview explains current literature available about the health, diet and migratory patterns which assisted with the eventual rise of this complex society, beginning from the Neolithic through to the Pre-Angkorian period (prior to the 9th century).

The Neolithic consisted of groups of hunter-gatherers who enjoyed broad-based subsistence patterns in different locations across Southeast Asia (Higham, 1989) that benefitted from an apparent environmental stability (Boyd & Chang, 2010). Archaeological evidence suggests the Neolithic inhabitants consisted of groups of hunter-gatherers in some cases living alongside farmers (Higham & Kijngam, 2010) and were becoming more sedentary through time, possibly due to the increased reliance on agriculture (Oxenham et al., 2008; Oxenham et al., 2005). There is evidence that not all Neolithic communities would have engaged in rice cultivation in Thailand (Higham, 2004) suggesting possible exchange of agricultural ideas through migratory patterns (Bentley et al., 2005). It is suggested that Neolithic inhabitants were migrating to new communities (Bentley et al., 2007) while participating in the exchange of goods with places such as China, and Vietnam based on exotic mortuary goods (Higham, 2004; Higham & Kijngam, 2010). Further east, the environment around the Mekong Delta would have been well-suited for rice cultivation and hunter-gatherer subsistence (O'Reilly, 2007). The evidence of domesticated rice in the archaeological record suggests it would have been an important part of the diet (Castillo, 2011), and there are suggestions that millet may have been incorporated into the diet (Weber et al., 2010). Changes to agricultural dependence seem to be linked with environmental changes (Higham, 2002), which then correspond with the health of populations. Health during the Neolithic has been documented as poor in several regions of Southeast Asia (see Domett (2001); Oxenham et al. (2005); Oxenham et al. (2008)).

The Bronze Age at Ban Non Wat was a time that saw the introduction of specialties such as bronze casting, which might have been initiated through long-distance links with China (Higham, 2004). Higham and Higham (2009) suggest the Bronze Age (BA) of Ban Non Wat was divided into a series of five mortuary phases (MP's). Some researchers suggest that the Bronze Age was a socially settled time (White 1982) with communities working independent of one another (O'Reilly 2007), while Higham (2004, pp. 55-57) suggests the presence of social elites occurring around Bronze Age 2 (BA 2) as "there is some limited evidence for social distinctions based on inherited wealth and status". There is evidence that migration patterns indicate people were relocating from distances outside of their immediate catchment areas during the Bronze Age (Bentley et al., 2009; Bentley et al., 2005), and the location of the majority of Bronze Age settlements along waterways probably facilitated exchange routes for these groups (Higham, 2004). Boyd and Chang (2010) indicate that the local environment in Thailand was quite stable during the Bronze and Early Iron Ages. The Bronze Age diet would have consisted of an abundance of resources, such as rice, fishing, and local resources gathered near the settlements (Higham, 2002). Domett (2001) demonstrates improvements of health throughout the Bronze Age as people were better able to exploit the environment. A healthy population was also suggested of prehistoric Myanmar (Tayles & Domett, 2001), and Vietnam (Willis & Oxenham, 2013). Meanwhile, evidence from Douglas (2006), suggests northeast Thailand does show evidence of a decline in health, in particular females.

The Iron Age presents an increase of militarism and warfare in the mortuary context, along with social changes and increasing social complexity, potentially evident of the increasing population (Domett & O'Reilly, 2009; Higham, 2004; O'Reilly & Sytha, 2001; O'Reilly, 2007). Areas of Thailand saw increasing settlement sizes in the Iron Age (Higham, 2004; McGrath et al., 2008). Population increases also occurred in Cambodia, evident from the number of settlements and the amount of people needed to construct such structures through time (O'Reilly, 2007).

The impacts from increased population density may have been a factor contributing to the environmental changes in the late Iron Age (McGrath et al., 2008; Penny & Kealhofer, 2005). The environmental changes consisted of a shift to drier conditions (Boyd, 2008) and the increasing population sizes may not have been able to keep up with the increasing demands for water. Environmental changes appear to have caused social changes for control of resources (Boyd & Chang, 2010). "It was probably during this later period, within the first five centuries AD, that social elites initiated the water control measures that are reflected in the extensive banks and moats that ring these settlements" (Higham & Kijngam, 2010, p. 254). Evidence of moats at Iron Age sites could suggest a means of defence, or control water (Higham, 2004; McGrath et al., 2008), as it was evident centres were starting to take control of resources for the emerging states (Stark, 2004) which included an increase in trade and conflict (Domett et al., 2011b; Stark, 2004).

The changing social and environmental patterns of the Iron Age appear to have had impacted health. It has been suggested that people would have been generally healthy in order to establish complex society (Domett, 2001; Domett & Tayles, 2006a). Oxenham et al. (2006) suggests a decline in health is not present until the Iron Age, due to the lack of available biological evidence. Lukacs (2008) and Watson (2010) have identified the negative impact a greater reliance on agriculture has for female dental health. Increasing dependence of the agricultural staple rice was evident in the Iron Age through its presence in the mortuary context (Higham et al., 2010). However, evidence comparing health from the Bronze Age to early Iron Age of Thailand indicates there is "not a clear pattern of health change over time" (Domett & Tayles, 2006a, p. 238), and recent studies from southern Cambodia indicate the people were generally healthy (Ikehara-Quebral, 2010; Pietrusewsky & Ikehara-Quebral, 2006).

Increasing interactions between groups from widespread locations and increasing population densities into the late Iron Age suggest repercussions on health. Evidence suggests communities in the Iron Age expanded trade networks. Extreme long-distance trade continued into the Iron Age between locations as far apart as Southeast Asia, India, China and Rome (Higham, 2004), and continuing its extensive networks into the late Iron Age (Reinecke et al., 2009). There is evidence for the emergence of infectious diseases, such as the first occurrence of leprosy during the Iron Age in Thailand (Tayles & Buckley, 2004), and increases of other infectious diseases in Vietnam (Oxenham et al., 2005). Growing population densities may have contributed to increased interactions and spread of disease, suggesting health may have been negatively impacted.

1.4 Research question

Using data from three archaeological sites, the main research question examined is: *Why did the rise of complex society in tropical Southeast Asia differ from the rest of the world?*

In order to explore this further, the following question is explored: *Do health, diet, and migration patterns change throughout Southeast Asia prior to the establishment of the Pre-Angkorian civilization?*

1.5 Background

The research stems from three ongoing projects investigating human responses to climate change over the last 4000 years. One project takes place in northeast Thailand and two projects are in northwest Cambodia. This study focuses on the analysis of the human skeletal remains from three important archaeological sites recovered as part of these three projects. The first site is Ban Non Wat in northeast Thailand (Fig. 1.1) and is important in that it is one of the few sites excavated to date that spans the Neolithic, Bronze Age (BA) and early Iron Age (IA) periods. In addition, excavations have been spread over the prehistoric mound. These aspects allow for spatial and temporal analyses of variables. The other two sites are Phum Sophy and Phum Snay located in northwest Cambodia, both late Iron Age (Pre-Angkorian) sites (Fig. 1.1). The excavation of the Phum Snay cemetery is noted for being one of the first Iron Age cemeteries in that area to be excavated (Domett & O'Reilly, 2009; O'Reilly & Sytha, 2001).

The series of projects based on these skeletal remains includes a combination of palaeopathological and isotopic analyses to address three research themes:

1. *Health and environmental change*: Through the observation of health and disease in past communities much information may be gained regarding the success of adaptation to the local environment – both on a cultural level and through the physical environment and the resources it provides. Through time, the health of the prehistoric people may be hypothesised to have improved as their ability to exploit their environment developed. However, this may have been intermittently disrupted by periods of climate change or social unrest, particularly at 'tipping point' phases when adaptations no longer provided a buffer from environmental change. This may be visible in the skeletal record through the presence of high stress indicators (such as an increase in infectious disease) through time. To date, many of the documented diachronic changes in health in Holocene Southeast Asia have been subtle, for example Domett and Tayles (2007); Douglas (2006), but it is not clear whether this a true representation of life in the past or a reflection of the small sample sizes available. This section of the project not only advances the general database and knowledge of health in prehistoric Southeast Asia with analyses of individuals from new excavations but it also synthesises this with published information to determine the broader influences on the quality of life in the region.

2. *Diet and environmental change*: By selecting appropriate individuals from the long time span from the Ban Non Wat site, particularly time periods known to have experienced environmental change (Boyd, 2008), it is possible to determine if dietary resources changed. It is then possible to overlay this information with health analyses to determine the impact on quality of life. Dental pathologies such as attrition and caries can potentially assist in identifying changes to the diet in ancient societies (Hillson, 2008), therefore dental pathology profiles and stable isotopes are examined to identify the trends of diet throughout time.

3. *Migration and environmental change*: Isotopes enable 'immigrants' and 'locals' to be identified through observations of their strontium isotopic signatures (Bentley, 2006b). Strontium isotopes from human tooth enamel are a reflection of the environment from which the person lived *as a child*. Differences in strontium ratios can indicate individuals with different childhood origins. Strontium isotope analysis provides a picture of human movement into Ban Non Wat, an important parameter in fulfilling the aim of observing the adaption strategies with environmental change. The objective is to examine the scale of migration into the community of Ban Non Wat as water

resources changed due to environmental and human impact. If migration was necessary to improve labour management to cope with the changing environment, did this result in a more hierarchical social structure, and who were moving – men and/or women? Very little similar work has been completed for this region (Bentley et al., 2007; Bentley et al., 2009; Bentley et al., 2005; Cox et al., 2011), and this project makes extensive comparisons to the small amount of published work throughout prehistoric Southeast Asia.

1.6 Aims and objectives

The aim of this research is to reveal the rise of state society in Southeast Asia ***did*** follow a similar trend to other state developments around the world. This study will look specifically at early stages of complexity (small Neolithic communities to Pre-Angkorian chiefdoms), which set the stage for subsequent Angkorian state development.

The objectives of the project are to gain a better understanding of the overall health of ancient peoples, which includes looking at any changes that might have occurred in the environment over time, and how those changes impacted the diet and migratory patterns of individuals in northeast Thailand and neighbouring northwest Cambodia. Importantly, consideration will be given to what stresses communities suffered and how they attempted to resolve them in light of environmental change. A better understanding of population movements related to changing patterns of health will also allow an investigation into the movement of disease and parasites in tropical climates.

In order to achieve this, the goal is to determine (1) the health of individuals through standard observations of palaeopathology, growth and dental health; (2) the diet of individuals through carbon isotope studies (both published and new analyses) combined with archaeological evidence from faunal material; and (3) the scale of migration at the sites based on strontium and oxygen isotopes (also from both published and new analyses). These three parameters will be combined to build a holistic picture of health, by answering such questions as: did health improve with time or did it decline as people moved towards state control? Was diet adequate and varied or did it lead to deficiencies? Did migration increase through time and did it bring with it new health challenges for the community? This not only advances the general database and knowledge of health and the rise of agriculture in prehistoric Southeast Asia with analyses of individuals from new excavations, but it also synthesizes this with published information to determine the broader influences on the quality of life in the region.

1.7 Significance

To date, Cambodia has very few published studies on human skeletal remains from prehistory (Domett & O'Reilly, 2009) and most of them have small sample sizes, and poor preservation. With the exception of Angkor Wat, prehistoric Cambodian archaeological material has not previously been available for research. "Unfortunately, this rich cultural heritage was severely damaged during the Indochinese wars and subsequent revolutions and field research virtually ceased between the mid-1960s and 1990s", and resumed in the mid-1990s (Stark, 2004, p. 89). Since the authorization of archaeological sites to be examined in Cambodia, there is still limited information available about prehistoric life. O'Reilly (2007) and Higham (2004) note the many gaps in the prehistory of Southeast Asia and further research is needed. Advances in this field have been made by research such as, Higham & Higham (2009); Higham (2008); O'Reilly & Sytha (2001), and O'Reilly (2007). However, O'Reilly and Sytha (2001) point out the deficiencies seen in the research done in close proximity to Angkor Wat. Our knowledge of the way of life in late prehistoric Southeast Asia has recently been uncovering exciting results markedly advancing our knowledge of Cambodian prehistory (Ikehara-Quebral, 2010; O'Reilly et al., 2006a; Reinecke et al., 2009; Stark, 2004). Recent excavations uncovering human skeletal collections have increased, along with bioarchaeological knowledge of Cambodia's prehistory through the excavations at Phum Snay and Phum Sophy, just 40 km apart (Fig.1.1), which were both occupied during the Iron Age which occurred from c. 500 BC to AD 500 (Domett & O'Reilly, 2009). As new sites are excavated, our picture of the quality of life and the influence of culture and environment on health are gradually being broadened. Nevertheless, bioarchaeology is a comparatively recent field of investigation in this part of the world, limited to the last few decades compared with other parts of the world (Tayles & Buckley, 2006). The increasing amount of bioarchaeological work in Southeast Asia, such as the information presented in this research project, will continue to broaden our knowledge of the past lives of these people.

Publications relating to health, in particular dental disorders, in Southeast Asia have been increasing (e.g. Domett & Tayles, 2007; Halcrow et al., 2013; Willis & Oxenham, 2013). The study of dental health from Ban Non Wat not only augments the data for the growing publications for prehistoric Thailand, but allows the exploration of dental health from the early Bronze Age through to the early Iron Age at a single site. The study of one site's occupation holds a great deal of information about health status during prehistoric times in northeast Thailand. While the research of Southeast Asian prehistoric health has been increasing throughout the last few years it is mainly concentrated on prehistoric Thailand. Therefore, evidence from prehistoric Cambodia is still deficient. For the first time, information about the health of people in prehistoric Cambodia is presented through the dental pathology profiles of Phum Snay and Phum Sophy. These sites are important because they offer interpretations of prehistoric health in Cambodia to assist with the understanding of prehistory in Southeast Asia. Together, with dental pathology information from Ban Non Wat in Thailand (early Bronze to early Iron), patterns of dental health from the Bronze Age through to Pre-Angkorian times is assessed.

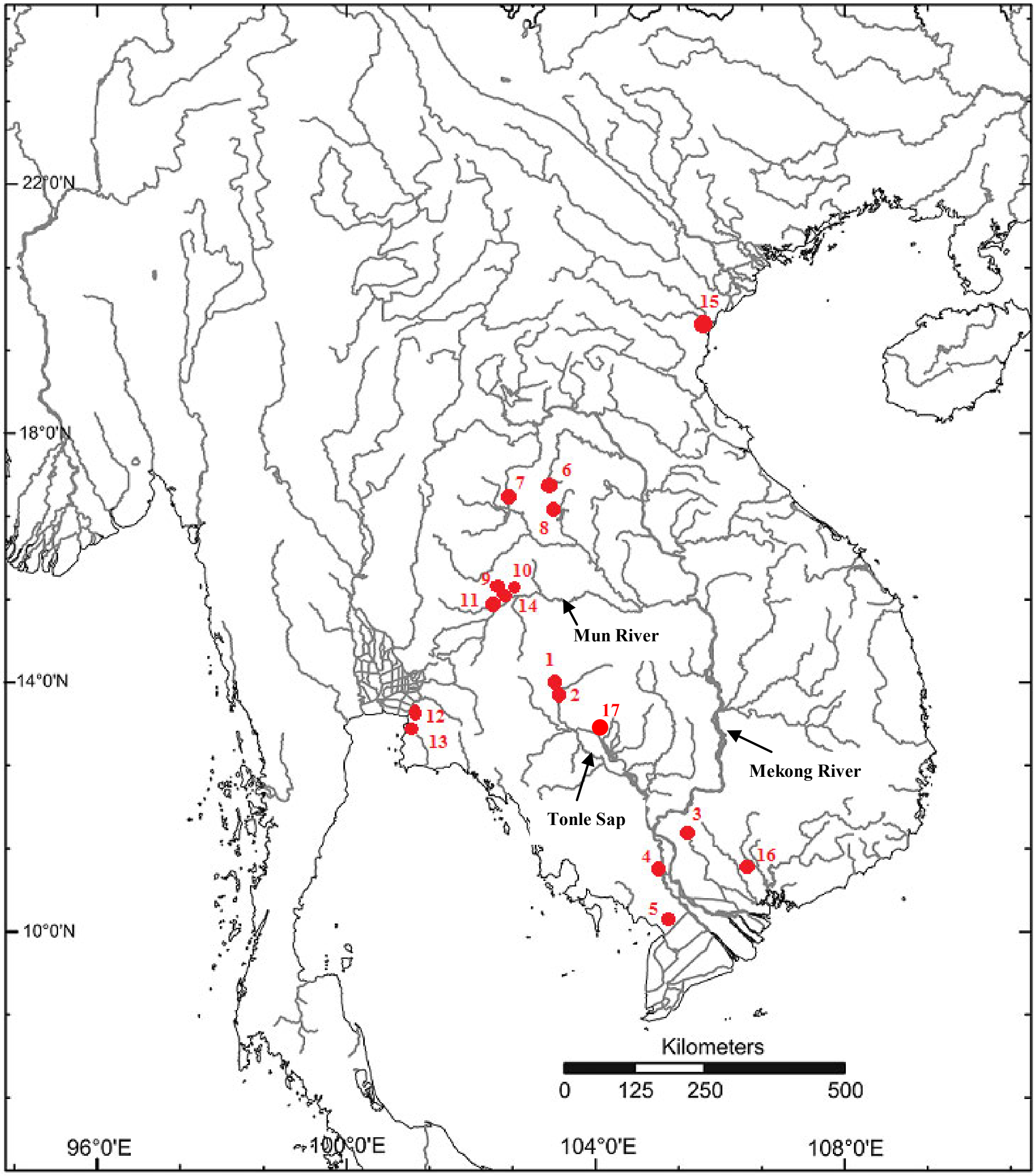


Figure 1.1Map of Southeast Asia indicating the location of sites mentioned in the study.

1. Phum Sophy, 2. Phum Snay, 3. Prohear, 4. Angkor Borei, 5. Oc Eo, 6. Ban Chiang, 7. Non Nok Tha, 8. Ban Na Di, 9. Ban Lum Khao, 10. Ban Non Wat, 11. Noen U-Loke, 12. Khok Phanom Di, 13. Nong Nor, 14. Ban Prasat, 15. Man Bac, 16. An Son, 17. Angkor Wat

Note: Vietnam Ma, Ca Rivers, and Vietnam Red River are located in Northern Vietnam

1.8 Thesis organisation

This thesis is organised into a series of chapters. Chapter 2 briefly explains the environmental and sociocultural background of the three archaeological sites examined in this thesis that are relevant to this study. Chapter 2 also explains the overall materials and methods used. Further details of materials and methods are explored in each theme chapter. The three themes are organised as separate chapters (Chapters 3-5). Hypotheses for each of the three themes are examined within the corresponding chapter to aid in answering the main research question. The culmination of the theme chapters are discussed in Chapter 6. The final Chapter (7) summarises the findings of this study.

A brief explanation of each hypothesis and theme chapter is below:

1.8.1 Hypothesis 1

Health declines through time

Hypothesis 1 is examined in Chapter 3. This chapter examines the health of three prehistoric communities and integrates this information into the broader Southeast Asian context. It is hypothesised that prehistoric health declined throughout time as people moved towards state formation. Through the examination of this hypothesis, further sub-hypotheses are posed to further suggest childhood stress and adult dental health declined throughout time.

1.8.2 Hypothesis 2

Changes to childhood diet will be gradual throughout the Neolithic to early Iron Age, after which, significant dietary differences will be present, negatively affecting health

Hypothesis 2 is examined in Chapter 4. This chapter examines the dietary changes through the Neolithic to early Iron Ages in Southeast Asia. It is hypothesised that the eventual dietary changes to diet in the late Iron Age will negatively affecting health. Isotopes from dental enamel and dental pathology profiles are examined. This project uses further sub-hypotheses to investigate if/when significant dietary changes occurred in the past and what impacts it had on human health.

1.8.3 Hypothesis 3

Migration in the Neolithic will bring new ideas and population growth in Southeast Asia though through time there will be a decrease in migration from outside the immediate catchment area of the community. However, extensive inter-community trade with groups from further distances will flourish, bringing negative health consequences

Hypothesis 3 is examined in Chapter 5. This chapter examines impact of migration and trade links throughout time. The foremost hypothesis for this chapter suggests migration in the Neolithic will bring new ideas and population growth in Southeast Asia, although through time there will be a decrease in migration outside of the immediate geographic community. However, extensive inter-community long distance trade will flourish throughout the late Iron Age, bringing negative health consequences. Further sub-hypotheses are explored to suggest those suspected changes would have negatively impacted the health of communities in the late Iron Age.

Chapter 2 Cultural and environmental context

The following presents a brief overview of the environmental conditions in Southeast Asia during the time periods discussed in this research.

Documented evidence of prehistoric environmental conditions is primarily from Thailand. The environmental conditions during Neolithic in northeastern Thailand were shown to be favourable to the inhabitants and these conditions remained stable throughout the Bronze and early Iron Ages (Boyd & Chang, 2010). However, there is evidence suggesting a demise of the stable environment in the late Iron Age due to a depletion of natural resources impacted by the increasing reliance on agriculture (Boyd & Chang, 2010) and depleting water supply (Boyd, 2008). There is evidence of moats beginning in the Iron Age in which McGrath and Boyd (2001) use previous literature to explain a few possibilities as to why they were constructed, including a link with rice agricultural purposes (McGrath & Boyd, 2001). In Vietnam, the climate consisted of two distinct zones, with instability in the north which may have caused difficulty for prehistoric groups (Oxenham et al., 2005). With the limited documented evidence of environmental conditions throughout Southeast Asian prehistory, Boyd and Chang (2010) suggested the environment was relatively stable into the early Iron Age, after which significant changes occur into the late Iron Age.

This chapter introduces the three archaeological sites examined within this thesis. First, the context of the site of Ban Non Wat is detailed, followed by comprehensive details of the excavation, burial distribution and the skeletal samples at the site used in this study. After this, the site of Phum Snay is explained in terms of location, occupation period, excavation details and skeletal material used in this thesis. Finally, similar information is discussed for the site of Phum Sophy.

2.1 Cultural and environmental context at Ban Non Wat

2.1.1 Neolithic Ban Non Wat

The broad prehistoric sequence in northeast Thailand indicates that the Neolithic period is characterized by a subsistence pattern reliant on hunting and gathering in small communities (Bentley et al., 2005), along with at least some investment in rice farming and an introduction of domesticated animals (Higham & Kijngam, 2010). Ban Non Wat is located on the edge of a floodplain (Boyd & McGrath, 2001b) and would have had ample forested areas (Boyd & Chang, 2010). According to Higham (2012a, p. 533) "[t]he Neolithic occupants of Ban Non Wat enjoyed an abundance of wild game, fish and shellfish. Their rice cultivation and the raising of domestic pigs and cattle continued into the BA”.

2.1.2 Bronze Age Ban Non Wat

The Bronze Age at Ban Non Wat is generally characterized by the beginning of copper-based metallurgy (Higham, 2011; Higham & T.G.F, 2009). There is some debate over the level of social complexity at this time with some evidence of egalitarianism and/or heterarchy (O'Reilly, 2000; White, 1995), while others argue that the introduction of metallurgy initiated a flurry of social competition and at least some increase in the differentiation of status positions in society (Higham, 2011). Higham (2011; 2013) argues that the extremely wealthy burials of BA 2 (Table 2.1) represent a significant elite appearing in the community. These elite individuals are collectively referred to as ‘superburials’ (Plate. 2.1) (Higham, 2009). Should the differences between lower and higher ranked individuals at this (or any other period) represent clearly recognized and differentiated status levels separating, for example, commoners and elites, then differences in diet might be observed. Other differences such as burial location and grave offerings might also be associated with different social groups. The differences may indicate a distinction between achieved status and inherited status; the latter generally thought to be associated with greater degrees of ranking. However, to date, this degree of ‘wealth’ has not been uncovered anywhere else on the site.

During the phases superburials were present, data from King et al. (2013, pp. 1684-1685) showed “an abrupt change to more negative $\delta^{13}C$ values between the first and second BA phases, and a gradual increase in $\delta^{13}C$ through the Iron Age”. The more negative $\delta^{13}C$ values might indicate an increase of C_3 foods, such as rice, which appears to correspond with the presence of elite individuals, and less C_3 reliance once the elite burials ceased. Archaeological evidence of the fauna from the excavations identified remains of pig, fish, cattle, chicken, and shellfish (Higham, 2011; Thosarat, 2012). Ongoing faunal and mortuary analyses indicate this continued into the Iron Age (Chang, per comm.). The extent of the fluctuation of $\delta^{13}C$ values will be examined to try and determine the prehistoric diet.

Plate 2.1 Superburial from Ban Non Wat (Photograph: Nigel Chang)

2.1.3 Iron Age Ban Non Wat

The Iron Age in northeast Thailand is often characterized as a period with increased social tension and population size (Higham & Thosarat, 1998; Higham & T.G.F, 2009). Significant changes in the socio-political climate were evident, including increasing hierarchical structures (O'Reilly, 2000). Specifically in the Ban Non Wat area, it is also associated with the construction of moats and changing natural water systems (Boyd, 2008; Boyd & Chang, 2010; McGrath et al., 2008), and a likely intensification in salt-making and rice agriculture as well as the appearance of iron artefacts (Higham & T.G.F, 2009). There was a gradual clearing of the forested areas throughout the Iron Age with an eventual regeneration of "grassland and scrubby vegetation" by the late Iron Age (Boyd & Chang, 2010:279).

2.2 Ban Non Wat

Ban Non Wat (BNW) is a prehistoric site in Thailand undergoing extensive archaeological analysis. An aerial photograph of Ban Non Wat displaying the excavated squares, land heights, and the size and location of the excavations is available (Plate 2.2). It is a moated site located in the Mun River Valley in northeast Thailand. This site is important in that it is one of the few sites excavated to date that spans the Neolithic, Bronze Age and Iron Age periods (Higham & T.G.F, 2009), incorporating approximately 2000 years of prehistory in Thailand (Table 2.1).

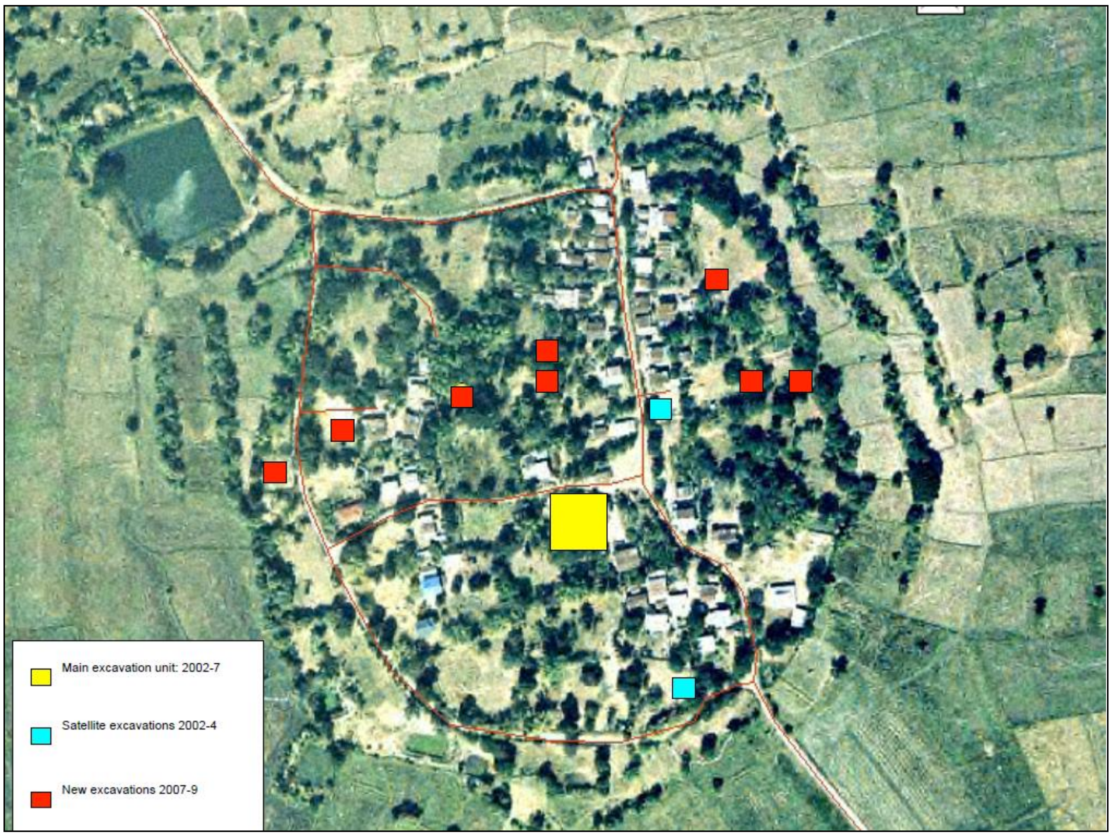


Plate 2.2 Aerial photograph of Ban Non Wat (Photograph courtesy of Nigel Chang)

Table 2.1

A summary of the prehistoric chronology of Ban Non Wat (Higham & Higham, 2009).

Cultural Period	Date in calibrated radiocarbon years (BC/AD)
Flexed burials	1750-1050
Neolithic 1	1650-1250
Neolithic 2	1250-1050
Bronze Age 1	1050-1000
Bronze Age 2	1000-900
Bronze Age 3	900-800
Bronze Age 4	800-700
Bronze Age 5	700-420
Iron Age 1	420-100
Iron Age 2	200 – AD 200
Iron Age 3	AD 200-400
Iron Age 4	AD 300-500
Early historic	AD 500-

BNW was first excavated in one central location from 2002-2007 under the direction of Professor Charles Higham. The skeletal remains from this project will be referred to as 'Series 1'. From 2007 to 2013 the excavations have been in conjunction with the project 'Origins of Angkor: resilience and opportunity in ancient Southeast Asia, Thailand', co-supervised by Drs Nigel Chang and Kate Domett from James Cook University. The skeletal remains from this portion of the project are referred to as 'Series 2'.

BNW also has archaeological significance due to the spread of excavations over the prehistoric mound, which is unusual in Southeast Asia (Fig 2.1). These aspects allow for both spatial and temporal analyses of variables. The bulk of the burials tend to be around the northern portion of the mound at the highest points, and to either side of the highest points down the slope.

The BNW materials used for this study includes Series 2, which consists of a total of 63 burials that were found and excavated from 2007 to present, of which there are 61individuals (see Table 2.2 and Fig. 2.2). There are 34 individuals excavated from the Bronze Age burials, 24 from the Iron Age, while three individuals are from an unknown time period. Age or sex distribution across these areas is available in Figures 2.3 and 2.4.

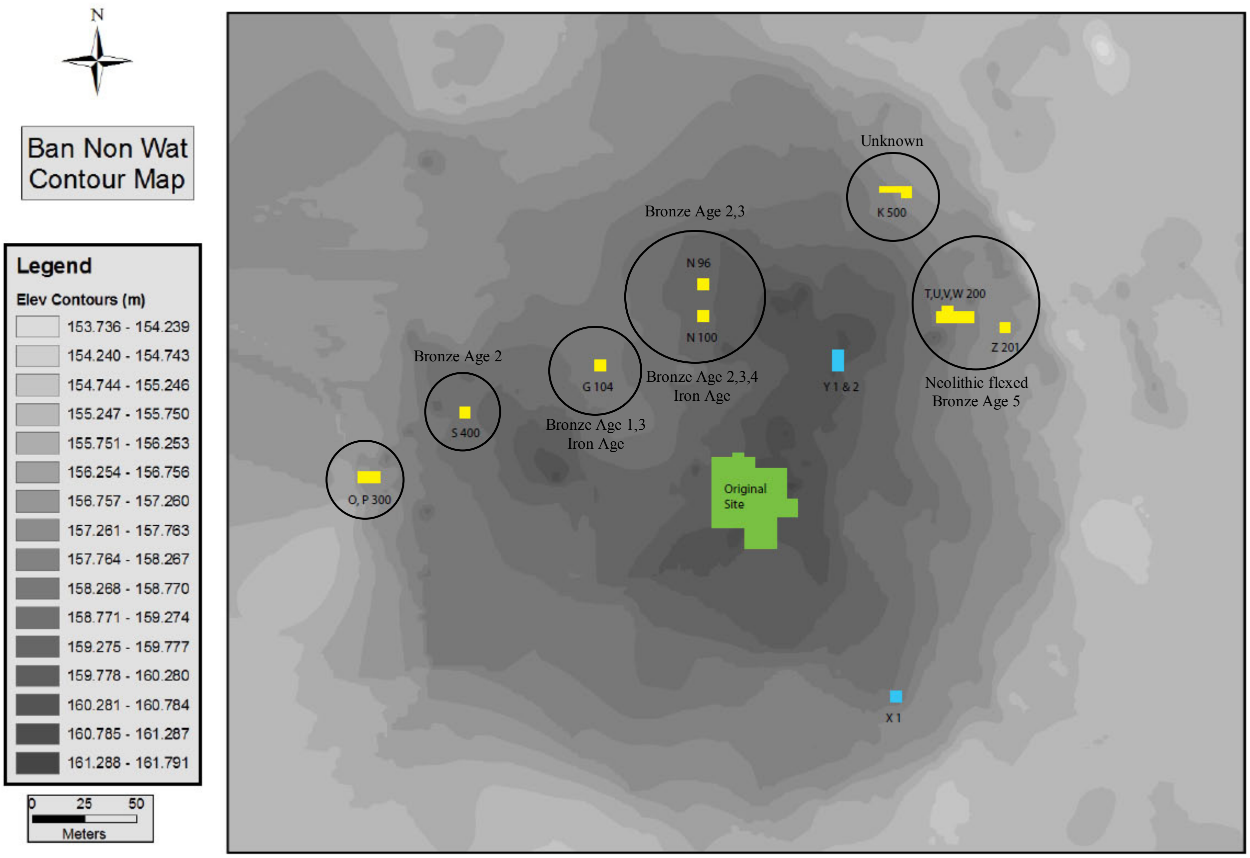


Figure 2.1 Ban Non Wat map outlining the excavation seasons and their corresponding squares. Circled areas indicate units excavated from 2007 to 2011 uncovering the Series 2 skeletal remains. The other three units were excavated between 2002 & 2007 (Higham & Kijngam, 2009) (Series 1 skeletal remains). Map courtesy of Nigel Chang and James Moloney. Note: Excavation units are not to scale.

Table 2.2

Ban Non Wat distribution of burials per excavation square.

Square	Total (N)	Male		Female		?Sex	
		Bronze	Iron	Bronze	Iron	Bronze	Iron
N100	11	4	0	4	0	1	2
N96	7	2	1	1	0	1	2
G104	11	2	2	2	1	0	4
S400	1	1	0	0	0	0	0
TUVW200	5	1	0	3	0	0	1
IK500	3	0	0	0	0	0	3
Total	38	10	3	10	1	2	12

Note: 2 individuals from W200, and 1 individual from V200 are not included in this chart due to unknown placement in time periods

Square	Total (N)	Subadult*		Young adult		Mid adult		Old adult		?Adult	
		Bronze	Iron	Bronze	Iron	Bronze	Iron	Bronze	Iron	Bronze	Iron
N100	18	3	4	2	0	3	0	0	0	4	2
N96	13	5	1	0	0	0	0	0	0	4	3
G104	15	1	3	1	1	1	0	1	0	1	6
S400	1	0	0	0	0	1	0	0	0	0	0
TUVW200	8	3	0	1	0	2	0	0	0	1	1
IK500	3	0	0	0	0	0	0	0	0	0	3
Total	58	12	8	4	1	7	0	1	0	10	15

***Subadult totals include neonates.**

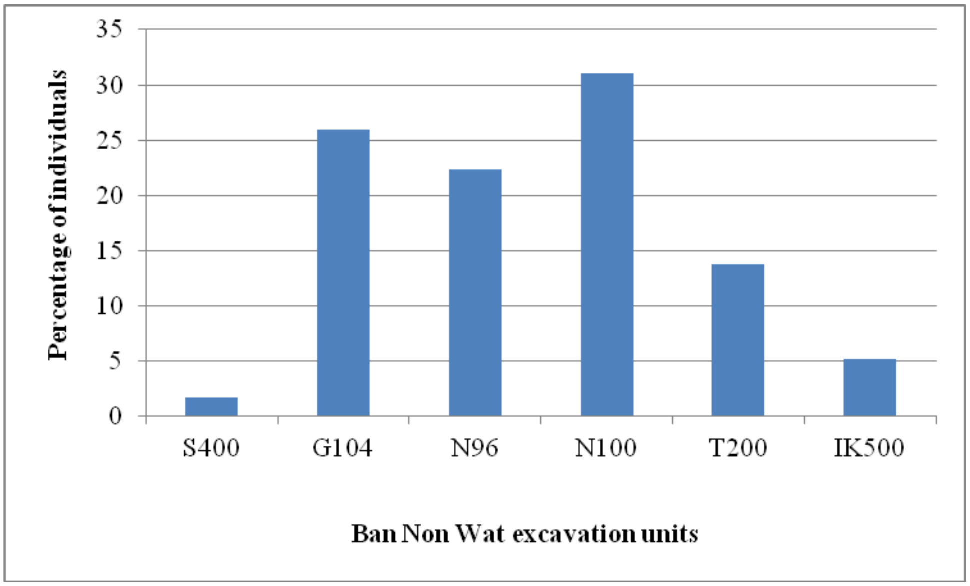


Figure 2.2 Ban Non Wat distribution of burials per excavation square.

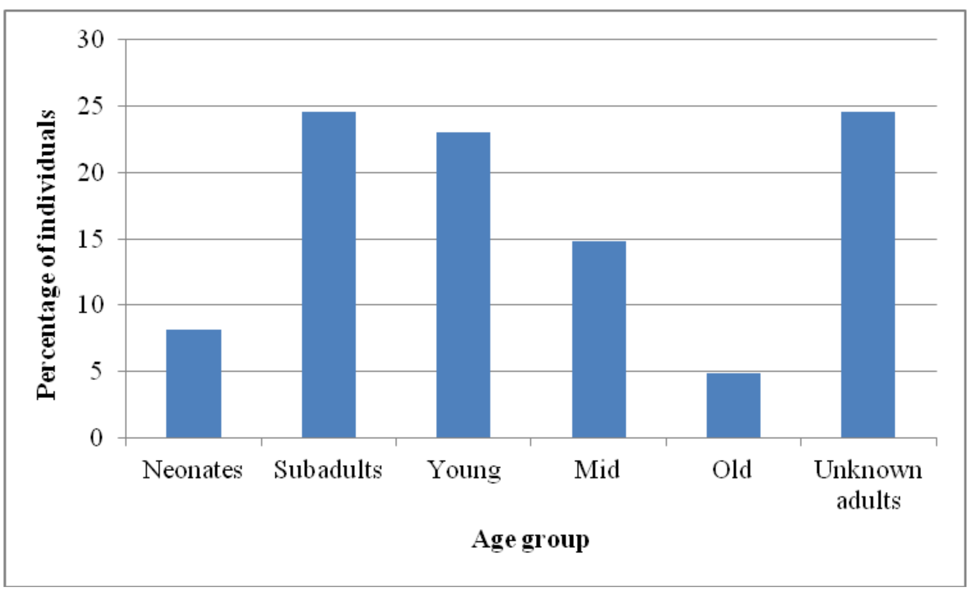


Figure 2.3 Ban Non Wat age distribution.

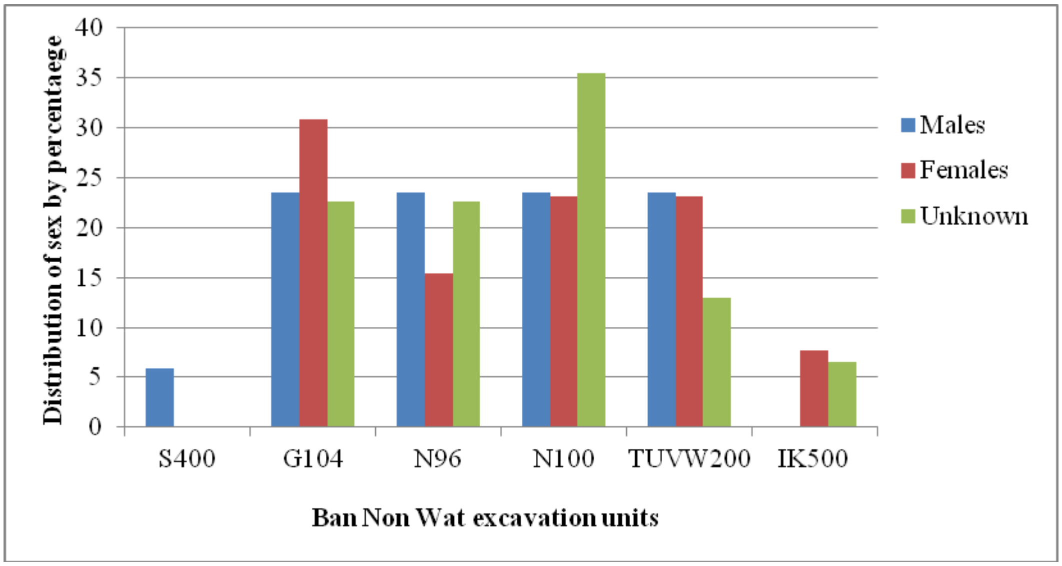


Figure 2.4 Ban Non Wat total sex distribution for each excavation unit. Unknown samples include subadults and neonates.

2.3 Cultural and environmental context in prehistoric Cambodia

The Late Iron Age/Pre-Angkorian period in Cambodia is known to be a time of increased social and environmental tension. The sites in discussion for this section are within close proximity to the centre of the eventual Angkorian civilisation. The region encompassing these Pre-Angkorian sites potentially shares similar cultural patterns with the regions of northeastern Thailand and spans to the location of Ban Non Wat.

"The pre-Angkorian period was an important period of transition that saw advances in technological sophistication and increases in social complexity" (Domett & O'Reilly, 2009, p. 60). Evidence of this is seen through the construction of moats, and the increased violent trauma, such as at Phum Snay (Domett et al., 2011b). Construction of moats and complex structures would have required a large population (as seen in Thailand) (Higham, 2008), suggesting an increased population size at this time. Similar hydrological structures referred to as circular mounds were present in Cambodia (Moore & Freeman, 1998).The landscape at this time would have been utilised for rice cultivation, and control over water resources would have been important (Higham, 2008).

2.3.1 Cultural and environmental context of Phum Snay

The diet for the people of Phum Snay appears to have contained an adequate amount and variety of protein, with a range of animal bones found at the site, such as those of wild deer, turtles, and tortoises, along with domesticated species of dog, pig, cattle, chicken and duck. The large number of wild species and freshwater fish suggests that hunting and fishing were important (O'Reilly et al., 2006a).

2.3.2 Cultural and environmental context of Phum Sophy

Like Phum Snay, evidence suggests that a wide variety of ecosystems at Phum Sophy (forests, grasslands, rivers and inundated rice fields) were exploited, and that diet was broad-based. Faunal remains include pig, cattle, water buffalo, and chicken, all of which were probably domesticated (Voeun, 2010). Phum Sophy's location on a rich flood plain also made it an ideal location for collecting freshwater snails, shellfish and fish.

2.4 Phum Snay

Phum Snay is a village located in northwest Cambodia, in the Banteay Meanchey Province (Domett & O'Reilly, 2009; O'Reilly et al., 2006a) (Fig 1.1 and Plate 2.3). Excavations took place at Phum Snay in 2001 and 2003. Based on the excavations, O'Reilly and colleagues (2006a) were able to date the site at 348-307 BC for the 2001 excavation and 75-209 AD for the 2003 excavation. The estimated dates coincide with the late Iron Age (or Funan) period in Cambodia (Domett & O'Reilly, 2009). The site of Phum Snay is one of the first late Iron Age cemeteries to be excavated in such close proximity to Angkor (O'Reilly & Sytha, 2001). Continued excavations took place from 2007–2010 by a collaborative group consisting of the Cambodian Ministry of Culture and Fine Arts and the International Research Center for Japanese Studies who examined a further 12 locations at Phum Snay (Miyatsuka & Yasuda, 2013).

Iron Age Phum Snay was a hierarchical society with a gender-based division of labour (Domett & O'Reilly, 2009). The presence of rice and sickles in some burial features indicates that rice cultivation was an important part of the subsistence regime (O'Reilly et al., 2006a). Male burials had grave goods associated with agriculture, hunting, and warfare, such as projectile points, swords, and sickles. Female burials typically contained spindle whorls and some iron tools. Similarities in artefact assemblages and mortuary rituals link them culturally and temporally to other Iron Age sites in northeast Thailand. The increased wealth and increase in social friction at

Phum Snay harmonizes with Thai Iron Age sites such as Noen U-Loke and Non Muang Kao, evident from the artefacts associated with the site (O'Reilly & Sytha, 2001).

The materials used for this study include excavated remains and a comingled ossuary collection. The sample size of the excavated human remains at Phum Snay was limited (N=23), but with the additional information gathered from a previously looted sample (MNI=134), a more accurate summary of health was obtained. The excavated remains were mainly complete but the bone was not very well-preserved overall (Domett & O'Reilly, 2009). The ossuary collection bone preservation was generally good, however the remains consisted of mainly fragmented portions affected port-mortem. The ossuary remains were collected by the villagers in the immediate area around the village after the material was looted and are believed to be related to the excavated material (Domett et al., 2011a).

Plate 2.3 Aerial view of Phum Snay. Image from GoogleEarth.

2.5 Phum Sophy

The village of Phum Sophy is located in northwest Cambodia, approximately 40 kms northwest from Phum Snay (Fig 1.1). The site of Phum Sophy is believed to be late Iron Age or Pre-Angkorian in time. Preliminary occupation dates of Phum Sophy from radiocarbon dating are approximately AD 100–600 (Beavan, per. comm., cited inDomett et al., 2011a) and place the site's occupation around the same time as Phum Snay (Domett et al., 2011a). Phum Sophy indicates a suite of artefacts similar to that of Phum Snay, and burials contained substantial wealth, such as semi-precious stones and large caches of ceramics and iron tools. Phum Sophy was excavated by O'Reilly and colleagues in 2009, when a total of six burials were found (Domett et al., 2011a). A follow up excavation in December 2010 found undisturbed skeletal remains in excellent condition. There were also large amounts of unprovenanced remains located in a local wat. These remains were collected by local villagers throughout the years as the site was being looted. These remains were placed in a large *Wat* at the village, were able to be analysed (Plate 2.4).

The materials examined in this study include the excavated sample (N=21) and a collection of looted human remains (MNI=37).

Plate 2.4 Unprovenanced collection of human skeletal remains at Phum Sophy.

2.6 Methods

The general osteological methods are outlined below. The methods specific to each chapter are outlined in the appropriate chapter.

The remains from Ban Non Wat were all excavated. However, most of the skeletal remains from Phum Snay and Phum Sophy were from comingled ossuary collections. While previous studies have examined samples from unprovenanced remains (e.g. Hanchant, 2004) and remains from ossuaries in other regions around the world (e.g. Hoppa & Gruspier, 1996; Papathanasiou et al., 2000; Smith, 1977; van der Merwe et al., 2003), the samples from Phum Snay and Phum Sophy represent the first use of prehistoric ossuary collections in Southeast Asia.

The age-at-death of many individuals could not be estimated due to sample insufficiency. Therefore, sexing and aging of the ossuary remains were based mainly on only a long bone, mandible and/or cranium for each individual using standard methods discussed below. Determination of sex and age was not possible for a significant amount of material.

Due to the large number of unknown sex mandibles and maxillae for Phum Snay and Phum Sophy, discriminant function testing for the possibility of assigning sex to as many individuals as possible was undertaken. In order to do this, the mandible and/or cranium measurements of the known sexed samples were used. Samples from the excavated samples were also included in the tests. If a significant difference was found between males and females for particular measurements, these results would be able to be used to help determine the sex of the unknown sex individuals. This was carried out by calculating the average of multiple measurements on the bone based on the male average and female average. Only two single measurements were deemed significant for use in determining ranges; however there were not enough, or any, of the unknown samples with those particular measurements. In the case where the samples exhibited both significant measurements, there were mixed findings. Therefore the results lacked confidence and those individuals remained as unknown sex.

2.6.1 Age-at-death estimation

Age-at-death estimations were assessed using late-fusing epiphyses, pubic symphysis morphology, and/or dental wear patterns, when available. If skeletons were complete, late-fusing epiphyses and pubic symphysis morphology were given priority. Aging from the dentition used Buikstra and Ubelaker's (1994) standards, modified for Southeast Asia due to later eruption times for certain teeth (Domett, 2001; Kamalanathan et al., 1960).

The ossuary collection age at death estimations were grouped into subadult, young adult, middle-aged adult, and older adult using the dentition. In the cases where adult age could not be determined, the individual was deemed 'adult'. Individuals younger than the classified 'young adult' were considered in the 'subadult' group including neonates and juveniles.

2.6.2 Sex determination

Sexing of the skeletal remains was made using the pelvis and/or cranium when available. For many of the unprovenanced remains this was not possible, either due to incomplete material or insufficient metric dimorphism in individuals sexed by other methods. The remains were therefore grouped into male, female and unknown sex. The remains were classified as unknown sex if not enough skeletal material was available to make a determination. All subadults in the sample are considered unknown sex.

2.6.3 Summary

This chapter identifies the three archaeological sites in detail which are being examined in this thesis.

Ban Non Wat is a site in northeastern Thailand with skeletal materials spanning the Neolithic to Iron Age. Human remains recovered from the site are associated with one of two projects at Ban Non Wat. A previous excavation under the direction of another group is identified in this project as ‘Series 1’. The skeletal remains from this study are associated with the current excavation and referred to as ‘Series 2’, which are the primary dataset for this research. The Series 2 remains consist of 61 excavated individuals who were excavated from a number of locations across the site.

Phum Snay is located in northwestern Cambodia with an occupation dated to the late Iron Age. A number of excavations have taken place at Phum Snay, run by two separate projects. The skeletal material examined in this study is from one project and consists of 23 excavated burials and an ossuary sample with a MNI of 134.

Phum Sophy is also located in northwestern Cambodia, approximately 40kms from Phum Snay. The site has been dated to the late Iron Age or Pre-Angkorian period. Two excavation seasons yielded human skeletal remains consisting of 21 excavated individuals and a very large ossuary collection of comingled remains. This study examines the 21 excavated individuals along with ossuary remains consisting of a MNI of 37.

Standard methods were used to age and identify sex of individuals. Individuals were identified as male, female or unknown sex if methods did not draw a conclusion. The age of individuals were classified into the categories of subadult, young, mid and old adults. If age was indeterminate the category unknown sex was assigned. Every effort was made to assign an age and sex to all individuals.

Chapter 3 Health

3.1 Introduction

There has been debate in the literature with a number of studies suggesting there was a global decline in overall dental health with the intensification of agriculture (e.g. Larsen, 1997; Larsen, 1995; Oxenham et al., 2006) while other studies show that Southeast Asia does not follow this model (e.g. Domett, 2001; Domett & Tayles, 2006a; Pietrusewsky & Douglas, 2002; Tayles et al., 2000). Evidence to date indicates Southeast Asia does not follow the assumptions for health that agriculture caused a decline in health, but rather it has been suggested that societies were generally healthy (Domett & Tayles, 2006a). It is suggested that populations would have had suitable health in order to develop state-like societies in order to maintain subsistence activities and daily work proficiencies (Domett & O'Reilly, 2009).

To explore human health in prehistoric Southeast Asia, this study analysed skeletal material from three archaeological sites (Ban Non Wat, Phum Snay and Phum Sophy). These analyses offer insights into the health of communities in the Bronze Age through to the late Iron Age. These communities existed during a period of significant cultural transformation in Southeast Asia, prior to the Angkorian civilisation (AD 802–1432) referred to as the Pre-Angkor period. A decline in health from Bronze Age to Iron Age is theorized, evident from the dentition and the rest of the human skeletal remains. The decline should be evident as the advancement of agriculture and further animal domestication arises. This work has assessed the health of ancient individuals found at these three archaeological sites, and indicates changes to subsistence patterns, changing environment and how this information compares to other sites in the area, and Southeast Asia. With this information the question of whether people became gradually healthier throughout time during the rise of state-like societies, or whether health declines during this time will be examined.

This study advances the general database and knowledge of health in prehistoric Southeast Asia with analyses of individuals from these excavations. It also synthesizes information with previously published data throughout Thailand, Cambodia and Vietnam to determine the broader influences on the quality of life in the region. The data used to evaluate health status are organised under the headings of ‘Indicators of stress’ (e.g. linear enamel hypoplasia) and ‘Dental health’ (e.g. advanced wear).

3.1.1 Indicators of stress

3.1.1.1 Linear enamel hypoplasia

Linear enamel hypoplasia is a form of enamel hypoplasia. Enamel hypoplasia is an enamel thickness deficiency, which indicates a stressful time during the person's life by the enamel inconsistencies on region(s) of the tooth (Goodman et al., 1980; Hillson, 1996). The cells which form the dental enamel are disrupted, causing enamel matrix hypotrophy to the developing dental enamel, resulting in a lack of enamel thickness to that area of the tooth (Griffin & Donlon, 2007). This is an irreversible and permanent effect on the teeth due to the inability of the dental enamel to reform after the disruption has been produced (Goodman & Armelagos, 1988). The analysis of enamel hypoplasia is useful in determining the health of individuals by documenting any signs of diseases during childhood (Hillson, 2008). Several studies have found that individuals with linear enamel hypoplasia have a lower mean age at death than those not affected (Duray, 1996; Goodman & Armelagos, 1988). These can be identified as lines (linear enamel hypoplasia) or pits on the tooth surface. The age at which the individual was affected by the stressor can be determined by measuring the distance from the hypoplasia to the cemento-enamel junctions (Goodman et al., 1980), although, Lewis and Roberts (1997) indicate the weaning process and higher susceptibility to environmental disturbance could impact the results, they also stress the standards by Goodman et al. (1980) work on the assumption that prehistoric children share similar dental development patterns to all modern healthy children populations which is not necessarily the case (Lewis & Roberts, 1997). Regardless, the Goodman et al. (1980) method is a standardized method that many researchers use, and will be used for the purpose of comparative study. The Goodman et al. (1980) method indicates each tooth has a timeline for eruption and growth. For example, the canine can record stress for ages 3-6.5 years, while the premolar from 6.5-7 years of age (Goodman et al., 1980). The majority of the sites compared in this study only report on linear enamel hypoplasia, and do not include pitting hypoplasia. Therefore, for the purpose of this study only linear enamel hypoplasia (LEH) defects will be investigated to establish health patterns.

3.1.1.2 Cribra Orbitalia

Cribra orbitalia can be described as a thinning of the orbit bone, exhibiting a pitted appearance in a less severe form, while a more spongy appearance if more severe (Carlson et al., 1974). "Porotic hyperostosis of the skull vault and cribra orbitalia are not characteristic of a specific disease, but rather they represent a symptom of several diseases" (Ortner, 2003, p. 102). Identification includes investigating for thickness of the cranial vault, often the frontal and parietal bones, and evidence of porosity in the orbits (Aufderheide & Conrado, 1998). While cribra orbitalia occurs in the roof of the orbits, reasons are still unknown as to why this location is affected (Naveed et al., 2012). Lesions typically affect both orbits to varying degrees (Naveed et al., 2012; Stuart-Macadam, 1989). As cribra orbitalia is considered a metabolic disease potentially affected by a number of factors such as environment, the degree of cribra orbitalia can help explain the living conditions at the time. It is often suggested that the incidence of cribra orbitalia is the result of iron deficiency anaemia (e.g. Jacobi & Danforth, 2002; Oxenham & Cavill, 2010; Stuart-Macadam, 1985; Stuart-Macadam, 1987). However, research from Stuart-Macadam (1992) suggests the origin to be a high pathogen load (microorganisms from the environment), while others suggest the evidence linking it solely to anaemia is lacking, and trace it to a number of factors (Walker et al., 2009; Wapler et al., 2004). Stuart-Macadam (1985) believes cribra orbitalia appears during childhood up until around the age of five, and in some cases, the lesions continue to be visible into adulthood due to an absence of remodelling (Stuart-Macadam, 1985). Cribra orbitalia does not appear to be sex-specific (Stuart-Macadam, 1987), however it appears more often in children than adults worldwide, suggesting that anaemia may be acquired during childhood (Stuart-Macadam, 1985). This project examines if iron deficiency anaemia as inferred from the presence of cribra orbitalia had an impact on health through time in prehistoric Southeast Asia. A high presence on young individuals could suggest the effect of malnutrition resulting in cribra orbitalia may have led to their early death. However, if large numbers of older individuals with remodelled (healed) cribra orbitalia are found at the site, Stuart-Macadam (1992) suggests the presence of the cribra orbitalia may be the body's way of adapting to invading pathogens. While the definitive causes of the cribra orbitalia are still under debate, the occurrence of these changes to the orbits can offer insight into the conditions of prehistoric inhabitants.

3.1.1.3 Stature

The "average population heights can be compared temporally to examine how conditions may have changed over generations" (Mummert et al., 2011, p. 286), suggesting a group's average stature can offer insight into general health in a population. There are links associating short stature with poorer health, assuming that groups with higher average statures would have been healthier during life than a group with a short average stature possessing the same genetic potential. There is an opportunity for 'catch-up growth', which is the skeletal growth process that takes place in order to make up for the stunted growth (Temple, 2008) and allows the individual to reach an average height if they are more nutritionally sound while their growth period is still active. Normally, the individual affected would need to be removed from the negative situation causing the ill effects on stature in order for the catch-up growth to be successful (Temple, 2008), alternatively, nutrition could be improved (de Wit et al., 2013). Effects on stature can affect the group as a whole, or in some cases perhaps only a subgroup of individuals are affected. Using calculations of sexual dimorphism between the males and females can also give insight into the general health at the site. "Changes in sexual dimorphism – the ratio of average male to average female dimension – provides clues to the relative nutrition, and activity patterns, of the two sexes" (Cohen & Bennett, 1993, p. 282). On average, males tend to be taller and more robust than females. The differences in sexual dimorphism have been associated with nutritional levels by some researchers (Gray & Wolfe, 1980), and are more susceptible in male populations (Frayer & Wolpoff, 1985). Gray and Wolf (1980) found that smaller degrees of sexual dimorphism in stature could point towards poor nutritional availability; however this may only be one contributing factor to the differences.

There are a number of regression formulae which can be used to estimate the stature of individuals from different populations, including Krogman and Iscan (1986), Trotter (1970), Buikstra and Ubelaker (1994), and Sangvichien (1985, n.d). However, issues have been noted for some of the formulae (Jantz et al., 1994), as many of the formulae population are restricted to 'Mongoloid', 'Caucasoid', and 'Negroid' groups for comparisons. Not all assemblages worldwide can be classified in one specific grouping; therefore it is clear formulae need to be created for population-specific collections. There is currently no regression formula for Thai-Cambodian populations, although Mahakkanukrauh et al. (2011) have comprised a specific stature formula for individuals from Thailand. However, this is a relatively new formula lacking widespread use with previously published Southeast Asian samples. For the purpose of this study, the formulae from Sangvichien, n.d.; 1985) are the most appropriate and will be used since they are based on Thai-Chinese stature, and have been widely used in previous literature being compared in this study.

3.1.2 Dental health

The dental pathology profile (DPP) is a tool used to help compare the dental data between sites. "Among the variables in the DPP are caries, enamel hypoplasia, calculus, alveolar resorption, severe attrition, antemortem tooth loss, periapical cavities (indicative of tooth infection) and variables of jaw robusticity and size"(Douglas, 2006, p. 191). Previous work on dental pathology has included a standardized dental pathology profile by Lukacs (1989), to record any pathological conditions of the dentition (Douglas, 2006). Some scholars do not believe the DPP should be viewed as a useful concept due to the unrelated variables examined (such as enamel hypoplasia and attrition). The DPP is used in this research to serve as a tool for examining a number of dental issues to determine health. This research observes enamel hypoplasia as a separate indicator of health than the dental pathology markers of attrition, caries, periapical lesions and AMTL.

The following four factors are examined for dental health, advanced wear, caries, periapical lesions and antemortem tooth loss.

3.1.2.1 Advanced wear

The study determines the health of the groups by investigating advanced wear, which is a high degree of "[t]ooth-on-tooth wear that creates wear facets on both teeth involved" (Hillson, 2008, p. 308). Teeth can show advanced tooth wear on not only the occlusal surfaces, but also at the contact points of the teeth in the same individual (Hillson, 2008). It is believed that the rate of advanced wear can be attributed to advancing age (Domett & Tayles, 2006a; Hillson, 2008; Manji et al., 1991; Thylstrup & Fejerskov, 1994). Additionally, the wear patterns can assist with determining what individuals were eating and the different patterns between hunter-gatherers and agriculturalists (Hillson, 2008). In the case of extreme dental wear, other forms of dental disease are possible, leading to inflammation and destruction of the alveolar bone (Aufderheide & Conrado, 1998).

3.1.2.2 Caries

Caries is probably the most studied dental pathology (Hillson, 2000). Caries is a disease found in the teeth, where the tissues are destroyed by the acid secreted by bacteria. "Dental caries is a progressive demineralization of the enamel, cementum, and dentine of the tooth by organic acids, which are produced through the fermentation of dietary carbohydrates by some plaque bacteria"(Hillson, 2008, p. 313). Caries can be located on the tooth crown and roots, and can form more than once per tooth. Hillson (2000) found that caries is a condition more commonly found in females than males and has been linked to female physiological differences (Lukacs, 2008; Lukacs & Largarspada, 2006). Lukacs and Thompson (2008) believe that overall oral health in females is generally worse than that of males worldwide. Physiological differences between the sexes, such as the rate of salivary consistency and flow, hormones, and pregnancy can differentially impact the dental health of females, resulting in more caries (e.g. Lukacs, 2011a; Lukacs & Largarspada, 2006). Based on animal research, caries rates increase with oestrogen fluctuations, with high fluctuations occurring during pregnancy (Lukacs & Largarspada, 2006; Watson et al., 2010). Hillson (2008) mentions that there is a strong age relation in caries rates in women, and the instance of caries in more commonly found in females. Sex differences in dental health profiles can suggest gender differences within communities. Frequency and prevalence of caries will enable this study to determine changes to oral health and diet.

3.1.2.3 Periapical lesions

Periapical lesions are an infection of the tooth spreading to the periapical tissue (abscesses), where it causes an inflammatory response, and in severe cases can cause a pus cavity to burst through the surface of the skin (Dias & N., 1997). Any dental lesion can potentially impact the individual's health (Dias & N., 1997), and could eventually cause the tooth to be lost. The formation of periapical lesions tends to be associated with advanced tooth wear and caries (Lucas et al., 2010).

3.1.2.4 Antemortem tooth loss

Antemortem tooth loss (AMTL) is the absence of a tooth with at least some evidence for healing of the surrounding alveolar bone (Lukacs, 1989). Evidence for an increase of pathological AMTL could determine poorer health of the group.

Together, these indicators of health will assist with the assessment of exploring prehistoric health for these three communities, and how they fit general trends in health with the rest of Southeast Asia prior to the rise of complex society.

3.2 Hypothesis 1

Health declines through time.

In order to explore Hypothesis 1 (Section 1.8.1) further, Hypothesis 1.1 suggests trends in dental and environmental health will show evidence of a decline in health. This will be examined in samples from northeastern Thailand and northwestern Cambodia, and temporal trends in dental health in relationship to the development and intensification of rice agriculture, along-side environmental and sociocultural changes throughout the Bronze and Iron Ages. The new data from three sites studied in this project will be assessed for trends within Southeast Asia from the Neolithic to Pre-Angkorian times. While the nature of available comparative data with other sites (variable methods, sample sizes and reporting) precludes testing for statistical significance, this is offered as an initial exploration of the hypothesis that health declined in the Iron Age in Southeast Asia.

3.3 Materials

The skeletal remains from Ban Non Wat comprise of an excavated sample (N=61), which included all remains from the combined time periods. While the total Ban Non Wat samples are evidence for occupation from the Neolithic to Iron Age, the majority of the samples examined for this study are from the Bronze Age, based on preservation (Table 3.1). This is the reason the data for Ban Non Wat are combined in the majority of cases and the site is presented in the Bronze Age section when discussing temporal trends.

The skeletal remains of Phum Snay and Phum Sophy consisted of both an archaeologically excavated sample (Snay N = 23; Sophy N = 21) and an unprovenanced collection (Snay MNI = 134; Sophy MNI = 37). Both unprovenanced collections contained prehistoric skeletal material, the result of looting by local villagers. These collections consisted of isolated bones with no association by individual, including mandibles with maxillae. There was considerable fragmentation and post-mortem tooth loss due to both looting and curation procedures; loose teeth disassociated from supporting mandibular or maxillary alveoli were not included.

Details of the teeth and tooth positions examined are presented for Ban Non Wat (Table 3.2), Phum Snay (Table 3.3) and Phum Sophy (Table 3.4). Tooth positions include spaces where teeth are present (whether complete or broken), or an empty socket remains, resulting in a count of all available positions present in the maxilla/mandible.

Table 3.1

Indicators of stress and dental pathologies distribution through mortuary phases for Ban Non Wat.

	Males (n)			Females (n)			Unknown sex (n) (includes subadults)	
	Bronze Age	Iron Age	Unknown mortuary period	Bronze Age	Iron Age	Unknown mortuary period	Bronze Age	Iron Age
Linear enamel hypoplasia	9	2	1	7	1	1	2	0
Cribra orbitalia	8	0	0	6	0	0	6	1
Stature	9	0	1	9	1	0	0	0
Dental pathologies	9	3	0	7	2	0	2	4

3.4 Methods

3.4.1 Age at death estimation and sex determination

General details are available in Sections 2.6.1 and 2.6.2.

If skeletons were complete, late-fusing epiphyses and pubic symphysis morphology were given priority. Age-at-death for individuals represented by isolated mandibles and maxillae was estimated, when possible, using molar wear; thus comparisons between different age groups within or between samples are not possible when analysing advanced wear. Permanent dentitions from subadults were included only when age could be estimated by dental development or diaphyseal length (Scheuer & Black, 2000).

3.4.2 Indicators of stress

3.4.2.1 Linear enamel Hypoplasia

Using a fine dental tool, each buccal surface of the tooth was examined for the presence of enamel defects, following methods in Buikstra & Ubelaker (1994). Only defects observable as a continuous line were recorded. For the purpose of comparison with other studies, only linear enamel hypoplasia (LEH) will be analysed in this study. The distance of the LEH from the cemento-enamel junction was measured using callipers, and age-of-occurrence was determined by using Goodman et al.'s (1980) method.

3.4.2.2 Cribra orbitalia

The orbits on each cranium were examined for cribra orbitalia and given a score for severity and type following Buikstra & Ubelaker (1994). For the purpose of this project, a person was indicated as having cribra orbitalia if they possessed any degree of the lesion.

3.4.2.3 Stature

Using sliding callipers, the maximum length of long bones (femur, tibia, humerus, radius and ulna) was recorded. If both the left and right long bones were available, the average of the two was taken. Since Phum Snay and Phum Sophy were mainly comprised of an ossuary collection, each long bone length is recorded as a separate individual. Stature for each individual was calculated using long bone lengths in the Thai-Chinese stature formulae (Sangvichien et al.; Sangvichien et al., 1985). For Ban Non Wat, consisting of excavated remains, the formulas by Sangvichien et al. (1985) for the lower limb bones and Sangvichien et al. (n.d.) were used with the following preference: 1) tibia and femur; 2) tibia; 3) femur; 4) humerus and radius; 5) humerus; 6) radius; and 7) ulna, based on the standard error.

3.4.3 Dental pathology assessment

The demographic structure of the samples showed significant age differences: Phum Sophy had more people of advanced age, contrasting to the younger profiles at Phum Snay and Ban Non Wat. Given these differences, interpretations of the results focus on comparing frequencies within age classes (between sexes and between sites) and not between different age classes. Phum Sophy and Phum Snay had very similar proportions of males and females overall (Teeth: Chi^2 p = 0.9759; Tooth positions: Chi^2 p-value = 0.5981) though there was slightly more female teeth from Phum Snay in the younger age sample (FET p-value = 0.0110) and more male teeth from Phum Snay in the older age class (FET p-value < 0.0001). Ban Non Wat had significantly more males than females overall (Teeth: Chi^2 $p<0.0001$; Tooth positions: Chi^2 $p<0.0001$) in all age classes.

Biases were created by differing age structures between Phum Snay and Phum Sophy and those from Ban Non Wat. There was a significant difference in the quantity of individuals between the same age classes across the sites. For this analysis, age groups were combined to form two age classes: 'young' (subadult and young adult permanent teeth), and 'old' (middle-aged and older adults) using molar wear grades for individuals whose ages were estimated by other parameters (such as pubic symphysis morphology). Total prevalence figures (sum of young, old, and unknown age permanent teeth) are also presented to facilitate comparisons with other Southeast Asian skeletal samples. These must, however, be treated conservatively due to demographic differences across samples.

Table 3.2

Age and sex distribution of BNW individuals and teeth.

	Number of individuals			Number of individuals with permanent dentition			Total number of permanent teeth[1]		
Age	**Male**	**Female**	**Unknown**	**Male**	**Female**	**Unknown**	**Male**	**Female**	**Unknown**
Subadult*	-	-	20	-	-	4	-	-	52/54
Young	6	7	1	5	7	1	153/160	203/214	27/32
Middle-aged	5	2	2	5	2	1	140/159	37/47	6/6
Older	2	1	0	2	0	0	50/55	-	-
Adult	4	3	8	-	-	-	-	-	-
Total	17	13	31	12	9	6	343/374	240/261	85/92

[1]Number of observable teeth/number of tooth positions.
***Subadult totals also include neonates.**

Table 3.3

Number of teeth and tooth positions for Phum Snay.

	Teeth									**Tooth positions**			
Phum Snay	**Excavated**	**% total teeth**	**Ossuary**	**% total teeth**	**Total**	**% total teeth**		**Excavated**	**% total teeth**	**Ossuary**	**% total teeth**	**Total**	**% total teeth**
Total	**222**	**100.0**	**1943**	**100.0**	**2165**	**100.0**		**279**	**100.0**	**3992**	**100.0**	**4271**	**100.0**
Young	103	46.4	542	27.9	645	29.8		125	44.8	861	21.6	986	23.1
Old	113	50.9	574	29.5	687	31.7		148	53.0	933	23.4	1081	25.3
unknown adult age	6	2.7	827	42.6	833	38.5		6	2.2	2198	55.1	2204	51.6
Male	**114**	**51.4**	**219**	**11.3**	**333**	**15.4**		**145**	**52.0**	**598**	**15.0**	**743**	**17.4**
Young	52	23.4	33	1.7	85	3.9		64	22.9	62	1.6	126	3.0
Old	62	27.9	100	5.1	162	7.5		81	29.0	202	5.1	283	6.6
unknown adult age	0	0.0	86	4.4	86	4.0		0	0.0	334	8.4	334	7.8
Female	**98**	**44.1**	**296**	**15.2**	**394**	**18.2**		**122**	**43.7**	**773**	**19.4**	**895**	**21.0**
Young	41	18.5	100	5.1	141	6.5		49	17.6	198	5.0	247	5.8
Old	51	23.0	50	2.6	101	4.7		67	24.0	84	2.1	151	3.5
unknown adult age	6	2.7	146	7.5	152	7.0		6	2.2	491	12.3	497	11.6
Unknown sex	**10**	**4.5**	**1428**	**73.5**	**1438**	**66.4**		**12**	**4.3**	**2621**	**65.7**	**2633**	**61.6**
Young	10	4.5	409	21.0	419	19.4		12	4.3	601	15.1	613	14.4
Old	0	0.0	424	21.8	424	19.6		0	0.0	647	16.2	647	15.1
unknown adult age	0	0.0	595	30.6	595	27.5		0	0.0	1373	34.4	1373	32.1

Table 3.4

Number of teeth and tooth positions for Phum Sophy.

Phum Sophy	Teeth						Tooth positions					
	Excavated	% total teeth	Ossuary	% total teeth	Total	% total teeth	Excavated	% total teeth	Ossuary	% total teeth	Total	% total teeth
Total	**124**	**100.0**	**967**	**100.0**	**1091**	**100.0**	**134**	**100.0**	**1738**	**100.0**	**1872**	**100.0**
Young	53	42.7	356	36.8	409	37.5	53	39.6	611	35.2	664	35.5
Old	28	22.6	484	50.1	512	46.9	30	22.4	809	46.5	839	44.8
unknown adult age	43	34.7	127	13.1	170	15.6	51	38.1	318	18.3	369	19.7
Male	**29**	**23.4**	**222**	**23.0**	**251**	**23.0**	**32**	**23.9**	**396**	**22.8**	**428**	**22.9**
Young	0	0.0	100	10.3	100	9.2	0	0.0	166	9.6	166	8.9
Old	0	0.0	120	12.4	120	11.0	0	0.0	223	12.8	223	11.9
unknown adult age	29	23.4	2	0.2	31	2.8	32	23.9	7	0.4	39	2.1
Female	**65**	**52.4**	**233**	**24.1**	**298**	**27.3**	**67**	**50.0**	**473**	**27.2**	**540**	**28.8**
Young	37	29.8	63	6.5	100	9.2	37	27.6	113	6.5	150	8.0
Old	28	22.6	127	13.1	155	14.2	30	22.4	215	12.4	245	13.1
unknown adult age	0	0.0	43	4.4	43	3.9	0	0.0	145	8.3	145	7.7
Unknown sex	**30**	**24.2**	**512**	**52.9**	**542**	**49.7**	**35**	**26.1**	**869**	**50.0**	**904**	**48.3**
Young	16	12.9	193	20.0	209	19.2	16	11.9	332	19.1	348	18.6
Old	0	0.0	237	24.5	237	21.7	0	0.0	371	21.3	371	19.8

Four parameters were recorded to assess overall dental health for each community 1) advanced wear, 2) caries, 3) periapical lesions, and 4) antemortem tooth loss.

3.4.3.1 Advanced wear

The Smith (1984) system for assessing dental wear (grades 1–8) was used to evaluate anterior teeth and premolars, with grades of 6–8 considered advanced wear. Each quadrant of each molar was scored from grade 0 to 10 following Scott (1979); the average of the four grades was then calculated. Molars with average grades 7–10 were considered to have advanced wear. These grades were chosen as they represent wear with large areas of dentine and exposure of the pulp cavity. The definition of advanced wear can vary between studies making direct comparisons difficult, but most Southeast Asian studies equate advanced wear to exposure of the pulp cavity, despite the use of different grading systems such as those of Molnar (1971) and Brothwell (1981).

3.4.3.2 Caries

Caries were identified by the demineralization of enamel or root surfaces (Hillson, 2008). Each tooth was scored for the presence or absence of caries; teeth with two or more caries were counted only once. Posterior teeth (post canine) are more prone to caries than the anterior (Hillson, 2008). The Phum Sophy and Snay samples had no significant differences in the presence of anterior and posterior teeth (Phum Snay: 27.7% and 72.3%; Phum Sophy: 27.3% and 72.7%, respectively; Chi^2 p-value = 0.7851), thus caries rates are not biased by the preservation of more posterior teeth in either sample. The Ban Non Wat samples had significantly more posterior teeth (Chi^2 $p<0.0001$) and this will be taken into consideration during discussion.

3.4.3.3 Periapical lesions

Periapical lesions (also known as 'abscesses') and other alveolar defects were observed either apically as a discrete lytic lesion near the tooth root (representing the drainage channel of the abscess) (Buikstra & Ubelaker, 1994) or as an extreme localised depression (antemortem vertical bone loss) in the alveolar bone exposing much of the tooth root (Hillson, 2008). As it was difficult to ascertain whether or not this combination of defects was recorded for other Southeast Asian samples, regional comparisons may be biased by methodological differences. The results are presented as the proportion of periapical lesions to the number of tooth positions with intact alveolar bone.

3.4.3.4 Antemortem tooth loss

Antemortem tooth loss (AMTL) is the absence of a tooth associated with at least some evidence of healing of the surrounding alveolar bone (Lukacs, 1989). Only the prevalence of pathological AMTL is reported here.

Sample sizes for the four classes of dental pathologies varied slightly from the overall sample sizes depending on preservation and the pathology being observed.

3.4.4 Statistical tests

Chi^2 (for larger sample sizes) and Fishers Exact Test (FET) p-values (for smaller sample sizes) were calculated to establish significant differences between samples. The p-value for significance was set at <0.05.

3.5 Results

3.5.1 Indicators of stress

3.5.1.1 Linear enamel hypoplasia (LEH)

The prevalence of linear enamel hypoplasia by tooth on the permanent adult dentition is presented in Table 3.5. Age and sex distributions of LEH per site are available in Appendix A for Ban Non Wat (Table 1), Phum Snay (Table 2) and Phum Sophy (Table 3).

The detailed distribution of linear enamel hypoplasia per individual is available in Appendix A for Ban Non Wat (Table 4), Phum Snay (Table 5) and Phum Sophy (Table 6).

Phum Snay has the most linear enamel hypoplasia overall, slightly higher than Ban Non Wat, but over three times higher than Phum Sophy (Table 3.5). Ban Non Wat and Phum Snay are both statistically more affected by linear enamel hypoplasia than Phum Sophy. Phum Snay has significantly more linear enamel hypoplasia on the female and male dentition than Ban Non Wat and Phum Sophy.

There are no sex differences within Ban Non Wat or Phum Snay (Table 3.5). Ban Non Wat females are slightly more affected than males, and Phum Snay males have almost identical amount of linear enamel hypoplasia as females. However, Phum Sophy has significantly more female teeth affected by linear enamel hypoplasia.

Ban Non Wat had a total of four males affected with linear enamel hypoplasia, of which three had at least two teeth affected (Appendix A Table 4). Of the total six females affected with linear enamel hypoplasia, three of those females had two or more teeth affected. The individual with the greatest number of teeth affected was a young adult of unidentifiable sex, who had 15/27 teeth affected by linear enamel hypoplasia. The prevalence of young individuals' teeth affected with LEH 38/370 (10.3%), was greater than the 8/94 (8.5%) of the older individuals teeth, though not significantly (p=0.7023).

Phum Snay had a total of 13 males affected, and five of those having more than two teeth with linear enamel hypoplasia (Appendix A Table 5). Twenty-one Phum Snay females were affected overall, with 11 of those females having two or more teeth affected by LEH. Similar to Ban Non Wat, it is the younger aged group at Phum Snay most affected by LEH. The younger group was significantly more affected by LEH than the older group (p=0.0114) with 56/485 (11.5%) of teeth, versus 28/424 (6.6%) of teeth affected in the older group.

Phum Sophy had two males affected by LEH and five females; however no individual had more than one tooth affected (Appendix A Table 6). The primary individuals affected with LEH were middle-aged females. There were 8/256 (3.1%) of young teeth affected with LEH, and a similar amount of older teeth 12/283 (4.2%), (p=0.6493).

Table 3.5

Prevalence of LEH by tooth.

	Ban Non Wat		**Phum Snay**		**Phum Sophy (A/O)**		Site diff. FET p-values		
	(A/O)	%	(A/O)	%	(A/O)	%			
Male	11/168	6.5	22/130	16.9	3/143	2.1	0.0053[1]	0.0967[2]	<0.0001[3]
Female	18/214	8.4	36/219	16.4	12/151	7.9	0.0132[1]	1.0000[2]	0.0182[3]
Total[4]	46/464	9.9	183/1520	12.0	23/609	3.8	0.2450[1]	<0.0001[2]	<0.0001[3]*
Sex diff. FET p-values	0.5625		1.0000		0.0317				

A, affected teeth; O, total observed teeth; [1]Ban Non Wat and Phum Snay; [2]Ban Non Wat and Phum Sophy; [3]Phum Snay and Phum Sophy; [4]includes those of unknown sex; *Chi 2 p-value; Significant values are highlighted in red.

3.5.1.2 Cribra orbitalia

A total of three individuals at Ban Non Wat have cribra orbitalia, all of which were female (Table 3.6). There was no significant difference in sex distribution of the cribra orbitalia (p=0.0549), however two of the females affected were young, while the third female was an unidentified age.

Phum Snay has 18 cases of cribra orbitalia, equally affecting the males and females (p=1.0000) (Table 3.6). The total number of cribra orbitalia cases, and cases affecting males at Phum Snay are not statistically different from Ban Non Wat (total p=0.4194, p=1.0000, respectively), however Ban Non Wat has statistically more cases of female cribra orbitalia (p= 0.0458).

Phum Sophy has six individuals with cribra orbitalia, affecting more females than males, though not quite statistically (p=0.0632) (Table 3.6). There is no statistical difference between Ban Non Wat and Phum Sophy, as males from both sites have no cribra and females have similar amounts (p=0.6224).

Table 3.6

Cases of cribra orbitalia by individual.

Site	Males A/O (%)	Females A/O (%)	Subadults A/O (%)	Unknown sex A/O (%)	Total A/O (%)	Site diff. FET p-value with Phum Snay	Site diff. FET p-value with Phum Sophy
Ban Non Wat	0/8 (0.0)	3/6 (50.0)	0/7 (0.0)	0/0 (0.0)	3/21 (14.3)	1.0000	0.7111
Phum Snay	6/54 (11.1)	7/57 (12.3)	2/5 (40.0)	3/19 (15.8)	18/135 (13.3)	-	0.2293
Phum Sophy	0/12 (0.0)	3/9 (33.3)	2/3 (66.7)	1/2 (50.0)	6/26 (23.1)	-	-

A, affected individuals; O, observed individuals

3.5.1.3 Stature

The average stature from the adult long bones for each site is presented in Table 3.7. Long bone length averages are also available in Appendix A (Table 7).

Ban Non Wat males have a greater range of variation in their stature, and the sexual dimorphism at the site is 7.8 (Table 3.7).

Sexual dimorphism for Phum Snay is 7.0, and males have almost double the variation in stature range than females, although sample size could be affecting this (Table 3.7).

Sexual dimorphism at Phum Sophy is also quite high at 9.8, and males share a similar range in height variation to females (Table 3.7).

Average stature between Ban Non Wat and Phum Snay or Ban Non Wat and Phum Sophy was not statistically different for males (p=0.6175, p=0.7578, respectively) or females (p=0.2796, p=0.1743, respectively). There was statistical significance between the female average statures at Phum Snay and Phum Sophy (p=0.0018), however there was no statistical difference between the males (p=0.6516).

Table 3.7

Average statures from the adult long bones.

Total Stature					
	N	**Mean**	**SD**	**Range**	**Sexual dimorphism**
Males					
Ban Non Wat	10	166.5	6.1	157.7-179.7 (22)	
Phum Snay	57	166.6	3.8	161.2-177.5 (16.3)	
Sophy	13	167.1	3.3	161.1-171.7 (10.6)	
Females					
Ban Non Wat	10	153.5	4.2	143.5-158.5 (15)	7.8
Phum Snay	15	154.9	2.6	150.3-158.7 (8.4)	7.0
Sophy	15	150.7	3.5	144.9-155.5 (10.6)	9.8

*Using the Sangvichien (1985), (n.d) Thai-Chinese stature formulas

3.5.2 Dental health

3.5.2.1 Advanced wear

Ban Non Wat

Overall, males have significantly more advanced wear than females (Table 3.8). However, the small number of older females at the site is probably affecting this. There was no significant difference in the younger age category.

Phum Snay

There was significantly more advanced dental wear in older adult males compared with older females at Snay (Table 3.8). Advanced wear was significantly more common in the anterior teeth in females and close to significant in older males.

Phum Sophy

Older males showed slightly higher, but not statistically significant, rates of advanced wear compared with older females (Table 3.8). Advanced wear was not significantly different in either the anterior or posterior teeth in males and females in either age class, though the total sample, including those of unknown sex, in the older age class showed more wear in the anterior teeth.

Table 3.8

Proportion of advanced wear by tooth position among the samples.

	Ban Non Wat					Phum Snay					Phum Sophy				
	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total
Young (A/O)	0/118	5/200	0.0834	0/92	5/410	0/71	4/110	0.1559	0/355	4/536	0/88	2/98	0.4988	0/161	2/347
%	0	2.5		0	1.2	0	3.6		0	0.7	0	2.0		0	0.6
Old (A/O)	43/132	4/30	0.0360	2/6	49/168	23/104	6/73	0.0141	20/400	49/577	27/114	22/135	0.1532	26/228	75/477
%	32.6	13.3		33.3	29.2	22.1	8.2		5.0	8.5	23.7	16.3		11.4	15.7
?age (A/O)						6/75	12/132		34/558	52/765	10/31	7/38		5/82	22/151
%						8.0	9.1		6.1	6.8	32.3	18.4		6.1	14.6
Total (A/O)	43/250	9/230	<0.0001	2/98	54/578	29/250	22/315	0.0753	54/1313	105/1878	37/233	31/271	0.1525	31/471	99/975
%	17.2	3.9		2.0	9.3	11.6	7.0		4.1	5.6	15.9	11.4		6.6	10.2

A = teeth affected, O = observed teeth; A = teeth affected, O = observed teeth; [1] Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value; [2] All subadults are considered of unknown sex. N.B. 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. Significant values are highlighted in red.

3.5.2.2 Caries

Ban Non Wat

Males have slightly more caries than females in both age categories, however not to a significant level (Table 3.9). Interestingly, younger males have more caries than younger females, but not significant statistically.

Phum Snay

Females were more commonly affected by caries than males in both age classes, but this was statistically significant only in the older class (Table 3.9).

Phum Sophy

Older males and females had very similar caries rates. Caries rates were significantly more common in females for the young age class compared with males (Table 3.9).

Table 3.9

Proportion of caries by tooth position among the samples.

	Ban Non Wat					Phum Snay					Phum Sophy				
	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total
Young (A/O)	11/120	8/197	0.0632	8/76	27/393	4/84	11/141	0.4241	38/398	53/623	1/94	11/93	0.0025	21/190	33/377
%	9.2	4.1		10.5	6.9	4.8	7.8		9.5	8.5	1.1	11.8		11.1	8.8
Old (A/O)	6/106	1/31	0.5882	0/6	7/143	7/130	12/86	0.0472	56/413	75/629	12/112	12/121	1.0000	18/219	42/452
%	5.7	3.2		0	4.9	5.4	14.0		13.6	11.9	10.7	9.9		8.2	9.3
Age diff. p-value[3]	0.3186	0.8243				1.0000	0.1737				0.0039	0.6631			
?age (A/O)						2/74	15/137		83/573	100/784	4/31	3/39		6/73	13/143
%						2.7	10.9		14.5	12.8	12.9	7.7		8.2	9.1
Total (A/O)	17/226	9/228	0.1012	8/82	34/536	13/288	38/364	0.0051	177/1384	228/2036	17/237	26/253	0.2644	45/482	88/972
%	7.5	3.9		9.8	6.3	4.5	10.4		12.8	11.2	7.2	10.3		9.3	9.1

A = teeth affected, O = observed teeth; [1] Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value; [2] All subadults are considered of unknown sex; [3] Fishers Exact Tests p-value indicating differences between ages. Significant values are highlighted in red.

3.5.2.3 Periapical lesions

Ban Non Wat

There are no significant differences for the older age groups; however younger females have significantly more periapical lesions than young males (Table 3.10). Overall, males and females have very similar rates of periapical lesions.

Phum Snay

Periapical lesions were not present in older or younger females; males presented a low percentage in both age classes (Table 3.10).

Phum Sophy

Periapical lesion frequency was slightly higher in older females compared with older males but low in young males and females (Table 3.10).

Table 3.10

Proportion of periapical lesions by tooth position among the samples.

	Ban Non Wat					Phum Snay					Phum Sophy				
	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total
Young (A/O)	0/76	8/127	0.0256	1/20	9/223	2/98	0/187	0.4241	2/474	4/759	2/86	0/60	0.5125	4/206	6/352
%	0	6.3		5.0	4.0	2.0	0		0.4	0.5	2.3	0		1.9	1.7
Old (A/O)	10/81	1/3	0.2900	0/0	11/84	8/207	0/86	0.1102	17/495	25/788	3/87	9/123	0.3665	8/202	20/412
%	12.3	33.3		0	13.1	3.9	0		3.4	3.2	3.4	7.3		4.0	4.9
Age diff. p-value[3]	0.0015	0.0683				0.5100					1.0000	0.0315			
?age (A/O)						9/237	24/350		53/1030	86/1617	3/25	9/61		6/103	18/189
%						3.8	6.9		5.1	5.4	12.0	14.8		5.8	9.5
Total (A/O)	10/157	9/130	0.8510	1/20	20/307	19/542	24/623	0.8764	72/1999	115/3164	8/198	18/244	0.1582	18/511	44/953
%	6.4	6.9		5.0	6.5	3.5	3.9		3.6	3.6	4.0	7.4		3.5	4.6

A = teeth affected, O = observed teeth; [1] Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value; [2] All subadults are considered of unknown sex; [3] Fishers Exact Tests p-value indicating differences between ages. Significant values are highlighted in red.

3.5.2.4 AMTL

Ban Non Wat

Pathological AMTL rates are similar between males and females of all groups (Table 3.11).

Phum Snay

Pathological AMTL percentage was low, and similar, in males and females for both age groups (Table 3.11).

Phum Sophy

Pathological AMTL percentages were all very low; older females showed the highest percentage but no statistical differences were calculated (Table 3.11).

Table 3.11

Proportion of AMTL by tooth position among the samples

	Ban Non Wat					Phum Snay					Phum Sophy				
	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total	Male	Female	Sex diff. p-value[1]	?sex[2]	Total
Young (A/O)	2/160	2/216	0.7620	1/38	5/414	1/126	0/247	0.3378	2/613	3/986	0/166	1/148	0.4713	1/349	2/662
%	1.3	0.9		2.6	1.2	0.8	0		0.3	0.3	0	0.7		0.3	0.3
Old (A/O)	11/214	5/47	0.1548	0/6	16/267	4/283	2/151	1.0000	20/647	26/1081	2/223	5/244	0.4529	1/371	8/838
%	5.1	10.6		0	6.0	1.4	1.3		3.1	2.4	0.9	2.0		0.3	1.0
Age diff. p-value[3]	0.0421	0.0002				1.0000	0.1433				0.5095	0.4157			
?age (A/O)						9/334	18/497		55/1373	82/2204	0/38	1/145		2/184	3/367
%						2.7	3.6		4.0	3.7	0	0.7		1.1	0.8
Total (A/O)	13/374	7/263	0.5617	1/44	21/681	14/743	20/895	0.7285	77/2633	111/4271	2/427	7/537	0.3125	4/903	13/1867
%	3.5	2.7		2.3	3.1	1.9	2.2		2.9	2.6	0.5	1.3		0.4	0.7

A = teeth affected, O = observed teeth; [1] Fishers Exact Tests p-value indicating differences between males and females; *Chi² p-value; [2] All subadults are considered of unknown sex; [3] Fishers Exact Tests p-value indicating differences between ages. Significant values are highlighted in red.

3.6 Discussion

3.6.1 Indicators of stress

3.6.1.1 Ban Non Wat

Ban Non Wat males and females had similar amounts of LEH by tooth. Females had more cases of cribra orbitalia per individual than males, but this was not quite significant (p-value = 0.0549). Males on average have a larger range of variation in stature than females, suggesting a greater variation in health. Maybe the larger range in male stature should suggest on average males were affected by stressors to a greater degree than females. However, the impact of stressors causing LEH does not appear to have arrested male stature. It appears males in this sample had the ability to overcome the health stressors inflicted at a young age. Interestingly, once the female with the very short stature (Burial 676) is omitted from the sample, the variation of female stature is approximately three times less than the range of male stature. The Ban Non Wat sample tested by Clark et al. (2013) (Series 1 collection) suggests a *positive* correlation between male stature and LEH, which might be linked with timing of the childhood stressors and males ability to utilise catch-up growth. This also appears to be the case for this sample of Ban Non Wat males. By removing the factors causing the stressors affecting growth, the individual has the opportunity to reach their growth potential (Ashworth & Millward, 1986). However, in order to achieve this "intake must not only meet the requirements for maintenance and normal growth but also replace the accrued nutrient deficit" (Cooke, 2010, p. S8). Of the females affected with LEH, only one had a stature which was much shorter than the female mean (Burial 676). Two people affected with cribra orbitalia, (a young female and a young adult of unknown sex) had statures which fall below the female average. The lack of sexual differences in the stress disruptions might suggest males and females generally had similar access to resources, were exposed to similar amounts of childhood stressors, and overall had similar health profiles. However, the greater range in variation for male stature suggests males possessed a greater ability to positively utilise to catch-up growth potential and were less frail.

There are significantly greater numbers of older adult male skeletal remains than females available for examination. There is however, a general lack of older individuals from this Ban Non Wat sample. Fewer older females at the site could suggest poorer health of females, causing them to die at earlier ages. One explanation for this could be related to the risk of childbirth on the mother. There were similar findings by Domett & Tayles (2006a) when they established that the nearby contemporaneous site of Ban Lum Khao also had a proportionally large number of young adult females. Skeletal evidence suggesting pregnancy occurred includes pitting on the pubic bone and a groove on the sacroiliac joint of the pelvis caused by the ligament (Houghton, 1975). A high incidence of females with pregnancy markers might imply these females may have been generally healthy, but dying early due to complications with childbirth. Unfortunately, due to the preservation issues with many of the Ban Non Wat remains, it was difficult to identify female pregnancy markers on the skeletal remains. Willis and Oxenham (2011) recently presented evidence of complications during childbirth during the Neolithic in Vietnam. The burial of a young female with poor dental health and evidence of childhood stress was uncovered interred with an unborn foetus (Willis & Oxenham, 2011). These findings suggest the possibility of mortality linked with pregnancy-related causes exacerbated by pre-existing frailty (Willis & Oxenham, 2011). The authors stress retrieval of such information is quite rare due to misidentification of the remains, or the remains are not recovered from the archaeological context (Willis & Oxenham, 2011), which might explain why foetal remains were not found in association with the young female burials at Ban Non Wat. Additional worldwide studies have noticed an increased prevalence of young female deaths, which appear to be associated with pregnancy or postpartum-related issues (Eshed et al., 2004; Tague, 1994). Another explanation could be burial distribution at Ban Non Wat. Perhaps older females were buried in another, unexcavated location of the village. However, this is probably not the case as burial distribution is unbiased due to numerous excavations throughout the site.

Three Ban Non Wat individuals are of particular interest due to high amounts of stressors recorded in their skeletal remains (Burials 654, 661, and 676). All three individuals have the highest amount of LEH. Burial 654 is a young male from Bronze Age 4 who was excavated from square N100 (see Fig. 2.1 for map of BNW excavation squares). He had six teeth affected by LEH, however the stressors endured during childhood do not appear to have affected his growth potential as his height is greater than the average male stature. Burial 661 (a possible young adult female) from Bronze Age 3 was also excavated from square N100. This individual had 15 of her 27 teeth affected by LEH, was affected with cribra orbitalia, and had a stature 2.1cm shorter than the female mean, which suggests she may not have reached her full growth potential suggesting her childhood stressors affected her growth. Burial 676 is a young female with a stature much shorter than the female mean. She was from Bronze Age 1 and her remains were excavated from the western part of the site at square G104. She was also heavily affected by LEH and had an extremely short stature of 143.5cm. The stresses she endured during childhood must have negatively impacted her stature and stayed with her into young adulthood. Alternatively, she was able to recover from the stressors affecting her childhood (albeit with reduced stature) and died of an unrelated reason. She is the shortest female at Ban Non Wat with a stature 10cm shorter than the female average. A further two females (one young and one of unknown adult age) also had statures below the female average, but are at least 8cm taller than Burial 676. Further details about Burial 676 are discussed in Chapter 5 (Migration). While the samples are small, there appears to be a positive correlation with early death, though not always reduced growth, if individuals were affected with LEH.

3.6.1.2 Phum Snay

Both sexes appear to have been affected by childhood stressors equally. There are no significant differences in the amount of LEH between males and females and males have almost identical amounts of cribra orbitalia as females. Of the males who were affected with cribra orbitalia and LEH, there was no strong association with early age at death – one died as a young adult, one in middle age and the other was not able to be assigned an age-at-death. This suggests males inflicted with childhood stressors had a good chance of overcoming the stressors and living into later adulthood. Alternatively, of the females with cribra orbitalia, only three of the seven were able to be aged from their remains. Of those three females, all had LEH and were aged as young adults. This suggests, as opposed to the males, females affected by childhood stressors were more susceptible to death at an early age due to higher frailty. The highest amounts of LEH were in a young female and a young male, both with four teeth affected by LEH. The young male was an excavated individual with a stature of 163.3cm (3.3cm shorter than the average). A stature could not be determined for the young female, as this individual was from the ossuary collection without corresponding long bones. Like Ban Non Wat, Phum Snay has a proportionally larger young adult population. At Phum Snay it is mainly younger individuals with LEH. Of the individuals surviving into adulthood with LEH, the majority have a lower age-at-death. While Phum Snay children may have been exposed to stressful times during childhood, it appears they were able to utilize the catch-up height and maintain a normal height into adulthood based on other stature averages from Southeast Asia. However, many died during young adulthood suggesting overall frailty of the population.

The evidence for an increase in violence may have contributed to the high mortality rates of the young population. Phum Snay has an increased amount of violence, based on evidence of cranial trauma (Domett et al., 2011b). It can be suggested the associated stress from violence may have affected these individuals during young adulthood. Overall, they appear generally healthy enough to overcome the stressors due to reaching an optimal adult stature. The increased amount of violence in the area, greater than other sites located nearby (Domett et al., 2011b), might indicate males were forced into battle. Domett et al (2011b) found primarily males most affected by cranial trauma and male graves associated with weapons. Domett and O'Reilly (2009) suggest accidents or violence may be the cause for the increased younger age-at-death. The young population could also be based on burial distribution, males may have died while away from the site on hunting trips or during intercommunity violence, therefore skewing the burial distribution (Domett & O'Reilly, 2009). Alternatively, an older population may be situated elsewhere on the site, yet to be located. As there are limited excavated samples available, and a large ossuary collection, it is difficult to determine burial distribution at the site, and if any bias is present, but it appears that intercommunity violence contributed to heightened stress at Phum Snay.

3.6.1.3 Phum Sophy

There is generally a low prevalence of LEH and cribra orbitalia present at Phum Sophy. Females have statistically more LEH than males and more cribra orbitalia, however these amounts are quite low and sample sizes are quite small. Only one individual, a young adult of unknown sex, had more than one tooth affected with LEH. The group affected with the greatest amount of LEH was middle aged females. While these females were impacted with childhood stressors, they were able to survive into middle age, seemingly not affected in the long-term. Similar to Phum Snay, many of the remains were from an ossuary collection, with long bones and crania which could not be linked to the same individual. Therefore, this study was unable to link any association of the health stressors to an individual's stature. There was no evidence of cribra orbitalia on any of the individuals with LEH. The lack of childhood stressors impacting the skeletal remains at the site suggest limited chronic stressors during childhood.

3.6.1.4 Health trends in prehistoric Southeast Asia

A number of prehistoric sites in Southeast Asia are examined to discuss health trends during childhood. This is limited to the identification of general trends evident within the Southeast Asia data in light of the three new samples from Ban Non Wat, Phum Snay and Phum Sophy. Refer to Figure 1.1 for geographic locations of other prehistoric Southeast Asian sites.

3.6.1.5 Temporal trends

The levels of LEH dropped dramatically from the Neolithic sample of Khok Phanom Di into the Bronze Age (Fig. 3.1). There was no general trend of LEH in the Iron Age compared to the preceding Bronze Age. There was evidence of a dramatic increase of cribra orbitalia in the Neolithic site of Man Bac (Fig. 3.2). After which, there is evidence of a decline of cribra orbitalia into the Bronze Age. There was no general trend throughout the Bronze and Iron Ages. Oxenham (2006, p. 228) found that an increase in cribra orbitalia appears when "communities were essentially sedentary, living in a subtropical environment, and had a coastal-riverine economic focus". There also appears to be a link between increased population density and the positive correlation with increased infectious disease and pathogens (Armelagos, 1990; Oxenham et al., 2005). The elevated levels of cribra orbitalia and LEH during the Da But period of Vietnam appear to be associated with decreased physiological health (Oxenham et al., 2005). "If general measures of physiological health in the form of enamel hypoplasia and cribra orbitalia are considered some gauge of the level of sample immunocompetence, it would seem that both the Metal and Da But period assemblages had less than optimal immune systems" (Oxenham et al., 2005, p. 373). This may also be the case for the communities of Khok Phanom Di with elevated LEH and Man Bac, Ban Chiang (late), Phum Sophy, and Angkor Borei with increased cribra orbitalia who could also be immunocompromised. Oxenham (2006) found a decrease in the amount of LEH and cribra orbitalia in prehistoric Vietnamese older adults, while greater proportions of LEH and cribra were associated with younger adults, associated with a larger amount of younger deaths. This suggests a positive correlation between cribra orbitalia and LEH with early mortality, as individuals not inflicted are able to live into older adulthood.

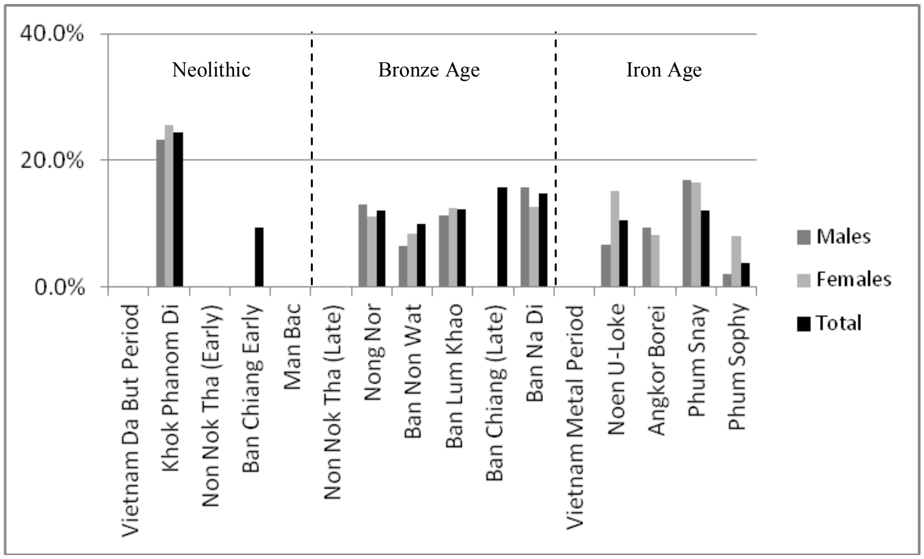


Figure 3.1 Linear enamel hypoplasia by tooth count in prehistoric Southeast Asia.

Percentages of linear enamel hypoplasia across Southeast Asian sites. Con Co Ngua, ~4000-3500 BC (Oxenham et al., 2006), Khok Phanom Di (2000-1500 BC), Nong Nor (1100-700 BC), Ban Lum Khao (1000-500 BC), Ban Na Di (600-400 BC), (Domett, 2001); Man Bac (2000-1500 BC), (Oxenham & Domett, 2011); Non Nok Tha (early:~2800-1400 BC), (late:~1400-200 BC), (Douglas, 2006); Ban Chiang (early:~2100-900 BC), (late:~900 BC-200 AD), (Douglas, 1996); Vietnam Ma, Ca Rivers (~500 BC-300 AD), Vietnam Red River (~200 BC-300 AD), (Oxenham et al., 2006); Noen U-Loke (~300 BC-200 AD), (Tayles et al., 2007); Angkor Borei (200 BC-200 AD), (Ikehara-Quebral, 2010).

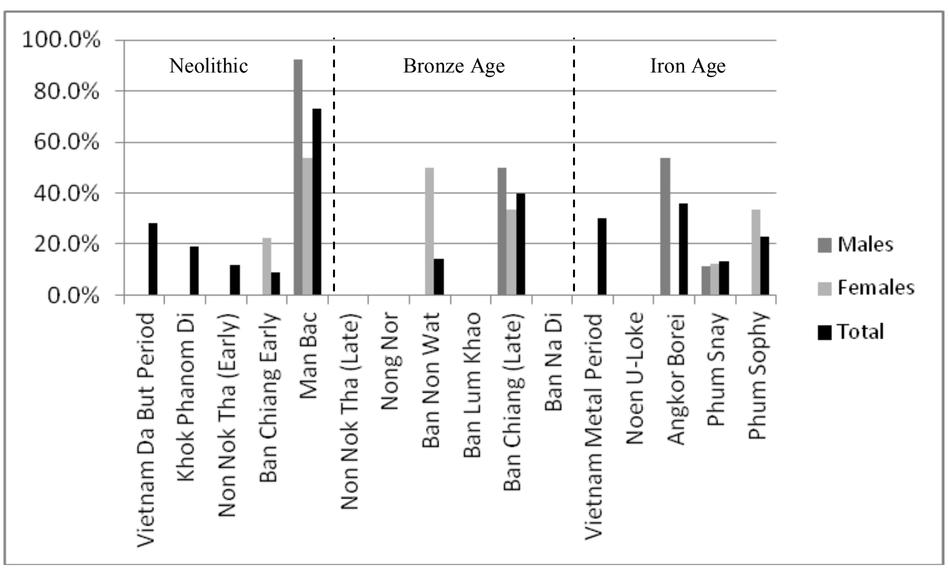


Figure 3.2 Individuals with cribra orbitalia in prehistoric Southeast Asia.

Refer to Fig. 3.1caption for dates and sources.

LEH during the Neolithic was quite high, however these numbers dropped into the early Bronze Age where they stayed relatively stable until into the Iron Age. As noted above, there does not appear to be a positive association for all prehistoric Southeast Asian sites with cribra orbitalia and LEH. While there still may be some association between the two stressors, such as in the Vietnamese samples (Oxenham et al., 2005), the Thailand and Cambodian samples do not show the same relationship. This might be explained by the environmental instability of northern Vietnam compared to Thailand and Cambodia (Oxenham et al., 2005) .

A number of studies have found the effects of LEH are not statistically linked with decreased stature (Larsen, 2002; Temple, 2008). The average Southeast Asian statures for males can be found in Table 3.12 and Table 3.13 for females listed in order of time period (dates of occupation are found on Fig. 3.1). Interestingly, out of the Iron Age groups, Phum Snay has the greatest amount of LEH, with minimal impact on the stature. While Phum Snay children may have dealt with an increase of stressors, it appears they were generally healthy enough at a young age during their growth phase to maintain a normal height into adulthood. Iron Age Noen U-Loke females were affected by LEH more than males, and the corresponding stature shows great variation between the sexes. This suggests females were more susceptible to childhood stressors than males. It might also suggest the introduction or hierarchical systems in the Iron Age where males and females are treated differently and allowed access to different resources. This also appears to be the case at Phum Sophy, which has significantly less LEH than other Iron Age groups overall, however the female prevalence is higher than the males, and females were also impacted by cribra orbitalia, corresponding with one of the shortest average female statures. Therefore, it appears females in the Iron Age were more susceptible to stressors during childhood. However, as stated previously, there is no way to determine if the affected individuals are the ones with the shortened statures. While there has been an argument for a decline in health over time, there are several studies which point towards stabilized (e.g. Domett & Tayles, 2006a; Pietrusewsky & Douglas, 2001) or healthier groups (Pietrusewsky & Ikehara-Quebral, 2006) of people during advances in agriculture and the rise of state-like societies in prehistoric Southeast Asia. However, Ban Chiang average statures stay relatively similar in the early and late phases, even though LEH and cribra orbitalia levels are much higher in the later phase. This suggests the inhabitants in the late phase of Ban Chiang were generally healthy enough to overcome childhood stress.

Sexual dimorphism appears to generally increase into the Iron Age (Table 3.13). The diet can have some influence on the amount of sexual dimorphism (Gray & Wolfe, 1980; Stock & Pfeiffer, 2004), which will be examined in Chapter 4. The wider range of male statures in the Iron Age could suggest males were more affected by stress than females, as seen at Ban Lum Khao (Domett & Tayles, 2006a). Domett & Tayles (2006a), report that increases in range of stature are typical to the Iron Age, with associated social complexity and inequality. The wide ranges of male statures "suggests that there was considerable variation in health, implying inequality in access to resources in this group", which is to be expected because this inequality is typical of the Iron Age (Domett & Tayles, 2006a, p. 234). Ban Lum Khao sexual dimorphism is lower than Ban Non Wat's, which is interesting since these two sites are contemporaneous and located in close geographical proximity. However, the sites seem to have been affected by stressors differently. Ban Non Wat males appear to have been able to overcome the stressors from early childhood based on average stature. In addition, the Bronze Age groups Nong Nor and Ban Na Di show the tallest average female statures of all the Southeast Asian sample, and have a similar LEH prevalence to the males at the sites. Evidence of stature estimates suggests childhood stressors might be one of a number of contributing factors affecting stature.

Table 3.12

Male stature estimates for prehistoric Southeast Asia.

		Total Stature			
Time period (descending to most recent)		N	Mean	SD	Range (%)
MALES					
Neolithic	Khok Phanom Di[1]	30	162.2	5.1	153.8-170.7 (16.9)
	Ban Chiang (Early)[2]	17	165.4	3.6	
Bronze	Nong Nor[3]	19	167.2	6.5	158.8-181.6 (22.8)
	Ban Non Wat[4]	10	166.5	6.1	157.7-179.7 (22.0)
	Ban Lum Khao[5]	18	164.7	6.2	152.4-174.9 (22.5)
	Ban Chiang (Late)[2]	12	166.0	3.7	
	Ban Na Di[3]	17	168.0	4.9	159.5-176.0 (16.5)
Iron	Noen U-Loke[5]	9	169.3	3.1	165.3-173.7 (8.4)
	Angkor Borei[6]	11	165.3	4.3	157.9-172.7 (14.8)
	Phum Snay[4]	57	166.6	3.8	161.2-177.5 (16.3)
	Phum Sophy[4]	13	167.1	3.3	161.1-171.7 (10.6)

Stature derived from the Sangvichien (1985, n.d.) stature formula. [1](Tayles, 1999); [2](Pietrusewsky & Douglas, 2001); [3](Domett, 2001); [4]this study; [5](Domett & Tayles, 2006a); [6](Ikehara-Quebral, 2010)

Table 3.13

Female stature estimates for prehistoric Southeast Asia.

Total Stature						
Time period (descending to most recent) FEMALES		N	Mean	SD	Range (%)	Sexual dimorphism (% of male stature)
Neolithic	Khok Phanom Di[1]	36	154.3	4.5	141.1-163.2 (22.1)	4.9
	Ban Chiang (Early)[2]	17	153.9	3.2		6.9
Bronze	Nong Nor[3]	14	156.1	3.6	150.7-162.1 (11.4)	6.6
	Ban Non Wat[4]	10	153.5	4.2	143.5-158.5 (15.0)	7.8
	Ban Lum Khao[5]	25	154.7	3.8	147.9-162.2 (14.3)	6.1
	Ban Chiang (Late)[2]	7	154.4	2.6		7.0
	Ban Na Di[3]	13	155.9	4.0	150.0-164.4 (14.4)	7.2
Iron	Noen U-Loke[5]	4	154.6	4.7	151.5-161.6 (10.1)	8.7
	Angkor Borei[6]	8	154.8	3.0	151.1-159.9 (8.8)	10.5
	Phum Snay[4]	15	154.9	2.6	150.3-158.7 (8.4)	7.0
	Phum Sophy[4]	15	150.7	3.5	144.9-155.5 (10.6)	9.8

Stature derived from the Sangvichien (1985, n.d.) stature formula. [1](Tayles, 1999); [2](Pietrusewsky & Douglas, 2001); [3](Domett, 2001); [4]this study; [5](Domett & Tayles, 2006a); [6](Ikehara-Quebral, 2010)

Stature throughout the Southeast Asia sample appears generally stable through the Bronze and Iron Ages (Fig. 3.3). Mummert et al. (2011) and Cohen & Armelagos (1984) found a decrease in stature worldwide with the intensification of agriculture due to increasing populations and infectious disease. However, the tallest mean male stature comes from the Iron Age site of Noen U-Loke, while the tallest mean female stature is from Bronze Age Nong Nor (Fig. 3.3). Domett and Tayles (2006a) found a positive correlation between increased amounts of LEH and a shortened mean stature at Ban Lum Khao. This also appears to be the case for Neolithic Khok Phanom Di, which experienced the greatest amount of LEH (see Fig. 3.1), and has the lowest mean male stature of the

Southeast Asian sites. However, Ban Chiang (late) and Ban Na Di sites, both with elevated LEH, do not have greatly shortened statures. Perhaps these individuals were able to cope with the childhood stressors better than the Neolithic Khok Phanom Di because of their ability to exploit the environment and create an established subsistence program with better nutrition. However, those societies who experience catch-up growth and overcome the stressors from early childhood have the possibility of attaining their full growth potential into adulthood. Adults with shorter statures may have been more severely affected by the stressors during childhood, lacking the ability to overcome them.

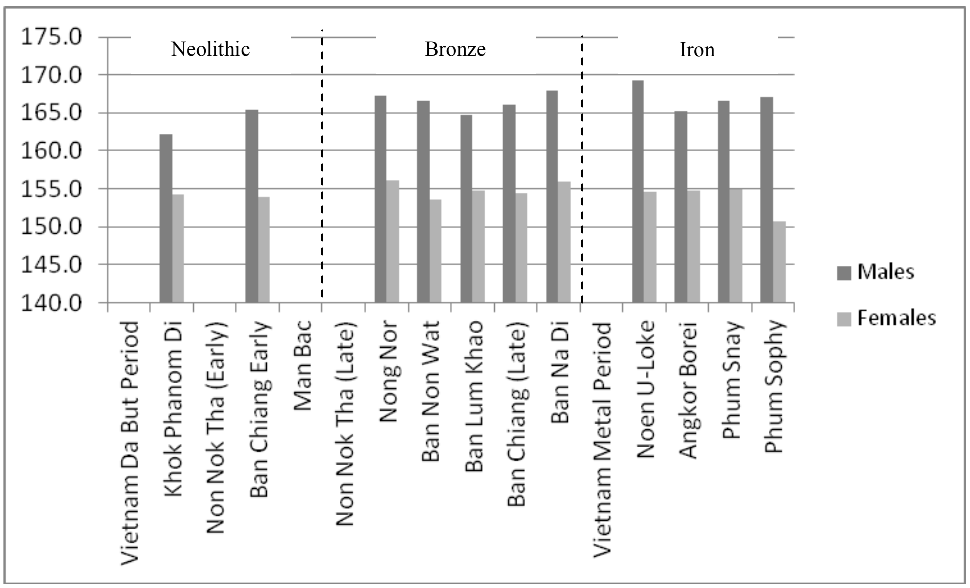


Figure 3.3 Average statures (cm) in prehistoric Southeast Asia.
Refer to Fig. 3.1 caption for dates and sources.

3.6.2 Dental health

3.6.2.1 Ban Non Wat

At Ban Non Wat (Series 2 samples) males and females lack significant differences in the overall prevalence of dental pathologies. A significantly smaller distribution of older females at the site makes it difficult to determine if any of these dental health sex differences may have continued into older age. There is a trend for males to have caries at a young age, and into older adult age; however a slight decline is noted, possibly due to the increased amount of advanced wear eliminating signs of caries. It is interesting that Ban Non Wat males have a higher amount of caries than females since females tend to have more caries than males in prehistory (discussed previously in Section 3.1.2.2) (Lukacs & Largarspada, 2006), but again this might be explained by an older population of males (Lukacs, 1996). The increase in AMTL into older age can illustrate males are managing to fight the infection into later adulthood before they eventually lose the infected teeth. The only statistical difference in younger males and females is the amount of periapical lesions in the females. An explanation would be that females are using their teeth for other things versus just eating, affecting the alveolar tissue, causing greater amounts of periapical lesions, however this is unlikely since the wear is equally favourable on the anterior dentition for both sexes. Overall, males and females at Ban Non Wat have a similar prevalence of all dental pathology except advanced attrition, which is probably explained by the lack of older female dentition. In turn, this might conclude that males and females had similar diets and dental health profiles, suggesting limited sexual division of labour. It is interesting to note that Ban Non Wat males and females have similar amounts of each overall dental pathology; however the female dentitions are significantly younger. Perhaps the females are generally unhealthier than the males, and the dental problems affect them at an earlier and more progressive rate. The results could also be due to small sample size.

3.6.2.2 Phum Snay

At Phum Snay, older females had more caries while males had significantly higher frequencies of advanced wear; both sexes had low rates of periapical lesions and AMTL. However, varying caries rates could be due to non-dietary, physiological factors. Higher caries frequencies in females compared with males are very common in archaeological samples from around the world (e.g. Lukacs, 2011b; Temple & Larsen, 2007), suggesting a non-dietary cause (Lukacs, 2011a) may have a partial impact, in addition to dietary factors. Physiological differences between the sexes, such as the rate of salivary consistency and flow, hormones, and pregnancy can differentially impact the dental health of females, resulting in more caries (Lukacs, 2011a; Lukacs & Largarspada, 2006). Grave good distributions (O'Reilly et al., 2006a) Previous studies in the region (Higham, 2001; Shoocongdej, 2002) and male grave goods (O'Reilly et al., 2006a) suggest that males at Phum Snay hunted and fished, and may, on these occasions, have been reliant on a different, perhaps coarser diet than females. The significantly higher wear rates in Phum Snay males compared with females may also be due to the use of their teeth for utilitarian purposes, as has been shown to be the case in prehistoric Vietnam (Oxenham et al., 2006). Evidence for using teeth as tools is often seen in the anterior teeth, though not exclusively (Blakely & Beck, 1984). Advanced wear was more common in anterior teeth than in posterior teeth in both males and females at Phum Snay; therefore, if there was a non-dietary use of teeth it was occurring in both males and females.

3.6.2.3 Phum Sophy

Statistically significant sex differences in the Phum Sophy dentition were not as apparent as in the Phum Snay samples. This suggests there may have been less differentiation in diet between the sexes in the Phum Sophy community. While many percentages were notably different between males and females, only the caries rates in the younger female age class were statistically higher than the males. Interestingly, the sex differences in caries did not continue into the older age class, though this may be a reflection of the small sample size. Alternatively, carious teeth may have been lost at a young age in females, however, the AMTL frequencies are low in all groups and as such cannot account for this difference. Female dentitions did show a significant increase in periapical lesions with age, which may reflect the high percentage of caries at a young age. Caries can lead to pulp exposure leaving an individual more prone to periapical lesions (Lukacs, 1989). The significant increase in caries from young to older males is enigmatic; it may reflect a change to a more cariogenic diet as male's age. Though the sample size is small, perhaps resource acquisition strategies varied between age classes. Older males may have been more sedentary due to agricultural practices while young males engaged in hunting, away from the village, thus exposing them to different diets.

3.6.2.4 Southeast Asian dental health trends

In many Southeast Asian studies population health has generally been stable with the intensification of rice agriculture (e.g. Domett & Tayles, 2006a; Pietrusewsky & Douglas, 2001). Placing the new data from these sites within a broader Southeast Asian context is complicated by methodological, sampling, and demographic issues that prevent statistical analyses. The following discussion is therefore limited to general trends, not statistically significant differences. In addition, some studies have not subdivided data by age, thus comparisons are based on total frequencies. The sites discussed include Neolithic (Con Co Ngua, Khok Phanom Di, early Non Nok Tha, early Ban Chiang, Man Bac), Bronze Age (late Non Nok Tha, Nong Nor, Ban Lum Khao, late Ban Chiang) and Iron Age sites (Ban Na Di, sites in the Ma and Ca Rivers, Noen U-Loke, Angkor Borei) (see Fig. 1.1). There is environmental variation across the samples with some coastal and many inland sites situated on river floodplains. This variation will be discussed where relevant below.

3.6.2.5 Temporal variation

The frequency of advanced wear does not show any consistent pattern through time (Fig. 3.4). There are a mix of low and moderate frequencies in the Neolithic and Bronze Age, though most Bronze Age samples show higher frequencies. During the Iron Age there are higher levels at Noen U-Loke and lower levels in the later Iron Age Cambodian samples. The correlation between tooth wear and diet is long established (Lukacs, 1989), however other causes such as food preparation methods and the use of teeth as tools can contribute to wear patterns. Prehistoric communities that depend heavily upon marine resources often show comparatively high wear rates, such as those in the Arabian Gulf (Littleton & Frohlich, 1993). Southeast Asian dentitions do not consistently follow this pattern (Domett, 2001) proving that geographic location cannot always predict dental pathology profiles. For example, coastal Khok Phanom Di, with evidence for a diet of shellfish and other marine resources, had a low frequency of advanced wear while the only other sample reasonably close to the coast with advanced wear recorded, Nong Nor, had the highest frequency (Domett, 2001). Inland Non Nok Tha males with a moderate wear frequency, particularly high on anterior teeth, may have used their teeth as tools (Douglas, 2006). Wear also increases in general at Non Nok Tha from the early to late groups and Douglas (2006) suggests dietary grit or fibre may also have increased. Anecdotally (no data provided), Reinecke et al. (2009) provide a similar dietary explanation for the advanced wear in the Iron Age Prohear community in southern Cambodia. Tooth wear at this site was so extensive that even young children were markedly affected.

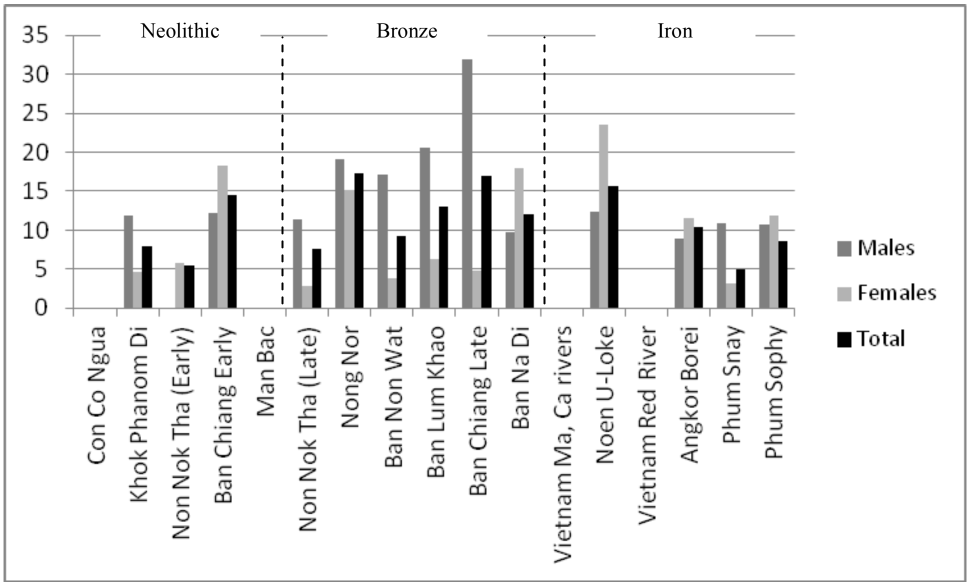


Figure 3.4 Percentages of advanced wear by tooth across prehistoric Southeast Asian sites. Refer to Fig. 3.1 caption for dates and sources.

Caries rates were variable during the Neolithic, low to moderate throughout the Bronze and early Iron Ages followed by higher levels in the late Iron Age (Fig. 3.5). New evidence from three prehistoric Vietnamese sites suggests an elevation of caries rates during the Vietnamese Neolithic, and a decline in the Bronze and Iron Ages (Willis & Oxenham, 2013). High caries frequencies among the northwest Cambodian Iron Age communities runs counter to previously observed trends for declining or stabilising rates during this period (Domett & Tayles, 2006a). Given that the other Iron Age samples do not show such high caries frequencies, this may underscore variation due to local factors or sampling bias. There is evidence for a drier climate in the Iron Age in the Upper Mun River Valley (UMRV) in northeast Thailand along with increased deforestation for rice cultivation and associated water management (Boyd, 2008); these factors would have affected the availability of foods consumed at Noen U-Loke. Whether this climate change was also experienced in northwest Cambodia is unknown, but this may be a point of difference between the two areas during the Iron Age.

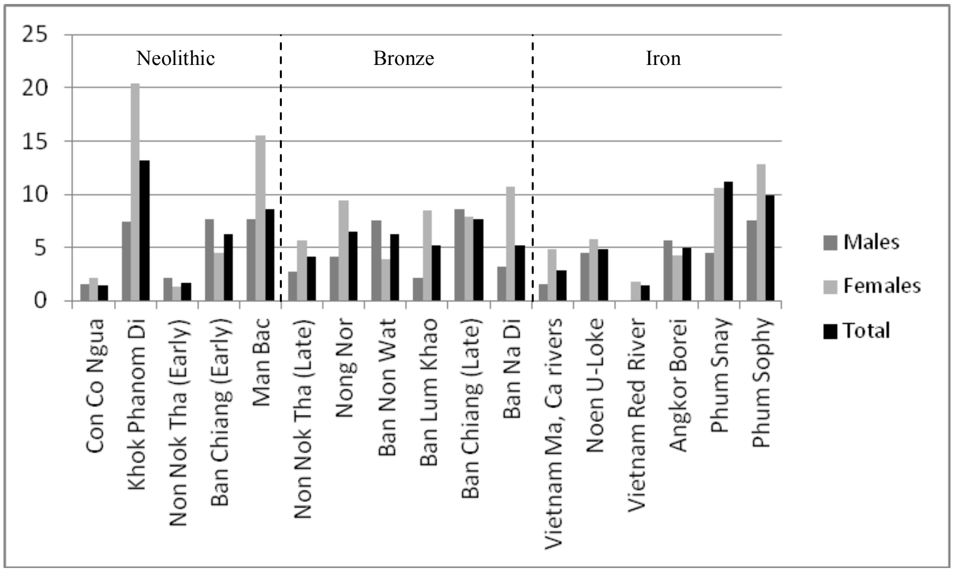


Figure 3.5 Percentages of caries across prehistoric Southeast Asian sites. Refer to Fig. 3.1 caption for dates and sources.

The frequency of periapical lesions was relatively low during the Neolithic, with the exception of the Khok Phanom Di sample. Levels were also generally low in the Bronze Age with the exception of Ban Non Wat (Fig. 3.6). Iron Age samples show more mixed results but tended to be moderate to high. The communities with the highest frequencies, Khok Phanom Di, Noen U-Loke, Phum Snay and Phum Sophy, all showed intentional ablation of anterior teeth (Domett et al., 2011a; Nelsen et al., 2001; Tayles, 1996), with the exception of Ban Non Wat. Dental modifications may have increased the risk for infections and inflammation of surrounding dental tissues. However, these sites also have either high caries or advanced wear, which includes Ban Non Wat.

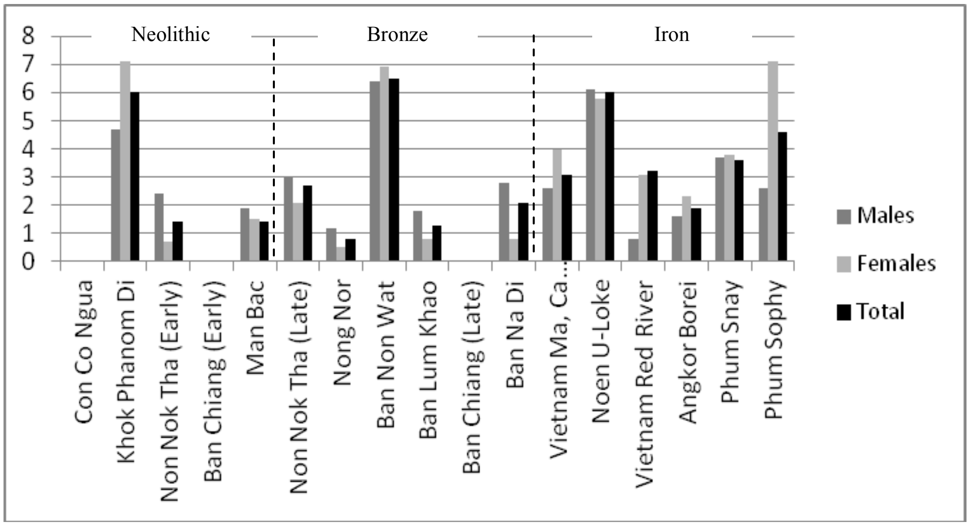


Figure 3.6 Percentages of periapical lesions across prehistoric Southeast Asian sites. Refer to Fig. 3.1caption for dates and sources.

Across Southeast Asia, AMTL frequencies are mixed but mostly moderate to high during the Neolithic and Bronze Age and generally low in the Iron Age (Fig. 3.7). Given that some of the Iron Age samples show the highest levels of periapical lesions, for example Phum Sophy and Noen U-Loke, this result may reflect an improvement in their ability to contain (or fight) infection without the loss of teeth. Domett and Tayles (2006a, p. 222) suggest that "through time, the health of the prehistoric people may be expected to have improved as their ability to exploit their environment developed". This low AMTL may be one sign that Phum Sophy individuals were healthier than their predecessors.

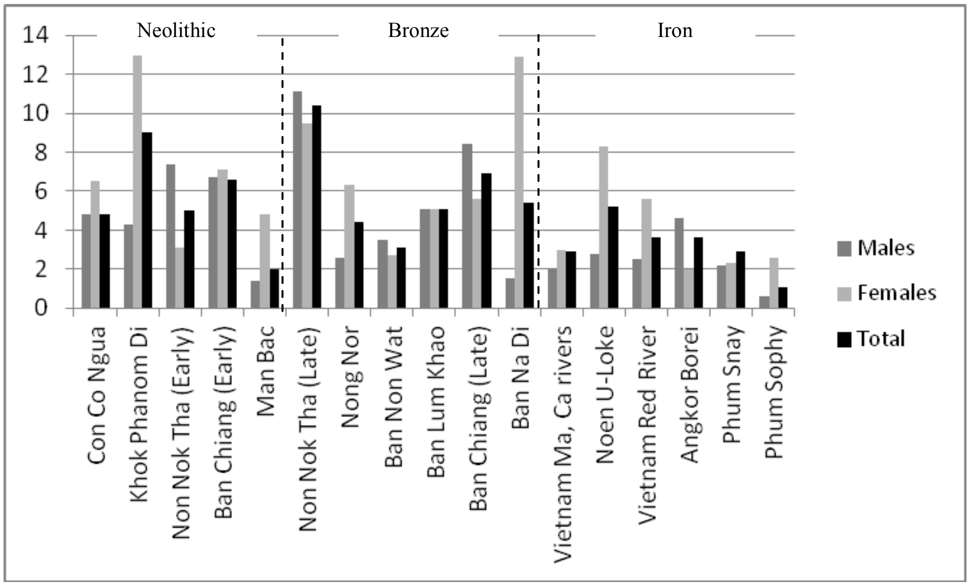


Figure 3.7 Percentages of AMTL across prehistoric Southeast Asian sites. Refer to Fig. 3.1 caption for dates and sources.

3.6.2.6 Sex differences

Sex differences in dental health profiles can suggest gender differences within communities. The development and severity of dental pathology can also be influenced by non-dietary factors such as age, varying hormone levels, genetic predisposition, as well as the general health of the individual. Sex differences in advanced wear rates are inconsistent through time. Douglas (2006, p. 216) found a reduction in advanced wear rates in females from early (Neolithic) to late (Bronze Age) Non Nok Tha people, attributing this to "a shift towards softer, more processed agricultural foodstuffs" in females. Ikehara-Quebral (2010) also attributes the sex differences in Angkor Borei dental remains to diet differences. Bronze Age males consistently had higher advanced wear rates compared with females, while the reverse was true in the early Iron Age (Fig. 3.4).

In 12 of the 17 (71%) Southeast Asian sites studied, caries rates are higher in females than males (Fig. 3.5). This is seen in many studies around the world, for example (Lukacs, 2011b; Temple & Larsen, 2007). Physiological differences between the sexes, such as the rate of salivary consistency and flow, hormones, and pregnancy can differentially impact the dental health of females, which may be one of the factors affecting an increase of caries rates (Lukacs, 2011a; Lukacs & Largarspada, 2006). Based on animal research, caries rates increase with oestrogen fluctuations, with high fluctuations occurring during pregnancy (Lukacs & Largarspada, 2006; Watson et al., 2010). In Phum Snay dentitions there was an increase in caries rates with age among females. This increase in caries and AMTL prevalence's in older age could result from the physiological factors associated with pregnancy as young adults. Thus, communities with evidence of high fertility may also have high caries rates in females (Lukacs, 2008). Sites with high fertility, based on calculations such as the Juvenile – Adult ratio and Mean Child Mortality, include Neolithic Khok Phanom Di, new evidence from Neolithic Vietnamese sites Man Bac and An Son, Bronze Age Ban Lum Khao and Iron Age Angkor Borei (Domett & Oxenham, 2011; Ikehara-Quebral, 2010; Willis & Oxenham, 2013). Of these, only the Neolithic sites have been shown also to have high caries rates (Willis & Oxenham, 2013); the other sites have more moderate caries rates suggesting that fertility may be only one of many factors affecting caries rates, in addition to dietary differences and physiological factors.

Males tended towards higher frequencies or periapical lesions in the Bronze Age, while females tended to have higher levels in the Iron Age. This relates to the pattern of advanced wear; Bronze Age males had higher advanced wear rates that may have resulted in their higher periapical lesions, meanwhile in the early Iron Age females show higher wear and higher periapical lesions. This suggests that the route of periapical infection is strongly linked with pulp exposure through advanced wear.

Sex differences in pathological AMTL across time are not particularly strong. Both the Neolithic and Iron Age samples frequently show more AMTL in females. This may be linked to a parallel trend in caries: when females develop caries they are more likely to lose their teeth prematurely.

3.7 Summary

This section focused upon estimating local trends in health for Ban Non Wat, Phum Snay and Phum Sophy. These sites were also placed within the wider Southeast Asian context by exploring temporal trends in relation to health.

The people at Ban Non Wat appear generally healthy. Males and females have similar health and dental profiles, indicating a similar access to resources. While there is a large younger female population, this is probably due to pregnancy or post-partum related issues.

Phum Snay males and females exhibit equally high childhood stressors, indicative of a stressful childhood, but their statures suggest a capacity to undergo catch-up growth. Sex differences are evident in the dental pathology profiles (but are not equal between males and females), which overall suggest a decline in oral health. There was a large amount of evidence pointing towards a very violent community, which was probably a reason for the increased stress and higher proportion of young adults in the cemetery population.

At Phum Sophy there was a lower prevalence of childhood stressors compared to the other two communities, which may be due to the small sample sizes or an inverse health during younger years. There is limited evidence to suggest sex differences with dental pathology, however overall the dental health profile suggests a decline of oral health.

Throughout Southeast Asia there was a decline in LEH through time, suggestive of an improvement in health into the Iron Age, which has been hypothesized by several scholars. However, even though there was a decline of childhood stressors, there was an oral health decline into the late Iron Age, especially for females. A decline of female stature at Phum Sophy and increased sexual dimorphism suggests female health was more negatively affected into the late Iron Age.

Note: A portion of this chapter has been incorporated into the publication *Dental Health in Iron Age Cambodia: Temporal variations with rice agriculture* in Appendix B.

Chapter 4 Diet

4.1 Introduction

Using newly recorded data from Ban Non Wat, Phum Snay and Phum Sophy, in conjunction with previously published data from prehistoric Southeast Asian sites, this chapter determines general trends of dietary change throughout time.

King et al. (2013) recently presented carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope results for two of the excavated areas of the Ban Non Wat prehistoric village (Series 1 skeletal remains). King et al.'s (2013) study identifies two separate times of subsistence change throughout time and significant dietary differences between males and females. The present study uses new data from five additional excavation areas (Series 2 skeletal remains; Fig. 2.1) to provide a more complete analysis of this important site.

The relationship between diet and dental pathology is explored and the influence of rice-based subsistence amid socio-cultural changes is considered. Subsistence changes may have affected diet as communities engaged in pre-state control of resources such as rice and agricultural land.

This chapter begins by examining diet across more than 2000 years at prehistoric Ban Non Wat in northeast Thailand using carbon isotope ratios of carbonate in dental enamel. Archaeological excavations at Ban Non Wat provide an exceptional opportunity to analyze bioarchaeological variables such as diet in a single community throughout an extensive time period. Moreover, this site provides an opportunity for study across many different locations within a single prehistoric community (Fig. 2.1). In order to allow direct comparisons between samples, the Series 2 skeletons are grouped into the same mortuary phases as the Series 1 remains, based on artefact associations and excavation stratigraphy in line with Higham and Higham's (2009) site chronology (Table 2.1). Using the combined datasets, the degree of variation in diet is investigated to test the validity of the suggestion of resilience and stability prior to the Iron Age (Boyd & Chang, 2010), or the suggestion of elites in the Bronze Age (Higham & Kijngam, 2012b), within the limits provided by stable isotope analysis. This research also examines how conclusions change as datasets are combined and grow in size. It is argued that what initially appears to be a significant difference in diet between some groups of individuals within the prehistoric society at Ban Non Wat is no longer apparent as the dataset is increased. That such a variation in interpretation can be shown as the dataset grows, even at such a comprehensively excavated site like Ban Non Wat, is an important reminder results and analyses can only be extrapolated to a certain extent in archaeological and physical anthropological datasets elsewhere.

4.1.1 Isotope $\delta^{13}C$

Carbon isotope analysis from dental enamel indicates the partial diet of an individual. Application of isotope analysis is in its infancy in Southeast Asia (King & Norr, 2006) and the results appear promising. By selecting appropriate individuals from the Thailand site of Ban Non Wat which spans over thousands of years, particularly time periods known to have experienced environmental change (Boyd, 2008), it is possible to determine if dietary resources changed. It is then possible to overlay this information with health analyses to determine the impact on quality of life.

Studies examining diet assess $\delta^{13}C$ in the enamel of the teeth and collagen in bones and compare the ratios of C_3 versus C_4 foods in the diet. C_3 plants, such as rice, fruits, most vegetables and probably freshwater fish, are indicated by a more negative $\delta^{13}C$, while C_4 diets comprise of items such as millet and marine foods corresponding with a less negative $\delta^{13}C$ (Cox et al., 2011). C_3 plants in Southeast Asia, including rice but also most fruits and vegetables in the region, predominate over C_4 plants (limited to millet, sorghum and Job's tears) (King & Norr, 2006). $\delta^{13}C$ values from tooth enamel apatite represent the $\delta^{13}C$ value in the whole diet and are enriched by 9.4‰ (percent per mil) compared with bone collagen values (Ambrose et al., 1997). A diet high in C_3 plants is indicated by more negative $\delta^{13}C$ values (approximately −16.1‰), while C_4 diets have less negative $\delta^{13}C$ values (−4.6‰) (Lee-Thorp, 2008). In addition, it may be possible to discriminate between a more broad-based hunter-gatherer diet compared with an agricultural one though values can change depending on the surrounding environment: closed-forest foraging yield more negative values (around −14‰) while open forest slightly more positive (−12‰) (Krigbaum, 2003). Other factors that can influence the $\delta^{13}C$ value are the consumption of fresh water fish and terrestrial meat (giving a 1‰ increase per trophic level) as well as altitude (Bentley et al., 2009).

Millet is not usually believed to have had an impact on the diet of prehistoric peoples in Thailand due to its lack of presence in the archaeological record (Weber et al., 2010). Research in this region has indicated that millet may have been more commonly cultivated than rice during the first millennium BC (Castillo, 2011), and Weber et al. (2010) found evidence of millet around the late third millennium BC in central Thailand. Mudar (1995), cited in King and Norr (2006), suggested millet or other C_4 crops may even have been grown at Ban Chiang. Rice, however, with its long history in Thailand, is believed to have been first cultivated around 2500 BC (Weber et al., 2010). Guedes (2011) argues that rice and foxtail millet may have been grown together from 2700 BC in order to provide a base for the local Baodun Neolithic society in Southwest China. Evidence from palaeobotanical records have located rice at Ban Non Wat from the earliest Neolithic layers at about 1700 BCE (Castillo, 2011). Castillo (2011) argues that rice was an important and very common crop in Thailand due to the frequency of recovery in excavation.

4.1.2 Subsistence changes

Dental pathologies such as advanced wear and caries can potentially assist in identifying changes to the diet in ancient societies (Hillson, 2008). What individuals were eating play a role on the rate of advanced wear on the teeth, with differences seen in hunter-gatherers versus agriculturalists (Hillson, 2008). The occurrence of caries was a rarity until agriculture became common (Larsen, 1997; Larsen et al., 1991; Larsen, 1995), and crops high in carbohydrates started to be consumed with the diet (Hillson, 2008). Lukacs (1992) documented a trend in South Asia of the frequency of caries to increase as the level of agriculture increased, specifically wheat and barley, and this trend can also be seen in places as far away as North America in groups who have maize as the major carbohydrate component of their diet (Oxenham et al., 2006). Based on the literature available on dental disease, Douglas (2006) identified lower frequencies of caries and high frequency of advanced wear in hunter-gatherer societies, while the opposite is seen in agricultural populations (Douglas, 2006; Tayles et al., 2009; Tayles et al., 2000).

The adoption and intensification of rice agriculture is a key subsistence change that dominates Southeast Asian prehistory. This transition appears to have had a limited affect on dental health (Domett & Tayles, 2006a; Oxenham et al., 2006) in contrast with many other parts of the world, where caries in pre-agricultural communities were rare and then increased markedly as carbohydrate-based crops, such as maize, barley, and wheat, were increasingly consumed (Hillson, 2008; Larsen, 1995; Lukacs, 1992). Previous studies have highlighted the low cariogenicity of rice as an explanation for the absence of a similar decline in dental health in Southeast Asian prehistory (Domett & Tayles, 2006a; Tayles et al., 2000). However, new evidence from Vietnam suggests agriculture intensification did cause a decline of oral health during the Neolithic, followed by a period of improving health from the Bronze to Iron Age (Willis & Oxenham, 2013). Additionally, Oxenham et al. (2006) hypothesise that a decline in oral health may not be apparent in prehistoric Southeast Asia until the Iron Age, a period marked by increased population aggregation and numbers of settlements alongside an intensification of rice agriculture (O'Reilly, 2000; O'Reilly, 2008). Furthermore, based on the conclusions of Chapter 3, the addition of new Cambodian skeletal samples suggests a decline of dental health in the late Iron Age.

Carbon isotopes from human tooth enamel, paired with the results from the dental health profile assist with establishing the diet of prehistoric people, and dietary changes throughout time. The selection of appropriate individuals from the long time span from the Ban Non Wat will make it possible to establish if dietary resources changed. Using isotope values from the dentition, these data are combined with dental health from the previous chapter. Results of the isotope analyses for Phum Snay and Phum Sophy are unavailable. Therefore, an estimation of their diet is constructed by comparing the known dental pathology profiles with the profiles of Ban Non Wat. This information will determine the impact diet may have had on the quality of life, along with dietary and environmental change in Southeast Asia.

4.2 Hypothesis 2

Changes to childhood diet will be gradual throughout the Neolithic to early Iron Age, after which, significant dietary differences will be present, negatively affecting health.

Given the varied archaeological context of the human remains, the aim of this research is to examine differences in diet between the prehistoric peoples of Ban Non Wat and those of Phum Snay and Phum Sophy, general dietary trends, and the impact on health in Southeast Asia. The main hypothesis (Section 1.8.2: Hypothesis 2) is examined through a series of sub-hypotheses where it is suggested:

Hypothesis 2.1: *The $\delta^{13}C$ values of prehistoric Ban Non Wat people indicate a diet comprised mainly of C_3 foods, such as rice, with limited variation from the Neolithic to the Iron Age, suggesting stability during this time.*

Hypothesis 2.2: *Childhood diet was similar in males and females throughout the Neolithic, Bronze Age and into the early Iron Age at Ban Non Wat.*

Hypothesis 2.3: *Prehistoric people from the Upper Mun River Valley had similar $\delta^{13}C$ values during parallel time periods, due to the proximity and accessibility of similar resources.*

Hypothesis 2.4: *The diet at Ban Non Wat will differ significantly from late Iron Age Phum Snay and Phum Sophy due to the increasing intensification of agriculture. This will be apparent through diverse dental pathology profiles.*

4.3 Materials

4.3.1 Isotope analyses

Carbon and oxygen isotope composition assesses childhood diet using dental enamel. The first, second and third permanent molar crowns are completed by the approximate ages of 3, 8, and 16 years, respectively (Hillson, 1996). There were 640 Series 1 burials at Ban Non Wat (Higham, 2011), from which King et al. (2013) reported isotopic data for 118 individuals.

The Series 2 human remains excavated across eight units at BNW (Fig. 2.1) consisted of 61 individuals. Of these, 26 had a permanent molar (see Appendix C Table 1 for details of selected tooth per individual) selected for isotopic analysis from five units: one Neolithic, 19 Bronze Age, five Iron Age, and one for which the assignment to mortuary phase remains uncertain (Appendix C Table 1). While samples from each of the excavation units were small, there was no apparent preference for age or sex in any of the units across the mound (Appendix C Table 2).

Adult diet can be determined from $\delta^{13}C$ values in collagen; however collagen is not well preserved at Ban Non Wat (King et al., 2011). Other studies from Thailand have had similar issues with bone collagen preservation and contamination problems (Bentley et al., 2007; Bentley et al., 2005; Cox et al., 2011). The absence of collagen also prevented the examination of nitrogen isotope values ($\delta^{15}N$). The use of nitrogen isotopes from collagen can assist with distinguishing the components of the diet, such as marine versus terrestrial resources (Deniro & Epstein, 1981; Schoeninger et al., 1983). Additionally, oxygen isotopes from the collagen assist with identifying water sources people and animals would have used (Bentley et al., 2007). Thus, due to the lack of collagen in these samples, analyses in this study are limited to carbon isotope composition from dental enamel as a reflection of childhood diet only.

Eight pig (*Sus scrofa*) teeth from various Series 2 excavation units were collected and combined with Series 1 pig samples to determine a 'local' signature for prehistoric Ban Non Wat faunal diet (Appendix C Table 1).

Previously published isotope data from other prehistoric sites in Thailand are available for comparative analysis with Ban Non Wat. These sites include Khok Phanom Di (see: Bentley et al., 2007), Ban Chiang (see: Bentley et al., 2005) and two sites within the Mun River Valley in close proximity to Ban Non Wat; Ban Lum Khao (see: Bentley et al., 2009) and Noen U-Loke (see: Cox et al., 2011).

4.3.2 Dental Pathology Profiles

Ban Non Wat

Refer to Section 3.3 and Table 3.2 for the dental pathology profile materials of Ban Non Wat.

Phum Snay and Phum Sophy

Refer to Section 3.4 and Tables 3.3, 3.4 for the dental pathology profile materials of Phum Snay and Phum Sophy, respectively.

4.4 Methods

4.4.1 Dental Pathology assessment

Refer to Section 3.4.3.

4.4.2 Carbon and Oxygen Isotope Procedure

This section specifying the technical details of sampling and analysis was prepared by Charlotte King and Dr. Christopher Wurster

Teeth were selected and sectioned to expose enamel, of which 10 (milligrams) mg was removed using a Dremel tool. Dentine and surface particulates were removed from enamel chips using either a dremel tool (James Cook University) or surgical scalpel (Durham). Samples were leached in 10% volume acetic acid and washed thoroughly with MilliQ water prior to analysis in order to remove diagenetic components (Balasse et al., 2002; Koch et al., 1997).

Carbon and oxygen isotope analyses were conducted at Durham University at the Stable Isotope Laboratory (Earth Sciences Department) or at the James Cook University Stable Isotope Laboratory. Carbon dioxide was evolved from the crushed samples by reaction with 100% orthophosphoric acid in exetainer vials after atmosphere was replaced with helium (He). At James

Cook University, gas was processed through a GasBenchIII and $\delta^{13}C$ and $\delta^{18}O$ values were determined using a Thermo Fisher Delta V ^{Plus} mass spectrometer. While at Durham University, gas was processed through a GasBench II with isotopic measurements conducted on a Thermo MAT253 instrument. Analyses conducted at Durham University were normalized to international standards NBS-19 and LSVEC, at JCU NBS-18 and NBS-19 were used. Sixteen internal standards were used to constrain temporal drift in measurement (DCS01 at Durham University, NBS-19 at JCU). Precisions standard deviations (s.d.) for internal standards were better than 0.1 ‰ for $\delta^{13}C$ and $\delta^{18}O$ values. The precision of analysis on samples was established using repeat measurements of samples, giving average error of 0.19‰ (Durham University). Results are reported relative to PDB ($\delta^{13}C$) and SMOW ($\delta^{18}O$). Four teeth were analysed at both James Cook University and Durham University to test reproducibility of results.

4.4.3 Statistical procedures

All comparisons of $\delta^{13}C$ values between the various subgroups were tested statistically using unpaired t-tests, non-parametric Mann-Whitney tests, or ANOVA depending on the nature of the datasets. A resulting *p*-value <0.05 deemed the comparison statistically significant.

4.5 Results

The $\delta^{13}C$ values of tooth enamel carbonate for the Series 2 individuals are presented in Figure 4.1. Complete $\delta^{13}C$ values for each Ban Non Wat individual is available in Appendix C (Table 1). The $\delta^{13}C$ values indicate no statistical differences across the excavation units (Appendix C Table 2). This data was combined with the 118 $\delta^{13}C$ values for Series 1 (King et al., 2013) (Fig. 4.2). ANOVA and subsequent post-tests (Mann-Whitney and unpaired t-tests) between the $\delta^{13}C$ values of Series 1 and 2 for each MP (where samples sizes allowed) indicated that only BA 2 values were significantly different between the two collections (Appendix C Table 3).

4.5.1 Hypothesis 2.1

The $\delta^{13}C$ values of prehistoric Ban Non Wat people indicate a diet comprised mainly of C_3 foods, such as rice, with limited variation from the Neolithic to the Iron Age, suggesting stability during this time.

The carbon isotope ratio average for Series 2 overall, including the outlier and unknown mortuary phase sample is -13.21‰. The carbon isotope ratio averages for Series 2 including outliers for the

Neolithic is −11.20‰, the BA is −13.33‰, and the IA is −13.15‰. There was one clear outlier (Burial 680) from the Neolithic with a carbon isotope ratio greater than two standard deviations from the mean. Three other individuals have carbon isotope ratios greater than one standard deviation (Burials 644, 653, and 697).

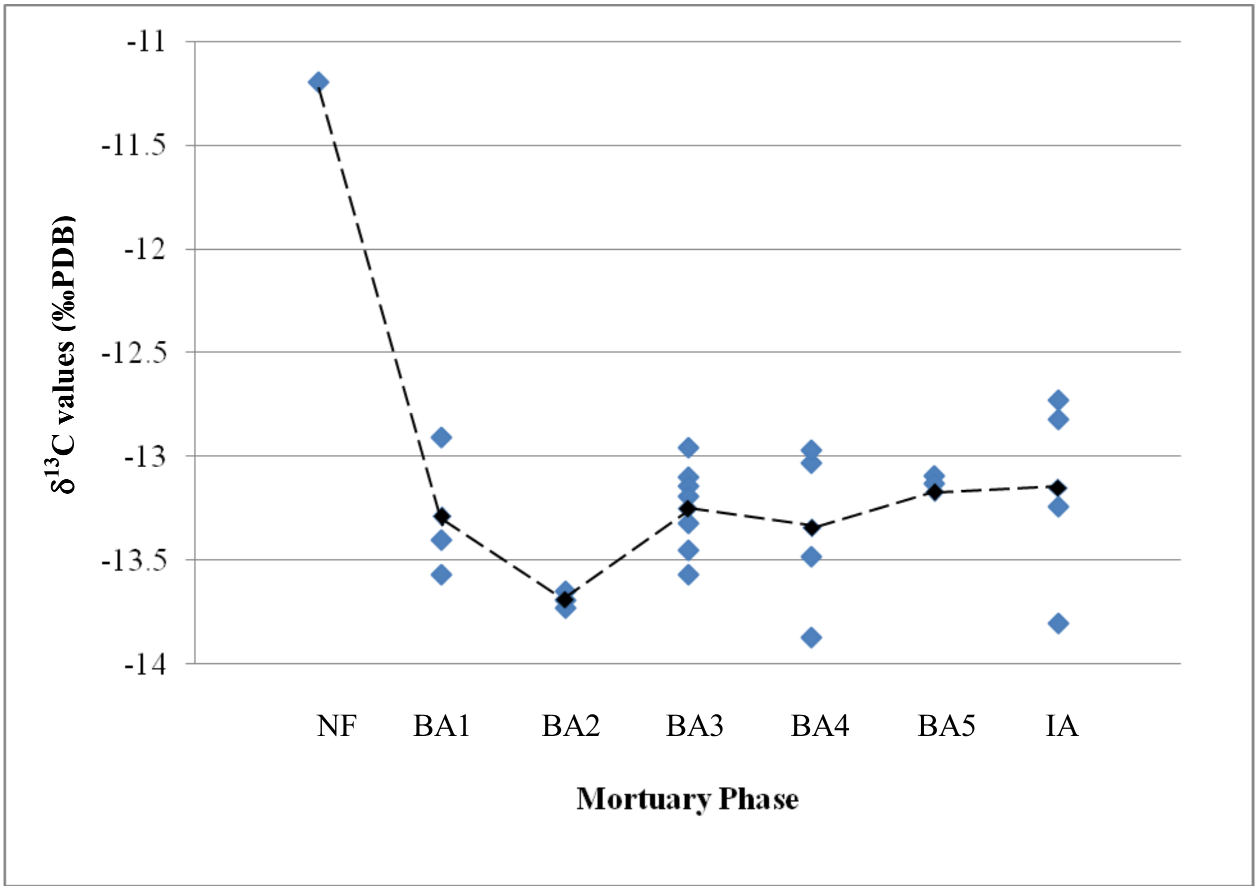


Figure 4.1 Carbon isotope ratios for BNW Series 2 mortuary phases. Dashed lines connect the average for each mortuary phase

Throughout all mortuary phases in the combined Series 1 and 2 (Fig. 4.2), the $\delta^{13}C$ values are consistent with a diet high in C_3 and minimal influence from C_4 foods. Average $\delta^{13}C$ values were highest in the Neolithic period (−11.6‰), and decreased gradually through time to its lowest point in BA 2 (−13.5‰) (Fig. 5.2). Interestingly, this is also the time period that shows the least variation in $\delta^{13}C$ values (see Appendix C Table 4 for range of variation throughout all mortuary periods). After BA 2, a gradual increase of $\delta^{13}C$ occurs up to Iron Age 1 but the levels do not return to the maximum observed in the Neolithic.

There are no significant differences in $\delta^{13}C$ values from one mortuary phase to the next (Kruskal Wallis non-parametric ANOVA p=0.0630); changes are evident, but very gradual. Since this level of significance was quite close to 0.05 individual post-tests were also performed though some tests had small sample sizes. The post-tests indicated that there was a significant difference between BA 2 and BA 3 (t-test p-value = 0.0128; Appendix C Table 5), which is probably a reflection of the difference in variation (0.5‰ compared 1.4‰, respectively) between these mortuary phases, rather than a meaningful difference in the average (equating to only 0.25‰; an extremely minor difference in actual diet). Series 1 data, excluding outliers, (King et al., 2013) indicated a statistically significant change in $\delta^{13}C$ values between BA 1 and 2 which is no longer evident in the combined dataset.

The $\delta^{13}C$ values of two of the five super-burials (B.20 and B.197) within BA 2 are reported by King et al. (2013). These individuals were not found to be significantly different (Mann Whitney p-value=0.4364) when compared with the other nine BA 2 values from the combined series. Therefore, these individuals had similar whole childhood diets to all other BA 2 individuals at the site. Interestingly, as noted above, the $\delta^{13}C$ values of BA 2 in Series 1 are significantly different to BA 2 Series 2.

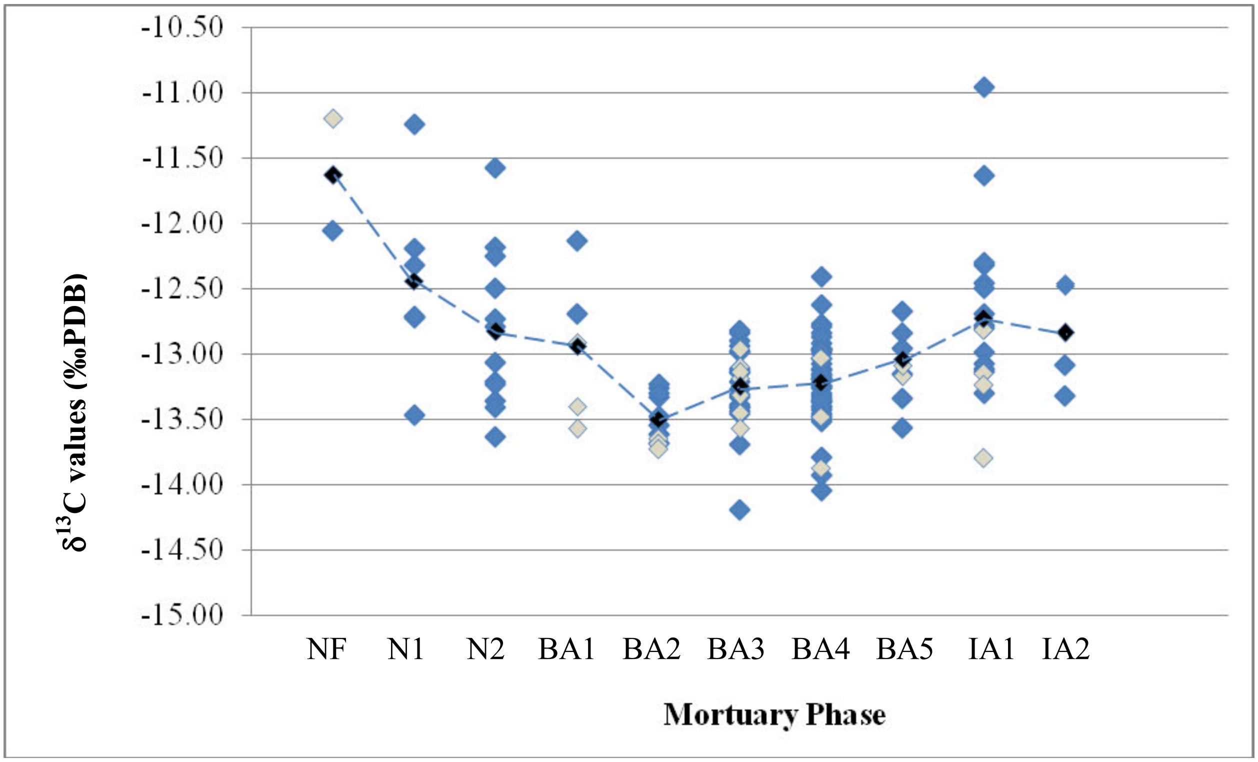


Figure 4.2 Ban Non Wat combined series δ13C values by mortuary phase (excludes Series 1 outliers).

Dark data symbols = Series 1 (King et al., 2013)
Light data symbols = Series 2
Dark points connecting lines = averages

The distribution of carbon and oxygen isotope compositions of tooth enamel carbonate for the combined series of both humans and pigs indicates five clear outliers from the Series 1 group, with elevated $\delta^{13}C$ values (Fig. 4.3), which were omitted from further comparisons within the combined series, as they were in King et al. (2013). These will be examined later in the discussion. There is a strong cluster of individuals with very few positioned outside the main cluster. This highlights the similarity in diet for the entire Ban Non Wat group (excluding extreme outliers). The pig values are scattered just outside the human cluster, indicating slightly more C_4 in the diet than humans.

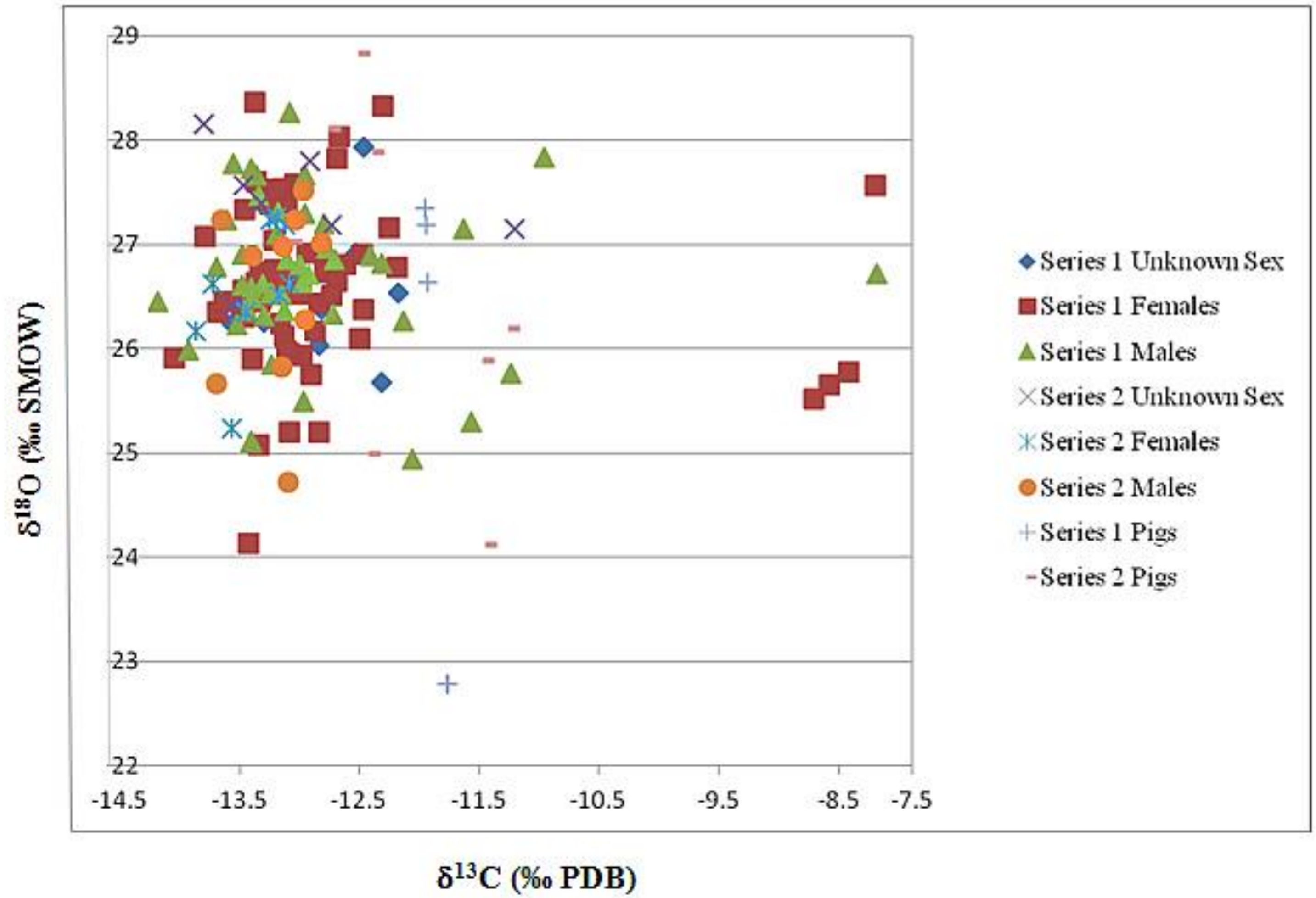


Figure 4.3 $\delta^{13}C$ and $\delta^{18}O$ values for Series 1 and 2 humans and pigs at Ban Non Wat

(Includes outliers) Analytical error ±2 S.E. for measured values is ±0.2 for $\delta^{13}C$ and $\delta^{18}O$ values.
***Series 1 = (King et al., 2013)values**

4.5.2 Hypothesis 2.2

Childhood diet was similar in males and females throughout the Neolithic, Bronze Age and into the early Iron Age at Ban Non Wat.

On average, females have slightly more negative $\delta^{13}C$ values than males in the majority of mortuary phases (Table 4.1), however this was not statistically significant in any of the mortuary phases that had large enough samples to test (see Appendix C Table 6).

Table 4.1

Average $\delta^{13}C$ values (‰) by mortuary phase and sex at Ban Non Wat for the combined Series 1 and 2.

Mortuary Phase	**Males (N)**	**Females (N)**	**Unknown Sex (N)**	**Overall mean $\delta^{13}C$ (‰ PDB)**	**Fauna from Series 2**
Neolithic Flexed (NF)	-12.1 (1)	-8.5* (2)	-11.2 (1)	-11.6 -10.1*	
Neolithic 1 (N1)	-12.3 (4) -11.4* (5)	-12.8 (2) -11.5* (3)	-	-12.4 -11.4*	-11.5 (2)
Neolithic 2 (N2)	-12.8 (3)	-12.9 (6)	-12.2 (1)	-12.8	
BA1	-12.8 (2)	-13.1 (2)	-12.9 (1)	-12.9	
BA2	-13.5 (6)	-13.6 (3)	-13.3 (2)	-13.5	
BA3	-13.4 (12)	-13.2 (11)	-13.1 (4)	-13.3	-12.4 (3)
BA4	-13.2 (17)	-13.2 (24)	-13.5 (2)	-13.2	
BA5	-13.2 (2)	-13.0 (5)	-13.1 (2)	-13.0	
IA1	-12.4 (6)	-12.9 (9) -12.5* (10)	-13.0 (3)	-12.7 -12.5*	-12.4 (3)
IA2	-13.1 (1)	-12.5 (1)	-12.9 (2)	-12.8	

Series 1 data from King et al. (2013) *Includes extreme outliers.

4.5.3 Hypothesis 2.3

Prehistoric people from the Upper Mun River Valley had similar $\delta^{13}C$ values during parallel time periods, due to the proximity and accessibility of similar resources.

Three Upper Mun River Valley populations, along with two other prehistoric samples from the distribution of sites in Thailand, all indicate a majority of the diet consisting of C_3 foods, with minimal influences from C_4 (Table 4.2). The two sites in closest proximity to Ban Non Wat, Ban Lum Khao (see: Bentley et al., 2009) and Noen U-Loke (see: Cox et al., 2011), both show significant differences in male and female $\delta^{13}C$ values compared with corresponding mortuary phases at Ban Non Wat (Table 4.2). Ban Non Wat has a greater influence from C_4 foods (*i.e.,* Ban Non Wat has less negative $\delta^{13}C$ values) than the neighbouring sites. Ban Non Wat also shows significant differences to the mid-late Phase Ban Chiang individuals and the early phase Ban Chiang females. Neolithic, coastal Khok Phanom Di is not significantly different from Neolithic Ban Non Wat.

Table 4.2

*Averages of $\delta^{13}C$ values at prehistoric Thailand sites *excludes all extreme outliers.*

Site	$\delta^{13}C$ (‰ PDB)		Tested against BNW Phase(s) (inclusive)	BNW[1,2] $\delta^{13}C$ (‰ PDB) for corresponding phases	
	Male	**Female**		**Male**	**Female**
Ban Chiang[3] Early Phase	-13.4 (19)	-13.7 (14)	NF-BA2	-12.9 (17) p=0.0709[c]	-13.1 (14)[a] p=0.00017[b]
Khok Phanom Di[4] Neolithic	-12.4 (23)	-12.5 (28)	N1-N2	-12.6 (8)[b] P<0.0001[c]	-12.9 (14)[a] p=0.0001[c]
Ban Lum Khao[5] Bronze	-13.9 (11)	-14.1 (15)	BA1-BA5	-13.3 (39)[a] p<0.0001[b]	-13.2 (45)[a] p<0.0001[b]
Ban Chiang[3] Mid/Late Phase	-13.5 (5)	-13.5 (3)	BA3-IA1	-13.1 (54)[a] p<0.4121[c]	-13.1 (48)[a] p<0.0291[c]
Noen U-Loke[6] Iron	-13.7 (16)	-13.9 (14)	BA5-IA2	-12.6 (9)[a] P<0.0001[c]	-12.9 (14)[a] P<0.0001[c]

[1]This study (Series 2), [2](King et al., 2013), [3](Bentley et al., 2005), [4](Bentley et al., 2007), [5](Bentley et al., 2009), [6](Cox et al., 2011).
[a]Indicates statistical difference with Ban Non Wat
[b]Unpaired t-test
[c]Mann-Whitney statistical test

4.5.4 Hypothesis 2.4

The diet at Ban Non Wat will differ significantly from late Iron Age Phum Snay and Phum Sophy due to the increasing intensification of agriculture. This will be apparent through diverse dental pathology profiles.

Table 4.3 presents a summary of the complete dental pathology profiles discussed in Chapter 3. This section will focus on using the known dental health profiles as an indicator of diet, whereas the previously detailed dental pathology prevalence's discussed in Chapter 3 were used as evidence of overall health. This section examines significant differences in dental pathologies between Phum

Snay and Phum Sophy with Ban Non Wat. With evidence from Ban Non Wat's $\delta^{13}C$ values, this section compares the profiles between the three groups suggesting the diet for Phum Snay and Phum Sophy.

Table 4.3

Proportion of total dental pathologies by tooth summary.

	Ban Non Wat	**Phum Snay**	**Phum Sophy**
Total advanced wear (A/O)	54/578	105/1878	99/975
%	9.3	5.6	10.2
Total caries (A/O)	34/536	228/2036	88/972
%	6.3	11.2	9.1
Total periapical lesions (A/O)	20/307	115/3164	44/953
%	6.5	3.6	4.6
Total AMTL (A/O)	21/681	111/4271	13/1867
%	3.1	2.6	0.7

A = teeth affected, O = observed teeth; [1] Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value; [2] All subadults are considered of unknown sex.

4.5.4.1 Advanced Wear

Comparison of dental pathology between Ban Non Wat and Phum Snay

Overall, Ban Non Wat's Neolithic, Bronze and Iron Age sequence has statistically more advanced wear than Phum Snay (Tables 4.4 and 3.8). Males and females between the sites have similar rates of advanced wear in both age classes. Older males have significantly greater amounts of advanced wear than females at both sites. In the older age class overall, Ban Non Wat has statistically more (approximately three times greater) advanced wear than the older Phum Snay.

Comparison of dental pathology between Ban Non Wat and Phum Sophy

Ban Non Wat older individuals have significantly more advanced wear than older people at Phum Sophy (Tables 4.4 and 3.8). The total number of females at Phum Sophy has statistically more advanced wear than the total number of females at Ban Non Wat. Younger males and females have similar low amounts of advanced wear. The older males at Ban Non Wat have greater quantities of advanced wear than the older Phum Sophy males, while the older Phum Sophy females have slightly greater prevalence than older Ban Non Wat females.

Comparison of dental pathology between Phum Snay and Phum Sophy

Advanced wear in the older age class was significantly more common in Phum Sophy than in the Phum Snay sample, despite similar low levels in the young age class at both sites (Tables 4.4 and 3.8). Phum Sophy and Phum Snay males had similar percentages in each age class and were higher than females in the older age class. Phum Sophy older females had nearly twice the percentage of teeth with advanced wear compared to older Phum Snay females, although the difference was not statistically significant.

Table 4.4

Site differences show Fisher's Exact Test (FET) p-values for advanced wear.

	Ban Non Wat and Phum Snay			**Ban Non Wat and Phum Sophy**			**Phum Snay and Phum Sophy**		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Young (A/O)	1.0000	0.7255	0.5123	1.0000	1.0000	0.6828		0.6861	1.0000
Old (A/O)	0.0814	0.4717	<0.0001	0.1563	0.7891	<0.0001	0.8722	0.1363	0.0004
Total (A/O)	0.0972	0.1381	0.0019*	0.7149	0.0025	0.6599	0.1864	0.0822	<0.0001*

FET p-value indicating differences between males and females; *Chi^2 p-value. Significant values are highlighted in red.

4.5.4.2 Caries

Comparison of dental pathology between Ban Non Wat and Phum Snay

Overall, Phum Snay had statistically more caries than Ban Non Wat (Tables 4.5 and 3.9). Phum Snay older females have significantly higher occurrences of caries than older Ban Non Wat females. Older adults at Phum Snay have significantly higher caries prevalence than older Ban Non Wat individuals. Ban Non Wat younger males have more caries than Phum Snay, while Phum Snay younger females have almost twice the amount of caries than Ban Non Wat. Statistically, the number of females at Phum Snay with caries was over double the number at Ban Non Wat. Also statistically, the number of older adults with caries at Phum Snay was greater than double the prevalence at Ban Non Wat.

Comparison of dental pathology between Ban Non Wat and Phum Sophy

Statistically, Phum Sophy young females had almost tripled the total caries than Ban Non Wat young females, while Ban Non Wat young males have statistically more caries than young Phum Sophy males (Tables 4.5 and 3.9). The total amounts of caries for females were significantly higher at Phum Sophy than Ban Non Wat. The total for the entire populations does not differ significantly, however Phum Sophy caries rates are higher than Ban Non Wat.

Comparison of dental pathology between Phum Snay and Phum Sophy

Caries rates are not significantly different between the Snay and Sophy dentitions for any age class or within either sex (Tables 4.5 and 3.9). Non-statistically, older Sophy males had nearly twice the caries frequency compared to Snay males. Female rates are generally similar in both age groups for both sites but are highest in Snay older females.

Table 4.5

Site differences FET p-values for caries.

	Ban Non Wat and Phum Snay			Ban Non Wat and Phum Sophy			Phum Snay and Phum Sophy		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Young (A/O)	0.2849	0.1565	0.4028	0.0137	0.0200	0.3490	0.1899	0.3617	0.9077
Old (A/O)	1.0000	0.1797	0.0152	0.2212	0.4692	0.1160	0.1526	0.3866	0.1969
Total (A/O)	0.1846	0.0045	0.0013*	1.0000	0.0081	0.0754	0.2567	1.0000	0.0835*

Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value. Significant values are highlighted in red.

4.5.4.3 Periapical lesions

Comparison of dental pathology between Ban Non Wat and Phum Snay

Periapical lesions were significantly higher overall at Ban Non Wat than Phum Snay (Tables 4.6 and 3.10), in all age categories except younger males.

Comparison of dental pathology between Ban Non Wat and Phum Sophy

Ban Non Wat and Phum Sophy have similar rates of periapical lesions (Tables 4.6 and 3.10). Old males at Ban Non Wat have significantly more lesions than males at Phum Sophy. Both younger groups do not differ significantly from one another. Ban Non Wat older individuals have a significantly greater prevalence of periapical lesions than the total Phum Sophy older group.

Comparison of dental pathology between Phum Snay and Phum Sophy

Periapical lesion frequencies were very low across the samples of Phum Snay and Phum Sophy. They were most common in Phum Sophy older females, significantly higher than Snay older females who showed no periapical infection (Tables 4.6 and 3.10). Males had very similar rates for both age classes across the sites.

Table 4.6

Site differences FET p-values for periapical lesions.

	Ban Non Wat and Phum Snay			Ban Non Wat and Phum Sophy			Phum Snay and Phum Sophy		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Young (A/O)	0.5051	0.0006	0.0004	0.4988	0.0563	0.1083	1.0000		0.0818
Old (A/O)	0.0128	0.0337	0.0003	0.0422	0.2213	0.0105	1.0000	0.0144	0.1521
Total (A/O)	0.1161	0.1531	0.0194*	0.3402	1.0000	0.1822	0.8248	0.0351	0.1992*

Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value. Significant values are highlighted in red.

4.5.4.4 AMTL

Comparison of dental pathology between Ban Non Wat and Phum Snay

Young males and females had similarly low prevalence of AMTL (Tables 4.7 and 3.11). Ban Non Wat AMTL rates for all older categories are statistically higher than Phum Sophy. However, Ban Non Wat and Phum Snay have comparably low rates of AMTL.

Comparison of dental pathology between Ban Non Wat and Phum Sophy

Ban Non Wat older age groups have statistically higher proportions of AMTL than Phum Sophy's older groups (Tables 4.7 and 3.11), however the younger age groups have equally low rates of occurrence of AMTL. Ban Non Wat total male AMTL rates are statistically greater than Phum Sophy older males. Overall, Ban Non Wat AMTL rates are statistically elevated compared to Phum Sophy.

Comparison of dental pathology between Phum Snay and Phum Sophy

Pathological AMTL was low in both samples, but the dentitions of older individuals from Phum Snay had significantly more than older Phum Sophy (Tables 4.7 and 3.11). Females in the older class at Phum Sophy had the highest percentage of AMTL, but this was not statistically significant. Phum Snay had a statistically higher frequency of AMTL than Phum Sophy.

4.5.4.5 Dental Pathology Profile

The dental pathology profile for Ban Non Wat, Phum Snay and Phum Sophy is presented in Table 4.8. The profile suggests a decline of advanced wear throughout time and increase of carious lesions. Periapical lesions decrease from Ban Non Wat to Phum Snay, then increase at Phum Sophy. AMTL declines slightly from Ban Non Wat to Phum Snay, with continued decreases at Phum Sophy.

Table 4.7

Site differences FET p-values for AMTL.

	Ban Non Wat and Phum Snay			Ban Non Wat and Phum Sophy			Phum Snay and Phum Sophy		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Young (A/O)	1.0000	0.2171	0.0542	0.2401	1.0000	0.1145	0.4315	0.3747	1.0000
Old (A/O)	0.0306	0.0090	0.0050	0.0103	0.0120	<0.0001	0.6988	0.7128	0.0220
Total (A/O)	0.1464	0.6465	0.5476*	0.0026	0.2486	<0.0001*	0.0639	0.2348	<0.0001*

Fishers Exact Tests p-value indicating differences between males and females; *Chi^2 p-value. Significant values are highlighted in red.

Table 4.8

Dental pathology profiles by sex and group of Ban Non Wat, Phum Snay and Phum Sophy.

	Total Males			**Total Females**			**Overall Total**		
	Ban Non Wat	**Phum Snay**	**Phum Sophy**	**Ban Non Wat**	**Phum Snay**	**Phum Sophy**	**Ban Non Wat**	**Phum Snay**	**Phum Sophy**
Advanced wear (%)	17.2	11.6	15.9	3.9	7.0	11.4	9.3	5.6	10.2
Caries (%)	7.5	4.5	7.2	3.9	10.4	10.3	6.3	11.2	9.1
Periapical lesions (%)	6.4	3.5	4.0	6.9	3.9	7.4	6.5	3.6	4.6
AMTL (%)	3.5	1.9	0.5	2.7	2.2	1.3	3.1	2.6	0.7

4.6 Discussion

4.6.1 Hypothesis 2.1

The $\delta^{13}C$ values of prehistoric Ban Non Wat people indicate a diet comprised mainly of C_3 foods, such as rice, with limited variation from the Neolithic to the Iron Age, suggesting stability during this time.

Results from King et al. (2013) indicate some significant differences in carbon isotope ratios between the mortuary phases in Series 1 which are not present with the addition of Series 2 burials and re-evaluation of the combined series. These additions to Series 1 allow for a greater representation of the prehistoric diet at this site. The Series 1 excavation was large in volume and sample size; however it only included one archaeologically excavated location at Ban Non Wat. The addition of Series 2 expanded the data set to allow a more holistic approach; however is it from these new results that the importance of additional work at this site, and other prehistoric sites is recognized.

Overall, the Ban Non Wat $\delta^{13}C$ values are consistent with a diet heavily reliant on C_3 foods, with minimal impact from C_4 foods throughout the Neolithic to the early Iron Age. Over the 2000 year period represented at Ban Non Wat, the average $\delta^{13}C$ values vary by a maximum of less than 2‰. According to Ambrose et al. (1997), a $\delta^{13}C$ value from enamel carbonate of −16.1‰ would indicate a pure C_3 diet, while a pure C_4 diet would lead to enamel with −4.6‰, and "[e]ach 1‰ difference in $\delta^{13}C$ thus equates to about 9 percent change towards the opposite end-member" (Cox et al., 2011, p. 667). This suggests that, on average, the Ban Non Wat diet was high in C_3 foods with a large component, roughly three quarters, of the diet consisting of predominantly C_3 foods such as rice and vegetables, with some freshwater fish and meat.

There was evidence of a gradual decrease in $\delta^{13}C$ values from the Neolithic to the early Bronze Age, presumably the time of greatest reliance on C_3 foods, followed by a slight increase in $\delta^{13}C$ values into the Iron Age (Fig. 4.2). Overall, this is indicative of a relatively stable childhood diet with only slight variations. The decreasing $\delta^{13}C$ values may indicate a gradual increase in reliance on rice from the Neolithic to Early Bronze Age which could coincide with a settling population (Neolithic) adapting to the local environment and increasing the community's ability to cultivate rice and therefore putting a greater emphasis on a rice diet as seen by the changing C_3/C_4

proportions in the diet. The decreasing $\delta^{13}C$ values may also be influenced by a reduction in meat or freshwater fish consumption and/or the environment from which the plant foods are sourced – more typical of closed-forest plants rather than open environments.

Average $\delta^{13}C$ values start to increase in BA 3 and continue to increase gradually into the early Iron Age; consistent with a gradual lessening reliance on C_3 relative to C_4 food. The significant difference from BA 2 to BA 3 (a difference of only 0.8‰) would actually equate to very little difference in the proportions of C_3 or C_4 foods consumed. This slight decrease in $\delta^{13}C$ values into the Iron Age supports evidence for the lack of major change; climate change effects were also thought to be gradual (Boyd, 2008) and not very evident until a particularly dry period in the mid-to-late Iron Age. The $\delta^{13}C$ values of pigs lie towards the more positive end (higher C_4) of the local cluster (Fig. 4.3). The slight increase towards more positive values after BA 2 may be the impact of pigs and other fauna in the human diet. These pigs were possibly consuming a more C_4 rich diet, as identified by the $\delta^{13}C$ values, such as millet, or perhaps humans were eating more meat or freshwater fish, which would also cause the $\delta^{13}C$ values to increase. There is no archaeological evidence of millet during this time at Ban Non Wat (Castillo, 2011), and millet is not believed to have had a large impact on the ancient diet in Thailand due to a lack of quantities discovered archaeologically (Weber et al., 2010). However, Guedes (2011) and Weber (2010) note that millet is a very small seed and is difficult to recover unless fine flotation recovery is carried out. Millet can grow in a wide range of environmental conditions (Weber et al., 2010; Weber & Fuller, 2008), so an increased reliance on millet during periods of drier climate at Ban Non Wat, such as during the Iron Age when rice may have been more difficult to cultivate, may not be out of the question. This would be consistent with the $\delta^{13}C$ values observed. Further analyses will be required to determine if millet was available during these times at Ban Non Wat in amounts that would have had an impact on human diet.

The superburials of BA 2 Series 1 are of archaeological significance. Series 1 $\delta^{13}C$ values indicated that a significant difference existed between BA 1 and 2; though the difference is now evident between BA 2 and 3 in the combined series. BA 2 superburials had a profusion of mortuary goods leading to the hypothesis that these were extremely wealthy and/or prestigious individuals in life (Higham & Hodges, 2013). There are no other individuals at Ban Non Wat who were interred with the abundance of artefacts seen in these burials. If the elite in a society had a different (and perhaps more luxurious) diet, as suggested by van der Veen (2003), then this could be reflected in the $\delta^{13}C$

values measured from these individuals, but more information such as $\delta^{15}N$ values and $\delta^{13}C$ values from bone collagen are needed to explore this further. With the addition of the Series 2 data allowing a greater representation of individuals within this community, no significant difference is evident between the super-burials and all other BA 2 burials, though there is a statistical difference between all of BA 2 and the BA 3 period. However, it needs to be emphasized that when the $\delta^{13}C$ values are translated into actual diet consumption the differences are very small (and are only just outside the 1 s.d. analytical error).

It is possible that even more extensive excavations across the site could reveal further super-burials. In this case it might be that the interpretation of these graves moves from a small group of elites in a hierarchical society to a representation of a 'style' (Kroeber, 1927) of grave popular for a short period of time (BA 2) in the history of Ban Non Wat. Smaller BA 2 graves, such as many of those in Series 2, might represent the beginning of the change in grave style evident during BA 3 when orientation and shape of grave differ from BA 2, as well as the amount of associated grave goods.

Alternatively, if we retain the assumption that hierarchy was in place during this period, it may be that the social competition that prompted the rise of social elites was very short-lived as suggested by Higham (2011). Perhaps this was so much so that childhood diets were not significantly different between elites and others in the living society even if adult access to high-status foods might have been different (it is important to keep in mind that the $\delta^{13}C$ values reported here only detail childhood diet). This could lead to a more interesting conclusion. Does a similarity in childhood diet, but a significant difference in grave wealth in adulthood, imply achieved rather than inherited status during BA 2 at Ban Non Wat? In this case, Boyd and Chang's (2010) argument of an essentially stable social structure through the Neolithic and Bronze Age and Higham's (2011) discussion of temporary 'high-status lineages' might not be so far apart. The ripple in society that coincides with the appearance of metallurgy may be simply that, a ripple that is quickly quieted as the new technology is incorporated into an otherwise stable social and environmental system.

4.6.2 Hypothesis 2.2

Childhood diet was similar in males and females throughout the Neolithic, Bronze Age and into the early Iron Age at Ban Non Wat.

The Series 1 data from King et al. (2013) found significant differences between the sexes within BA 2 and within BA 3 and suggested there were distinct gender roles within the society. This sex difference in childhood diets is not present in the combined series data, nor is any other sex differences within other mortuary phases. King et al. (2013) noted a lack of sex difference in mortuary goods in Series 1, and this lack of sexual differentiation in mortuary practice is also seen in Series 2, suggesting that a lack of distinction between the sexes was carried through from childhood to adult life.

4.6.3 Hypothesis 3.3

Prehistoric people from the Upper Mun River Valley had similar $\delta^{13}C$ values during parallel time periods, due to the proximity and accessibility of similar resources.

Rice was an important staple of the diet in all three Upper Mun River Valley sites (Ban Non Wat, Ban Lum Khao and Noen U-Loke), leading to the generally low $\delta^{13}C$ values (Table 4.2). However, results indicate that the Ban Non Wat males and females had statistically more positive $\delta^{13}C$ values than their close neighbours at Ban Lum Khao and Noen U-Loke when time periods are contemporaneous. This is similar to that found when comparing Series 1 data to surrounding sites (King et al., 2013).

Differences between Ban Non Wat and Ban Lum Khao could be due to a sampling bias as the Ban Lum Khao sample was excavated from the edge of the village mound where it is possible that people with less access to high status foods might be buried (Bentley et al., 2009). On the other hand, the people of Ban Lum Khao most likely consumed a diet similar to the occupants of Ban Non Wat, comprising predominantly C_3 foods, fish, rice, and cattle (Bentley et al., 2009) but with some variation in the proportion of freshwater fish or terrestrial meat between the communities.

The comparable Iron Age periods between Ban Non Wat and Noen U-Loke coincide with the appearance of evidence of moats around these villages. This "appears to have been a response to change in water availability, especially the reliability of that supply" (Boyd & Habberfield-Short, 2007, p. 1). Moats are present at both sites suggesting a similar economy and diet; however, $\delta^{13}C$

values representative of childhood diet are lower at Noen U-Loke and could suggest that rice was a more important component of childhood diet, or that the overall diets consisted of different proportions of C_3 and C_4 foods compared to Ban Non Wat just 2km away. One explanation may be that as the water supply became less reliable communities experimented with different agricultural responses. At Noen U-Loke, located within the floodplain, this might have involved more intensive rice production, reflected not only in the diet but also in the 'rice-bed' burials (Higham et al., 2007) that indicate increased ritual use of rice as well (Boyd & Chang, 2010; Talbot, 2002). At Ban Non Wat, located immediately on the edge of the flood plain with easy access to drier land, it is possible that millet began to be incorporated into the diet, or other C_4 foods affecting human $\delta^{13}C$ values. This could explain the direction of shift in $\delta^{13}C$ values between the two communities, but direct evidence of millet in the region remains to be found (Castillo, 2011; King et al., 2013).

In the larger picture, differences in male and female overall childhood consumption of C_3 and C_4 foods of Noen U-Loke, Ban Lum Khao and Ban Non Wat were very small. The question is whether these numbers represent a substantial difference in lifestyle and economic activity in the living communities. It seems unlikely that societies so close to each other would have lived in such different ways at any one time. However, there is evidence for distinctive differences in health between prehistoric Upper Mun River Valley communities that may contribute to this picture (Domett & Tayles, 2006a). Future research is required to determine if these statistically significant differences in the balance between C_3 and C_4 foods actually reflected significantly different lifestyles.

Turning to comparisons within Thailand, the upper northeastern Thailand site of Ban Chiang has significantly different $\delta^{13}C$ values than Ban Non Wat in the mid-to-late phase and in the early phase females (Table 4.2). However, Ban Chiang also appears to be heavily reliant on C_3 foods such as some domesticated animals and rice (Bentley et al., 2005).

The dietary isotope signature of males and females at Ban Non Wat does not differ significantly from that of Khok Phanom Di, a Neolithic coastal site in southeast Thailand (Fig. 1.1 and Table 4.2). This is interesting since Khok Phanom Di inhabitants would have had access to more C_4 foods or marine resources, though there was some evidence for rice during some MPs (Bentley et al., 2007) and Neolithic Ban Non Wat people did not have access to coastal marine foods. Therefore, the Khok Phanom Di diet was probably reliance on a greater amount of marine resources, while the latter would have relied on another C_4 source causing similar $\delta^{13}C$ values.

Looking more closely to Ban Non Wat, the outlier individuals are important. Series 1 identifies five outliers who fall well outside the standard deviation of the sample (1 male from the Neolithic, 3 females from the Neolithic and 1 female from the Iron Age) (King et al., 2013), and these remained outliers once the datasets were combined, with $\delta^{13}C$ values ranging from −8.2‰ to −8.7‰. These values represent a higher proportion of C_4 foods in the diet (remembering a pure C_4 diet would give a $\delta^{13}C$ value of −4.6‰). A diet rich in millet might cause values in this order. Could it be that these outliers are individuals coming to Ban Non Wat from millet growing areas such as Central Thailand (Weber et al., 2010) or even as far away as Yunnan (d'Alpoim Guedes, 2011)? The potential for isotopic analysis from Central Thailand represents an exciting opportunity to examine this question.

More importantly in the present argument, the considerably larger differences between these outlying individuals and the remainder of the Ban Non Wat population suggest that we should be careful of making too much of the smaller differences observed between Ban Non Wat and its immediate neighbours.

4.6.4 Hypothesis 4.4

The diet at Ban Non Wat will differ significantly from late Iron Age Phum Snay and Phum Sophy due to the increasing intensification of agriculture. This will be apparent through diverse dental pathology profiles.

Note: the majority of the Ban Non Wat individuals examined for their dental pathology profiles were from the Bronze Age, with limited samples from the early Iron Age.

The dental health profiles suggest the late Iron Age Phum Snay and Phum Sophy had significantly different diets from (primarily) Bronze Age Ban Non Wat. Interestingly, the dental health profiles also contrast significantly between Phum Snay and Phum Sophy. This variation is surprising, since the two communities are in close proximity and had access to similar resources. The demographic profiles of the samples were not identical, with a significantly greater number of older male teeth (but not tooth positions) and younger female teeth (but not tooth positions) at Phum Snay compared with Phum Sophy, but this does not explain all the differences. A greater number of older males at Phum Snay with advanced wear are expected, for example, but this is not the case. The key may be the difference in the way the communities interacted with and utilised their local environments, for example with a significant subsistence change.

A decline in advanced wear is present in many agricultural communities around the world, in comparison to hunter-gatherer societies (Eshed et al., 2006). It can be suggested that in general, the decreased extent of advanced wear at Phum Snay and Phum Sophy suggests a softer diet compared to Bronze Age Ban Non Wat. Ban Non Wat's increased advanced wear and lower incidence of caries is suggestive of a more abrasive diet lower in carbohydrates, but high in protein, similar to hunter-gatherer populations in the Levant (Eshed et al., 2006). Males have a higher prevalence of advanced wear than females. However, at Ban Non Wat this could be due to the very small older female sample. At Phum Snay the younger age groups have similar percentages of advanced wear, while significant changes are seen in older age, suggesting sexual differences in diet into adulthood with male diet constituting tougher and/or grittier foods. The prevalence of advanced wear between males and females is not statistically different at Phum Sophy, but appears to be higher in the older males. The higher frequency of advanced wear in the older age class at Phum Sophy may be explained by dietary differences, such as a higher consumption of shellfish. Phum Sophy older males may have eaten a softer diet in old age, which could also explain why older individuals at Phum Sophy had such low levels of AMTL. Males do have more advanced wear than females in the older and overall groups, which could be contributed to differences in diet starting after younger adulthood. Males may shift to a softer diet if they are not involved with hunting and/or fishing trips when an older adult. The lower amounts of advanced wear at Phum Snay and Ban Non Wat females could also be associated with the generally younger population at these sites, in comparison to Phum Sophy. However, the higher proportion of anterior versus posterior teeth with advanced wear in the Phum Snay and Phum Sophy samples suggests this may be more than a dietary difference. Further investigations into antemortem chipping, interproximal wear facets and general wear patterns may be useful for determining potential changes in use of teeth and distinguishing dietary from non-dietary causes of wear.

The Phum Snay and Phum Sophy profiles identify increased amounts of caries in comparison to Ban Non Wat, especially in the female sample. Increased dental pathologies, in particular female caries rates, are evident in agricultural communities and appear to be caused by a number of factors such as increased cariogenic foods and female physiology (Larsen, 1995; Lukacs, 1996; Lukacs, 2008, 2011b). This may be due to variation in food preparation methods; refined rice (milled and polished) has a higher cariogenicity than unrefined brown rice (Juliano, 1993). A range of non-dietary factors can also influence caries development that are difficult to discern from prehistoric skeletons including frequency of eating, oral pH levels, and dental hygiene (Tayles et al., 2009). As a general trend, females tend to have a higher amount of caries throughout prehistory (Lukacs &

Largarspada, 2006), but this is not evident at Ban Non Wat, probably due to the small older adult female population. Lukacs (1996) determined sex differences in caries become more apparent, and female oral health declines at a greater rate than male oral health during the transition to agriculture (Lukacs, 2008). It has been suggested that cultural factors (such as sexual division of labour) (Okazaki et al., 2013) contribute to the increases of caries in females. The sex differences at Phum Snay and Phum Sophy are indicative of different diets stemming from a sexual division of labour and both sites demonstrate evidence of higher female caries. Lukacs (1989) explains the combination of low caries and high advanced wear is typical of hunter-gatherers, which is seen in the Phum Snay older males. Meanwhile, high caries with low advanced wear is associated with agricultural diets, as seen in the Phum Snay older females. Differences in labour indicated females had greater contact with the agriculture, and therefore ate a diet higher in carbohydrates, while males had a diet higher in protein than females (Douglas, 2006). The significant differences between male and female diet at Phum Snay and Phum Sophy are suggestive of females from these groups had greater dependence on agricultural foods. It can also be suggested that older males from Phum Sophy may have had a diet with a higher contribution from carious foods into older age by the significant increases in caries from younger to older age, and similarities of carious lesions with the older females at the site.

Ban Non Wat has a higher prevalence of periapical lesions compared to Phum Snay and Phum Sophy. However, the higher percentage of periapical lesions at Ban Non Wat stems from just the profiles of two individuals (one male and one female); otherwise the periapical lesion levels were very low for the population (Table 4.6 & 4.8). Excluding these individuals from the sample, the periapical lesions for Ban Non Wat females would be 1.7%, and 2.3% for males, with a much lower total population percentage at 2.2%. The female population had a significant rise of periapical lesions into older age, potentially due to increased infections from poor health, or as suggested above, perhaps females were using their teeth for other non-dietary causes. Therefore, it can be suggested that the overall prevalence of periapical lesions also increased into the late Iron Age, especially for the Phum Sophy females.

The similar percentages of dental pathologies between males and females at Ban Non Wat may indicate dental health sex differences were not evident during the Bronze Age into the early Iron Age. The higher caries rate in Phum Snay and Phum Sophy females could be due to the consumption of more cariogenic and softer foods such as taro, yams, rice and millet, and sugars from bananas and palm sugar (Tayles et al., 2000; Weber et al., 2010). However, millet consumption is not always correlated with high caries rates, as seen in the Shaanxi province in Northeastern China (Pechenkina et al., 2002). Alternatively, the introduction of C_4 foods into the diet has been documented to increase the caries and alveolar resorption levels, in particular for females, in groups such as the Bunun Tribe of Taiwan (Okazaki et al., 2013). While evidence of C_4 foods is limited in late Iron Age Cambodia, the introduction of such foods may have entered the communities through trade. More sugary foods, rather than more starchy carbohydrates, may be the culprit, alongside non-dietary factors.

During the late Iron Age local control over resources, including water and agricultural land, and commodities for exchange including salt and fish, is likely (Domett et al., 2011b; O'Reilly et al., 2006a) and may have lead to intercommunity violence. This is evident through the significantly higher levels of violence recorded at Phum Snay (23.4% with cranial trauma compared with only 2.8% at Phum Sophy) (Domett et al., 2011b). Subsistence practices at Snay may have been affected by the greater social tension in this community and as a result, procurement territories may have been restricted. However, archaeological evidence does indicate a large number and range of wild and domesticated species were available at Phum Snay (O'Reilly et al., 2006a). The sample from Phum Sophy is from later in the Iron Age (AD 100–600) compared with Phum Snay (350 BC to AD 200) and perhaps socio-political changes were now in place with increased control and less violence. Additionally, Phum Sophy is approximately 40 km west of Phum Snay, further from the eventual centre of the Pre-Angkorian Empire, and may have been less exposed to its influences. However both Phum Sophy and Phum Snay are in close proximity to Angkor, in the region identified as the Pre-Angkorian state between the expansions of Angkorian influence in northeast Thailand and the city of Angkor in northwest Cambodia. The Phum Snay and Phum Sophy communities were also much closer to the eventual centre of the Angkorian civilization and may have been more affected by the increasing levels of external control prior to establishment of state rule compared to northeast Thailand and southern Cambodia. This may have meant that certain foods were increasingly under external control and thus limited in their availability.

4.7 Summary

Hypothesis 2.1: *The $\delta^{13}C$ values of prehistoric Ban Non Wat people indicate a diet comprised mainly of C_3 foods, such as rice, with limited variation from the Neolithic to the Iron Age, suggesting stability during this time.*

Ban Non Wat childhood diet is consistently high in C_3 with minimal C_4 contributions throughout all mortuary phases.

The Neolithic to mid-Bronze Age at Ban Non Wat witnessed a gradual decrease of $\delta^{13}C$ values, corresponding to a greater reliance on C_3 foods.

There was a significant dietary change between BA 2/3 (also corresponding with the least dietary variation), after which the diet gradually increases in $\delta^{13}C$ values into the Iron Age however not to the same levels as the Neolithic.

The superburials have similar childhood diets to the other burials in the same mortuary phase, suggesting status was earned, rather than inherited.

Hypothesis 2.2: *Childhood diet was similar in males and females throughout the Neolithic, Bronze Age and into the early Iron Age at Ban Non Wat.*

Males and females have consistently similar childhood diets from the Neolithic to early Iron Age at Ban Non Wat.

Hypothesis 2.3: *Prehistoric people from the Upper Mun River Valley had similar $\delta^{13}C$ values during parallel time periods, due to the proximity and accessibility of similar resources.*

Ban Non Wat had statistically greater amount of C_4 contributions to the diet than neighbouring sites Ban Lum Khao and Noen U-Loke, suggesting a different diet (though still largely based on rice), landscape and use of resources.

Ban Non Wat also had a statistically different diet than Ban Chiang mid/late phases, and early phase females. However, there was no statistical difference between the diets at Ban Chiang early phase males, and Khok Phanom Di, suggesting similar dietary reliance and resources.

Hypothesis 2.4: *The diet at Ban Non Wat will differ significantly from late Iron Age Phum Snay and Phum Sophy due to the increasing intensification of agriculture. This will be apparent through diverse dental pathology profiles.*

Phum Snay and Phum Sophy dental pathologies profiles suggest a softer diet high in cariogenicity, especially for females, than at Ban Non Wat.

Note: A portion of this chapter has been incorporated into the article in review *Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand* in Appendix D.

Chapter 5 Migration

5.1 Introduction

This section uses evidence from strontium isotopes, mortuary context and health from individuals at Ban Non Wat to examine the migratory patterns at this site. In addition, cultural evidence in the form of intentional dental modification and mortuary goods from Phum Snay and Phum Sophy will be examined in an attempt to identify migrants and evidence of trade.

Strontium isotope signatures ($^{87}Sr/^{86}Sr$) have been used in numerous studies worldwide to determine migratory patterns (e.g. Bentley et al., 2004; Ericson, 1985; Ezzo et al., 1997). Using dental enamel, residence during childhood while the enamel was forming, can be established (Ericson, 1985; Knudson, 2008; Price et al., 1994) by comparing dental isotope markers to local strontium signatures. Human tooth enamel is formed in the permanent molars until approximately age 16 years (Hillson, 1996) and does not alter past this point, allowing isotopic signatures from the enamel to geologically determine where the child spent most of their time during enamel formation (Wright, 2005). Isotopes can also help establish links with subsistence change. However, since strontium analysis is relatively new in Southeast Asia, limited comparative site data are available to determine childhood residence. Instead, strontium isotope values can assist with identifying individuals who migrated into the community. Many studies of migration focus solely on $^{87}Sr/^{86}Sr$ values to determine outliers to a community, while some studies have started pairing other isotopic methods, such as lead (Budd et al., 1998; Montgomery et al., 2000), and oxygen (Budd et al., 2004; Evans et al., 2006). Shaw et al. (2011) explored the correlation between isotopes, biology and archaeology to establish the social identity of individuals, and found it useful to assess a number of factors. Health and diet information, such as linear enamel hypoplasia and differences in local diet, from the previous section will be used to identify outliers. Using a timeline established from dental linear enamel hypoplasia it can be determined when the stressors took place, and if the stressors impact caused migration. Conceivably, stressors from their original community caused these individuals to relocate, and differences in diet would be identified. It can be suggested individuals decided to leave their community for environmental or socio-political stressors. For example, Ahlstrom, et al. (1995) revealed people in the late 13th century from North America probably relocated to more favourable environmental conditions. Additionally, Ezzo, et al. (1997) suggest unfavourable environmental conditions in North America may have led to migration, such as an unstable food supply, or the need for protection during violent times, or even disease. Therefore, evidence of childhood stress might assist with identification of migrants.

5.1.1 Migration at Ban Non Wat

Chapter 4 identified that the diet was generally stable at Ban Non Wat, evident by gradual changes of $\delta^{13}C$ into the early Iron Age and indicating access to similar foods. However, those results suggest Ban Non Wat had statistically different whole diets from the neighbouring groups at Ban Lum Khao and Noen U-Loke. Isotopic evidence suggests strontium present in the dental enamel and local geology should be a reflection of the local diet (Price et al., 2002). Therefore, based on significantly different diets from nearby communities, Ban Non Wat should display its own distinctive strontium values than the neighbouring sites of Ban Lum Khao and Noen U-Loke.

If dental enamel or bone collagen is unavailable, isotopic data analyses are incapable of being assessed. Ban Non Wat skeletal remains lack collagen, which means testing the bone is unfeasible (King et al., 2011). Therefore, the use of other factors such as archaeological and biological evidence might be the only opportunity to support the suggestion of migration to a prehistoric community. The goal is to approach this study by using isotopes and then identify bioarchaeological clues which may assist with identification of migrants. “Biocultural information such as age, sex, burial position and the distribution of burial goods in a cemetery may also offer detailed insights into the social structure of a prehistoric community” (Shaw et al., 2011, p. 344). Therefore, this study incorporates additional information such as indicators of stress, and mortuary goods to assist with identifying outliers to the prehistoric communities.

5.1.2 Phum Snay and Phum Sophy

At this stage the $^{87}Sr/^{86}Sr$ results undertaken by other investigators for Phum Snay and Phum Sophy have not been released. Alternative methods, for example biological and cultural evidence, are therefore examined as a possible way of identifying migrants into these two communities. The small number of excavated individuals in possession of grave goods is analysed to link mortuary goods with migration. This section observes all available resources for identification of migrants such as mortuary goods and dental modification as a substitute for isotopic signature data.

5.1.3 Prehistoric Southeast Asian migratory patterns

Examination of migratory patterns is imperative for determining the populations and numbers who were relocating, and why, in prehistoric Southeast Asia. One hypothesis by Bentley et al. (Bentley et al., 2007) suggest migration was a factor which assisted with the spread of agriculture in Southeast Asia. This leads to a second hypothesis by Bentley et al. (Bentley et al., 2007) stating that the Neolithic people of Khok Phanom Di were initially patrilocal, until about 1700-1650 BC, after which time they change to matrilocal social structures, which appears to coincide with an increase in rice production. The Bronze Age site of Ban Chiang exhibits a high amount of $^{87}Sr/^{86}Sr$ variation until ~900 BC, after which female variation decreased, suggesting an increase of local female residency (Bentley et al., 2005). Bentley et al. (2007; 2005) suggest the shift to matrilocal societies in prehistoric Thailand may have contributed to the intensification of agriculture in Southeast Asia. It is thought that women bringing new agricultural skills and being prized for their pottery making abilities may be contributing factors, along with sexual divisions in labour limiting female movement from the settlement during the Neolithic (Bentley et al., 2007). The nearby Bronze Age site of Ban Lum Khao showed distinct groups of women and early outliers to the community migrating from outside the Mun Valley (Bentley et al., 2009), indicative of a patrilocal society.

In prehistoric Cambodia and surrounding regions, the evidence of prehistoric migration has been limited. Recently, Morita et al. (2012), and Kusaka et al.(2009; 2008; 2011) examined the possibility of migratory patterns paired with dental modification in Japan. Tayles (1996) examined the possible burial patterns linked with dental modification at Khok Phanom Di, suggesting some possible links to family patterns within the site during certain time periods. It is suggested distinct dental modification patterns may be a way to identify groups. Evidence of similar patterns across different sites may indicate movement of groups, while unique patterns might indicate immigrants from other communities not yet discovered. To date, the only evidence of documented dental modification is investigated by Domett et al. (2011a). Through their work, potential reasons for practices of ablation are explored. Finucane et al. (2008) express the need for further research to determine if dental modification has any links with identification between groups. Evidence for community identification may have been required during periods of rapid socio-political change. Additionally, as noted in Section 1.3 the Iron Age witnessed widespread trade between communities. This could further suggest a requirement to identify oneself from different communities.

5.2 Hypothesis 3

Migration in the Neolithic will bring new ideas and population growth in Southeast Asia though through time there will be a decrease in migration from outside the immediate catchment area of the community. However, extensive inter-community trade with groups from further distances will flourish throughout the late Iron Age bringing negative health consequences

This chapter explores Hypothesis 3 (Section 1.8.3) by examining the following sub-hypotheses:

Hypothesis 3.1: *There will be a discrete range of local $^{87}Sr/^{86}Sr$ values at Ban Non Wat identifying Ban Non Wat from other communities in Thailand. Individuals outside these values are considered migrants to the community.*

Hypothesis 3.2: *There will be very few migrants from outside of the Mun River catchment area after the significant dietary change around BA 2/3.*

Hypothesis 3.3: *Bioarchaeological evidence might provide proof of migrants where isotope studies are not available.*

5.3 Materials

Refer to Sections 3.3

5.3.1 Isotope materials

The Series 2 human remains excavated from BNW consisted of 61 individuals. Of these, 26 had a permanent molar (see Appendix E Table 1 for details of selected tooth per individual) selected for isotopic analysis from five units: one Neolithic, 19 Bronze Age, five Iron Age, and one for which the assignment to mortuary phase remains uncertain (Appendix E Table 1).

5.4 Methods

5.4.1 Age and sex estimation

Refer to Sections 2.6.1 and 2.6.2.

5.4.2 Statistical analysis

Statistical testing was performed using unpaired t-tests with Welch's correction, and Mann-Whitney tests, with the significance set at $p<0.05$.

5.4.3 Strontium Isotope analysis

The following section was written by Charlotte King.

Each analysis was conducted upon a chip of dental enamel weighing between 5 and 10 milligrams (mg). These chips were removed from the body of the tooth, scraped clean of their dentine and mechanically cleaned of particulates and calculus on their surfaces using a surgical steel scalpel. Removal of diagenetic components was conducted according to the method of Koch, et al. (1997), through soaking each sample in 10% volume acetic acid overnight followed by removal of the leachate, washing with MilliQ and drying down.

Strontium was purified from samples before MC-ICP-MS analysis using established procedures of column chemistry (Charlier et al., 2006). Enamel samples were dissolved in 500 micro litres (µl) 16 molar (N) nitric acid (HNO_3) on a hotplate (at 90ºC) for one hour. Excess HNO_3 was then removed through evaporation, and the sample dried down on the hotplate (at 120ºC). 400µl of 3N HNO_3 was then added to the residue and the sample re-dissolved. Repeated dissolution ensures that the final solution is clear and free of precipitates.

Columns were made up of a standard 1 millilitre (ml) pipette tip fitted with polypropylene frit. Columns were washed thoroughly with one column volume of 6N hydrogen chloride (HCl), then 2 column volumes of MilliQ water, before 100µl strontium (Sr) spec™ resin was loaded into the column. Samples were loaded into columns using standard pipetting procedures, and washed through with a further two 200µl aliquots of 3N HNO_3. Collection beakers were then placed under columns and collection beakers beneath the columns, and strontium released by washing with two 250µl aliquots of MilliQ.

In order to ensure that contamination of the sample was not occurring during column chemistry, procedural blanks were prepared and analysed alongside samples. At least two procedural blanks were included in each batch of column chemistry. In order for results to be valid the amount of Sr in blanks should be <1% of the sample's Sr concentration, in this study no procedural blanks exceeded 75pg Sr, while the threshold for analysis was set at 1000pg.

5.4.4 Carbon and Oxygen Isotope analysis

Refer to Section 4.4.2

5.4.5 Indicators of health

Refer to Sections 3.4.2 and 3.4.3.

5.4.6 Dental modification

The following dental modification methods are from Domett et al. (2011a).

The condition of all teeth was recorded in detail, with differentiation of antemortem and postmortem loss of teeth based on evidence of alveolar remodelling. The absence of a tooth may be caused by a variety of factors, including congenital failure to develop (agenesis), failure to erupt, pathological or accidental loss, or intentional removal (ablation). Differentiating between these causes requires a detailed assessment of the surrounding alveolar bone and teeth. In order for intentional ablation to be considered the most likely 'diagnosis' there should be no evidence for disease in the adjacent teeth or alveolar bone, symmetry or near symmetry of tooth loss should be apparent, and the pattern of loss should be repeated among individuals within the sample (Buikstra, 1987). In addition, the amount of space remaining and the presence or absence of interproximal wear facets on remaining adjacent teeth were recorded (Milner et al., 1991). The presence of the last two characteristics confirms that a tooth had been present, allowing a differentiation between antemortem loss and agenesis. Only maxillae and mandibles with a complete set of anterior teeth (canines, lateral and central incisors) were included in this analysis. Results are presented as proportions of the total number of complete maxillae or mandibles and not presented by individual as the majority of observations were made on isolated maxillae or mandibles.

Dental abrasion (filing) was also recorded systematically. Abrasion can be defined as "[w]ear that results from contact with objects other than teeth" (Hillson, 2008: 309). Differentiating between intentional abrasion and that resulting from using teeth as tools requires careful observation of the pattern and location of abrasions, the symmetry of teeth affected and the overall prevalence in a population (Blakely & Beck, 1984). For example, when used as tools, teeth typically display asymmetrical wear, while intentional modification tends to be symmetrical. This might be through deliberate modification, using teeth as tools, or through contact with abrasive foodstuffs or other artefacts (Domett et al., 2011a). In addition, task-related activities are inclined to affect the occlusal or interproximal surfaces of teeth, while intentional abrasion is carried out on crown edges or labial surfaces (Blakely & Beck, 1984). Results on the abrasion of teeth are presented per maxilla or mandible but included some incomplete anterior dentitions if they had obvious signs of intentional abrasion.

5.5 Results

5.5.1 Hypothesis 3.1

There will be a discrete range of 'local' $^{87}Sr/^{86}Sr$ values at Ban Non Wat identifying Ban Non Wat from other communities in Thailand. Individuals outside these values are considered migrants to the community.

5.5.1.1 Series 2

The Ban Non Wat $^{87}Sr/^{86}Sr$ values are found in Appendix E Table 1. The average $^{87}Sr/^{86}Sr$ at Ban Non Wat is 0.709656 +/- 0.0002, inclusive of all individuals from Series 2. A range of two standard deviations includes the values 0.709256-0.710056. Males and females have similar $^{87}Sr/^{86}Sr$ values and ranges, p=0.0937.

Two outliers at Ban Non Wat are identified by their $^{87}Sr/^{86}Sr$ values of 0.710154 (B.654) and 0.708912 (B.676) (Fig 5.1). Omitting these extreme outliers, the average $^{87}Sr/^{86}Sr$ is 0.709666 +/- 0.00009, with a range of 0.709522-0.709818. The range recognizes wherein most BNW individuals lie. The $^{87}Sr/^{86}Sr$ value Burial 654 is 0.710154, which is greater than six standard deviations from the mean and the $^{87}Sr/^{86}Sr$ value for Burial 676 is 0.708912, which is greater than seven standard deviations from the mean.

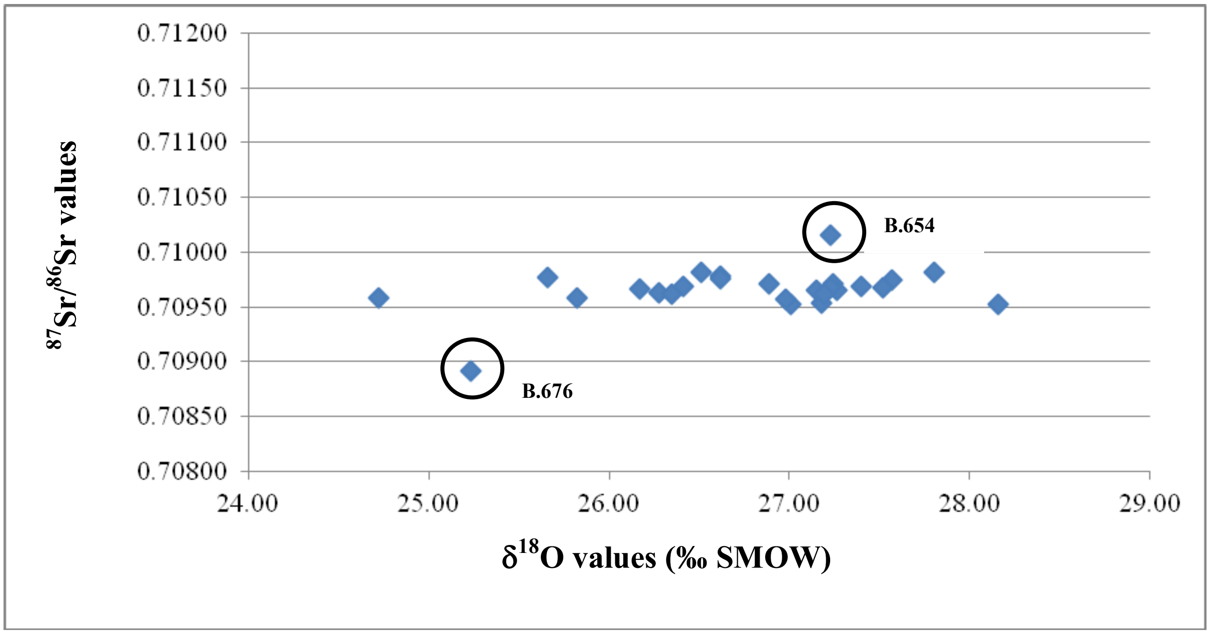


Figure 5.1 Ban Non Wat $^{87}Sr/^{86}Sr$ values per individual with outliers identified

***The circled individuals are suggested $^{87}Sr/^{86}Sr$ migrants to Ban Non Wat.**

Figure 5.2 shows the $^{87}Sr/^{86}Sr$ values for Ban Non Wat Series 2 and other prehistoric distributed sites in modern day Thailand. Table 5.1 displays the statistical significance between the $^{87}Sr/^{86}Sr$ values of other prehistoric sites within Thailand. Ban Non Wat's $^{87}Sr/^{86}Sr$ values from Series 2 are statistically different from all other Thailand sites ($p<0.05$). The average Ban Non Wat $^{87}Sr/^{86}Sr$ values are statistically different to the nearby sites of Ban Lum Khao and Noen U-Loke, ($p=0.0160$, $p=0.0014$ respectively). However, Ban Lum Khao and Noen U-Loke are not statistically different ($p=0.6553$) from each other while all other sites statistically differ from one another ($p<0.0001$). Both Ban Chiang and Khok Phanom Di, sites a great distance away from Ban Non Wat, also display significantly different $^{87}Sr/^{86}Sr$ values (both $p<0.0001$).

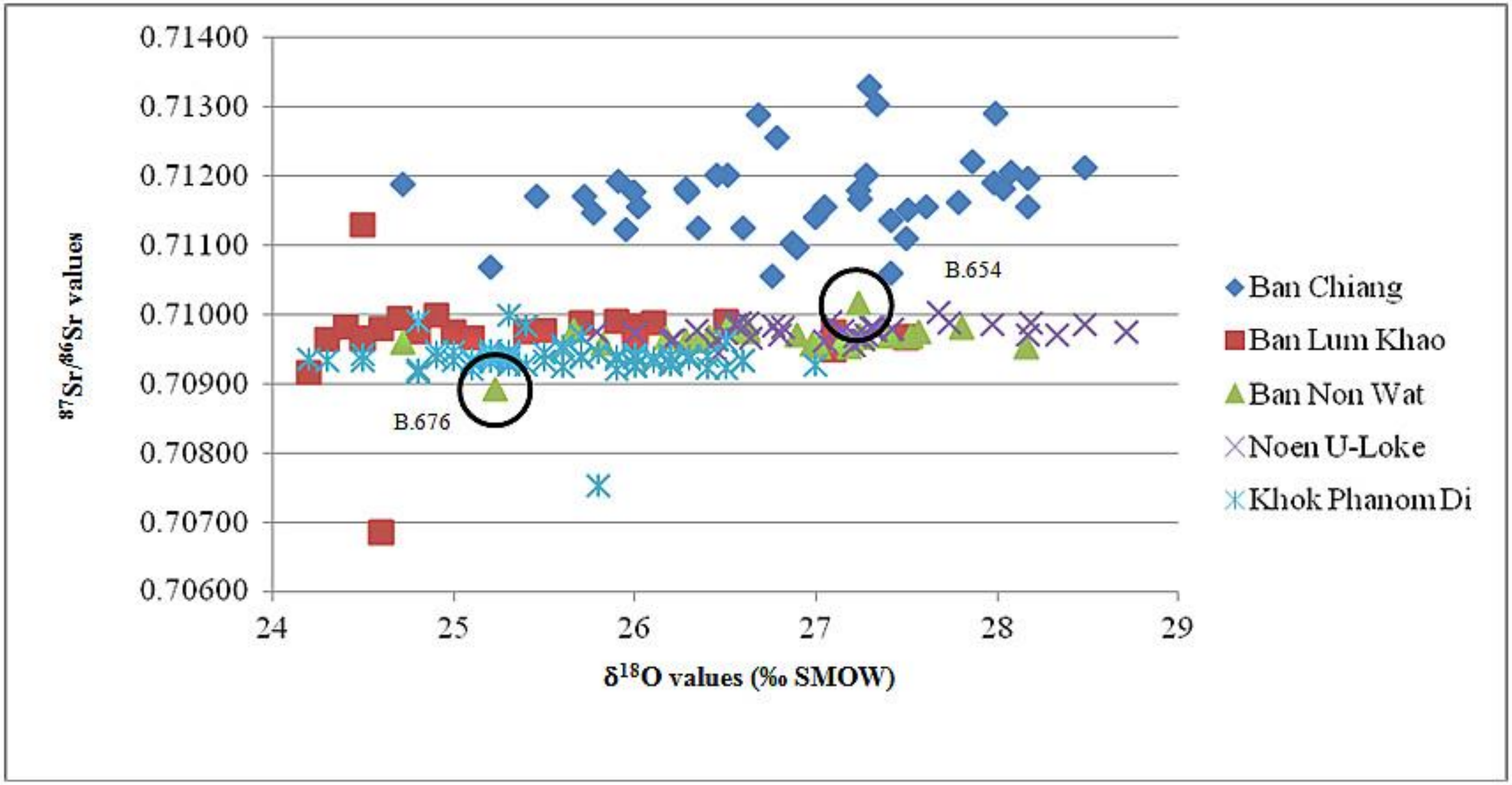


Figure 5.2 $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values for individuals from prehistoric sites in Thailand

Ban Non Wat: This study (Series 2); Ban Chiang:(Bentley et al., 2005); Ban Lum Khao: (Bentley et al., 2009); Khok Phanom Di:(Bentley et al., 2007); Noen U-Loke: (Cox et al., 2011)
Circled individuals are identified as Ban Non Wat $^{87}Sr/^{86}Sr$ outliers.

Table 5.1

$^{87}Sr/^{86}Sr$ significance (p-value) between sites within Thailand and Ban Non Wat Series 1

Site^	Ban Non Wat[1]	Ban Chiang[2]	Ban Lum Khao[3]	Khok Phanom Di[4]	Noen U-Loke[5]
Ban Non Wat	-				
Ban Chiang	<0.0001#	-			
Ban Lum Khao	0.0160#	<0.0001#	-		
Khok Phanom Di	<0.0001#	<0.0001#	<0.0001#	-	
Noen U-Loke	0.0014*	<0.0001#	0.6553*	<0.0001*	-

[1] This study (Series 2); [2](Bentley et al., 2005); [3](Bentley et al., 2009); [4](Bentley et al., 2007); [5](Cox et al., 2011)
***Unpaired t-test, #Mann-Whitney test, ^Values do not include outliers.**

5.5.1.2 Ban Non Wat Combined Series

The Ban Non Wat combined series $^{87}Sr/^{86}Sr$ values are represented in Fig. 5.3. The $^{87}Sr/^{86}Sr$ values for Series 1 can be found in King et al.'s (2013) supplementary data. The combined $^{87}Sr/^{86}Sr$ average is 0.709696 with a standard deviation of 0.00031. The two standard deviation range includes values of 0.710351 – 0.709041. Of the total 163 individuals tested at Ban Non Wat, there are six individuals from the combined sample who have $^{87}Sr/^{86}Sr$ values falling outside this range (Table 5.2). Two of the individuals (Burials 296 & 440, from the Neolithic flexed and BA4 mortuary phases, respectively) are not included in the charts compared with $\delta^{18}O$ values due to unavailability of data. These individuals can be found in Figure 5.4 by mortuary phase.

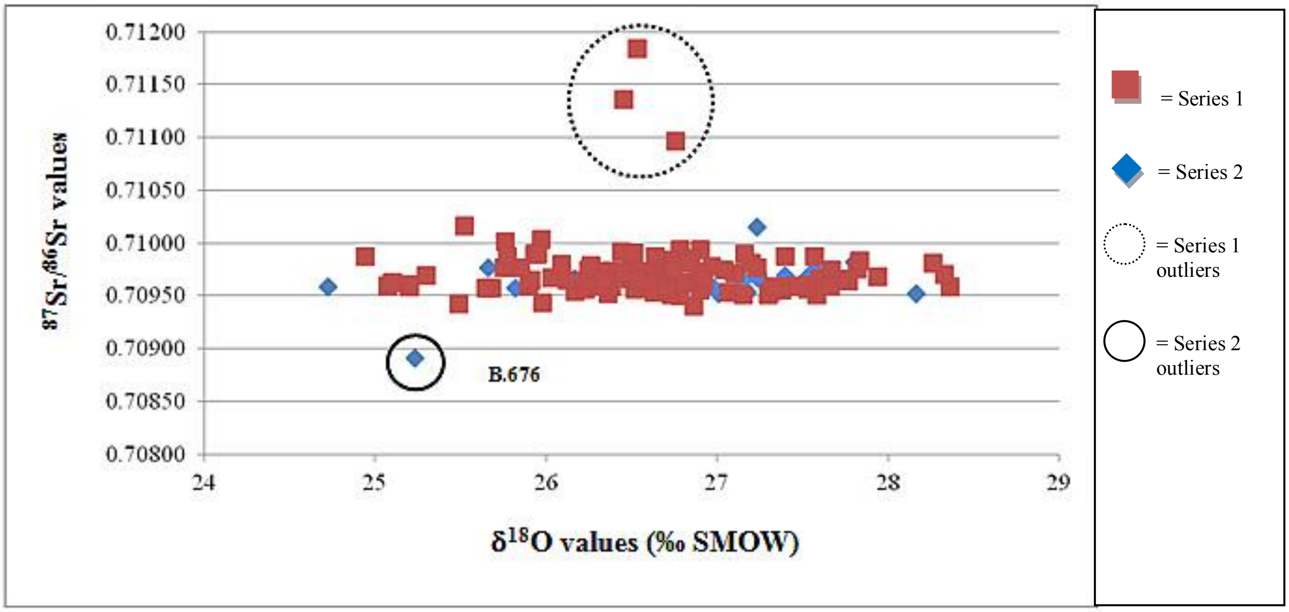


Figure 5.3 Ban Non Wat combined Series $^{87}Sr/^{86}Sr$ values per individual with outliers identified.

***Not included are two individuals from Series 1 without $\delta^{18}O$ values (Burials 296 and 440, both $^{87}Sr/^{86}Sr$ values of 0.708130)**

Table 5.2

Ban Non Wat $^{87}Sr/^{86}Sr$ outliers.

Burial Number	$^{87}Sr/^{86}Sr$ value	Mortuary Phase	Sex
97	0.711840	BA 2	Male
153	0.710960	N2	Female
194	0.711360	N2	Female
296*	0.708130	NF	Male
440*	0.708130	BA4	Female
676	0.708912	BA 1	Female

*** $\delta^{18}O$ values not available.**

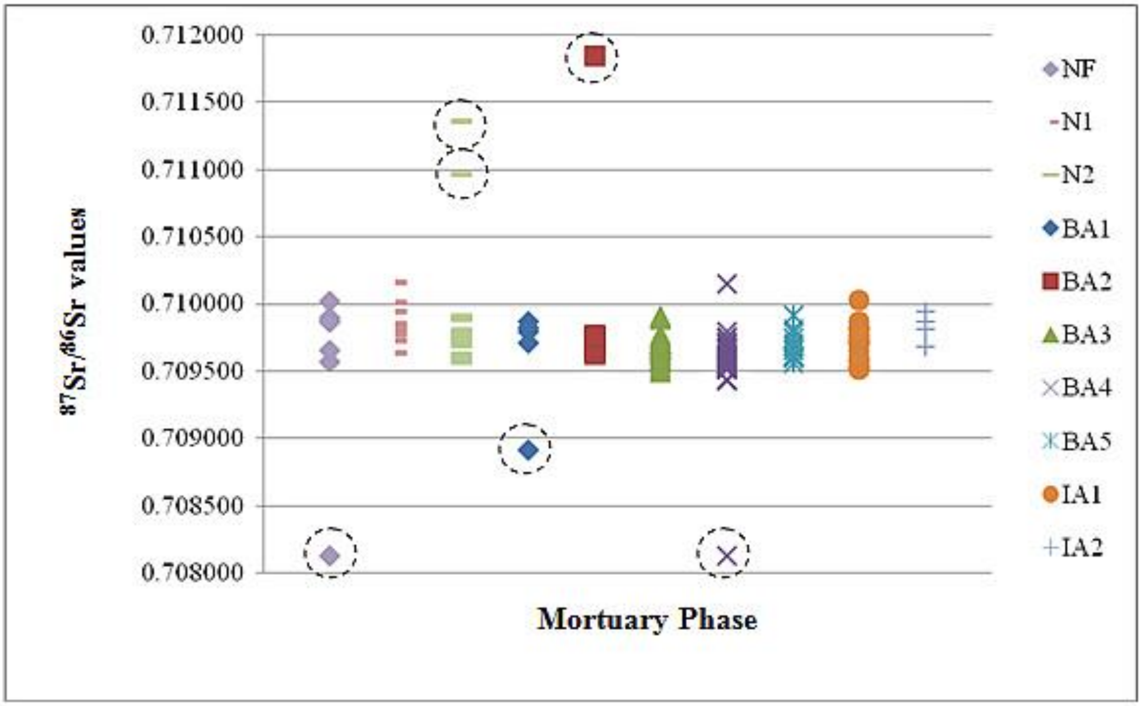


Figure 5.4 $^{87}Sr/^{86}Sr$ outliers by mortuary phase.

Figure 5.5 includes Ban Non Wat's combined Series 1 and 2 $^{87}Sr/^{86}Sr$ values plotted against other prehistoric sites in Thailand. The increased sample size of Ban Non Wat eliminates one of the original outliers from Series 2 (Burial 654); however Burial 676 is still identified as an outlier, together with five individuals from Series 1.

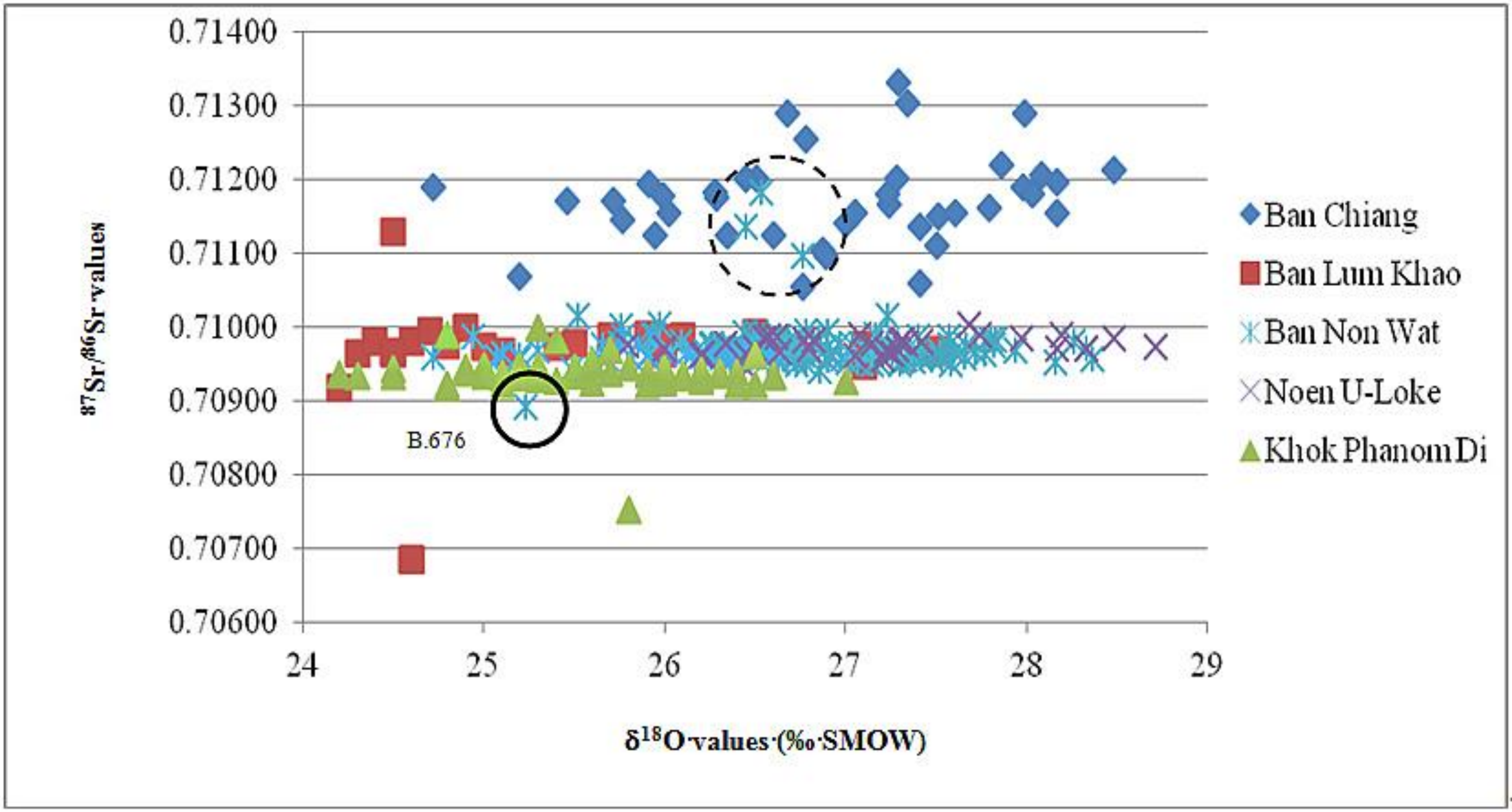


Figure 5.5 Strontium and oxygen isotope values for Southeast Asian sites

***(includes combined Series from Ban Non Wat).**

Ban Non Wat: Series 2 (This study) and Series 1 (King et al., 2013); Ban Chiang:(Bentley et al., 2005); Ban Lum Khao: (Bentley et al., 2009); Khok Phanom Di:(Bentley et al., 2007); Noen U-Loke: (Cox et al., 2011)
Circled individuals are identified as Ban Non Wat Series 2 $^{87}Sr/^{86}Sr$ outliers. Dash circled individuals are identified as Ban Non Wat Series 1 $^{87}Sr/^{86}Sr$ outliers.
***Not included are two individuals from Series 1 without $\delta^{18}O$ values (Burials 296 and 440, both $^{87}Sr/^{86}Sr$ values of 0.708130)**

The increased sample sizes (Series 1 and Series 2 combined) have eliminated the statistical difference between Ban Non Wat and Ban Lum Khao (p=0.1845) (Table 5.3). Ban Non Wat displays no $^{87}Sr/^{86}Sr$ value average range overlap with Ban Chiang and Khok Phanom Di. However, there is overlap between Ban Non Wat and both Ban Lum Khao and Noen U-Loke.

Table 5.3
$^{87}Sr/^{86}Sr$ averages for each site and their significance between other sites within Thailand

(includes combined series from Ban Non Wat).

Site^	**Ban Non Wat[1]**	**Ban Chiang[2]**	**Ban Lum Khao[3]**	**Khok Phanom Di[4]**	**Noen U-Loke[5]**
$^{87}Sr/^{86}Sr$ range	0.709825-0.709551	0.711120-0.712340	0.709020-0.710360	0.709240-0.709430	0.709600-0.709900
Ban Non Wat	-				
Ban Chiang	<0.0001#	-			
Ban Lum Khao	0.1845*	<0.0001#	-		
Khok Phanom Di	<0.0001*	<0.0001#	<0.0001#	-	
Noen U-Loke	0.0053*	<0.0001#	0.6553*	<0.0001*	-

[1] This study (Series 2) and Series 1 from King et al. (2013); [2](Bentley et al., 2005); [3](Bentley et al., 2009); [4](Bentley et al., 2007); [5](Cox et al., 2011)
***Unpaired t-test, #Mann-Whitney test, ^Values do not include outliers.**

5.5.2 Hypothesis 3.2

There will be very few migrants from outside of the Mun River catchment area after the significant dietary change around BA 2/3.

Six individuals with $^{87}Sr/^{86}Sr$ values categorizing them as migrants were identified at Ban Non Wat (Fig. 5.6 circled). Figure 5.6 presents the $^{87}Sr/^{86}Sr$ distribution during the Neolithic, Bronze, and Iron Ages in relation to $\delta^{13}C$ values to determine if diet changes occurred in conjunction with migratory patterns. There are three individuals with outlying $^{87}Sr/^{86}Sr$ values from the Neolithic, three from the Bronze Age, and none from the Iron Age. The migrants from the Bronze Age are from mortuary phases 1, 2, and 4. One burial from BA 4 (Burial 440) has an $^{87}Sr/^{86}Sr$ value evident of migration from outside of the Mun River catchment area after the significant dietary changes around BA 2/3.

Of the six $^{87}Sr/^{86}Sr$ outliers (not circled), four are females while two are males. Figure 5.7 identifies it was primarily females with $^{87}Sr/^{86}Sr$ values suggesting they came from outside of the Upper Mun River Valley at Ban Non Wat. The variation of female $^{87}Sr/^{86}Sr$ values decreases from the Neolithic to the Bronze Age (0.00054, 0.00021 respectively), and further into the Iron Age (0.00013). Meanwhile, male variability increases from the Neolithic to the Bronze Age (0.00012, 0.00038, respectively), then decreases again into the Iron Age (0.00015).

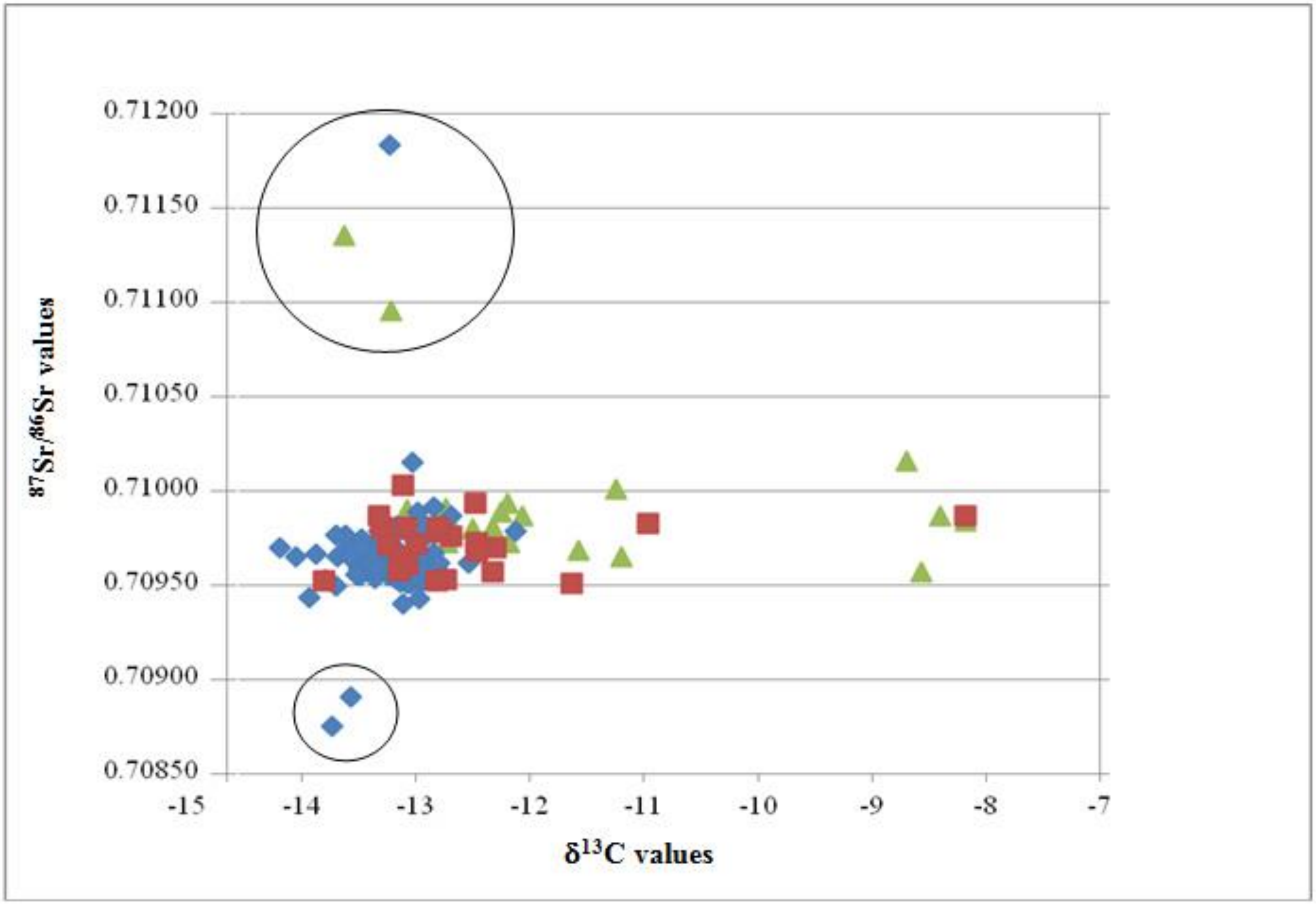


Figure 5.6 Mortuary phase migratory patterns at Ban Non Wat.

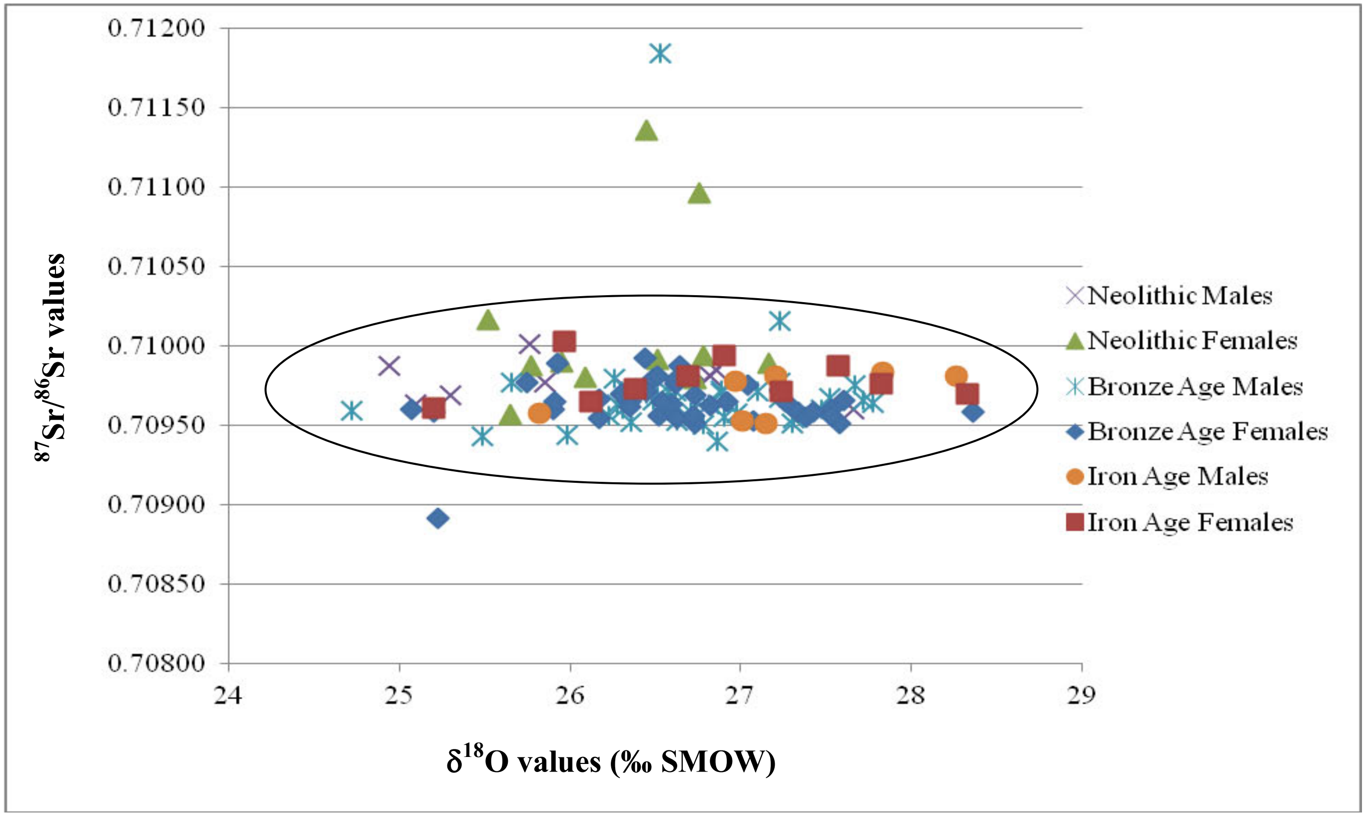


Figure 5.7 Identification of migrants into Ban Non Wat through mortuary phase and by sex.

***Not included are two individuals from Series 1 without $\delta^{18}O$ values (Burials 296 and 440, both $^{87}Sr/^{86}Sr$ values of 0.708130) .This study (Series 2) and Series 1 from King et al. (2013)**

5.5.3 Hypothesis 3.3

Bioarchaeological evidence might provide proof of migrants when isotope studies are not available.

5.5.3.1 Burial distribution and orientation

Burial 693 was buried near the edge of the site in I500. Unfortunately her mortuary phase is undetermined due to poor preservation and intense concretions. This burial with no evidence of a grave cut is a young female whose body appears to have been carelessly discarded in this location. The disregard for proper burial might suggest this individual was not local to the village. Alternatively, she was relocated from her original burial site.

5.5.3.2 Pathological

Burial 690's excavation only yielded the upper portion of the skeletal remains to be collected, therefore analysis was incomplete. This individual is an older male from Bronze Age 3 and stands out due to the pathology found on the skeletal remains. This individual had an array of pathological conditions including new bone growth and porosity on both clavicles which were angled, suggesting they had protruded anteriorly. In turn, this has created new notches on the sternum. This individual displayed a number of pathologies which was uncharacteristic of the individuals at Ban Non Wat. Perhaps he migrated to Ban Non Wat because of disease and malnutrition at his previous village. Interestingly, Burial 690 is one of the only individuals from the Series 2 collection with evidence of potential violence (only other is Burial 660 discussed below). There is also evidence of two depressions on the right parietal bone of the skull, possibly from well-healed depression fractures. This individual may have migrated into the Ban Non Wat community because of interpersonal violence at their previous village. Alternatively, he may have received the fractures accidentally.

Burial 660 is a young female from Bronze Age 3 who appears to have a perimortem spear injury to her ilium. Similar to Burial 660, this could be evidence of interpersonal violence or an accidental injury. It appears unlikely she was an intruder at Ban Non Wat since she was given a proper burial. However, she may have been a victim to violence by a local resident or outsider. She also had a possible healed greenstick fracture on the left radius, and two lesions on the parietal bones of the skull. The two skull lesions are circular and approximately 12mm in diameter, however appear unrelated as one lesion is a possible case of remodelled porotic hyperostosis. The other lesion appears to have smoothed and remodelled underlying diploe, while the outer table is destroyed, or it could be new spiculated surface bone with irregular pitting on the underlying surface. As the Series 2 sample had relatively few pathological lesions per individual Burial 660 is remarkable because of the abundance and nature of the physical indicators.

5.5.3.3 Linear enamel hypoplasia

The sample available for testing LEH consisted of seven subadults, and 21 adults. Of these individuals, 44/413 (10.6%) of the permanent dentition, and 2/51 (3.9%) of the deciduous dentition exhibited LEH.

Burial 654 is a young male from Bronze Age 4 who had 11/29 teeth affected, the greatest number of defects for a male in this sample. Goodman et al.'s (1980) measurements indicate this person experienced the enamel defects around 2.5-3 years of age.

Burial 676 had 9/27 teeth affected with LEH, which was the greatest number of LEH for a female recorded from this sample. Based on the measurements of LEH from Goodman et al. (1980), this enamel defects seem to have formed when she was about 2.5-3 years of age.

5.5.3.4 Stature

The average stature for females at Ban Non Wat is 153.5cm with a range of 143.5cm to 158.5cm. Average male stature for Ban Non Wat is 166.5cm, range of 157.7cm to 179.7cm.

There are two individuals with stature values lying outside two standard deviations from the mean. One is a female, Burial 676, who displayed a height of 143.5cm calculated from the left femur. She is over 7cm shorter than the next shortest female at Ban Non Wat, and greater than two standard deviations from the mean.

5.5.3.5 Dental Modification

Phum Snay and Phum Sophy share four patterns of ablation: three for the maxilla, and one for the mandible (Table 5.4; for example Plate 5.1). While sample sizes are small, there does not appear to be a particular age or sex distribution pattern for ablation at both sites (Domett et al., 2011a). For the complete chart and details of patterns refer to Appendix E (Table 2) and Appendix F.

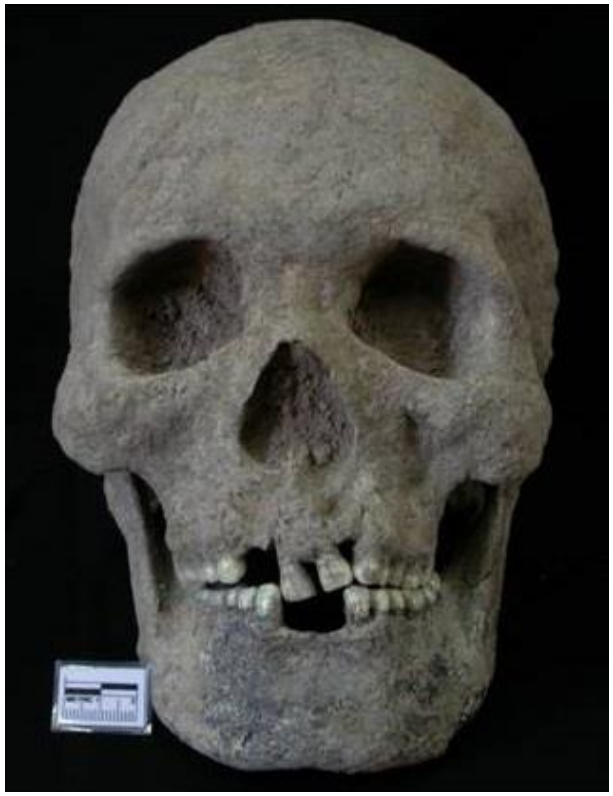


Plate 5.1 Dental ablation at Phum Snay (Photograph: Kate Domett).

Note: Ablated teeth include left and right maxillary lateral incisors and canines in addition to the left and right mandibular central and lateral incisors. There is post-mortem damage to the maxilla.

Table 5.4

Patterns of ablation in the maxilla and mandible at Phum Snay and Phum Sophy.*

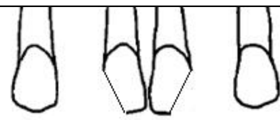
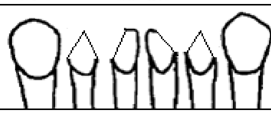
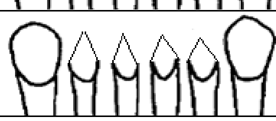
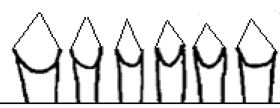
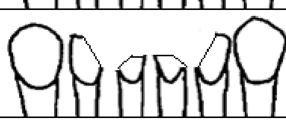
	Right			Left			Phum Snay	Phum Sophy
Pattern No. Maxillae	**C**	**LI**	**CI**	**CI**	**LI**	**C**		
1		A			A		✓	✓
2	A	A			A	A	✓	✓
3	A	A			A		✓	
		A			A	A		
4	A				A	A	✓	
5	A						✓	
6		A					✓	✓
					A			
7		A	A		A		✓	
8				A			✓	
Mandibles								
9		A	A	A	A		✓	✓
10			A	A			✓	
11		A	A	A	A	A	✓	
12		A		A	A		✓	
13	A	A	A		A	A	✓	
14	A		A	A			✓	
15			A				✓	
16					A		✓	
17						A	✓	

Key: C = canine, LI = lateral incisor, CI = central incisor; A = AMTL (ablation), ✓ = pattern present at site
***Chart modified from Domett et al. (2011a).**

A total of 10 dental filing patterns were found in Phum Snay and Phum Sophy (Table 5.5). Of the patterns, seven were unique to Phum Snay, two unique to Phum Sophy, and one pattern was shared between the groups. While the majority of the filing cases were from young adults (41.2%), there does not appear to be a link between age and sex (Domett et al., 2011a). Complete details of the filing patterns of the maxillae can be found in Appendix E (Table 3), the mandible in Appendix E (Table 4) and both originate from Domett et al. (2011a) (see Appendix F). Plate 5.2 is an example of dental filing from Phum Sophy.

Table 5.5

Patterns of intentional filing in the maxillae and mandibles of Phum Snay and Phum Sophy^.

Pattern		Individuals affected: Phum Snay	Individuals affected: Phum Sophy
A		✓	
B		✓	
C		✓	✓
D		✓	
E		✓	
F			✓
G		✓	
H		✓	
I		✓	
J			✓

^Chart modified from Domett et al. 2011. Patterns A-D (inclusive) are maxillary patterns, patterns E-J (inclusive) are mandibular patterns, ✓ = pattern present at site.

Plate 5.2 Evidence of dental filing at Phum Sophy (Photograph: Kate Domett).

5.6 Discussion

5.6.1 Hypothesis 3.1

There will be a discrete range of 'local' $^{87}Sr/^{86}Sr$ values at Ban Non Wat, identifying Ban Non Wat from other communities in Thailand. Individuals outside these values are considered migrants to the community.

Limitations of the identification of an 'outlier' to the community were presented in this study. This study was able to demonstrate the implications of an outlier method with an increased sample size. While geology of the landscape determines the ^{87}Sr/^{86}Sr values "conveyed from eroding geologic materials through soils and the food chain, into the human skeleton" (Bentley, 2006b, p. 136), this also suggests similar landscapes may produce ^{87}Sr/^{86}Sr values which give a false sense that someone may have migrated from a community outside of the 'local' range. Factors such as variability of minerals within the geological landscape, weathering, concentration of minerals and groundwater have the ability to impact the ranges of ^{87}Sr/^{86}Sr values within the same rock (Bentley, 2006b). While a different ^{87}Sr/^{86}Sr ratio may suggest the individual was eating foods from non-local sources (Bentley, 2006b; Bentley et al., 2004; Montgomery et al., 2007), it does not necessarily indicate the individual migrated from a far distance. The individual may have frequented different areas throughout childhood while the dental enamel was still forming (e.g. seasonal residence), or relocated from a similar geological location (Bentley et al., 2007).

Communities with similar landscapes and geographical proximity might portray the same range of ^{87}Sr/^{86}Sr values due to similar geological landscapes. Ban Lum Khao's range of ^{87}Sr/^{86}Sr values indicated no statistical significance with Ban Non Wat, demonstrating the inability to identify individuals who migrated between these communities based solely on isotopic values. The lack of statistical significance between Ban Non Wat and Ban Lum Khao might be associated with the high variance for Ban Lum Khao (+/- 0.00061). The high variance might suggest the Ban Lum Khao community has a greater geographical range of subsistence than Ban Non Wat. Noen U-Loke is statistically different from both Ban Non Wat and Ban Lum Khao; however again, this could be due to the large variance for Ban Lum Khao. Alternatively, it may be associated with the different geological landscapes (Bentley et al. 2004), as Noen U-Loke was situated within the floodplain, while both Ban Non Wat and Ban Lum Khao were communities on the edge of the floodplain. However, there was overlap between all three communities, adding to the difficulty of distinguishing individuals from a particular community. Additionally, Ban Non Wat had significantly different $^{87}Sr/^{86}Sr$ values than the communities of Ban Chiang and Khok Phanom Di, with no overlap of $^{87}Sr/^{86}Sr$ ranges, suggesting distinct $^{87}Sr/^{86}Sr$ ranges identifying members of those communities. It appears $^{87}Sr/^{86}Sr$ signatures may be advantageous for distinguishing migrants to the Ban Non Wat community from outside of the Mun River catchment, but not for short-distance migrants. However, with the lack of isotopic analyses in prehistoric Thailand, and until more isotopic work is completed in Southeast Asia, this can only be speculation.

5.6.1.1 Ban Non Wat Isotopic Outliers from Series 2

From the $^{87}Sr/^{86}Sr$ values, the Ban Non Wat community included two individuals, burials 654 and 676 in the Series 2 collection of possible migrants. Interestingly, with the addition of a larger sample size, combining Series 1 and 2, burial 654 was no longer considered an outlier. There was a clear cluster of $^{87}Sr/^{86}Sr$ values suggesting a local signature, which Bentley et al. (2004) suggest is a good indicator for identification of locals. Therefore, individuals statistically outside this group by greater than two standard deviations are considered migrants to Ban Non Wat.

Burial 676 (Plate 5.3) was a person identified as a potential migrant based not only on her $^{87}Sr/^{86}Sr$ values but also her mortuary goods. She was buried with more pots than the neighbouring burials, and while there is nothing 'wealthy' about these pots, the large number of cups placed around the outside of her grave indicates there was considerable labour involved with her mortuary ceremony. She also possessed a bracelet around her wrist made from marble which had been made with care and attention to detail. The thin structure of the bangle is unlike any others seen at Ban Non Wat to date, however only half of the bracelet was recovered. It is possible that someone intentionally broke the bracelet and placed one half on her wrist, and perhaps kept the other portion. Alternatively, the bracelet was already broken and that half was placed with the burial. There are no other mortuary indications as to where she could have migrated from, however her $^{87}Sr/^{86}Sr$ values suggest outside of the upper Mun River Valley. Burial 676 may have migrated from somewhere quite a distance away, as there are no similar strontium values similar to hers yet reported in Thailand. Burial 676's third molar was tested, indicating it might not have been until her mid-teens that she migrated to Ban Non Wat (Hillson, 1996). Bentley et al. (2007) identified one individual from a heavily disturbed grave at Khok Phanom Di with an $^{87}Sr/^{86}Sr$ value of 0.70753. There was also an individual from Ban Lum Khao with an $^{87}Sr/^{86}Sr$ of 0.70685 potentially from as far as Laos or Cambodia on the basis of a potential geological match of $^{87}Sr/^{86}Sr$ values (Bentley et al., 2009). On the other hand, this individual may have migrated from an area within Southeast Asia where strontium studies have not yet been conducted. Further analysis of the stone bracelet and further isotopic analysis in Southeast Asia might assist in determining where this woman migrated from.

Plate 5.3 Ban Non Wat Burial 676 (Photograph: Nigel Chang).

This woman also had biological features identifying her as a possible migrant to the community. She had one of the shortest statures ever recorded for prehistoric Southeast Asia at only 143.5cm; the shortest being a female from Khok Phanom Di at 141cm (Tayles, 1999). Analysis of her dental health showed the highest amount of linear enamel hypoplasia of all the Ban Non Wat women examined, which would have affected her around 2.5-3 years of age. Perhaps unfavourable conditions within her original community led to her departure, such as malnutrition or disease, as she displays evidence of poor health. Her ill health might have continued into young adulthood, as she died at a young age. Alternatively, she may have been forced to relocate communities, or left the area for marriage purposes. However, it appears she may have integrated well into the Ban Non Wat community based on her mortuary goods and treatment.

5.6.2 Hypothesis 3.2

There will be very few migrants from outside of the Mun River catchment area after the significant dietary change around BA 2/3.

Bentley et al.'s (2007) findings suggest prehistoric Southeast Asian societies were initially patrilocal, eventually changing to a matrilocal society with the spread of agriculture in Southeast Asia (Bentley et al., 2007; Bentley et al., 2005). There was a gradual decrease of outlier female $^{87}Sr/^{86}Sr$ values from the Neolithic to late Bronze Age at Ban Non Wat. This suggests females were migrating from places beyond the site and immediate catchment area during the Neolithic, but eventually display local signatures. On the other hand, there was an increase of male $^{87}Sr/^{86}Sr$ variation from the Neolithic into the Bronze Age, followed by a decline into the Iron Age. This suggests local males during the Neolithic with evidence of migration outside of the Mun River into the later Bronze Age. During the Iron Age there was limited movement from both sexes. The $^{87}Sr/^{86}Sr$ results from the combined series data suggests females migrated more often than males during the Neolithic and Bronze Ages. While the evidence of migrants is limited to five individuals, movement of females during the Neolithic and Bronze Ages at Ban Non Wat appears to follow Bentley et al.'s (2007) trends.

After BA 4 migrants with significantly different $^{87}Sr/^{86}Sr$ values to Ban Non Wat are no longer present, opening the suggestion for only migration within the Mun River, or no migration from this point onwards. However, it cannot be determined if people migrated from nearby communities to Ban Non Wat based on $^{87}Sr/^{86}Sr$ values alone because of the variation in averages between neighbouring communities. Cox et al. (2011) noted based on narrow $^{87}Sr/^{86}Sr$ ranges and similar diet, only migration from nearby communities was occurring at the Iron Age site of Noen U-Loke. This is consistent with the migratory patterns identified with the combined Ban Non Wat sample. Alternatively, people may have been migrating from outside of the Mun River from locations with similar $^{87}Sr/^{86}Sr$ ranges. The evidence of only local signatures at Ban Non Wat coincides with the narrowing ranges of $^{87}Sr/^{86}Sr$ values also evident at Ban Chiang by Bentley et al. (2005). Migration within a close geographic location by males also corresponds with a decline of mortuary goods seen during the Series 1 excavation at Ban Non Wat by (Higham & Kijngam, 2012b). Could the changing migratory patterns have impacted mortuary goods? Bentley et al. (2009) suggested after the early phase at Ban Lum Khao, groups of women may be identifiable as having kinship links though distinctive pottery types. However, similar patterns of identifiable pottery types have not been identified at Ban Non Wat in Series 2 to trace whether migration occurred with groups nearby or communities from further afield.

Subsistence patterns support the evidence of migration at Ban Non Wat, with the Neolithic period seeing the majority of migrants moving from outside the Mun Valley to the site. The $^{87}Sr/^{86}Sr$ values thus far indicate lone migrants to the community, versus larger kinship groups coming to Ban Non Wat. Perhaps Ban Non Wat inhabitants were staying close to the community to work on new subsistence patterns. Population sizes also appeared to increase throughout the Bronze Age, as seen by the number of burials discovered from each mortuary phase from Series 1 (Higham & Kijngam, 2012c), and Series 2. As population sizes increased, the changing subsistence patterns could correspond with the demand for more resources at the site. A higher reliance on different crops and resources were taking place, identified by the significant $\delta^{13}C$ values change between Bronze Age 2 and 3 (Chapter 4). The Bronze Age appears to be a time where a change to the subsistence regime was one factor which contributed to the impact of the scale of migration. Male and female diet was similar throughout all MP's at Ban Non Wat into the early Iron Ages according to findings from the previous chapter. Evidence from this research shows a limited subsistence range for the inhabitants at Ban Non Wat, even the individuals with non-local $^{87}Sr/^{86}Sr$ values. However, definite conclusions cannot be stated based on only five potential migrants to Ban Non Wat. Overall, there is limited evidence of migration to Ban Non Wat from outside of the Mun Valley.

In the Iron Age, while the $^{87}Sr/^{86}Sr$ values suggest only local residents, the variation of the diet is growing. Perhaps during the Iron Age there was an increase of trading with other communities, introducing new skills and foods into the area. Higham and Kjingam (2009) noted the increasing range of exotic mortuary goods evident in the Iron Age at Ban Non Wat, suggesting trade with communities such as India. The escalating trade networks could have meant a greater amount of time spent way from the site hunting and gathering as individuals were busy exchanging goods. Alternatively, the community was incorporating other subsistence items into the regular diet. The link with a diet with higher contributions of C_4 (marine sources) could coincide with local members travelling along the coast and trading. While there appears to be a decline of migrants from communities outside of the immediate geographic area into the Iron Age, increasing trade is proposed. This would have brought exotic mortuary goods to Ban Non Wat, and possibly a range of foods and skills.

5.6.3 Hypothesis 3.3

Bioarchaeological evidence might provide proof of migrants when isotope studies are not available.

5.6.3.1 Ban Non Wat

Burial 654 is an $^{87}Sr/^{86}Sr$ outlier at Ban Non Wat only when Series 2 was examined. With the additional data from Series 1 this individual was no longer considered an isotopic outlier. Burial 654 had his second molar tested, therefore if he is a migrant, he would have left his childhood community anytime after the age of seven (Hillson, 1996). Perhaps he is a migrant to the Ban Non Wat community who came from a similar geological location. His $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values fall within the range for nearby and contemporaneous Ban Lum Khao (Bentley et al., 2009). Biologically, his dental health indicates a large amount of stress during childhood. He had the highest amount of linear enamel hypoplasia for a male at Ban Non Wat from Series 2. Interestingly, males at Ban Lum Khao also had high amounts of LEH, averaging 11.4%, and had a wide range of variation in health (Domett & Tayles, 2006a). His stature (166.7cm) was average at Ban Non Wat and was only 2cm shorter than the average male stature at Ban Lum Khao. Perhaps the poor health affected him early in childhood, but the impact was not severe and long-term enough to affect his growth into adulthood. Or perhaps his movement into the Ban Non Wat community at a young age introduced him to better nutrition. The comparable isotope values suggest it is possible this male might have migrated from the nearby community of Ban Lum Khao. His death occurred during BA 4, which could place him at Bronze Age Ban Lum Khao. However, is also possible this individual migrated from another nearby community which has not been excavated and isotopically sampled. Alternatively, he is a local from Ban Non Wat who shares a similar isotopic signature with nearby Ban Lum Khao residents.

Current evidence cannot determine whether people migrated from a number of different communities. Tests analysed only one tooth using isotope analyses, and lacked collagen to test the signatures from bone. Collagen from the bone is indicative of the geological environment the final six years of life (Ericson, 1985). Bentley (2006a, p. 170) suggests that "a single $^{87}Sr/^{86}Sr$ ratio from enamel does not automatically distinguish a migrant from Place A to Place B from a person who travelled widely throughout childhood, since a non-local $^{87}Sr/^{86}Sr$ ratio only implies that the person once ate foods which, averaged over the formation of enamel, came from non-local sources". Migration might have occurred after the cessation of their dental enamel formation, or individuals migrated from a community with similar $^{87}Sr/^{86}Sr$ values. However, there is no way to definitively say other individuals have not migrated into the community.

5.6.3.2 Phum Snay and Phum Sophy

Dental modification in Southeast Asia has also been identified in Neolithic Thailand, while evidence of dental modification in Southeast Asia during the Bronze Age is absent. Evidence from the Neolithic site of Khok Phanom Di in Thailand suggests the group was practicing ritual ablation as a group, with 72% exhibiting ablation (Tayles, 1996). Limited cases of ablation in Thailand have been recorded, and cases from Cambodia only include Phum Snay and Phum Sophy (Domett et al., 2011a). Ikehara-Quebral (2010) noted Angkor Borei in Southern Cambodia has evidence of dental filing, but no cases of ablation. However, the suggestion of other Cambodian groups displaying certain patterns cannot be dismissed. Additional archaeological samples will help distinguish patterns and links between groups throughout Southeast Asia. Additionally, this idea of linking ablation patterns to migration will be tested more thoroughly once the isotope results from Phum Snay and Phum Sophy are made available.

The communities of Phum Snay and Phum Sophy are approximately 40km apart, with partial overlap of occupation during a time of apparent increased social tension. "Differences in patterns of ablation and filing between the sites may also reflect an intention to visually link oneself with a particular community or region" (Domett et al., 2011a, p. 284). Cases of dental filing to identify tribal association are seen elsewhere around the world, such as the Ngangela of Angola, Africa (Jones (1992) cited in Finucane et al. (2008)). Phum Snay and Phum Sophy share similar patterns of ablation and dental filing, as well as their own distinct patterns. Due to the presence of some unique patterns at Phum Snay and Phum Sophy, the filing patterns, in particular, may have linked individuals to groups, (Domett et al., 2011a) especially in times of increased violence, such as during Phum Snay occupation (Domett & Buckley, 2006), or times of extensive trade. By the Iron Age there is evidence suggesting groups in Southeast Asia would have had interactions with a range of different assemblages and communities based on the trade networks within Southeast Asia (Domett & O'Reilly, 2009; O'Reilly et al., 2006b). There is further evidence supporting extensive trade networks between Southeast Asia with other parts of the world in the Iron Age, such as East

Asia (Klaus & Tam, 2010b), India (Robbins et al., 2009), and South Asia (Robbins Schug et al., 2012), suggesting the necessity for group identification from foreigners.

There is no evidence to support the suggestion of a direct link between intentional dental modification and migration at Phum Snay and Phum Sophy. There was no link between ablation patterns and strontium values in Japanese samples, however a possible relationship between kin groups and certain patterns have been suggested in the Jomon people (Kusaka et al., 2009; Kusaka et al., 2011; Temple et al., 2011). Tayles et al.(1996) mentions many reasons for which intentional modification may have been practiced, including group rites of passage to signify particular life stages (e.g. marriage). Domett et al. (2011a) suggest ablation patterns in the Cambodian samples may also be socially linked, such as a coming-of-age, or marriage rituals during adolescence. The migration to a new community could require the individual to take on the new community's dental modification practices and patterns, probably eradicating evidence of migratory patterns from dental modification, or they brought their own patterns with them.

5.7 Summary

Hypothesis 3.1*: There will be a discrete range of 'local' $^{87}Sr/^{86}Sr$ values at Ban Non Wat identifying Ban Non Wat from other communities in Thailand. Individuals outside these values are considered migrants to the community.*

Ban Non Wat Series 2 had an identifiable ^{87}Sr/^{86}Sr range of 0.709656 +/- 0.0002, with two outliers. The addition of Series 1 eliminated one of the Series 2 outliers. In total there were six ^{87}Sr/^{86}Sr outliers at Ban Non Wat, with a combined series ^{87}Sr/^{86}Sr range of 0.709696 +/- 0.00031.

The Ban Non Wat combined series ^{87}Sr/^{86}Sr values are significantly different from other sites in Thailand ^{87}Sr/^{86}Sr values except Ban Lum Khao. This is probably due to the proximity and similar landscape utilization.

Hypothesis 3.2*: There will be very few migrants from outside of the Mun River catchment area after the significant dietary change around BA 2/3.*

In general, there are very few migrants outside of the Mun River catchment to the Ban Non Wat community. Of those migrants there is evidence of two individuals joining the Ban Non Wat community during the Neolithic, with coincides with the greatest variation of diet at the site.

It appears that trade networks were increasing and expanding into the Iron Age, suggesting trading taking place at the site or further distances.

Hypothesis 3.3*: Bioarchaeological evidence might be a method for identifying migrants when isotope studies are not available.*

Interestingly, the identified Series 2 migrants from Ban Non Wat were also the individuals with the greatest amount of childhood stressors.

Once the series were combined, the only Series 2 outlier was an identified outsider before isotopic analyses were conducted. This individual has a high amount of childhood stressors, dental pathology, and a different mortuary ritual than others within the Series 2 group.

Dental ablation does not appear to directly identify migration within a community.

Filing patterns might assist with group identification, however further analyses are required from Phum Snay and Phum Sophy strontium isotopes once the results are released.

The above evidence suggests bioarchaeological evidence might assist with the identification of migrants to a community when examined alongside strontium isotope values.

Note: A portion of this chapter has been incorporated into the publication *Cultural Modification of the Dentition in Prehistoric Cambodia* in Appendix F.

Chapter 6 Discussion and conclusions

6.1 Discussion

This discussion incorporates the results and discussions from the proceeding chapters and integrates all three themes (health, diet and migration) to explore how they impact each other to address the primary question of this research: *Why did the rise of complex society in tropical Southeast Asia differ from the rest of the world?*

First, the discussion of the primary sites explored in this project are presented in order of time periods: Ban Non Wat (Neolithic to mid-Bronze Age and late Bronze Age to early Iron Age), then Phum Snay and Phum Sophy (late Iron Age). Following the integrated discussion of each site, the main research question is examined in the context of additional interpretations available from other Southeast Asian sites (see Figure 1.1). The interpretation of Southeast Asia in reference to the three themes is divided into time periods. First, the discussion of the Neolithic followed by the Bronze Age, Iron Age and finally the late Iron Age.

6.2 Ban Non Wat

6.2.1 Neolithic to Mid-Bronze Age

The results of this study suggest the stability of the social and natural environment allowed the Ban Non Wat community to exploit the landscape and grow in size during the Neolithic to mid- Bronze Age. Evidence from Ban Non Wat $\delta^{13}C$ values suggests a stable diet that consisted primarily of C_3 resources (i.e. rice) with some input from C_4 (i.e. certain plants) foods from the Neolithic to the early Bronze Age. Additionally, all groups may have been reliant on a mixed economy of agriculture and hunter-gatherer subsistence for maintaining a surplus of food. Overall, the stable environment would have given the community flexibility to continue to cultivate the land and utilize the abundance of available resources.

It can be suggested that migrants from several distant locations, with different subsistence and cultural practices, were moving to Ban Non Wat during the Neolithic. Higham (2013) suggests Ban Non Wat had utilized coastal exchange routes during the Neolithic. The increase of exotic mortuary goods in varying quality and quantity are evidence of trade with other communities. Cowrie shells in the burial context suggest coastal marine trade networks during the Neolithic (Boyd & Chang, 2010; Higham & Kijngam, 2010) with Ban Non Wat. In addition, individuals appear to have been using these routes for migration routes from coastal communities. Coastal locations are known for higher C_4 foods contributions from the diet, therefore the higher contributions of C_4 may have been associated with migration of coastal inhabitants to Ban Non Wat. Individuals from the Neolithic display a wide variety of diets (Fig. 4.2), which may be evident of people relocating from different communities with diverse subsistence availability. Higham & Kijngam (2010) proposed the Neolithic inhabitants at Ban Non Wat had similarities in their material culture with that of groups from central and northeastern Thailand.

The introduction of migrants from outside of the immediate catchment area into the community may have brought farming and other skills. Higham & Kijngam (2010) suggested hunter-gatherers and agriculturalists were cohabitating during the Neolithic phases of Ban Non Wat. Higham (2013) noted different mortuary placement of bodies (flexed burials for hunter-gatherers) and types of goods in Ban Non Wat Neolithic burials. This cohabitation could explain the increased diet variance of the Neolithic $\delta^{13}C$ values, which implies diet was broad-based and consisting of variable amounts of C_3 and C_4 foods. The cohabitation could mean the groups were sharing or trading resources. Alternatively, the inhabitants of Ban Non Wat were considered local, but relying on different foods, with perhaps different subgroups spending a great deal of time away from the site during different seasons. However, strontium values indicate a small percentage of these people would have spent thei childhood at a location outside of the Upper Mun River catchment area. Additionally, information such as pottery motifs from the ceramic record at Ban Non Wat links the community with groups in south and west Thailand (Higham & Kijngam, 2010), and central Thailand (Higham, 2012b). This might suggest some of the earliest inhabitants of Ban Non Wat had migrated into the community with distinct pottery styles and subsistence patterns, and exchanged these ideas with the local members.

During the majority of the Neolithic to mid-Bronze Age, the Ban Non Wat community underwent gradual changes in subsistence patterns. Throughout this period the individual's in the community would have relied on a diet high in C_3 foods (such as rice) with minimal C_4 contributions. However, significant changes to the diet occur during BA2/3 reflected in a gradual decrease in $\delta^{13}C$ values until BA 2/3, when the community displayed the lowest $\delta^{13}C$ values, denoting mainly C_3 reliance. This shift also coincided with a decrease of dietary variation across the site, which is taken as a marker of an agricultural community as opposed to hunter gatherers in other parts of the world (Larsen, 1995). One possibility for dietary change may have been a communal shift in reliance on some forms of agriculture, such as an increased dependence on rice (which is high in C_3), or decreased reliance of hunting and collecting C_4 resources (such as millet). The pressures of feeding a larger community would also take food production to potentially new levels. One possible response may have been to concentrate on intensifying agriculture, probably rice, which could feed a larger number of people than hunting and gathering alone. Environmental evidence suggests that land clearing of larger trees began to create an open landscape (Boyd & Chang, 2010), most likely for farming and rice agriculture. The eventual changes of the landscape to increasingly open grassy areas caused plants in cleared areas to be comprised of less negative $\delta^{13}C$ values (higher C_3) (Heaton, 1999) as cited in Bentley et al. (2007). The local pig diet at Ban Non Wat also correlates with this shift to more negative $\delta^{13}C$ values, probably due to pigs eating human scraps at the site. This gradually changing subsistence model was most likely a product of a denser population throughout the Neolithic and Bronze Ages.

Significant dietary changes appear to coincide with social variation at the site. The dietary changes occur during a time when elite superburials appear at the site consisting of approximately six to seven generations (Higham & Higham, 2009). No obtainable bone collagen meant ancient DNA testing could not be undertaken to determine if these individuals were related. These burials were given a lavish mortuary display which coincides with significant changes to the Ban Non Wat diet. While these individuals do not appear to have different childhood diet contributions of C_3/C_4 foods from the rest of the community, they do have an immense amount of wealth associated with their burials. Similar diets suggest that everyone at the site had access to similar foods and that if some individuals did have privileged access to some foods, then this must have occurred from younger adulthood onwards (by which time it would no longer be recorded in the tooth chemistry). It can be argued that these people were high status individuals, but as to whether their wealth was prescribed at childhood, or perhaps from a role they would have played during adulthood is unknown. Subsisting on prestige foods could identify elite individuals from the rest of the community (Weber et al., 2010). Evidence from isotope results of bone collagen would be useful determining their adult diet, although unfortunately this was unable to be tested owing to poor collagen preservation.

A lavish mortuary display might also be evidence of highly-valued individuals at Ban Non Wat who were revered community contributors during life. For example, people may have been honoured for their hunting success, skill as potters or as traders. New technologies, such as copper production, are evident in the Bronze Age (Higham & Hodges, 2013). Higham & Higham (2009) identify an individual as a bronze founder or specialist based on his mortuary context including an abundance of clay moulds. This prestigious burial ritual may have been performed for individuals who displayed expertise or strengths in a particular task, or people who made significant contributions to the community. A similar type of mortuary wealth was identified at Ban Na Di, and Higham & Thosarat (1998, p. 105) suggest these individuals "were the senior in line of descent from the founding ancestors". This may have been the cause for this sudden influx of mortuary wealth for a period of time during BA 2. Individuals may have contributed to the increasing agricultural basis at Ban Non Wat, or perhaps developed new technologies which gave them recognition during trade. This supports a proposal that contributions to the community would have been displayed in death by opulence of mortuary context.

It has been suggested that the superburials at Ban Non Wat denote the development of hierarchical social structures during the Bronze Age. Hypothesised by Higham & Higham (2009) and Higham (2011), the superburials were possible evidence of the start of a complex social change at the site based on familial links. However, the elite burial distribution discussed above consists of "four spatially discrete sets of outstandingly rich burials" (Higham & Higham, 2009, p. 134), not suggestive of a kinship link. The proposal by Higham (2011) suggests subadults buried with elite status are presumed to have also been wealthy if they had reached adulthood based on lineage. However, the isotopic results from Chapter 4 do not support a dietary difference between the superburials and other burials in childhood. This assigned status has also been suggested at Non Nok Tha where subadults were buried with extensive wealth (Bayard, 1984) as cited in White (1995). However, there is also the proposition that if these individuals would have survived into adulthood, status would only be given in death if they also contributed to the society. This may have been in a similar fashion to the parents/kin contributions in life, or through association with their newly acquired adult kin group. It can be suggested that death at a very young age meant burial similar to their parents/kin. Only the small groups of elite people were given larger burials filled with an abundance of goods. Alternatively, it must be recognized that further excavations may prove that there were more pockets of elite groups throughout other mortuary phases. Chang (pers. comm. 2013) mentions the nearby site of Ban Prasat, which also displays immense wealth in the burials during a similar time period the elite superburials are present at Ban Non Wat. While there is no direct evidence linking the individuals from Ban Prasat to Ban Non Wat, one theory to test in the future is whether there is any relation between the elite from Ban Non Wat and Ban Prasat. This influx of mortuary opulence may have only been a short trend at this site, or perhaps wealth was distributed in different ways during later mortuary phases. Further evidence of potential wealth during later mortuary phases will need to be examined in the future.

Increasing population size may have negatively impacted the females of Ban Non Wat since evidence from the 2007 to 2013 excavations presents a high young female population from the large mortuary context potentially due to increasing demands for births. A decrease between birth spacing is evident during times of increasing fertility (Buikstra et al., 1986), which in turn would escalate the demand on the female body. Impacts from pregnancy or birth-related complications were also suggested of nearby Ban Lum Khao females, who, similar to Ban Non Wat, have an increased number of young females in the mortuary context (Domett, 2001; Higham et al., 2004). Patterns of burial distribution at Ban Non Wat do not suggest the sample is biased, as the excavation area encompasses several locations at the site. Additionally, females were not as healthy as males during this time. However, the dental pathology profiles and other indicators of health suggest similar pathological trends between the sexes. While not all young females at Ban Non Wat demonstrate evidence of pregnancy and giving birth, it can be suggested, similar to Ban Lum Khao women, the indicators of birth on the pelvis had been remodelled or were not imprinted on the skeletal remains (Domett, 2001, p. 43). Therefore, these females may have been dying due to complications with pregnancy, birth, or post-partum issues and were not necessarily unhealthier than males. Overall, the general health of Ban Non Wat individuals appears to have remained relatively stable throughout all occupation periods.

6.2.2 Mid-Bronze Age to Early Iron Age

The diet at Ban Non Wat was consistently higher in C_4 foods than other groups located nearby, meanwhile the diet differs significantly from Ban Lum Khao, which encompasses the same mortuary phases as the entire Ban Non Wat Bronze Age. Therefore, the two communities were probably relying on different diets during the Bronze Age. One possible explanation could be communities in the area were separate from the other nearby Mun River groups and had their own subsistence regime with little influence from other communities. Additionally, Ban Non Wat may have been reliant on different specializations. Isotopic studies by Tomszak (2003) in South America notes dietary differences between nearby groups, suggesting specialists at each site. The Ban Non Wat community had been utilizing the land since the Neolithic so they may have constructed a more solid agricultural infrastructure and ability to exploit the environment. Another suggestion is they were much more involved with trading items of food than their neighbours.

The community may have been large enough to take care of their own tasks at the site. Based on similarities of local $^{87}Sr/^{86}Sr$ signatures at the site in the late Bronze Ages and early Iron Age, any migratory exchanges were probably done with other neighbouring communities for social reasons such as marriage. The Ban Non Wat community appears to have increased in size into the Iron Age and Higham & Higham (2009) suggest the late Bronze Age would have seen an increase in population size, based on the grave distribution. This increase of population density from in situ population growth would have allowed for particular individuals to take certain roles. As evident in the Bronze Age (mentioned above), new specialists were beginning to emerge at the site. People in smaller communities were probably responsible for a number of tasks. As the community populations became larger it meant additional people were able to assist with tasks, freeing up time for individuals to focus on one skill in which they excelled. At this stage, the inhabitants of Ban Non Wat may have had certain roles at the site which contributed to the dietary and trade regime for the community.

The possible cessation of migrants outside of the Mun Valley at Ban Non Wat recognizable from $^{87}Sr/^{86}Sr$ values occurs around BA 4 (King supplementary data in King et al. (2013) and this study). Higham (2011) noted the decline of coastal shell mortuary goods after BA 3. There was also a large drop in numbers of exotic items at the site, and it appears that primarily locally crafted goods were being utilized for burials (Higham & Kijngam, 2012b). The decline in the general number of goods was also noted by Higham (2011), which could be associated with the lack of time and energy people had to put into the mortuary period due to the changes to subsistence and increasing population density. The increasing reliance on agriculture may have required the groups to stay local to take care of the crops/animals at the site leaving less time for trade with other communities from great distances. Alternatively, the development of distinct social identity led to greater regulations of interactions with outsiders. The decline of exotic goods could suggest trade opportunities were only available to certain people at the site. It is suggested that groups were no longer looking for new settlements, but instead concentrating on greater trade opportunities for highly sought after goods. However, even though evidence of migrants from communities outside of the Mun River is lacking in the mortuary context, there is evidence of exotic shell goods trade with coastal groups was still taking place but in decreased quantities.

The Iron Age presents new goods introduced from long-distance trade. Items such as glass, agate and carnelian beads begin to appear in the mortuary context at Ban Non Wat during the Iron Age. Ban Non Wat's position, situated along a trade route, would allow the opportunity for exchange (Higham & Hodges, 2013). Trade links appear with groups as far away as India, China, the Near East, and Mediterranean (Higham & Hodges, 2013, p. 77) and India (Bellina, 2003). It appears the desire for trade was more focused on opportunity for status (Bellina, 2003). The trade network appears to have extended to further distances throughout the Iron Age.

Evidence of minimal environmental changes appears during the Iron Age at Ban Non Wat. (Boyd & McGrath, 2001b). Ban Non Wat saw a shift to drier conditions in the Iron Age, coinciding with a decrease of forest cover, and subsequent increase of grasses probably for rice cultivation (Boyd & Chang, 2010; Boyd & McGrath, 2001a). Drier conditions are also acknowledged for the late occupation at nearby Noen U-Loke, whose location on the floodplain and environment may have made it a more ideal location for rice farming, with an open landscape due to the decline of tall trees in the area (Boyd & Chang, 2010). Interestingly, Ban Non Wat's diet continues to differ significantly from nearby communities, which show increased influence from C_3 foods. White (2011, p. 15) explains that C_4 plants tend to thrive in drier contexts, C_3 in moister contexts. The differences in $\delta^{13}C$ averages between the communities suggest Noen U-Loke may have been more dependent on rice agriculture based on its location in the floodplain (and higher C_3 contribution to the overall diet). Meanwhile, Ban Non Wat's location slightly above the floodplain (Higham & Hodges, 2013) may have contributed to the significant differences. The importance of rice is portrayed at Noen U-Loke in the burial context, with the incorporation of rice with many burials (Higham et al., 2007). In addition to rice, fish was probably a large contributor to the diet in this region during the Bronze and Iron Ages. The lack of fish remains indicate periods the unreliability of water sources (Higham et al., 2007, p. 520), with lower than expected quantities of fish remains at Noen U-Loke, especially in comparison to the abundance of fish at Ban Lum Khao (Higham et al., 2004), and the remains at Ban Non Wat (Higham & Kijngam, 2012a). There is no evidence which suggests Ban Non Wat was subject to depleted water sources up until the early Iron Age.

Throughout all mortuary phases there are no significant differences between male and female biological indicators, suggesting sexual division of labour was limited into the early Iron Age. Evidence from the mortuary context suggests similar rituals for males and females (Harris & Tayles, 2012). $\delta^{13}C$ values indicate the males and females had similar childhood diets from the Neolithic to the early Iron Age. The dental pathology profiles between the sexes are different probably due to the young female population at the site. As most dental pathologies are age progressive, the lower quantity of dental pathologies in the female sample is due to the lack of older females. The young female mortuary population suggests more females were dying at a younger age than males. Health indicators suggest males and females were impacted in a similar manner by health disruptions. There are no other indications on the female skeletal remains pointing to any decline in female health at this time. However, recent work by Clark et al. (2013) has identified an increase of LEH and corresponding decline of stature for females at Ban Non Wat during the mid-to-late Bronze Age, while male stature remained static, suggesting a slight decline of female health. Overall, the burials from this study suggest male and female adult health was similar during the Bronze Age. Other than the early ages at death (probably from pregnancy-related issues), the females from this study appear generally healthy, as do the males.

6.3 Phum Snay

The site of Phum Snay was occupied in the late Iron Age and located on the southern side of the Dangrek Mountain Range (Ban Non Wat is north of this range). There is limited evidence documenting the environmental conditions of the late Iron Age in Cambodia, however, the drier conditions in northeast Thailand during the late Iron Age were probably impacting northwest Cambodia. These conditions would have increased reliance on water resources, evident with the construction of moats, which may have led to conflict over access to resources.

The people of Phum Snay most likely participated in extensive trade networks. Burial goods are linked with goods from locations within southern Cambodia (Reinecke et al., 2009), northeastern Thailand (Domett & O'Reilly, 2009; O'Reilly et al., 2006a; O'Reilly et al., 2006b; Reinecke et al., 2009), Vietnam (Reinecke et al., 2009), and China (Hirao & Ro, 2013). Evidence of animal and fish remains not local to the Phum Snay community, such as the serow and a number of fish from large river systems, suggest trade with other communities (O'Reilly et al., 2006b). Alternatively, migrants to the community may have brought exotic materials to Phum Snay. Dental modification similarities were also noted between Phum Snay and a nearby Cambodian site, as well as China and Southeast Asia (Domett et al., 2011a). This information gives further evidence to support the claim trading was used extensively and Phum Snay had widespread contact with other communities. Could this also suggest possible migratory paths of people during this time by way of the Mekong River?

The Phum Snay community appears to have been heavily involved in violence and warfare. A lack of older adult male remains suggests males were required to fight and died at a young age. It could also be that older male remains are located outside of the community, with males buried elsewhere if they succumbed to death while in battle away from the site (Domett & O'Reilly, 2009). However, it appears violence was not limited to males, as female remains show evidence that they also experienced trauma at the site (Domett & O'Reilly, 2009). Milner et al. (1991) as cited in (Larsen, 1995, p. 198) noted in other parts of the world “there was an increase in frequency of deaths arising from conflict and warfare among late prehistoric agriculturalists compared with earlier groups”, possibly due to increase competition of resources. Evidence that the people of Phum Snay were rice agriculturalists is provided by the addition of rice in the burials and tools required for rice agriculture, such as sickles (Domett & O'Reilly, 2009; O'Reilly et al., 2006b) and dental pathology profiles. Due to impending threats, the community may have taken action and created defensive measures such as creating a large number of weaponry.

The large variety of dental filing patterns may indicate how the Phum Snay population identified themselves internally and to external groups. Such dental modification has been used as a link between social and political groups in other contexts (Williams & White, 2006). Burial distribution patterns and burial goods suggest Phum Snay may have been made up of a number of different groups (O'Reilly et al., 2006a; Voeun, 2013). The notion that filing is age progressive has been rejected by Domett et al. (2011a). As to whether these groups were kin-related is unknown, but the filing patterns and burial distributions could have been a mode for these people to be identified at death. The clustered locations of burial groups identified by the collaborative excavation by the Ministry of Culture and Fine Arts, Cambodia and the International Research Centre for Japanese Studies from 2007-2010 at Phum Snay also identified a potential identifying custom of individuals being buried with only the left side of faunal remains in the grave, while another group of individuals are associated with only the right side (Voeun, 2013). O’Reilly et al. (2006b) also made note of this occurrence during their excavations. While this may have been a coincidence, it appears from the several excavations that it was executed with intention. Further excavations in different locations may identify other such groupings.

Adult males and females were treated differently during life and in the mortuary context at Phum Snay. However, there is evidence of similar rates of childhood stress (LEH and cribra orbitalia) affected the sexes. There seems to be an increased prevalence of LEH at this site compared to other Iron Age sites. Could this suggest increased violence at the site may have been a factor for the amplified childhood stress when compared to minimal evidence for violence in northeastern sites in Thailand? However, it was not possible to link the cases of increased LEH with stature or individuals affected by violence, as the majority of the remains examined were individual bones from an ossuary collection. Otherwise, the additional stressors during childhood could mean children were susceptible to an array of diseases and/or malnutrition impacts. The increase in sexual dimorphism signifies increased differences in adult male and female stature, suggestive of the inability for individuals to overcome childhood stress. Conversely, stature for both sexes followed a general trend within Southeast Asia, indicating that increased sexual dimorphism was probably due to the different social and biological factors associated with sexual division of labour during agricultural reliance. Armelagos et al. (1991) has argued that other factors such as increased contact with animals, or increased interactions with other communities, may have brought disease to communities. The differing social factors impacting males and females at Phum Snay (Domett & O'Reilly, 2009; O'Reilly et al., 2006a) support the speculation that sex differences were evident at the site.

The evidence of increased violence at the site was probably one of the contributing factors to the high proportion of young adults in the mortuary context. The overall health of the Phum Snay community appears relatively poor. The health was declining made apparent by the evidence of an increased number of dental pathologies, even for a younger population. Many dental pathologies are age progressive and the elevated amounts of other lesions on the teeth suggests these people were displaying dental pathology profiles more evident of a community with an older population even though most were dying at young ages. The prevalence of periapical lesions could be explained by both sexes using their anterior teeth for reasons other than dietary needs. For example, males may have been manufacturing items for hunting and fishing, such as fishing lines, while females were constructing items for the site, such as baskets. If these people lived into older adult age they may have exhibited even poorer dental pathology profiles. The evidence does point to a more stressful childhood and social structure at the site, implying a decline of health. The nutritional deficiencies could be linked with other events at the site, for example the increased violence (Domett et al., 2011b), due to a decreased availability of resources. This is interesting because the immense variety of food resources available at the site based on zooarchaeological evidence (O'Reilly et al., 2006b; Voeun, 2013) should have allowed for a nutritionally sound diet. The increased amount of violence portrayed by the mortuary context and evidence from the skeletal remains may have impacted what these people were consuming. Traditional access to the abundance of resources would have been made difficult with the impeding threat of violence (Milner et al., 1991). Therefore, based on social changes which appear to have negatively impacted dental and childhood health, it appears the Phum Snay population suffered from markedly less healthy situations relative to earlier Iron Age communities, but they may have been like this for generations.

The changing social and environmental structure during this time may have influenced the level of violence in the area. The occupation at Phum Snay coincides with time the Funan polity was beginning to decline in the south, while the northern Chenla period was gaining power (O'Reilly, 2007). The unstable environment during the late Iron Age (Boyd & McGrath, 2001b), probably increased stressors for people as availability of food and water resources would have been limited and unpredictable. Evidence from the increased amount of violence at Phum Snay suggests a significant change to the social structure at the site during this period. The Phum Snay community may have been forced to fight against elements of the Chenla period since the eventual Chenla model encompassed the geographical location of Phum Snay. The Chenla was probably comprised of a number of small competing states rather than one central force (Sedov, 1978) and its desire for power and control over resources (such as land and water) in this area was evident. The battle for social and environmental control possibly increased during this time being in close proximity to where the Angkorian Empire would later be centred. The increased uncertainties may have put pressure on people to fight for what resources they required for survival.

6.4 Phum Sophy

It appears Phum Sophy inhabitants were not as negatively impacted by the social changes occurring during this time in comparison to Phum Snay. It is apparent that social changes were occurring at this time since the Chenla period had established social hierarchies (Higham & Hodges, 2013), especially during this crucial time during development of the future states. Perhaps during the occupation of Phum Sophy the social changes had already reached a stage where local political control was out of Phum Sophy's power. Chenla had probably gained total control over the group/region and had implemented social structures. During the time of Phum Sophy's occupation, Chenla would have had control over several resources and workers, with an increasing military presence for control and expansion (Higham 2013). There is no evidence suggesting interpersonal violence was present at this site to a degree similar to nearby Phum Snay. Based on evidence from other parts of the world, a decline of violence coincides with evidence of a newly established control (Torres-Rouff & Costa Junqueira, 2006), which may suggest the occupants of Phum Sophy were being subjected to a change in state control. Evidence of dental filing was still present at Phum Sophy, which could be a sign of the defined establishment of groups within the larger community setting.

There is evidence of differential treatment between males and females during life and death. This may have been evidence of the increasing social complexity of a hierarchy in Cambodian society at this time. Female wealth primarily consisted of semi-precious stones and bronze bangles, while males were interred with bronze bells, and iron implements, suggestive of different treatment and community roles for males and females during life. It has been suggested that these mortuary goods were evidence for social standing, such as carnelian and glass beads which were known to originate from international locations (Bellina, 2003).

The dental pathology profiles suggest male and female diets differed during young adulthood. However, the increase of older male caries might suggest older males consumed a similar diet to the females at the site. This might be explained if the younger men were participating in hunting/fishing trips, but older men were staying local and assisting with agriculture. Periapical lesion levels were high for the older adult females, suggesting tooth use for means other than food consumption. However, this may have also been the result from of high levels of caries in young adulthood.

It appears female health was declining since significantly more females were affected with LEH than males, and there was no evidence of cribra orbitalia affecting males, only females. This suggests an increase in childhood stressors only impacting females at the site, which can also be supported by the increase of sexual dimorphism for the stature, symptomatic of higher stress for females in the late Iron Age, adding to the new sexual dimorphism evidence presented by Clark et al. (2013). Based on the increase of developmental health problems and stature differences, females appear more susceptible to increased nutritional stressors and/or diseases as children, and were not able to overcome the stressors into adulthood. Individuals who are considered short for their age might be nutritionally deficient, and frequencies of skeletal nutritional indicators are typically much higher in these individuals, such as LEH and cribra orbitalia (Larsen, 1995). Even in different forms, rice provides limited protein to the diet (Larsen, 1995) and this could account for the larger percentages of cribra orbitalia in the female population compared with males. Females at the site would be subsisting on foods which are typically protein deficient, while the foods from hunting and fishing activities would provide males with adequate protein. However, based on the females' ability to survive into middle adulthood, this may be an indication that females were generally healthier, as they were able to sustain stress during childhood but live well into adulthood. On the other hand, female dental health is more susceptible to decline in agricultural communities (Lukacs, 2008; Watson et al., 2010) from the additional stress of increased fertility which occurs with increasing population sizes during increasing dependence on agriculture (Lukacs, 2008), corresponding with increasing fertility with minimal time between each birth for women (Armelagos et al., 1991). "The shorter intervals between births have, however, a negative impact on the health and nutrition of infant and mother" (Armelagos et al., 1991, p. 20). A female's biology (e.g. hormones and factors relating to pregnancy) appears to negatively impact dental health (Lukacs, 2008; Lukacs & Largarspada, 2006; Watson et al., 2010) which possibly accounts for the decline in dental health for the females at Phum Sophy. From the evidence so far, it appears females may have been more susceptible to stressors and a decline of health at Phum Sophy.

6.5 Southeast Asia

This discussion now considers the broader pattern of change across the Southeast Asian region.

6.5.1 Neolithic

The Neolithic period of Southeast Asia witnessed increasing population sizes and changes to social structure and subsistence patterns. Bellwood & Oxenham (2008) suggested that populations began to increase with the spread of agriculture, since it requires an increase of labour to maintain, in contrast to a hunter-gatherer lifestyle (Higham & Thosarat, 1998; White, 2011). The occupation during the Neolithic appear to have expanded from groups travelling along water routes, which are thought to have had knowledge of agriculture by the time they set up settlements (Higham & Kijngam, 2010, p. 208), and may have spread this information to other inland communities. Bellwood (2012) suggests hunter-gatherers adopted agriculture through learned experiences with groups who were already practicing it. Neolithic sites such as Khok Phanom Di would have been transitioning to agriculture (Bentley et al., 2007), but still utilizing hunting and gathering to contribute to the diet. It has been suggested the initial occupants were a mix of hunter-gatherers and agriculturalists in Thailand (Higham et al., 1992; Higham & Kijngam, 2010). Evidence from Ban Non Wat suggests the inhabitants followed this pattern during the Neolithic. Increasing population density would increase the demands for food production (Bellwood, 2012). Crops requiring little effort to maintain, but with large returns would benefit groups subsisting on a mixed economy, as they would have food to fall back on during times of decreased food availability (Greaves & Kramer, 2014). It appears a number of Southeast Asian groups, such as Ban Non Wat, Ban Chiang, and Khok Phanom Di (White, 2011), and An Son (Piper et al., 2012) utilized a variety of subsistence strategies as a backup plan.

Neolithic populations witnessed an increasing fertility rate coinciding with an increase on agricultural reliance. Fertility rates can be determined using the juvenile – adult ratio and mean child mortality rates (e.g. Domett & Tayles, 2006a). There was an increase of fertility in prehistoric Vietnam (Domett & Oxenham, 2011; McDonell & Oxenham, 2012; Oxenham et al., 2008), specifically during Neolithic Vietnam (Willis & Oxenham, 2013), which consequently appears to correspond to a decline of health. Oxenham et al. (2006, p. 283) suggests a decline of oral health with the intensification of agriculture. Evidence of increased fertility is noted at such sites as Khok Phanom Di (Tayles, 1999) and Man Bac (McDonell & Oxenham, 2012; Oxenham et al., 2008), and rates of increased child mortality during this period also suggest an increasing population (Jackes, 1994), also evident in Ban Non Wat's population.

From worldwide studies the adoption and intensification of agriculture is associated with a decline in general and oral health (Watson et al., 2010, p. 100). The addition of high stress in the form of cribra orbitalia was found on the Neolithic inhabitants at Ban Chiang and Khok Phanom Di (Oxenham et al., 2008, p. 201). The increasing reliance on agriculture is linked with 'civilization pathogens': diseases prevalent in agricultural communities where the large population densities allow easier transmission of diseases not seen in small hunter-gatherer societies (Pearce-Duvet, 2006, p. 370). In particular, Lukacs (2008) suggests female health faced a decline with the intensification of agriculture as the corresponding increase of fertility would have put extra strain on female health, in particular oral health. Evidence of a decline of maternal health has been documented in Neolithic Vietnam (McDonell & Oxenham, 2012; Willis & Oxenham, 2013). In Thailand, there is evidence of young females buried with newborns, suggesting complications during pregnancy (Halcrow & Tayles, 2008). In addition, Halcrow et al. (2008) suggest a large number of infant deaths take place at or around the time of birth at the Neolithic site of Khok Phanom Di. These maternal complications might be linked with the decline of oral health and corresponding poor health, especially by younger females during the Neolithic.

6.5.2 Bronze Age

During the Bronze Age it appears communities may have been largely autonomous, without major influences from neighbouring sites. This is evident from differences in mortuary records from nearby and contemporaneous sites Ban Lum Khao (Higham, 2002; Higham et al., 2004), Noen U-Loke (Higham et al., 2007) and Ban Non Wat, all located within Thailand. These differences in nearby sites were noted by White (1995) at Ban Chiang and Ban Na Di, also within close proximity to one another, reflective of different material and social culture. It can be proposed that the Bronze

Age communities in Southeast Asia had the resources required for sustaining independent communities. Even during the Neolithic there is evidence of groups following different subsistence patterns, basing it on the availability of resources (Piper et al., 2012). This suggestion appears feasible in this analysed sample from Ban Non Wat, as it shows significant dietary differences from communities nearby (Chapter 4). This is not to say communities were isolated, but it appears that communities primarily dealt with their own social and subsistence situations, separate from other communities in the surrounding area.

The Bronze Age socio-political structure in Southeast Asia appears generally stable. Higham & Thosarat (1998, p. 127) suggest Bronze Age sites would not have been large, consisting of no more than 250 people per community. Trade may have been occurring at the time, as exotic mortuary goods suggest trade networks (Higham, 2004), in particular, the exotic marine mortuary goods excavated from the mid-Bronze Age at Ban Non Wat suggest exchange with other groups (Higham, 2011). There is also no evidence to date suggesting interpersonal violence during the Bronze Age based on the lack of warfare in the mortuary context (Domett & Tayles, 2006b; White, 1982). The lack of dental modification in the Bronze and early Iron Ages could indicate social and environmental stability as people were not fighting for ownership or land resources. Neolithic hunter-gatherers would be relocating more often, and used dental modification as a way to identify themselves to other communities. Modification to the body is evidence of ritual such as during times of warfare (Martin et al., 2013), and therefore the established autonomous and non-violent communities in the Bronze would not require such a means of identification.

Were certain communities more involved with long distance trade and then migrating into new communities? Evidence from this study and previous literature (see: Bentley et al., 2009; Bentley et al., 2005) suggests gradual population growth may have been assisted by immigrants entering prehistoric communities in Thailand through migration outside of the community catchment. In comparison to other Thailand sites such as Non Nok Tha, Ban Lum Khao, Nong Nor, and Ban Na Di, the mortuary wealth and quantity at Ban Non Wat supersedes the others (Higham, 2011). Ban Non Wat's location would have allowed access to exotic sources as well (Higham, 2011) suggesting Ban Non Wat may have had a greater exchange influence. However, overall during the Bronze Age there is no evidence of hierarchical social structures in place (O'Reilly, 2000).

Previous research suggests an improvement of health throughout the Bronze Age. The health of the people within northeastern Thailand appears generally improved from the previous Neolithic. Clark et al (2013) propose an improvement of health into the middle Bronze Age at Ban Non Wat. Further improvements into the Bronze Age are noted at several sites within Thailand, for example (Douglas, 2006; Higham & Kijngam, 2012b; Higham et al., 1998). There is also evidence suggesting a healthy population as far away as Bronze Age Burma (Tayles & Domett, 2001). The exception of the Ban Lum Khao males (Domett, 2001). These males may have been generally unhealthier than males from the other nearby communities, however sample size and excavation location bias must be considered (Domett, 2001; Higham et al., 2004).

Could the improvement of health be linked with the decline of fertility? While there was a reduction of fertility in the Upper Mun River Valley (Domett & Tayles, 2006a), the reduction may have been caused by increasing young female mortality. Consequently, there were not enough females of childbearing age to increase the numbers of births each year. Alternatively, there was a reduction in the number of children born by each female, or an increased spacing between births which caused the decline. Interestingly, female oral health in the Iron Age seemed to improve as the percentage of female dental caries declined with the decline of fertility. Ultimately, this appears to have improved health for the community, in particular female oral health. Vietnam experienced lower fertility in the metal age, which corresponded with improved health (Willis & Oxenham, 2013).

While the overall trend of health appeared to be improving, female health was negatively impacted during times of pregnancy. Bellwood and Oxenham (2008, p. 30) suggest "once populations began the shift to agriculture, many would have found it difficult, or unnecessary, to slow the process, at least not until environmental limitations were reached or mortality rates increased". The complications due to pregnancy or childbirth (Domett, 2001) may have been a contributing factor to a decrease of fertility in the area. Evidence of a decline of maternal health due to nutritional deficiencies, which in turn has the capacity to negatively inflict the foetal health and potential of birth complications, was identified in Neolithic Vietnamese samples (McDonell & Oxenham, 2012; Willis & Oxenham, 2013). During the Bronze Age, Clark et al. (2013) noted that female stature decreased and stress increased during the latter half of the Bronze Age at Ban Non Wat. This evidence suggests there may have been factors negatively impacting maternal health throughout these periods since a decline of stature is linked with poorer maternal health (Wells et al., 2012). This increase of young female deaths may be a result of a trend in Thailand and the rest of Southeast Asia. Alternatively, this increase of young female mortality may have been limited to the Upper Mun River Valley of Thailand. Evidence from other Bronze Age communities in Thailand

(Pietrusewsky & Douglas, 2001) suggest this could just be isolated and limited to these two communities in the Upper Mun River Valley. However, Higham & Thorsarat (1998) note the increased number of young female deaths at Ban Na Di, also suggestive of pregnancy complications and risks. Therefore, while the indications of an improvement of health is suggested throughout the Bronze Age of Southeast Asia, there is evidence suggesting female health may have been starting to recover from the negative impacts of increased fertility in the Neolithic due to increasing fertility.

6.5.3 Iron Age

The Iron Age of Southeast Asia was witness to population increases of settlement numbers and sizes increased intrinsically by increasing fertility (Cox et al., 2011). There were also increased numbers of Iron Age communities situated along the banks of rivers (Domett & Tayles, 2006a). Some Iron Age sites were potentially up to 10 times larger than the previous Bronze Age (Higham & Thosarat, 1998, p. 137). During this time drier environmental conditions in Thailand are correlated with the construction of moats (Boyd, 2008; Cox et al., 2011; Higham et al., 2007). Population growth into the Iron Age meant increasingly closer proximity of sites, and probably competition for resources, especially during times of drought, which would be contributing factors for warfare. Increased interpersonal violence could have been a way for communities to take control of water resources. Evidence of warfare paraphernalia in the mortuary record has been recorded at Noen U-Loke (Higham & Thosarat, 1998) and Ban Non Wat (Higham & Hodges, 2013). There must have been some social structure in place at this time in order to control water and food resources for such a large number of people. Increases to population density meant competition for power over resources in what was previously a less dense and non-competitive environment.

It could be suggested that communities were coming under increased reliance on agriculture throughout the Iron Age when social constraints and water dependencies occur due to the changing environment. These hydrological changes may have caused a reduced reliance on particular food resources, potentially allowing for a variety of mixed economies. It may be suggested the communities had a growing dependence on agricultural crops, and lessening on other foods previously consumed. Reliance on one crop, such as rice, on its own would not create a nutritionally complete diet, since rice does not provide all the necessary means for a complete nutritional diet (Domett, 2001, p. 146), therefore the reliance of the single crop may have caused a decline of health, suggested at the site of Ban Chiang (Pietrusewsky & Douglas, 2001). Increased use of rice is identified at many sites in the Iron Age in the mortuary context (Domett & O'Reilly, 2009; Domett & Tayles, 2007; Higham et al., 2007; O'Reilly et al., 2006b) providing evidence of farming/agriculture. The Southeast Asian environment produced an abundance of different resources, capable to subsiding on a mixed economy. It can be suggested that communities may have been also involved with fishing and incorporating some hunting and gathering during agricultural production (Tayles & Oxenham, 2006). However, increases of population density and the number of settlements would have meant a decline in natural landscape which was probably more plentiful in the Bronze Age. The need to clear areas for rice fields and agricultural production would have meant a loss of other resources previously used for subsistence.

Shorter stature suggests an increase in dietary stressors, while taller stature suggests the opposite (Larsen, 1995). This is evident when contrasting the Ban Lum Khao shorter males and Noen U-Loke taller males, suggesting poorer health at Ban Lum Khao, while the taller male statures at Noen U-Loke might indicate an improvement to health (Domett & Tayles, 2006a). However, "in some populations, nutritionally deprived children may have had better diets during adolescence, resulting in growth rebounds and, hence, full growth and normal attainment of stature as adults" (Larsen, 1995, p. 191). This might be the case for Phum Sophy and Noen U- Loke males, while the female stature was still negatively impacted, evident of poor nutritional health as children. A decrease in childhood stressors may explain that childhood was generally better for people and less stressful, but perhaps the impact during adulthood was much greater. Conceivably people were making sure children were well fed to eventually maintain the community in adulthood; therefore adults are sacrificing some of their nutritional needs.

Dental health improves in the early Iron Age. Increasing reliance on agriculture was present by the Iron Age in Thailand, and corresponds with a decline of caries, since rice is suggested to have low cariogenicity (Tayles et al., 2000). Similar patterns of diet in the Noen U-Loke sample supports that the groups in the Upper Mun River Valley probably acted separately from one another and the lack of environmental changes at the time initiated the sexual division of labour between males and females evident in later Iron Age communities. The increasing reliance upon agriculture and sedentary lifestyle may have negatively impacted communities' health. The Metal period of Vietnam noted increases of pathological lesions in the samples, suggesting sedentary lifestyles, increased populations, and animal domestication as reasons for these increases (Oxenham et al., 2005). Animal domestication is also linked with increased interaction with animals, and therefore an increase of disease linked with domesticated animals such as tuberculosis and smallpox (Pearce-

Duvet, 2006). Faunal evidence from sites across Southeast Asia indicates the presence of domesticated animals during this time (such as pigs and dogs); therefore the animals would have been in close proximity to the villages and potential disease vectors. The environmental and social changes during the early Iron Age may have caused a continual improvement of health as was previously recorded for the Bronze Age. Previous Southeast Asian research suggests there was an improvement to health into the early Iron Age, with a subsequent decline of health occurring during the middle to late Iron Age.

It can be argued that increasing exchange networks during the Iron Age may have been a factor in the spread of disease. There is evidence of some diseases which may have offered an opportunity for spreading with increasing interactions between populations in the late Iron Age. For example, there was an increase of pathological lesions in the Iron/Metal ages, in Vietnam (Oxenham et al., 2008) and Thailand (Domett & Tayles, 2007; Tayles & Buckley, 2004). The appearance of newly-emerging diseases in the Iron Age is evident by the presence of lytic lesions never witnessed previously in Cambodia (Domett & Buckley, 2012), along with tuberculosis (Pietrusewsky, 1974; Tayles & Buckley, 2004) and leprosy in Thailand (Tayles & Buckley, 2004). The escalating number of settlements in the Iron Age may have led to amplified opportunities for illness, and unsanitary conditions (Armelagos et al., 1991). There were increases in systemic infections in Iron Age samples in comparison to the Bronze Age (Domett & Tayles, 2007). Additionally, the increase of trade networks may have been brought new diseases not previously present in the area (Tayles & Buckley, 2004). For example, Robbins et al. (2009) have identified the presence of leprosy and tuberculosis on human skeletal remains dating from 2000 B.C to the Iron Age in India. To-date, there is no evidence of tuberculosis in Southeast Asia prior to the establishment of trade links with India. Trade links with may have allowed the transfer of those diseases into the Southeast Asia region. In many cases skeletal indicators of disease and infection may not be available (Tayles & Oxenham, 2006). With the increases of population sizes from increased fertility, and the increases of exchange into the Iron Age, it makes the transfer of disease more readily possible between groups. There is archaeological evidence for links with China, Rome and India at this time (Bellina & Glover, 2004). Exchange appears to have taken place with several locations, for example, the Vietnamese waterways (Higham, 2004) and Cambodian Mekong River and other waterways (Stark, 2004) would have allowed opportunities for trade.

6.5.4 Late Iron Age

The eventual abandonment of several Iron Age sites in Thailand could be due to an inability to adapt to the changing environmental conditions in the area (Boyd, 2008). In particular, hydrological changes in the Iron Age may have caused the eventual abandonment of communities in this region during the Iron Age because of unreliable water sources (Boyd, 2008; Boyd & Chang, 2010; Boyd et al., 1999; McGrath et al., 2008). The drier conditions of the Iron Age would have put a strain on subsistence within the communities, potentially resulting in violent interactions for control over water and environmental resources suggested of the Phum Snay community.

The increases of settlement density and community size appear to have led the way for the eventual friction between groups for control of resources. The early state of Funan was active during the late Iron Age (approximately AD 245 – 550) and shows evidence of violence (Coe, 2003, pp. 57-60). In the south of Cambodia the site of Prohear (site cemetery dated between 200 BC and AD 100 and located near the Funan centre of Angkor Borei), had a large number of female burials at the site, lacking evidence of male burials, suggesting males were away hunting and/or fishing (Reinecke et al., 2009). However, the increased amount of warfare is not evident from the mortuary ritual at Prohear (Reinecke et al., 2009). The site of Angkor Borei was also active during the Funan period, and may have been the capital (Stark, 2007). Ikehara-Quebral (2010) suggests males at Angkor Borei may have been brought to the site to assist with labour, since the number of males is approximately double the female population. Alternatively, these individuals may have been brought as slaves, as the Funan was known for taking slaves and being associated with violence (Coe, 2003). The Funan is suggested to have been made up of a number of smaller independent communities (Sedov, 1978), therefore the desire for control over trading ports and resources would have been high at this time. While Phum Snay mortuary evidence and assessment of skeletal remains identified violence at the site (Domett & O'Reilly, 2009), Phum Snay was not located near the centre of Funan (located in the Southern portion of Vietnam and Cambodia) and may have been subject to the social complexities associated with the rise of the subsequent Chenla period/Pre-Angkorian period and its associated complex of small states. During the time of AD 400 – 600 (early Chenla) the Mun Valley (northeast Thailand) was witness to increasing social complexity and warfare (Higham & Hodges, 2013, p. 283).

The negative effects accompanying increasing reliance on agriculture and population density might explain why the spread of disease and illness did not affect populations until the later Iron Age. Studies around the world show declines of health with associated denser agricultural populations, for example (Armelagos et al., 1991; Larsen, 1995). Environmental and social changes have been known to introduce and spread disease, including increasing population density, poor sanitation, and increasing contact with animals (McMichael, 2004). "Generally speaking, the origin of infectious diseases present in the world today and in the recent human past can be traced to the time populations became large enough to sustain the pathogenic organisms that are responsible for their spread" (Larsen, 2002, p. 123). During the late Iron Age an increasing population relying on sedentary lifestyle based around agriculture appears to have had negative repercussions on health.

Increasing social interaction with other communities through trade may have exacerbated disease. In prehistoric Southeast Asia, it has been suggested that disease may have been spread through long-distance trade (O'Reilly, 2000; Pietrusewsky & Douglas, 2001; Tayles & Buckley, 2004). As mentioned above in Section 5.4.3, the social and environmental changes taking place during the Iron Age may have allowed an ideal habitat for the spread of disease. The extensive trade networks during the polity of Funan in southern Cambodia suggests these communities may have experienced a plague around the 5th century (Shaffer, 1996). Epidemics such as plagues took place around AD 542 in the Roman Empire, which spread through other communities such as China and the Mediterranean (McMichael, 2004). These and other infectious diseases may have transferred to Southeast Asian communities introduced during heightened trade. There are stylistic links between Prohear and other sites in Cambodia, in particular with the personal ornaments, for example bronze buffalo bracelets at Phum Snay, and gold-silver earrings from Oc Eo (Reinecke et al., 2009) and Noen U-Loke (Chang, per. comm.). Additionally, there are links with Phum Snay and northeast Thailand through the mortuary ritual (O'Reilly et al., 2006b). Phum Snay showed evidence of dental modification links/similarities with China and parts of Southeast Asia, while nearby sites also exhibit some similar patterns of ablation (Domett et al., 2011a). Mortuary evidence suggests interaction by means of trade, between communities (O'Reilly et al., 2006b; Reinecke et al., 2009). Evidence of trade suggests an extensive network for increasing interaction and opportunity for spread of disease between groups.

Female health appears more negatively impacted than male health in the late Iron Age. Evidence from the three sites examined in this study and additional information from previously documented sites (refer to Chapter 3) showcases the increasing amount of sexual dimorphism into the late Iron Age. The shortest females at late Iron Age Angkor Borei were also the ones most affected with indicators of stress, suggesting females had increased and longer periods of exposure to stress (Ikehara-Quebral, 2010). Males may have been culturally buffered, since their statures suggest catch up growth occurred so they reached their growth potential after childhood stress (Ikehara-Quebral, 2010). The decline in women's health probably accounts for the physiological demand from increasing fertility. Cox et al. (2011) suggest the evidence of an increased number of Iron Age sites during the Iron Age corresponded with population growth as a result of increased fertility. The increasing fertility throughout the late Iron Age would have decreased birth spacing to shorter intervals than the preceding time periods. The physiological implications associated with increased fertility (Lukacs, 2008; Lukacs & Largarspada, 2006) along with the evidence of poor oral health from Willis and Oxenham (2011) and this study (Chapter 3) suggests a similar decline of health during the late Iron Age analogous to the Neolithic. Evidence suggests female health declines as fertility increases (McDonell & Oxenham, 2012; Willis & Oxenham, 2013) and therefore decreased time between pregnancies therefore causing more stress on the female body. Angkor Borei witnessed an increasing population with increasing fertility rates corresponding with overall decline of oral health (Ikehara-Quebral, 2010; Pietrusewsky & Ikehara-Quebral, 2006). This study's dental health results suggest this pattern was occurring at Phum Snay and Phum Sophy. Additionally, the dental health may have been negatively impacted by the introduction of new (cariogenic) foods through the international exchange/influence (Klaus & Tam, 2010a). While there is evidence of disease decline at Angkor Borei, there is also the possibility acute infectious diseases may have been present but no indicators are present on the skeletal record as many deaths in the mortuary sample were young adults (Ikehara-Quebral, 2010).

A decline of female health can be linked with the conditions faced by females in the late Iron Age. Sexual division of labour, for example females staying at the site for cooking, would require the females to be local more often than the males. This labour division is indicative of matrilocal societies, where women would tend to the necessities of the village (Bentley et al., 2005). "Reduced population mobility and increased aggregation provide conditions that promote the spread and maintenance of infectious and parasitic diseases and the increase in pathogen load in humans. That is, close, more crowded living conditions facilitate greater physical contact between members of a settlement, and permanent occupation can result in decreased sanitation and hygiene" (Larsen, 1995, p. 198). This evidence suggests female health may have been negatively impacted by remaining local at the site to perform their tasks. As documented in other parts of the world, women were typically restricted to the site and responsible for domestic duties (Klaus & Tam, 2010a). If the females were only given access to agricultural foods (cariogenic and high in carbohydrates), and lacking the nutritional substance from meat and other foods, this could assist with the explanation of health deficiencies. Furthermore, males may have been subject to disease while away on trade, coming into contact with numerous people from different locations and allowing the transmission of pathogens between sites upon their return. Larsen (1984) has suggested agriculture negatively impacted female health more than male health. On the other hand, is this decline of health only evident for the late Iron Age of Cambodia? Or is it present in other parts of Southeast Asia? The demand for a larger sample of late Iron Age sites throughout Southeast Asia is necessary in order to explore this further. However, at this stage it appears the increasing demand on women and consequential gender roles may have negatively impacted female health late in the Iron Age of Southeast Asia.

6.6 Summary and conclusions

Through the analysis of the skeletal collections and their context from Ban Non Wat, Phum Snay and Phum Sophy this research provides a unique examination of the health, diet and migration over a period of 2000 years spanning a crucial time in Southeast Asian prehistory. The Ban Non Wat sample allowed the examination of an archaeological site encompassing the Neolithic to early Iron Ages over eight excavation locations at the site. The numerous sampling locations at Ban Non Wat is unique and showcases its archaeological significance. Ban Non Wat also provided archaeological evidence from a single site and the considerable changes that occurred throughout such important environmental and socio-political times during Thailand's prehistory. The study of Phum Snay and Phum Sophy introduced bioarchaeological results from some of the first late Iron Age remains from Southeast Asia. While a large number of these remains were collected from an ossuary containing human remains from previously looted burials, this is further support for the call to continue archaeological research in Cambodia in order to preserve and analyse its prehistory. Looting of archaeological sites is a significant problem, especially in Cambodia. Therefore, the examination of these two sites greatly expands on current knowledge about Cambodia's prehistory. Overall, these three sites offer an abundance of information pertaining to the environmental and socio-political changes Southeast Asian people in the late prehistoric period.

This research posed the following question: *Why did health during the rise of complex society in tropical Southeast Asia differ from the rest of the world?*

Throughout this research, the aim was to test whether the rise of state society in Southeast Asia ***did*** follow a similar trend to other state developments around the world.

Therefore, the purpose of this study was to examine whether health, diet and migration patterns followed the recently described trend in Southeast Asia of a maintained improvement of health, or alternatively, with the addition of these three new samples these factors followed a similar downward trend as most of the world during the rise of complex society. This research supplied evidence suggesting a number of complex factors are associated with the changes to health, diet and migration throughout prehistory. In order to explore the main conclusions of this research the main hypotheses from each chapter are reintroduced and discussed below.

6.7 Key Findings

6.7.1 Hypothesis 1

Prehistoric health declines throughout time as communities moved towards state control.

The findings from this research agree with Hypothesis 1 and suggest health declines just before state control, especially for females. Evidence from the samples at Ban Non Wat, Phum Snay and Phum Sophy suggest a number of factors associated with diet, migration and the sociocultural changes throughout time appear to have caused a decline of health into the late Iron Age.

The results of this study suggest poor health during the Neolithic from increases of childhood stressors and poor dental health. Previously published data suggests health improved throughout time into the Iron Age. This study supports that finding with additional health information from the (primarily) Bronze Age samples at Ban Non Wat. These results point toward generally low amounts of childhood stress which impacted males and females at a similar rate. There is an increase of young with an early age-at-death at Ban Non Wat, which is probably associated with pregnancy and birth-related factors. Otherwise, the Ban Non Wat sample follows the Southeast Asian trend of improving health into the Iron Age. However, the Iron Age samples suggest a decline through time, especially the late Iron Age. Phum Snay skeletal remains show a substantial increase of linear enamel hypoplasia from previous mortuary periods. Evidence of increased violence at the site probably impacted these stress levels. It was noted, however, that while males and females were impacted by a similar amount of childhood stress, males were more capable at overcoming the childhood stress, while females tend to have an earlier age-at-death, indicating they were more susceptible to succumb to stress. Dental health also declined at this time and was also evident at Phum Sophy. While skeletal evidence is limited for many diseases, this study also suggests an increase of infectious diseases may have impacted individuals in the late Iron Age.

6.7.2 Hypothesis 2

Changes to childhood diet will be gradual throughout the Neolithic to early Iron Age, after which, significant dietary differences will be present, negatively affecting health.

Major shifts occurred from hunter-gatherers to mixed hunter-gatherers to agriculturalists, seen through declining health status in several indicators. Isotopic evidence from Ban Non Wat suggests childhood diet gradually shifted to a greater reliance on C_3 foods (such as rice, and most vegetables) into the middle of the Bronze Age. During a period of time in the middle Bronze Age there was a significant dietary change, which appears to have started the gradual shift of dietary dependence incorporating increasing amounts of C_4 foods into the diet (e.g. some grasses, the suggestion of millet) into the early Iron Age. The significantly different dental pathology profiles evident between Ban Non Wat and Phum Snay/Phum Sophy suggest the late Iron Age had a high dependence on agricultural foods. Throughout Southeast Asia, the Neolithic and Bronze Age seemed reliant on a mixed economy with increasing reliance of agriculture into the Iron Age. An agricultural dependence introduced a sexual division of labour throughout the Iron Age and increased fertility, which appears to include negative health repercussions for children. Evidence from the increased dental pathologies and increased sexual dimorphism in the late Iron Age suggests a number of factors associated with significant dietary changes played a role in the decline of health, especially in females. Those factors would have included an increase of fertility associated with intensification of agriculture and a sedentary lifestyle, corresponding with increased population density, interaction with animals and unsanitary conditions.

The findings support Hypothesis 2, suggesting factors associated with dietary changes through time negatively affected health.

6.7.3 Hypothesis 3

Migration in the Neolithic will bring new ideas and population growth in Southeast Asia though through time there will be a decrease in migration from outside of the immediate catchment area of the community. However, extensive inter-community trade with groups from further distances will flourish throughout the late Iron Age, bringing negative health consequences.

Isotopic evidence from Ban Non Wat suggests the cessation of migrants from outside of the Mun River catchment towards the end of the Bronze Age. However, mortuary evidence suggests an extensive trade network was in place throughout Southeast Asia during the Iron Age. The increase of traded goods and lack of isotopic evidence from the late Iron Age samples of Phum Snay and Phum Sophy made it difficult to conclude whether migration from far distances outside of the community continued throughout the Iron Age since it was difficult to determine whether items were traded or introduced to the community through migration. However, bioarchaeological evidence might prove to be useful in the determination of migrants when paired with isotopic evidence. Isotopic evidence from Ban Non Wat identified one migrant from this Series of skeletal remains. Interestingly, this individual's mortuary ritual differed from burials during the same time period and had one of the poorest health profiles from the entire Ban Non Wat sample. Throughout Ban Non Wat's occupation there was evidence of trade via the presence of exotic goods originally from sea-faring communities. The trade intensified into the Iron Age when evidence of goods from locations located far distances away started becoming evident in the mortuary context. Intensified trade appears to have continued throughout the late Iron Age as evident from the mortuary goods found at Phum Snay and Phum Sophy suggesting trade increased throughout time. This intensified trade network may have introduced a number of new diseases into the region as new diseases were first documented as appearing in Southeast Asia starting in the Iron Age.

The results support a portion of Hypothesis 3, suggesting the migration of people and ideas in the Neolithic and extensive inter-community trade throughout the late Iron Age with negative health implications. However, it cannot be concluded whether migration from outside of the immediate catchment area did completely cease.

6.7.4 Health, diet and migration in Southeast Asian prehistory

Southeast Asia appears to have been affected at a later date than other parts of the world probably because the rise in complexity occurred much later. The research findings suggest Southeast Asian communities relied on a stable environment until gradual environmental changes forced them to make necessary changes. The introduction of migrants into communities appears to have introduced new opportunities for prehistoric Southeast Asia during the Neolithic. The introduction of new ideas (and perhaps foods and food-producing technologies) gave communities the ability to modify subsistence regimes that led to an increasing reliance on farming throughout time. Chapter 4 (Diet) suggests new subsistence regimes being introduced into the Ban Non Wat community, potentially through migration with the introduction of new foods (possibly millet) and technologies in the Neolithic.

It can be suggested that the tropical climate in Southeast Asia was a much more favourable place in regards to environment for a longer period of time in comparison to other parts of the world. The opportunity for an abundance of subsistence choices allowed each community to act autonomously and utilise the resources made available to them. As environmental and social changes ensued, including increasing population densities and food demands, changes to the community, including shifting food reliance, took place. However, this increase in population density led to an increased strain on the population and environment to keep up with the escalating demands. Communities were faced with an increase of people utilising resources once abundant. A decline of natural resources because of the increasing number of communities and population densities meant groups vying for control and the eventual increase of violence between communities.

Increases in population density and increasing connectivity with a number of populations also meant an increase of infectious disease. It is apparent from goods in the mortuary context that people were moving for trade purposes (although not necessarily for permanent residency), sometimes great distances. Evidence from Chapter 5 (Migration) indicated exchange and migration was occurring between and/or outside of the communities of Ban Non Wat, Phum Snay and Phum Sophy during their respective time periods. The late Iron Age of Southeast Asia shows evidence of new diseases never before apparent on the skeletal remains, interestingly appearing with an increase in trading intensity. These trade networks appear to have opened up opportunities for the spread of not only new foods and jewellery, but infectious disease. Increased contact with animals and other communities from far distances made an ideal way for disease transfer. During the Iron Age negative health impacts are evident through the addition of new diseases (Tayles & Buckley, 2004) and decline in health (see Chapter 3), in particular for females.

6.7.5 Directions for future research

The results from this research demonstrate the requirement for additional human remains analyses from Southeast Asia, in particular the Neolithic and Iron Ages.

It is evident the Neolithic was a crucial time for the expansion of people and ideas which assisted with significant transitions in Southeast Asian prehistory. Further examination of Neolithic sites could assist with understanding why these transitions occurred and how they spread throughout the entirety of Southeast Asia. Additionally, further examination of late Iron Age/Pre-Angkorian sites will increase evidence during the significant sociocultural changes Southeast Asia faced during times of increasing social complexity during the Funan and Chenla/Pre-Angkorian periods. In particular, is there evidence of immense warfare in other parts of Cambodia similar to Phum Snay? It would be valuable to determine how the state-like civilizations of Chenla and Funan eventually became powerful entities spanning portions of Southeast Asia. Further research can assist with determining whether a decline of health was witnessed across all of Southeast Asia, or only particular locations. An increased skeletal sample from greater numbers of late Iron Age sites in Southeast Asia will significantly add to the findings of this research. In particular, an emphasis should be to further bioarchaeological research in Cambodia, utilising not only current field recovery methods, but improved methods to compensate for the potential of disturbed or highly fragmented materials (as examined in this research). It should be noted that this period is key for advancing knowledge of Southeast Asian prehistory because it predates cremation.

6.7.6 Conclusion

This research demonstrates a decline of health in prehistoric Southeast Asia beginning during the later Iron Age. This health decline occurs in association with shifting environmental and social conditions experienced by the prehistoric inhabitants. The development of social complexity in Southeast Asia and its corresponding impact on diet and health does appear to follow a similar trend as many other complex societies worldwide. However, Southeast Asian trends appear to take place at a later stage in the emergence of social complexity. The lack of archaeological evidence from the late Iron Age in Southeast Asia is probably one of the reasons the decline of health had not been previously identified. Indeed, it does appear that health improved into the early Iron Age of Southeast Asia, however, owing to a range of factors, health conditions changed negatively in the late Iron Age. Therefore, it appears that health, diet and migration all played a crucial role in changing societies during the rise of complexity in the region prior to state formation.

Appendices

Appendix A Health

Appendix A Table 1

Ban Non Wat LEH by tooth.

Sex	Age	LEH A/O*	Percentage (%)
?	subadult	2/51	3.9
?	young adult	15/27	55.6
?	mid adult	0/4	0.0
?	old adult		
?	adult		
	Total ?sex	17/82	20.7
female	young adult	13/192	6.8
female	mid adult	5/22	22.7
female	old adult		
female	?		
	Total females	18/214	8.4
male	young adult	8/100	8.0
male	mid adult	3/66	4.5
male	old adult	0/2	0.0
male	?		
	Total males	11/168	6.5
	TOTAL Ban Non Wat	46/464	9.9

***A/O (affected/observed)**

Appendix A Table 2

LEH at Phum Snay by tooth.

Sex	Age	LEH A/O*	Percentage (%)
?	subadult	8/27	29.6
?	young adult	32/334	9.6
?	mid adult	15/267	5.6
?	old adult	5/93	5.4
?	adult	65/450	14.4
	Total ?sex	125/1171	10.7
female	young adult	11/97	11.3
female	mid adult	5/23	21.7
female	old adult	0/2	0.0
female	?	20/97	20.6
	Total females	36/219	16.4
male	young adult	5/27	18.5
male	mid adult	2/27	7.4
male	old adult	1/12	8.3
male	?	14/64	21.9
	Total males	22/130	16.9
	TOTAL Phum Snay	183/1520	12.0

Appendix A Table 3

Phum Sophy LEH by tooth.

Sex	**Age**	**LEH A/O***	**Percentage (%)**
?	subadult		
?	young adult	5/136	3.7
?	mid adult	1/79	1.3
?	old adult	2/62	3.2
?	adult	0/38	0.0
	Total ?sex	8/315	2.5
female	young adult	1/48	2.1
female	mid adult	9/53	17.0
female	old adult	0/20	0.0
female	?	2/30	6.7
	Total females	12/151	7.9
male	young adult	2/72	2.8
male	mid adult	0/44	0.0
male	old adult	0/25	0.0
male	?	1/2	50.0
	Total males	3/143	2.1
	TOTAL Phum Sophy	23/609	3.8

Appendix A Table 4

Ban Non Wat occurrence of individuals with LEH.

Sex	Age	Total individuals with LEH	Percentage (%)
?	subadult	1/4	25.0
?	young adult	1/1	100.0
?	mid adult	0/1	0.0
?	old adult		
?	adult		
	Total ?sex	**2/6**	**33.3**
female	young adult		
female	mid adult	2/2	100.0
female	old adult	4/7	57.1
female	?		
	Total females	**6/9**	**66.7**
male	young adult	2/5	40.0
male	mid adult	2/5	40.0
male	old adult	0/1	0.0
male	?		
	Total males	**4/11**	**36.4**
	TOTAL BNW	**12/26**	**46.2**

Appendix A Table 5

Phum Snay occurrence of individuals with LEH.

Sex	Age	LEH A/O*	Percentage (%)
?	subadult	4/10	40.0
?	young adult	19/54	35.2
?	mid adult	7/41	17.1
?	old adult	3/16	18.8
?	adult	33/129	25.6
	Total ?sex	**66/250**	**26.4**
female	young adult	7/14	50.0
female	mid adult	2/3	66.7
female	old adult	0/1	0.0
female	?	12/26	46.2
	Total females	**21/44**	**47.7**
male	young adult	2/4	50.0
male	mid adult	2/6	33.3
male	old adult	1/3	33.3
male	?	8/15	53.3
	Total males	**13/28**	**46.4**
	TOTAL SNAY	**100/322**	**31.0**

***A/O (affected/observed)**

Appendix A Table 6

Phum Sophy occurrence of individuals with LEH.

Sex	Age	Total individuals with LEH	Percentage (%)
?	subadult	0/1	0.0
?	young adult	4/36	11.1
?	mid adult	1/20	5.0
?	old adult	2/20	10.0
?	adult	0/16	0.0
	Total ?sex	**7/93**	**7.5**
female	young adult	1/8	12.5
female	mid adult	2/7	28.6
female	old adult	0/6	0.0
female	?	2/8	25.0
	Total females	**5/29**	**17.2**
male	young adult	1/12	8.3
male	mid adult	0/8	0.0
male	old adult	0/7	0.0
male	?	1/1	100.0
	Total males	**2/28**	**7.1**
	TOTAL SOPHY	**14/150**	**9.3**

Appendix A Table 7

Long bone averages for Ban Non Wat, Phum Snay and Phum Sophy by sex.

	Ban Non Wat Males	**Phum Snay Males**	**Phum Sophy Males**	**Ban Non Wat Females**	**Phum Snay Females**	**Phum Sophy Females**
Humerus						
N	8	23	1	5	2	4
Mean	165.4	164.8	164.9	153.7	153.5	151.9
SD	4.2	3.6		2.5	4.5	2.7
Range	159.4-171.6	161.2-177.5		150.5-157.4	150.3-156.6	149.2-155.5
Radius						
N	6	8	5	5	N/A	3
Mean	167.3	166.6	169.9	153.1	N/A	153.3
SD	3.8	2	1.8	1.1	N/A	1.8
Range	162.6-173	164.3-169.7	168.0-171.7	151.3-154	N/A	151.1-154.3
Ulna						
N	5	2	1	4	N/A	2
Mean	169.6	171.1	170.4	154.4	N/A	148.3
SD	4.8	1		2.8	N/A	2.7
Range	163.6-175.3	170.4-171.8		152.3-158.5	N/A	146.4-150.2
Femur						
N	6	11	1	5	6	1
Mean	164.8	165.7	161.1	150.9	155.6	150.8
SD	3.6	2	-	4.4	2.3	-
Range	159.4-170.4	162.6-169.2	-	143.5-154.8	152-158.8	-
Tibia						
N	4	14	5	3	7	6
Mean	167.9	169.6	165.3	154.4	154.8	149.6
SD	9.9	4	1.9	1.6	2.6	4.3
Range	159.2-181.8	162.7-175.7	163.3-167.7	153.2-156.2	150.9-157.7	144.9-154.7

N=number, SD= standard deviation

Appendix B Publication associated with Chapter 3 (Health)

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of publication: Dental health in Iron Age Cambodia: Temporal variations with rice agriculture

This publication was used in Chapter 4 of the thesis. A copy of this publication is found in Appendix B.

Author	Contribution
Jennifer Newton	Field and laboratory work. Abstract, introduction, materials, methods, results, figures and tables, discussion, conclusions.
Kate Domett	Grant holder and financial support for excavation. Field and laboratory work. Overall assistance with all sections.
Dougald O'Reilly	Grant holder and financial support for excavation. Field work. General comments.
Louise Shewan	Grant holder and financial support for excavation. Field work. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Dr Kate Domett

Signature

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of publication: Dental health in Iron Age Cambodia: Temporal variations with rice agriculture

This publication was used in Chapter 4 of the thesis. A copy of this publication is found in Appendix B.

Author	Contribution
Jennifer Newton	Field and laboratory work. Abstract, introduction, materials, methods, results, figures and tables, discussion, conclusions.
Kate Domett	Grant holder and financial support for excavation. Field and laboratory work. Overall assistance with all sections.
Dougald O'Reilly	Grant holder and financial support for excavation. Field work. General comments.
Louise Shewan	Grant holder and financial support for excavation. Field work. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Louise Shewan and Dougald O'Reilly

Signature

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Research article

Dental health in Iron Age Cambodia: Temporal variations with rice agriculture

J.S. Newton[a,*], K.M. Domett[a], D.J.W. O'Reilly[b], L. Shewan[c]

[a] James Cook University, Townsville, Queensland, Australia
[b] Australian National University, Canberra, ACT, Australia
[c] University of Sydney, Sydney, New South Wales, Australia

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Appendix C Diet

Appendix C Table 1

*δ^{13}**C** values for Ban Non Wat Series 2 human and pig populations*

Burial number	**Square**	**Period**	**δ^{13}C (‰ PDB)**	**δ^{18}O (‰ SMOW)**	**Sex**	**Age**	**Tooth Sampled**
640	G104	Iron Age 1 (?)	-12.8	27.0	Male	Young	27
644	N100	Iron Age 1	-13.8	28.2	?	Subadult	26
645	G104	Iron Age 1 (?)	-13.2	25.8	Male	Mid	28
646	G104	Iron Age 1	-13.2	27.2	Female	Young	27
647	G104	Iron Age 1	-12.7	27.2	?	Subadult	46
651	N100	Bronze Age 4	-13.5	27.6	?	Subadult	36
653	N100	Bronze Age 4	-13.9	26.2	Female	Mid	16
654	N100	Bronze Age 4	-13.0	27.2	Male	Young	27
655	N100	Bronze Age 4	-13.0	27.5	Male	Mid	27
660	N100	Bronze Age 3	-13.2	27.3	Female	Young	47
661	N100	Bronze Age 3	-13.3	27.4	?	Young	16
663	T200	Bronze Age 5	-13.2	26.5	Female	Young	26
664	T200	Bronze Age 5	-13.1	26.6	Female	Young	17
667	N100	Bronze Age 2	-13.7	27.2	Male	Young	27
671	G104	Bronze Age 3	-13.0	26.3	Male	Young	16
672	G104	Bronze Age 1	-13.4	26.9	Male	Mid	17
675	G104	Bronze Age 1	-12.9	27.8	?	Subadult	46
676	G104	Bronze Age 1	-13.6	25.2	Female	Young	48

Burial number	Square	Period	$\delta^{13}C$ (‰ PDB)	$\delta^{18}O$ (‰ SMOW)	Sex	Age	Tooth Sampled
679	S400	Bronze Age 2	-13.7	25.7	Male	Mid	17
680	T200	Flexed Neolithic	-11.2	27.2	?	Subadult	16
688	N96	Bronze Age 3	-13.5	26.4	Female	Young	46
690	N96	Bronze Age 3	-13.1	24.7	Male	Old	17
692	N96	Bronze Age 3	-13.6	26.4	?	Subadult	26
693	I500	Unknown	-13.1	27.2	Female	Young	18
696	N96	Bronze Age 3	-13.1	27.0	Male	Mid	27
697	N96	Bronze Age 2	-13.7	26.6	Female	Mid	26
Pig	G104	Bronze Age	-13.2	27.0	-	-	-
Pig	G104	Neolithic	-11.4	24.1	-	-	-
Pig	N100	Bronze Age	-12.7	28.1	-	-	-
Pig	N100	Neolithic	-11.5	25.9	-	-	-
Pig	P300	Iron Age	-12.5	28.8	-	-	-
Pig	S400	Bronze Age	-11.3	26.2	-	-	-
Pig	U200	Iron Age	-12.4	25.0	-	-	-
Pig	Z201	Iron Age	-12.4	27.9	-	-	-

Appendix C Table 2

Average $\delta^{13}C$ values for each excavation unit of Series 2

Excavation Unit	Total $\delta^{13}C$	Male	Female	Unknown sex
G104	-13.1 (8)	-13.1 (4)	-13.4 (2)	-12.8 (2)
N100	-13.4 (8)	-13.2 (3)	-13.5 (2)	-13.5 (3)
N96	-13.4 (5)	-13.1 (2)	-13.6 (2)	-13.6 (1)
T200	-12.5 (3)		-13.1 (2)	-11.2 (1) (B.680 outlier)
I500	-13.1 (1)		-13.1 (1)	
S400	-13.7 (1)	-13.7 (1)	-	
p-value	0.1038*	0.9222*	0.9333*	

***Kruskal Wallis Test (excluding samples with only one burial).**
Excludes the one Neolithic sample (B680).

Appendix C Table 3

Mortuary phase's $\delta^{13}C$ values for Series 1, 2, and combined series (excluding Series 1 extreme outliers)

Mortuary Phase	*Series 1 $\delta^{13}C$	Series 2 $\delta^{13}C$	Combined Series $\delta^{13}C$	Series 1 vs. Series 2 *p*-value
NF	-12.1 (1)	-11.2 (1)	-11.6 (2)	n/a
N1	-12.4 (6)	-	-12.4 (6)	n/a
N2	-12.8 (10)	-	-12.8 (10)	n/a
BA1	-12.4 (2)	-13.3 (3)	-12.9 (5)	0.2000[a]
BA2	-13.4(8)	-13.7 (3)	-13.5 (11)	0.0242[a]
BA3	-13.3(20)	-13.3 (7)	-13.3 (27)	0.9949[b]
BA4	-13.2 (39)	-13.3 (4)	-13.2 (43)	0.6306[a]
BA5	-13.1 (7)	-13.1 (2)	-13.0 (9)	0.6667[a]
IA1	-12.6 (13)	-13.2 (5)	-12.5 (19)	0.0981[b]
IA2	-12.8 (4)	-	-12.8 (4)	n/a

***Series 1 data from King et al. (2013)**
[a] Mann Whitney non parametric test used as samples small
[b] Student t-test

Appendix C Table 4

Series 1 and 2 $\delta^{13}C$ range of variation in percent per mil

Mortuary Phase	**Series 2**	**Series 1***
BA1	0.66	0.56
BA2	0.08	0.45
BA3	0.61	1.29
BA4	0.90	1.43
BA5	0.08	1.04
IA1	1.07	2.34

***Series 1 data from King et al. (2013)**

Appendix C Table 5

Statistical significance between the MP's of Series 1 and 2 (outliers removed)

MP comparison	**Test**	***p*-value**
NF vs. N1*	Mann Whitney	0.1429
N1 vs. N2	unpaired t-test (equal s.d)	0.2543
N2 vs. BA1	unpaired t-test (equal s.d)	0.7299
BA1 vs. BA2	unpaired t-test with Welch correction for different s.d	0.1007
BA2 vs. BA3	unpaired t-test (equal s.d)	0.0128
BA3 vs. BA4	unpaired t-test (equal s.d)	0.7269
BA4 vs. BA5	unpaired t-test (equal s.d)	0.1363
BA5 vs. IA1	unpaired t-test (equal s.d)	0.2107
IA1 vs. IA2	Mann Whitney	0.8648

***Two or less sample size in at least one MP**

Appendix C Table 6

Sex differences and t-tests results for the combined Series Ban Non Wat average $\delta^{13}C$ values (excluding Series 1 extreme outliers)

Mortuary Phase	Males	Females	p-value
NF	-12.0 (1)	-	N/A
N1	-12.3 (4)	-12.8 (2)	p=0.8000[a]
N2	-12.9 (4)	-12.9 (7)	p=0.5273[a]
BA1	-12.8 (2)	-13.1 (2)	p=0.6667[a]
BA2	-13.5 (6)	-13.6 (3)	p=0.5476[a]
BA3	-13.4 (12)	-13.2 (11)	p=0.1183[b]
BA4	-13.2 (17)	-13.2 (24)	p=0.4197[b]
BA5	-13.2 (2)	-13.0 (5)	p=0.5714[a]
IA1	-12.4 (6)	-13.0 (8)	p=0.2824[a]
IA2	-13.1 (1)	-12.5 (1)	N/A

[a] Mann Whitney non parametric test used as samples small
[b] Student t-test

Appendix D Article in review associated with Chapter 4 (Diet)

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of article in review: Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand

This article was used in Chapter 5 of the thesis. A copy of this article can be found in Appendix D.

Author	Contribution
Jennifer Newton	Field and laboratory work. Isotope analysis. Abstract, introduction, materials, methods, results, figures and tables, discussion, conclusions.
Kate Domett	Grant holder and financial support for excavation. Field and laboratory work. Overall assistance with all sections.
Nigel Chang	Grant holder and financial support for excavation. Field work. General comments.
Charlotte King	Isotope analysis. Methods. General comments.
Christopher Wurster	Isotope analysis. Methods. General comments.
Colin Macpherson	Isotope analysis. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Nigel Chang

Signature:

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of article in review: Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand

This article was used in Chapter 5 of the thesis. A copy of this article can be found in Appendix D.

Author	Contribution
Jennifer Newton	Field and laboratory work. Isotope analysis. Abstract, introduction, materials, methods, results, figures and tables, discussion, conclusions.
Kate Domett	Grant holder and financial support for excavation. Field and laboratory work. Overall assistance with all sections.
Nigel Chang	Grant holder and financial support for excavation. Field work. General comments.
Charlotte King	Isotope analysis. Methods. General comments.
Christopher Wurster	Isotope analysis. Methods. General comments.
Colin Macpherson	Isotope analysis. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Dr Kate Domett

Signature:

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of article in review: Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand

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Charlotte King	Isotope analysis. Methods. General comments.
Christopher Wurster	Isotope analysis. Methods. General comments.
Colin Macpherson	Isotope analysis. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Charlotte King

Signature:

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of article in review: Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand

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Christopher Wurster	Isotope analysis. Methods. General comments.
Colin Macpherson	Isotope analysis. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Colin Macpherson

Signature: 15 January 2014

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of article in review: Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand

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Christopher Wurster	Isotope analysis. Methods. General comments.
Colin Macpherson	Isotope analysis. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Christopher Wurster

Signature:

Examining local stability: diet and society at prehistoric Ban Non Wat, Thailand

Jennifer S. Newton[a,*], Kate Domett[a], Nigel Chang[b], Charlotte L. King[c], Christopher M. Wurster[d], and Colin G. Macpherson[e]

[a] School of Medicine and Dentistry, James Cook University, Townsville, 4811, Australia
[b] School of Arts and Social Sciences, James Cook University, Townsville, 4811, Australia
[c] Department of Anthropology, Durham University, DH13LE, United Kingdom
[d] School of Earth and Environmental Sciences, James Cook University, Cairns, 4870, Australia
[e] Department of Earth Sciences, Durham University, DH13LE, United Kingdom

*Corresponding author.
E-mail address: Jennifer.Newton@my.jcu.edu.au
Phone: +61 7 4781 6232

Abstract

This study examined over 2000 years of stability at Ban Non Wat, in northeast Thailand, by investigating prehistoric diet using carbon isotope composition of human tooth enamel. Carbon isotope data from five new excavations across Ban Non Wat were combined with a previously published dataset. The combined dataset casts doubt over previous interpretations of statistical significances and identifies new significant relationships between diet and time. Analyses of $\delta^{13}C$ values indicated very little variation in diet composition during the Neolithic to early Iron Age. Throughout all mortuary phases, the people of Ban Non Wat had $\delta^{13}C$ values suggesting a diet comprised mainly of C_3 foods, with minimal impact from C_4. With minor variation, $\delta^{13}C$ values stay fairly consistent, indicating the potential ability of Ban Non Wat to adapt positively to environmental changes. Other sites from the Upper Mun River Valley also display $\delta^{13}C$ values indicative of a mainly C_3 diet, but were significantly different to Ban Non Wat. We suggest these significant differences do not indicate vastly different overall diets but represent a minor variation in C_3/C_4 proportions. This study examines the questions surrounding social stability, and achievement of status, through the examination of diet at Ban Non Wat.

Keywords: Ban Non Wat, carbon isotopes, diet, prehistoric Thailand

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Appendix E Migration

Appendix E Table 1

Ban Non Wat isotope values and burial information.

Burial number	Square	Period	$\delta^{18}O$ (‰ SMOW)	$^{87}Sr/^{86}Sr$ in enamel	Sex	Age	Tooth Sampled
640	G104	Iron Age 1 (?)	27.0	0.709524	Male	Young	27
644	N100	Iron Age 1	28.2	0.709522	?	Subadult	26
645	G104	Iron Age 1 (?)	25.8	0.709578	Male	Mid	28
646	G104	Iron Age 1	27.2	0.709713	Female	Young	27
647	G104	Iron Age 1	27.2	0.709531	?	Subadult	46
651	N100	Bronze Age 4	27.6	0.709748	?	Subadult	36
653	N100	Bronze Age 4	26.2	0.709665	Female	Mid	16
654	N100	Bronze Age 4	27.2	0.710154	Male	Young	27
655	N100	Bronze Age 4	27.5	0.709673	Male	Mid	27
660	N100	Bronze Age 3	27.3	0.709652	Female	Young	47
661	N100	Bronze Age 3	27.4	0.709692	?	Young	16
663	T200	Bronze Age 5	26.5	0.709812	Female	Young	26
664	T200	Bronze Age 5	26.6	0.709785	Female	Young	17
667	N100	Bronze Age 2	27.2	0.709674	Male	Young	27
671	G104	Bronze Age 3	26.3	0.709628	Male	Young	16
672	G104	Bronze Age 1	26.9	0.709706	Male	Mid	17
675	G104	Bronze Age 1	27.8	0.709818	?	Subadult	46
676	G104	Bronze Age 1	25.2	0.708912	Female	Young	48

Burial number	Square	Period	$\delta^{18}O$ (‰ SMOW)	$^{87}Sr/^{86}Sr$ in enamel	Sex	Age	Tooth Sampled
679	S400	Bronze Age 2	25.7	0.709767	Male	Mid	17
680	T200	Flexed Neolithic	27.2	0.709651	?	Subadult	16
688	N96	Bronze Age 3	26.4	0.709615	Female	Young	46
690	N96	Bronze Age 3	24.7	0.709588	Male	Old	17
692	N96	Bronze Age 3	26.4	0.709689	?	Subadult	26
693	I500	Unknown	27.2	0.709614	Female	Young	18
696	N96	Bronze Age 3	27.0	0.709576	Male	Mid	27
697	N96	Bronze Age 2	26.6	0.709757	Female	Mid	26

Appendix E Table 2

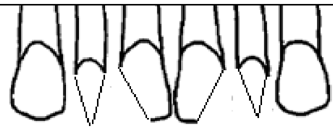
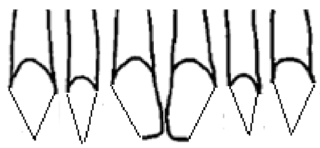
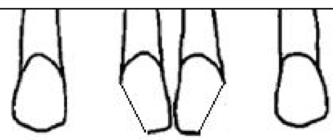
Patterns of ablation in the maxilla and mandible at Phum Snay and Phum Sophy.*

	Right			Left			Males	Females	?sex	Young	Mid	Old	?adult	n	%
Pattern No.	**C**	**LI**	**CI**	**CI**	**LI**	**C**									
<u>Maxillae</u>															
1		A			A		27	24	11	11	12	6	33	62	72.9
2	A	A			A	A	4	5	0	4	0	1	4	9	10.6
3	A	A			A		1	2	1	0	0	1	3	4	4.7
		A			A	A									
4	A				A	A	1	1	0	0	1	0	1	2	2.4
5	A						0	1	0	1	0	0	0	1	1.2
6		A					2	3	0	0	3	1	1	5	5.9
					A										
7		A	A		A		0	1	0	0	0	0	1	1	1.2
8				A			1	0	0	0	0	1	0	1	1.2
														85	100
<u>Mandibles</u>															
9		A	A	A	A		3	2	5	2	2	2	4	10	55.5
10			A	A			0	0	1	0	0	0	1	1	5.6
11		A	A	A	A	A	0	1	0	0	1	0	0	1	5.6
12		A		A	A		0	0	1	1	0	0	0	1	5.6
13	A	A	A		A	A	0	0	1	0	0	1	0	1	5.6
14	A		A	A			0	0	1	0	0	1	0	1	5.6
15			A				0	0	1	0	0	0	1	1	5.6
16					A		0	0	1	0	1	0	0	1	5.6
17						A	0	0	1	0	0	0	1	1	5.6
														18	100

Key: C = canine, LI = lateral incisor, CI = central incisor; A = AMTL
***Chart from Domett et al. 2011**

Appendix E Table 3

Patterns of intentional filing in the maxillae of Phum Snay and Phum Sophy^.

Maxilla		**Crown Abrasion**	**Individuals affected**	
			Phum Snay	**Phum Sophy**
A		Central incisors: distal Lateral incisors: mesial. Canines unaffected	2 Young adults 1 Older adult	
B		Central incisors: distal. Lateral incisors: mesial and distal; pointed. Canines unaffected.	2 young adult female 2 adults	
C		Central incisors: distal. Lateral incisors: mesial and distal; pointed. Canines: mesial and distal; pointed.	1 adult male	1 Young adult female 1 Young adult male 1 Older adult male*
D		Central incisors: distal. Lateral incisors: AMTL. Canines unaffected	1 Middle aged adult male	

*** These individuals are thought to belong to this pattern, but not all had complete anterior maxillae.**
^Chart from Domett et al. (2011a)

Appendix E Table 4

Patterns of intentional filing in the mandibles of Phum Snay and Phum Sophy.*

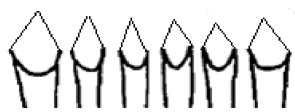
Mandible	Crown Abrasion	Individuals affected	
		Phum Snay	**Phum Sophy**
E 	Central incisors: distal. Lateral incisors: mesial and distal; pointed. Canines unaffected.	1 middle aged adult 1 young adult	
F 	Central incisors: distal. Lateral incisors: mesial and distal; pointed. Canines: mesial and distal; pointed.		1 adult female & 1 middle aged adult: Pattern F, H or J.
G 	Central incisors: distal and mesial, pointed Lateral incisors: mesial and distal; pointed. Canines unaffected.	1 older adult 1 young adult 1 middle aged adult 1 adult	
H 	Central incisors: distal and mesial, pointed Lateral incisors: mesial and distal; pointed. Canines: mesial and distal; pointed.	1 adult	
I 	Central incisors: distal; and worn much lower than lateral incisors. Lateral incisors: mesial. Canines unaffected.	1 young adult	
J 	Central incisors: distal; and worn much lower than lateral incisors. Lateral incisors: mesial. Canines: mesial and distal; pointed.		1 middle aged adult 1 middle aged adult female

***Chart from Domett et al. (2011a).**

Appendix F Publication associated with Chapter 5 (Migration)

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of publication: Cultural Modification of the Dentition in Prehistoric Cambodia

Thesis Chapter 6 uses modified versions of the tables from this publication. A copy of this publication can be found in Appendix F.

Kate Domett	Grant holder and financial support for excavation. Primary contributor. Field and Laboratory work. Abstract, introduction, materials, methods, results, discussion, conclusion.
Jennifer Newton	Laboratory work. Abstract, Results, Tables. General comments.
Dougald O'Reilly	Grant holder and financial support for excavation. Field work. Discussion. General comments.
Nancy Tayles	Grant holder and financial support for excavation. General comments.
Louise Shewan	Grant holder and financial support for excavation. Field work. General comments.
Nancy Beavan	Grant holder and financial support for excavation. Field work. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Dr. Nancy Beavan

Signature:

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of publication: Cultural Modification of the Dentition in Prehistoric Cambodia

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Jennifer Newton	Laboratory work. Abstract, Results, Tables. General comments.
Dougald O'Reilly	Grant holder and financial support for excavation. Field work. Discussion. General comments.
Nancy Tayles	Grant holder and financial support for excavation. General comments.
Louise Shewan	Grant holder and financial support for excavation. Field work. General comments.
Nancy Beavan	Grant holder and financial support for excavation. Field work. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Dr Kate Domett

Signature:

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of publication: Cultural Modification of the Dentition in Prehistoric Cambodia

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Louise Shewan	Grant holder and financial support for excavation. Field work. General comments.
Nancy Beavan	Grant holder and financial support for excavation. Field work. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Louise Shewan and Dougald O'Reilly

Signature:

Statement on the Contribution of Others

Thesis Title: Health, diet and migration prior to the establishment of the Angkorian civilization of Southeast Asia

Name of Candidate: Jennifer Newton

Title of publication: Cultural Modification of the Dentition in Prehistoric Cambodia

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Louise Shewan	Grant holder and financial support for excavation. Field work. General comments.
Nancy Beavan	Grant holder and financial support for excavation. Field work. General comments.

I confirm the candidate's contribution to this paper and consent to the inclusion of the paper in this thesis.

Name: Nancy Tayles

Signature:

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Cultural Modification of the Dentition in Prehistoric Cambodia

K. M. DOMETT,[a]* J. NEWTON,[a] D. J. W. O'REILLY,[b] N. TAYLES,[c] L. SHEWAN[d] AND **N. BEAVAN[c]**

[a] *James Cook University, Townsville, Queensland, Australia*
[b] *Australian National University, Canberra, ACT, Australia*
[c] *University of Otago, Dunedin, New Zealand*
[d] *University of Sydney, Sydney, New South Wales, Australia*

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