ASSESSING QUALITY OF LIFE FOR THE URBAN INHABITANTS OF CLASSICAL ANGKOR, CAMBODIA (C. 802-1432 CE)

A Thesis Submitted to the Committee on Graduate Studies
In Partial Fulfillment of the Requirements for the Degree of Master of Arts
in the Faculty of Arts and Science

TRENT UNIVERSITY
Peterborough, Ontario, Canada
© Copyright by Sophie Goldberg 2019
Anthropology M.A. Graduate Program
May 2019
ABSTRACT

ASSESSING QUALITY OF LIFE FOR THE URBAN INHABITANTS OF CLASSICAL ANGKOR, CAMBODIA (C. 802-1432 CE)

Sophie Goldberg

This thesis examines the interrelationship of urban planning and population health at the site of Angkor (c. 802-1432 CE), the capital city of the Classical Khmer state, now found within modern-day Cambodia. The inhabitants of Angkor developed a settlement strategy that relied on the dispersal of water management features, rice fields, temples and residential areas, to best utilize the spread-out environmental resources of the surrounding monsoon-forest climate. Thus, the main question to be answered by this thesis is this: did the city-planning practice of dispersed, low-density agrarian urbanism promote resilience against the disease hazards associated with tropical environments?

To answer this question, methods involved creating assessing environmental and socio-cultural factors which habituated the urban inhabitants of Angkor’s relationship to disease hazards. The results of this assessment demonstrate that it was not until the last stages of Angkor’s urban development, when non-farming members of the population were concentrated into the “core” area of temples within city, that the city’s inhabitants’ vulnerability to infectious disease increased. As the city took a more compact settlement form, it was not as environmentally compatible as the earlier dispersed pattern. Significantly, archaeological case studies such as this can illustrate the long-term development and end-result of urban planning to deal with disease hazards, both in terms of everyday occurrences, as well as during crisis events, which has important implications for contemporary research on environmental disasters today.

Key words: Adaptive Strategies, Pre-industrial Urbanization, Tropical Diseases, Resilience, Mainland Southeast Asia
ACKNOWLEDGEMENTS

The completion of this thesis could not have occurred without the help and support of numerous individuals and institutional bodies that I would like to acknowledge here, and to whom I am eternally grateful.

Firstly, I would like to thank my supervisor, Dr. Gyles Iannone, for not only your guidance as my thesis supervisor, but also for the opportunity to participate in the SETS project. Thank you for all your help and advice, from providing edits for my early drafts, fielding my questions surrounding my findings, and directing me to numerous academic sources that enhanced my writing. I could not be the researcher that I am today without your direction. I appreciate all the opportunities that you provided for me throughout my time as your student.

Secondly, I would like to thank the members of my thesis committee, Dr. Hugh Elton and Dr. Anne Keenleyside, for the numerous suggestions throughout the course of my thesis writing process and during our committee meetings. These helped shaped the document into the form it is today and as such, I greatly appreciate your advice and the time you took to help me with the conception and the editing of this project. I would also like Dr. Jocelyn Williams, and Dr. Jennifer Newton, for chairing and acting as the external, respectively, during my defense. Your comments and feedback helped my thesis document become the final form it is today. Furthermore, you, along with the rest of the committee, made the defense feel like one of the biggest accomplishments of my life.

I would also like to thank the numerous members of the Trent Anthropology Department who I interacted with throughout my time as a Trent student, and whose instruction provided the foundational skills as a graduate student, either as my teachers in coursework, or as supervisors during my TA-ship. These skills are things that I will take into the next stage of my career, and I appreciate the impartation of your knowledge very much. I would also like to give particular thanks to Yumi Pedoe and Judy Pinto, who helped field the numerous administrative questions I had throughout my time as a Trent student, and helped ease me into my experience as a graduate student.
I would like to thank the members of the Socio-Ecological Entanglement of Tropical Societies project, especially Zankhna Mody and Natalie Baron, who were my primary sounding boards for ideas as we worked on the SETS project together. I would also like to thank the SETS alumnae for their support during my participation in the 2016 SAAs, which was a highlight of my graduate experience. I would like to thank our Cambodian host, Mr. Bunteay, who acted as our primary guide throughout my fieldwork in Cambodia, as well as his family, for graciously accommodating us and providing us such a wonderful international experience during our trip there in 2016.

I would also like to acknowledge the scholarship funding provided by outside funding bodies, such the Social Sciences and Humanities Research Council for the generous provision of a SSHR CGSM scholarship, as well as the OGS program for an Ontario Graduate Scholarship. I also greatly appreciate the financial aid provided by Trent University through several internal entrance scholarships and bursaries provided through the graduate office. I would also like to thank Dr. Michael Eamon, Dana Capel, and Tom Mohr for allowing me to present my thesis research at a number of different public speaking venues in Peterborough, which were both a humbling and enlightening experiences.

I would like to thank the numerous members of the 2014, 2015 and 2016 graduate cohorts for the social opportunities and academic collaboration that we had at my time on Trent’s campus. In particular, I would like to thank Renee Hendricks, Dan Worby, Kathleen Forward and Ellie Tamura. I enjoyed the time we spent together in class, in the office and outside the university, and your continued encouragement of my work. My experience at Trent would have not been made without all of you.

Finally, I would like to finally thank my friends, co-workers and family for their unconditional care and support. You were my cheerleaders as I finished the document and I treasure all your kind words and actions as I completed the draft. To my parents and sisters, I would like to thank you for helping me get through this enriching, if challenging experience with all your love and understanding.
# TABLE OF CONTENTS

ABSTRACT ........................................................................................................... ii
ACKNOWLEDGEMENTS ..................................................................................... iii-iv
TABLE OF CONTENTS ...................................................................................... v-viii
LIST OF FIGURES ............................................................................................ ix-xi
LIST OF TABLES ............................................................................................... xii
GLOSSARY OF TERMS ...................................................................................... xiii-xxi
INTRODUCTION ................................................................................................. 1-20
Water, Rainfall, and Disease in the Tropics ....................................................... 2-3
What are Tropical Diseases? .............................................................................. 3-5
Southeast Asia ..................................................................................................... 5-10
Tropical Diseases and Southeast Asia ............................................................... 10-12
The Problem ....................................................................................................... 12-14
  Potential Challenges ....................................................................................... 14-16
Research Questions and Objectives ................................................................. 16-18
Chapter Summaries ........................................................................................ 18-20
CHAPTER 2: BACKGROUND ........................................................................... 21-56
The “City” in Archaeological Study .................................................................. 22-26
Major Epidemiological Transitions in the Pre-industrial World ..................... 26-29
The Diseases of Pre-industrial Cities ............................................................... 29-33
Population Numbers and Density in Pre-industrial Southeast Asia ............... 33-36
Population Health and Settlement in Pre-Classical Southeast Asia .............. 37-48
  Incipient Agricultural Communities in the Neolithic (c. 2500 BCE-1500 BCE) 38-40
  Bronze Age Village Settlements and Cemeteries (c. 1500-500 BCE) ............ 41-44
  The Iron Age Moated Sites (c. 500 BCE-500 CE) .......................................... 44-48
The Development of the State in Southeast Asia ............................................. 48-50
The Funan Sites of Angkor Borei and O’c Eo (c. 200 CE-600 CE) ................. 51-54
CHAPTER 4: SOCIAL COMPLEXITY AT ANGKOR AND ITS HEALTH IMPACTS...91-121

The “Classical State” of Angkor (c. 800-1432 CE).................................................................91-92
Angkor’s Physical Environment................................................................................................92-96
Angkor: The Capital City of the Khmer Empire.......................................................................96-103
The Urban Archaeology of Angkor..........................................................................................103-119
  Length and Longevity of Settlement......................................................................................108-110
  Participation in Community Works: Water Management and Agricultural
  Intensification.........................................................................................................................110-113
  Population Growth and Dynamics: Temple Administration and Labour.........................113-119
The End of Angkor (And Its Public Works)? Ability to Withstand External Shocks..........119-121
Conclusions...........................................................................................................................121

CHAPTER 5: A BIOCULTURAL MODEL FOR ANGKOR.......................................................122-160

The Growth/Exploitation, or $r$-Phase....................................................................................123-131
Conservation, or $K$-Phase.......................................................................................................131-144
Collapse or release ($\omega$)-Phase..........................................................................................144-156
Reorganization, or $a$-Phase.....................................................................................................156-159
Conclusions...........................................................................................................................159-160

CHAPTER 6 DISCUSSION AND CONCLUSION.................................................................161-176

Research Questions.................................................................................................................162-167
  1. Did the city-planning practice of dispersed, low-density agrarian urbanism promote
     resilience against the health hazards and risks associated with tropical, wetland
     environments?.....................................................................................................................162-164
  2. Or, does low-density, dispersed urbanism create unique health problems comparable
     to the population health issues comparable to other pre-industrial urban
     sites?........................................................................................................................................164-165
  3. Which tropical disease hazards were likely to have been present in mainland
     Southeast Asia during the Classical era?.............................................................................165
4. What adaptive strategies would the inhabitants of Angkor have used to prevent the risk of contracting these diseases? .......................... 165-166

5. How did these patterns of disease risk and vulnerability change over time with the transformation of Angkor’s “urban footprint?” or city plan over time and space? ................................................................. 167-168

Challenges ........................................................................................................... 168-170

Future Research ................................................................................................. 170-173

Key Findings and Conclusions .......................................................................... 174-176

REFERENCES CITED ......................................................................................... 177-211
LIST OF FIGURES

1.1 Climate Zones of the World (Southeast Asia Highlighted), modified from M.C. Peel et al. 2007 (Fig. 10)...........................................................................................................................................2

1.2 Map of Southeast Asia, modified from Free Vector Maps.com........................................6

2.1 Mainland Southeast Asia's Position in the Maritime Silk Road, modified from Cambodian National Commission for UNESCO (2016), fig. 2.3, pg. 51......................................................35

2.2 Pre-Angkorian Sites Discussed in Chapter 2, modified from Oxenham and Buckley 2016: Fig. 2.1................................................................................................................................................37

2.3 War Scene Showing Jayavarman VII’s Enemies Thrown into Tonle Sap, Bayon Temple, c. 12th century CE (Personal Photo taken May 2016).................................................................49

2.4 Early Complex States of the Cambodia Basin: Funan, Chenla, and Angkor, modified from Cambodian National Commission for UNESCO 2016. Figure 2.20, pg. 36.................................50

2.5 Saka (Central Asian visitors) at Temple N15, Sambor Prei Kuk (c. 7-8th century CE). Cambodia National Commission for Unesco, Figure 230, pg. 47.................................................................55

2.6. Fan-shaped rice fields from the Greater Angkor region, arrows to show orientation, modified from Hawken 2013 (Fig. 1.5 Pg.356)..................................................................................56

3.1. Map of Areas Visited at Angkor Archaeological Park, modified from canbypublications.com......................................................................................................................................................59


3.3. Assessment of Community Quality of Life (Adaptive Cycle)..................................................77

3.4. Examples of aquatic, wetland species in the Greater Angkor region; Bas-relief of Banteay Chhmar’s Lokeswara gallery, c. 12-13th century CE (Personal photo taken May 2016)..................................................................................................................78

3.5. Bas-relief of prisoners of war from Banteay Chhmar temple’s Lokesevara Gallery, c. 12th century CE (Personal Photo taken May 2016).................................................................81

3.6. Bas-relief scene of Food Preparation, Bayon temple, c. 12 century CE (Personal Photo taken May 2016)..................................................................................................................82

3.7. The large-scale West Baray during the dry season (Personal photo taken May 2016)............83
3.8. Example of the stilted and raised housing that was the basis of Angkor's domestic architecture; Lokesevara gallery, Banteay Chhmar temple, c. 12-13th century CE (Personal Photo taken May 2016).................................................................85

3.9. Daily Scenes of Trade at Marketplace, Bayon Temple, c. 12th century CE (Personal Photo taken May 2016).................................................................87

4.1. Location of Angkor Archaeological Park, modified from freevectormaps.com.............91

4.2. Location of Angkor in relation to the Tonle Sap in the Cambodia Basin, modified from Kummu (2009: 1414, figure 1).................................................................93

4.3. Important temples and sacred sites related to state-sponsored water management features discussed throughout this thesis, modified from A New Archaeological map of Greater Angkor (Evans et al. 2007, 14277-14282).................................................................107

4.4. LIDAR evidence of Angkor Thom's settlement patterns, modified from Evans (2016: 173; Fig.7)...........................................................................109

4.5. LIDAR evidence of regularly-spaced house mounds near East Baray, modified from Evans (2016: 168, fig. 3g and 3h). Arrows show likely direction of water-flow.......................110

4.6. Lidar evidence of trapeang of Preah Khan’s “temple city,” modified from Evans (2016: 171; Fig. 6d)...........................................................................110

4.7. Angkor’s state-sponsored water management system, modified from Kummu 2009 (Fig 4, pg. 1417) to show the direction of water flow.................................111

4.8. Location of important inscriptions that describe and illustrate the processes of Angkor’s, “cultivated,” or “artificial” landscape/agro-eco-system, modified after Hawken 2013 356, Fig.3). Arrows indicate the orientation of fields.........................................................116

4.9. Examples of orthogonal and rectilinear-orthogonal rice fields (arrows indicating orientation), modified after Hawken 2013 (Fig. 1.1 and 1.2 Pg. 351).........................................................118

4.10. Examples of co-axial and fan-shaped rice fields (arrows indicating orientation), modified after Hawken 2013 (Fig. 1.3 and 1.4 Pg. 351).........................................................118

5.1. Poster image depicting canal, from Angkor Archaeological Park (Personal photo taken May 2016).................................................................................125

5.2. Preah Koh c. 9th century CE (Personal Photo taken May 2016).................................133

5.3. Mountain Temple of Bakheng, c. 9-10th centuries CE. (Personal Photo taken May 2016)..133
5.4. Buddha Relief of the Baphuon temple, c. 12th century CE (Personal photo taken May 2016) ........................................................................................................................................ 134

5.5. Interiors of Ta Phrom and Preah Khan Temple Complexes (Personal Photo taken May 2016) ........................................................................................................................................ 140

5.6. Interiors of Ta Phrom and Preah Khan Temple Complexes (Personal Photos taken May 2016) ........................................................................................................................................ 140

5.7. Hospital Chapel, Ta Phrom Kel (Personal Photo taken May 2016) .................................. 141

5.8. Banteay Srei Temple (Personal Photo taken May 2016) .................................................. 142

5.9. Inner Temple enclosure of Ta Som, built c. 12-13th centuries CE (Personal Photo taken May 2016) ........................................................................................................................................ 146

5.10. Temple Engraving at the Bayon, 12th c. CE, showing Khmer doctor treating patient, for leprosy? (Personal Photo taken May 2016) .................................................................................................................. 149

5.11. Doctor Treating Patient, Hospital Chapel at Ta Phrom Kel, c. 12th C. CE (Personal Photo, May 2016) ........................................................................................................................................ 149

5.12. View from Phnom Bakheng showing bunded rice fields during the dry to wet season transition (Personal Photo taken May 2016) .................................................................................................................. 151

5.13. Free-wandering cow at Neak Pean water temple, temple dated to the c. 12th C. CE (Personal photo taken May 2016) ........................................................................................................................................ 154
**LIST OF TABLES**

Table 1. Important Chronological Dates and Stages of Angkor’s Development (c. 802-1432 CE)..................................................................................................................................................................................................................................................................................98-103

Table 2. Identifying Disease in the Pre-Angkorian Period, Mainland Southeast Asia........128-131

Table 3. City-Building Stages during the Intensification (K-) Phase.................................134-140
GLOSSARY OF TERMS

**Agent**: The infectious organism causing the disease. Also known as a *pathogen* (Keesing and Ostfeld 2012: 218). This includes micro-organisms, like bacteria, protozoa, rickettsiae, or viruses (Keesing and Ostfeld 2012: 218); as well as macro-parasites like helminths, worms, and filariae (Barnes 2005: 12; Keesing and Ostfeld 2012: 218; McNeil 2010: 17).

**Artificial landscape**: The transformation of a landscape through the human modification of natural processes over the long term to better meet a society’s need(s) (Iannone 2015a: 5). Also known as a “cultivated landscape” (Dearing et al. 2007: 266; Van der Leeuw 2007: 215) or “agro-ecosystem”, as discussed in Weisz et al. (2001: 124).

**Adaptive Strategy**: The biological and cultural characteristics that enhance human survival in given environments (McElroy 1990: 249)

**Adaptive Cycle**: A resilience theory concept wherein dynamics of human-environmental interrelationships are divided into four phases: growth or exploitation (*r*) conservation (*K*), collapse or release (*omega*), and reorganization (*a*) (Redman 2005: 71-72).

**Angkor**: Angkor means “city” or “Holy City,” in the Khmer language and script, and it is commonly conceptualized as the main capital of the Classical Khmer empire (c. 802-1432 CE; (Coe 2003: 12). Angkor itself is not the traditional name of the city; its actual name is Yasodharapura. Furthermore, the term is also used to refer both to the archaeological site and the historical civilization it represents (Coe 2003: 12).

**Baray**: Khmer word used to refer to the large water reservoirs, which served populations on a city-level (Kummu 2009: 1415).

**Charter States**: Term coined by Victor Lieberman to refer to the early and complex state-level societies which developed in southeast Asia roughly between the 800/850 CE and 1250-1300 CE, which provided a template or “charter” for the indigenous states that would follow after (Lieberman 2003: 23).

**Crowd Disease**: Infectious diseases of large, closely-habituating human populations. Also referred to as “density-dependent” diseases (Barnes 2005: 189; R. Storey 2006: 279; Sachs 2001: 16).

**Collapse**: Also known as critical “tipping points” or upheavals in a society’s adaptive cycle, wherein a society’s ability to adapt to perturbances is interrupted, leading to the end of the socio-political fragmentation and reorganization (Aimers and Iannone 2014: 26; Diamond 2005: 3; Penny et al. 2018: 1; Redman 2005: 73).

**Complex Societies**: Societies where social interaction between groups is not just governed by familial or kinship relations, but also by cultural, economic, or ideological institutions beyond the family group (Ross and Steadman 2017: 2).
**Demographic Sink**: Where the deaths are occurring internally in a population cannot be balanced out with births from within that population, so immigration is the process by which this depopulation is offset. This process is often associated with the pre-industrial city (de Vries 1984: 179-198; Wrigley 1967).

**Dependence**: An entanglement theory concept, where the mutually constituting relationships between humans and things allow for societal innovation and adaptability against new challenges (Hodder 2012: 97).

**Dependency**: An entanglement theory concept, where the established relationships between humans and things limits or “constrains” a society’s ability to adapt to new challenges (Hodder 2012: 100).

**Devaraja**: Title for rulers of the Classical Khmer state. Refers to the role that the ruler plays as the intermediary between the earthly and heavenly realms. Failure to do so could lead to calamity and disaster (Boomgaard 2007: 60; Ross and Steadman 2017: 251).

**Disease**: The word disease implies discomfort, or “lack of ease” within the body (Barnes 2005: 2). Whenever the functioning of the body or any of its parts becomes impaired or dysfunctional, disease occurs. Most human diseases are caused by micro-organisms or macro-parasites from the environment, though human behaviour patterns influence how these disease-bearing agents spread and are contracted (Barnes 2005: 2).

**Disease Burden**: The measure of a disease or diseases’ impact on a human population(s), based on loss of life, injury, loss of financial resources, or the ability to have a high quality of life (Sachs 2001: 16).

**Disease Origin**: The most likely source from which a pathogen reached humans (Wolfe et al. 2007: 18).

**Disease Ecology**: The environmental conditions required for a disease pathogen to survive and spread. Can include variables such as temperature, elevation, soil composition, water composition, all of which condition the ways that the environment facilitates interactions between the pathogen, animal and human hosts (both intermediate and primary), and vector species (Keesing and Ostfeld 2012: 227-228; Sachs 2001: 16).

**Disaster**: An acute and severe natural or technological event that causes mass loss of life, injury, property damage, and loss of livelihood (K. Smith 2011: 5).

**Drought**: A temporary period of no rain, drier conditions, and a threat to food harvests and river flows; droughts can be further sub-divided (though these definitions are not mutually exclusive; Glantz and Wilhite 1985: 4-9; Iannone, Yaeger, and Hodell 2014: 65; McMichael, Woodward and Muir 2014: 39). Droughts can be divided into:
**Meteorological droughts**: are associated with below-normal rainfall and (often) warmer temperatures, they do not normally affect food yields (Glantz and Wilhite 1985: 4-6; Iannone, Yaeger, and Hodell 2014: 65; McMichael, Woodward and Muir 2014: 39).

**Agricultural droughts**: are due to reduced rainfall (total or seasonal) and increased evaporation; these reduce crop and livestock yields (Yaeger, Iannone, and Hodell 2014: 65; Glantz and Wilhite 1985: 6-7; McMichael, Woodward and Muir 2014: 39).

**Hydrological droughts**: are when river flows or water storage falls critically in the long-term; these droughts often evolve slowly, though their consequences can quickly mount up. This type of drought will affect crop yields, livestock numbers, and human livelihood (Glantz and Wilhite 1985: 7-8; Iannone, Yaeger, and Hodell 2014: 66; McMichael, Woodward and Muir 2014: 39).

**Socio-economic droughts**: Can incorporate the components and effects any of the above types of droughts, but this type of drought is distinguished by its impact on a community’s ability to participate in their economy or otherwise maintain a livelihood (Glantz and Wilhite 1985: 8-9; Iannone, Yaeger, and Hodell 2014:65-66).

**Duration**: Approximate duration of a disease’s effects on the host, from infection to death or recovery (Wolfe et al. 2007:18).

**Ecological Niche**: The ideal environment for an organism to live and reproduce in (Willig 2003: 273).

**Ecological Niche-construction**: The transformation of an environment through human manipulation of ecological processes to better serve the needs—whether they be subsistence, economic, ideological, social or a combination thereof—of a human population and/or society (Dearing et al. 2007: 266; Iannone 2014a: 6; van der Leeuw 2007: 215; Weisz et al. 2001: 126-7).

**Empire**: Polities or states which have expanded both geographically and politically, allowing for the intermixing of different communities and ethnic groups in their overarching territory, who, in turn, contribute their local political, economic and cultural practices to the overarching social order (Sinopoli 1994: 159).

**Endemic**: Constant, low-level contraction of disease that affects a population, often seasonally. Consequences are often not acute at the onset of the contraction of a disease, but they may be debilitating in the long-term (Sachs et al. 2001: 18). Are often diseases where transmission is parasite-based, insect vector-based, or are contracted through contaminated food or water (Dearne et al. 2015; Sachs 2001: 16 Wolfe et al. 2007: 280).

**Epidemic**: Widespread and concurrent outbreaks of disease that acutely affect a population, often with severe consequences in the form of a high mortality rate, a reduction in fertility rate, and the loss of the ability to maintain a high quality of life (Brooke 2014: 279-280; K. Smith 2014: 273). Are often diseases whose disease ecology relies on high-density populations of
humans and domesticated animals which are living together, which allow for the pathogen to spread (Sachs 2001: 16, 18; Wolfe et al. 2007: 120).

**Epidemiological Transition**: Macro-scale socio-cultural transformations that transform disease burden and quality of life on the population level. Commonly discussed examples are the adoption of agriculture and the development of cities in the pre-industrial past (Barnes 2005: 51-4; Bocquet-Appel and Naji 2006; Brooke 2014: 158; Larsen 1995).

**Exposure**: The risk of being affected by an ecological or human-made hazard (K. Smith 2011: 4).

**Famine**: A temporary period where the subsistence needs of a population are not being met. Famines are often due to different causes but can roughly be divided into both natural and human-made reasons (Morgan 2013: 120).

**Fertility Rate**: The number of births per individual within a pre-defined period, which adds to the population (Chamberlain 2006: 1; Gage and DeWitte 2009: 652-3).

**Hazard**: An ecological or technical process that has the potential to have detrimental effects on human life, well-being, livelihood, or property (K. Smith 2011: 5).

**Health**: Not merely the absence of disease, but the holistic evaluation of person’s physiological state that allows them to live a high-quality life (Clark et al. 2014: 485; Gage and Dewitte 2009: 654; Barnes 2005: 25).

**Heterarchy**: A society where social organization is not based on ranking, but a multitude of different possible interactions between groups, often on a horizontal axis (Crumley 1995: 1; Scarborough and Burnside 2010: 330).

**Hierarchy**: A society where social organization is based on ranking, and interactions are based on status relative to one another on a vertical axis (Scarborough and Burnside 2010: 330).

**Host**: An organism that is afflicted by an infectious agent (Keesing and Ostfeld 2012: 218; Wolfe et al. 2007: 18).

**Intertropical Convergence Zone (ITCZ)**: Area in the Pacific where several monsoon systems—the Indian Ocean Monsoon, the Southeast Asian Monsoon, and the East Asian monsoon—meet, the interaction of causes variation in the severity of the precipitation and winds (Buckley et al. 2014: 1-2; Brooke 2014: 166-7).

**Khmer**: The ethnolinguistic group that makes up most of Cambodia’s population, both past, and present (Au 2011: 18).

**Khum**: The Khmer word that is often translated as “slave,” but is often used to refer to the labourers of temples who did not own land (E. Lustig et al. 2007: 6). This demographic likely only made up a small stratum of Angkor’s population, however (see Haberl et al. 2011, Table 1;
It may have been made up of social “undesirables,” such as conquered tribes from the Cambodian highlands, war prisoners and criminals (Harris 2007: Introduction, IX; E. Lustig 2009: 75).

**Labour:** The work an individual does to support their livelihood. Relationships within societies are often based on who has access to the products of an individual’s labour. Traditional models see labour benefitting families or kin-groups in less complex societies versus the products of labour uplifting the state or other bureaucratic organizations in more complex societies (Ross and Steadman 2017: 16).

**Labour-Tasking:** Adaptive strategies which rely on the culmination of collective human labour to manage the challenges of the environment, and often, to transform the landscape gradually over time (Scarborough and Burnside 2010: 334-336; Scarborough and Lucero 2010: 188).

**Low-density, dispersed urbanism:** This is a term coined by Roland Fletcher to describe the type of cities that developed in the pre-industrial tropics. Common characteristics of this city-type are spread-out settlement structure, blurred boundaries between the hinterland and the central core of the city, and patches of agricultural space within the city that allow for subsistence and food security without reliance on a non-urban, hinterland population. Altogether, these traits reflect a different urban form than the dense, easily bounded cities that are found in pre-industrial, temperate zones (Fletcher 2012: 265-7).

**Medieval Climate Anomaly (MCA):** A period of warm and stable climate between the 9th and 14th centuries CE, which translated into a series of more predictable monsoon seasons for Southeast Asia during the rise of the Charter States, during the “Classical” age (Buckley et al. 2014: 1-2).

**Migration:** the proportion of individuals entering (immigration) or leaving the population (emigration), other than through fertility or mortality (Chamberlain 2006: 2).

**Monsoon:** Wind systems which, on a seasonal basis, convey large amounts of precipitation to certain world regions, such as mainland Southeast Asia (McMichael, Woodward, and Muir 2014: 36).

**Mortality rate:** The likely chance of death to occur to an individual within a pre-defined period. The mortality rate adds to the number of people who leave a population (Chamberlain 2006: 2; Gage and DeWitte 2009: 651).

**Mortality Crisis:** Mass deaths and disruption of baseline living conditions resulting from a severe natural disaster or an outbreak of disease with high infectivity. This sort of event will truncate the structure of a population, with mortality rates reflecting the loss of population members most at risk (Brooke 2014: 107, 255; Barnes 2005: 100-1).

**Mratan:** Khmer word that refers to the head administrator of a temple (Higham 2014: 297; Ross and Steadman 2017: 250).
**Neak Ta**: Khmer word that refers to a local spirit, often attached to a sacred landmark, that must be appeased with offerings in the form of prayer and physical goods, to avoid disaster befalling the community (Au 2011: 9).

**Organic Economy**: Economies that rely on animal or human power, rather than mineral resources, to supply the energy needed to maintain a society’s “metabolism” (Brooke 2014: 261).

**Phnom**: Khmer word that translates to “mountain” or “hill.” Often, these were the sites of temples and other sacred spaces modelled after Mount Meru, the most important mountain in the Hindu, Buddhist, and Jain cosmologies (Ross and Steadman 2017: 250).

**Phum**: Khmer word that translates to “village” or “town.” It is used for modern-day villages in Cambodia, as well as to designate ancient villages identified in the archaeological record (Newton 2013: 1).

**Pon**: Regional leader of a coalition of Khmer villages during the pre-Angkor and Angkor periods in Cambodia (Higham 2014: 297; Ross and Steadman 2017: 250).

**Population**: In biology, a population is a group of closely connected organisms that are most likely to reproduce with one another. In the social sciences, a population is a social unit in which individuals are grouped based on common linguistic, cultural or historical experiences. Much of archaeological analysis—especially in the study of ancient human health—utilize aspects of both these definitions (Chamberlain 2006: 1).

**Population Dynamics**: The growth or decline in population numbers, or segments within the population, over time (Chamberlain 2006: 2; Waldron 2007: 26).

**Population Density**: The number of individuals present in a pre-defined space (often one kilometer squared) (Chamberlain 2006: 2; Hanus and Evans 2015: 2,7).

**Population Size**: The number of individuals in the population (Chamberlain 2006: 2).

**Population Structure**: The demographic makeup of a population, with categorizations principally made based on age and sex. (Chamberlain 2006: 2).

**Primary/direct Transmission**: The spread of a disease pathogen from human to human (Wolfe et al. 2007: 18).

**Pre-Industrial**: The period before the Industrial Revolution that took place in Western Europe, North America, and China (Andaya and Andaya 2015: 8-9; Brooke 2014: 7-8).

**Quality of Life**: The measure of standard of living. For individual households, this may be signified in the richness and diversity of domestic goods, as well as household participation within the overarching society. On the community level, quality of life is qualitatively measured in population growth (especially in terms of the ability of a community to incentivise the
drawing in of immigrants), the ability to participate in community projects, stability and length of settlement, and the ability to withstand external shocks (M.E. Smith 2015: 2, 7-9).

**Reservoir**: A non-human source of pathogens immediately capable of infecting humans without evolutionary change. Reservoirs may enable a pathogen to persist even in the absence of a susceptible population large enough to support the pathogen on its own. Reservoirs can be animal or environment-based, such as the case of soil-borne anthrax (Wolfe et al. 2007: 18).

**Resilience**: The ability of a system to withstand shocks and perturbations against it without fundamentally changing its basic organizational form (Redman 2005: 71).

**Resilience Theory**: Is an ecological sciences concept which examines the adaptability and sustainability of human-environmental interactions over the long-term. It was adapted for archaeological purposes by Charles Redman and Anne Kinzig (Redman 2005: 71; Redman and Kinzig 2003: 14).

**Resource**: An ecological process that has the potential to have positive effects on human life, well-being, livelihood, or property (K. Smith 2011: 4).

**Rigidity Trap**: A more severe form of “path dependency.” When an adaptive strategy becomes inflexible and entrenched, it can be incredibly difficult, even impossible, to divert from (Iannone 2014a: 7; Janssen and Scheffer 2004; Walker and Salt 2006: 87).

**Risk**: The quantified potential for a disaster and its associated consequences to take place (K. Smith 2014: 11).

**Route/Mode of transmission**: The means by which a disease is transmitted to a host (Wolfe et al. 2007: 18).

**Secondary Transmission**: The spread of a disease pathogen from an animal to a human (Wolfe et al. 2007: 18).

**Solar/ Galactic Polity**: Also referred to as a Theatre State (Geertz 1960) or Mandala State (Tambiah 1977), though these terms emphasize different aspects of this phenomenon. A primary trait of early states in Southeast Asia, wherein the primary urban centre/core exerts increasingly diminished control over settlements as one moves from the heartland into the hinterlands. Political control in such states is also more ideological than economic (Lieberman 2003: 23; Hall 2011: 113-15).

**State**: An (archaic) state or complex society is a larger and more complicated chiefdom or regional polity, due to the difference of the nature and degree of its political, social, and economic institutions (Yoffee 2005: 16); it has diverse, institutionalized “subsystems” that tend to operate on a somewhat independent basis, and provide a number of services for the society’s inhabitants (Yoffee 2005: 16). Complex societies tend to involve populations in the hundreds of thousands, and as such, it is economic roles, rather than kinship, that tend to be the basis of social relationships (Ross and Steadman 2017: 44). Social organization tends to be composed of both
hierarchical and heterarchical components, creating multiple classes of non-elite producers, as well as an elite class of rulers, nobles, and often, a warrior class, which are internally ranked (Haberl et al. 2011; Ross and Steadman 2017: 43). The methods used by elites and rulers to accumulate power often involve organizing risk management practices and strategies, which ostensibly benefit the whole of this society (Peterson and Drennan 2012: 75). This includes protection against invasion and disasters, such as through warfare to accumulate new land and resources, and the creation of public works (Peterson and Drennan 2012: 75, 76); their role in risk management is part of the justification for the elite classes’ control of the non-elite classes’ labour (Ross and Steadman 2017: 44). The creation of urban hubs, which centralize administrative institutions, and concentrate public works and services for the well-being of the population, is also a part of this risk management strategy (Yoffee 2005: 16, 54). Conversely, since the state risk management system is often organized on the macro-scale, it becomes too complicated to track the well-being of people at the individual or household level (Ross and Steadman 2017: 44). As such, many members of the non-elite class can fall into poverty or overdependence on the state’s institutions to maintain their quality of life (Ross and Steadman 2017: 44-5).

**Sunk-cost fallacy**: When the investment into an adaptive strategy is (or is perceived to be) too deeply entrenched for it to be abandoned, regardless of changing circumstances (Iannone 2014a: 7; Janssen and Scheffer 2004; Walker and Salt 2006: 87).

**Systems Theory**: A system—e.g., a river, the global atmosphere, or a social grouping—acts as a set of components to produce an output (Penny et al. 2018: 1; K. Smith 2011: 46). Previous attempts to understand such systems tended to simplify the model to illustrate key inputs, internal flows, and outputs. In practice, natural or social systems were conceptualized as “machines” that delivered an expected product (Ross and Steadman 2017: 3-4).

**Societal Metabolism**: The means by which a society collects biomass and energy to support their way of life (Fischer-Kowalski 2003: 24; Iannone 2014a: 6).

**Techno-Tasking**: Adaptive strategies which rely on fast-paced technological breakthroughs to manage the challenges of the environment, often resulting in the environment transforming rapidly (Scarborough and Burnside 2010: 330).

**Trapeang**: Khmer word that translates to a “water tank” or “pool,” that is used to supply water on the neighbourhood level (Pottier 2012: 18).

**Tropics (the)**: The geographic area between 23 degrees N (tropic of Cancer) and 23 degrees S (tropic of Capricorn) of the equator. Can be divided into the humid-equatorial, or inner tropics (roughly 5 degrees N and S of the equator), and the seasonally wet-dry (monsoonal) tropics. A common characteristic of this climatologic zone is that there is no winter season (M. C. Peel et al. 2007: 1639).

**Urbanism**: The way of life that takes place in a city (Fisher and Creekmore 2014: 1; M.E. Smith 2016: 151).
**Urbanization:** The process by which a city is developed over time and space; it is created through the interactions of different social groups (Fisher and Creekmore 2014: 2).

**Vector:** Non-human organism, often an insect, that acts as a carrier of disease pathogens to a host (Keesing and Ostfeld 2012: 218; Wolfe et al. 2007: 18).

**Virgin-soil epidemic:** A type of epidemic where exposure of a new pathogen to a previously unexposed population causes a disastrous loss of life, mainly due to the lack of acquired immunity (Brooke 2014: 221; Warrick 2002: 262-3).

**Vulnerability:** The characteristics and circumstances of a community, system, or asset that makes it susceptible to an environmental or technical hazard (K. Smith 2011: 4).

**Wat:** Khmer word that translates to “temple” (Au 2011: 242). Temples can also be referred to as *Prasat* (Cambodia Commission for UNESCO 2016: ii).

**Zoonoses:** Infectious diseases whose pathogenic agents originally afflicted animals (either wild or domestic), but which evolved to exclusively affect humans (Barnes 2005: 137-43; Wolfe et al. 2007: 18).
CHAPTER 1: INTRODUCTION

Access to potable, or fresh, uncontaminated water, is a foremost concern for all human societies, for hydration, subsistence, washing, and other hygiene practices (Dearne et al. 2015: 45; Lucero et al. 2015: 1141; McMichael, Woodward and Muir 2014: 39). Because of their concentration of natural resources, many of the major sites for human habitation throughout history were situated near “natural” wetland environments, such as rivers, lakes, and marshlands. These include the famous “hydraulic civilizations” of the Near East (Wittfogel 1957; as discussed in Scarborough and Lucero 2010: 185), the major urban sites in the Mediterranean, such as Rome (Cook 2014: 7; O’ Sullivan 2008, Soren 2003), and, the dispersed low-density settlements of tropical state-level societies like the Maya (Scarborough et al. 2012; Scarborough and Burnside 2010: 336-7) and those of South and Southeast Asia (Fletcher 2012: 285-6).

Not having access to water resources can have major consequences for human health and well-being. Wetlands, encompassing marshes and swamps, estuaries and coasts, rivers and lakes, but also cultivated rice paddies, provide important buffering services against certain environmental hazards, such as physical protection from storms, floods, and pollutants (Dearne et al. 2015: 46; Horwitz et al. 2012: 1), and the regulation of disease-carrying pathogens (Lambin et al. 2010: 1; Horwitz et al. 2012: 3). On the other hand, wetlands provide an aquatic or semi-aquatic, often relatively stable environment with the right conditions (in terms of water flow, nutrients, temperature, and salinity) for the propagation of certain bacteria, protozoa, viruses, and helminths (parasitic worms), as well as their plant and animal hosts, animal reservoirs or insect vectors (Dearne et al. 2015: 47). Wetlands and their modification by humans have in the past and continuing today play an important role in the well-being of human populations living in “the tropics” (Horwitz et al. 2012: 1). Specifically, this thesis focuses on the case of the inhabitants of the city of Angkor—the capital city of the Classical Khmer state (c. 802-1432 CE). The people
who lived there had to use creative methods to adapt their settlements to this wet-dry, monsoonal-forest environment (Iannone 2015b: 2; Isendahl and Smith 2013: 132), but what remains to be known is how they dealt with the hazard of infectious disease.

**Water, Rainfall, and Disease in the Tropics**

Tropical and sub-tropical ecological zones are identified by climate regimes of intermittent rainfall and warm to hot temperatures, occupying latitudes between zero-to-five and five-to-twenty-three degrees North and South of the equator. This area is largely between the Tropics of Cancer and Capricorn (Barnislaug et al. 2014: 18). According to the Koppen-Geiger classification system, the tropics are further divided into the wet-dry tropics (Aw), the monsoonal tropics (Am), and the humid or equatorial tropics (Af) (M.C. Peel et al. 2007: 1639; see also Boserup 1965; Sachs 2001: 1-2; Meggers 1954; Winzeler 1976 for further discussions).

![World map of Köppen-Geiger climate classification](image)

Figure 1.1 Climate Zones of the World (Southeast Asia Highlighted), modified from M.C. Peel et al. 2007 (Fig 10).
The reason why the tropics are characterized as “marginal” or “fragile” environments (Iannone 2015a: 2) is because with greater sunlight exposure comes high ambient temperatures, a greater burden of insect pests and parasites, high plant respiration, and variability in water sources—due to seasonality and dispersal throughout the landscape (Sachs 2001: 13-14). These environmental factors were thought to be major ecological barriers to the development of “social complexity” in the tropics; it was thought that health and agricultural technologies lagged here due to these ecological limitations, and corresponding food insecurity and a higher burden of infectious disease made them easy targets for economic and colonial exploitation (Gould 2014: 29-30; Sachs 2001: 13-14).

In the temperate, Old-World climate regions, the major infectious diseases do seem to have originated from the diseases of domesticated animals, creating a disease complex that is distinct to that of the New World. On the other hand, the origins of tropical infectious diseases—or at least the ones originating in the Old-World—did not come from domesticated animals (Merbs 1985; 1992; Wolfe et al. 2007: 279, 10). Their “pathogens” (or disease-bearing “agents”) are thought to best survive in warm and humid climates (Wolfe et al. 2007: 1).

**WHAT ARE TROPICAL DISEASES?**

Infectious diseases account for over one-quarter of all human deaths globally and two-thirds of all deaths in children less than five years old (K. Smith 2011: 273). Among infectious diseases, those that thrive in the hot and humid climate of the tropics are some of humanity’s most prolific killers (Chongsuvivatwong 2011: 430). Millions of people each year, in South and Southeast Asia, equatorial Africa, and other areas in the “Global South,” are killed or seriously debilitated by neglected “tropical” diseases like malaria, dengue fever, dysentery, cholera and leprosy (Shetty and Shetty 2009: 24). These are diseases that disproportionately afflict those...
living in poverty in world regions like sub-Saharan Africa, Asia, and Central and South America; they are also diseases which are more likely to be difficult to prevent and treat, either due to a systematic lack of funds, or because they have become drug-resistant (Shetty and Shetty 2009: 28). While these diseases are largely eliminated in temperate regions, they are still endemic in tropical countries to this day (Barnislaug 2014: 18; Chongsuvivatwong et al. 2011: 430; Cook 2014: 1; Petney 2001: 921 WHO N.D. WHO 2013a).

The term “tropical disease” was first introduced in the medical literature by Sir Patrick Manson in 1898 with his *Manual on the Diseases of Warm Climates*. This text would later be the basis for *Manson’s Tropical Diseases*. Twenty-three editions later, in the newest version of the manual, Barnislaug et al. (2014: 18) define tropical diseases as diseases that are “unique,” or perhaps more pertinent for this thesis, are “…more prevalent in tropical and sub-tropical areas and are typically infectious.” What should be noted, however, is that the infectious diseases that fall under the “tropical umbrella” were also present in North and Western Europe and North America. It was only with the discovery of specific aetiologies of diseases (concurrent with the development of “germ theory”), the institutionalization of public health programmes, the creation of disease surveillance technology, new vaccines and other drugs, that these diseases have been largely eliminated from the temperate countries of the Global North (Brooke 2014: 414, 416; Bloom and Fink 2014: 23; McMichael, Woodward and Muir 2014: 38).

Past writers, for instance, like William Shakespeare, discuss their experience with the symptoms of malaria. In the play, *Henry VII*: “‘he is so shak’d by the burning tertian quotidian that it is most lamentable to behold (Henry VII. i. 123; as cited in Cook 2014: 3). Writer Thomas Sydenham (1624-1689) famously used “fever-tree” bark (quinine) to manage intermittent fevers caused by malaria in the seventeenth century (as cited in Cook 2014: 3). Even earlier, however,
some populations in antiquity resorted to the draining of swamps to destroy mosquito breeding grounds, sometimes with great success (Dearne et al. 2015: 101). Most famously, malaria played a role in the urban development of Rome. Etruscan farmlands in Italy were thought to be free of malaria until the 2nd century BC, but with the takeover of the Roman Republic, they destroyed the Etruscan land development system and allowed marshy areas to develop, which increased the incidence of malaria (Barnes 2005: 97). O’Sullivan et al. (2008: 756-60) have also discussed how Rome’s city-planners then, in turn, used certain land-use strategies to manage malaria outbreaks in the later Republic and Imperial periods (Cook 2014: 3; see also McNeil 2010: 116).

Typhoid, tuberculosis, and dysentery were major health hazards in Britain, including London, during the Victorian era (Barnes 2005: 284). Cholera, of course, was a globalized disease that was thought to spread from the ports of the Ganges in India from a variety of European ships to different nations in Western Europe (Barnes 2005: 284-85; Cook 2014: 3-4). Thus, it becomes apparent that diseases we consider “tropical” have also impacted temperate areas in the past. Nevertheless, the tropics and subtropics’ stable and warm temperatures, and the absence of freezing winter months—which regulate the population dynamics of parasites and pests in temperate areas—create the ideal conditions for opportunistic vector and parasite species year-round (Gallup et al. 1998: 18; Miksic 1999: 169; Sachs 2001: 13-14). This high disease load is well-known environmental feature in the case of Southeast Asia.

SOUTHEAST ASIA

Geographically, Southeast Asia consists of a continental projection and a string of archipelagos. The region’s mainland is made up of the nation-states of Myanmar (formerly known as Burma), Vietnam, Cambodia, Laos, and Thailand. The maritime nations consist of the
islands of Malaysia, Indonesia, the Philippines, Brunei, Singapore, and Timor-Leste. (Chongsuvivatwong et al. 2011: 429-30; Yuen and Kong 2009: 1-2; see Figure 1.2).

![Map of Southeast Asia](Figure_1.2.png)

**Figure 1.2:** Map of Southeast Asia, modified from Free Vector Maps.com.

Mainland Southeast Asia is divided between four major rivers: The Red River in Northern Vietnam, the Chao Praya in Southwest Thailand, the Ayeyarwady in Myanmar, and the Mekong, which starts in Tibet and runs through the entire mainland (Boomgaard 2007: 20). The river valleys are (and were) much more densely populated than the mountainous, highland areas; above one thousand meters above sea level, no prehistoric settlements are found (Andaya and Andaya 2015: 24; Boomgaard 2007: 20; Hall 2011:6). In Northern Vietnam, from Hanoi to the Chinese border, the climate is subtropical—winters can be cold, rainy and rice agriculture more
difficult (Boomgaard 2007: 20). The rest of Southeast Asia has a tropical climate; temperatures
are rarely below 21 degrees Celcius and range up to the thirties for most of the year, with high
humidity (Ross and Steadman 2017: 237). In the North-central part of the region lies the Khorat
plateau, home to some of the earliest settlements in the region, such as the Mun valley sites of
Ban Chiang, Ban Kum Lao, Nong Nor, Noen U-Loke, among numerous others (Ross and
Steadman 2017: 238-40; see Figure 2.2 in this thesis). South of Khorat plateau is the Cambodian
Basin. A vital resource for Cambodia—both today and in the Khmer empire’s past—is the Tonle
Sap (“Freshwater” lake), which is the largest lake on the mainland. The Tonle Sap River
emerges from the lake and flows southward to meet the Mekong before it empties into the South

The climate of the Southeast Asian peninsula is defined by the monsoon season, as it is in
the middle of the Intertropical Convergence Zone, or ITCZ (Buckley et al. 2014: 1-2; Brooke
2014: 166-7; McMichael, Woodward and Muir 2014: 36). Coming from the Arabic word
mausim, meaning season, monsoons governed the rhythm of life in Southeast Asia: they
provided rains that would feed the irrigation canals of rice fields of agriculturalists; and, until the
age of steam-powered boat technology, they directed the maritime movement of traders in and
out of Southeast Asia (Andaya and Andaya 2015: 18). Through November and December,
northeast monsoon winds blow across the South China sea until January, and up to late February.
During an interim of five weeks, stronger monsoon winds grow in the Indian Ocean from May to
June, and during this transition, the winds move towards eastern Indonesia and the Melaka
Straits, giving travellers the greatest ease of movement. This cycle ends between August and
September, and the winds begin to weaken. It was because these periods of low wind, when the
sail-dependent sailors had to stay in maritime Southeast Asia, that this sub-region firmly
established itself as an important entrepot—both as resting point and resource base—along the maritime Silk Road during the Iron Age (c. 500 BCE to 500 CE; Andaya and Andaya 2015: 18-19).

During the summer monsoon, rains feed the rivers and lakes. The rainy season so affects the Cambodian basin that the Tonle Sap River reverses its course and flows back into the Tonle Sap lake during the summer months, expanding its already large boundaries (Penny 2006: 311). For this reason, people residing around the lake live on stilted houses to remain dry during the six-month rainy season (Reid 1990: 51). In general, annual rainfall is between around 140 and 240 centimeters a year. In the intermediate tropical zone, where Southeast Asia is geographically located, the rainfall pattern is governed by the monsoons, which means the rainy and dry seasons alternate. In continental Southeast Asia, the rainy season begins in the summer on the islands close to the equator; on the islands to the South of the equator, the rainy season is in the winter (Boomgaard 2007: 18-19). Where average rain annual rainfall is low, a long dry season is characteristic. (Boomgaard 2007: 19).

The many differences in precipitation, temperature, topography, elevation, and soil types have encouraged biotic diversity across the Southeast Asian region (Boomgaard 2007: 20; Andaya and Andaya 2015: 25; Hall: 6-7). These factors have had a major effect regarding agricultural planting cycles, settlement patterns, and daily activities (Ross and Steadman 2017: 239). In lowland areas further from the equator, where the annual rainfall is interrupted by the dry season, the typical forest cover is semi-deciduous, unlike the more tropical rainforests of island Southeast Asia (Andaya and Andaya 2015: 23; Boomgaard 2007: 20). Bamboo groves and grass plains provide habitats for elephants, deer, wild pigs, and water buffalo (Andaya and Andaya 2015: 23; Boomgaard 2007: 20). Mangroves line river deltas and coasts; and, where
waterlogged sediment accumulates, mangroves are replaced by freshwater swamp forests—home to the sago palm and its oil, fruit, and sugar (Andaya and Andaya 2015: 23). At higher elevations, tropical evergreen forests are dominated by conifers (Andaya and Andaya 2015: 23; Hall 2011: 6). All Southeast Asian forests have trees and plants which supply woods, resins and rattans used for timber, perfume, dye, and especially medicines (Andaya and Andaya 2015: 24). These plant-based medicines formed the basis of treatment for numerous medical practitioners (both lay and temple-based) across South and Southeast Asia, and China (Andaya and Andaya 2015: 24; Au 2011: 20-21; Chhem 2005, 2006; Hall 2011: 6-7).

The important resource of salt was also found throughout Southeast Asia’s coastlines, as well as saline springs and saltwater ponds (Andaya and Andaya 2015: 24). Salt is very important as a preservative of foods like fish, as well as to provide electrolytes to maintain general physiology in the hot and humid climate (Miksic 1999: 174; Reid 1990: 29). Salt also played a role in spiritual health, to appease jealous spirits during rituals—such as “Mistress Salt”—who could cause calamity or disaster (Andaya and Andaya 2015: 24). Thus, having access to salt was a major concern for lowland populations located away from the coast, and the highland communities that controlled the deposits of rock salt almost inevitably took on an important position (Andaya and Andaya 2015: 24; Hall 2011: 7).

Considering all the natural resources that the populations of pre-industrial Southeast Asia had at their disposal, one would think that this would have conveyed a good quality of life among this region’s inhabitants. Nevertheless, Southeast Asia also holds distinction as one of the most “disaster-prone” regions in the world, with many environmental hazards—floods, droughts, heat waves, earthquakes, volcanic eruptions, tsunamis and typhoons (Boomgaard 2007: 120, 127)—disproportionately afflicting the modern population compared to other world regions.
(Boomgaard 2007: 127). Many disease outbreaks and epidemics—both historical and current—also find their origin in this world region (Coker et al. 2011: 599).

**TROPICAL DISEASES AND SOUTHEAST ASIA**

Modern Southeast Asia is often considered the “epidemiological crossroads” of the globe, as a region where new and re-emerging infectious diseases frequently originate and spread from its industrial megalopolises (Au 2011: 99; Chongsuvivatwong et al. 2011: 429; Coker et al. 2011: 599; Gould 2009: 34). With both inland and maritime points of contact with the countries of South Asia, East Asia, and Oceania, Southeast Asia is the ideal location for new and re-emergent diseases to spread across international borders, alongside the import and export of raw goods, manufactured products, and human labour and services (Boomgaard 2007: 127; Chongsuvivatwong et al. 2011: 429; Coker et al. 2011: 601-2; Petney 2001: 922).

There are about 600 million people living in Southeast Asia today (Chongsuvivatwong et al. 2011: 429), but the distribution is uneven, with large numbers of people either concentrated in “megalopolises” (also known as “mega-cities”[Rimmer and Dick 2010: 27]) or spread out in pockets of population enclaves (known as “desakota,” or “edgeless cities”[Rimmer and Dick 2010: 29]) in the rural hinterland and peri-urban areas (Coker et al. 2011: 602; Chongsuvivatwong et al. 2011: 429). These highly contrasting settlement patterns have their specific health impacts, with cities seeing more outbreaks of respiratory diseases—where pathogen transmission has to do with the inhalation of aerosol droplets—that spread easily in the populously dense areas. Common diseases include influenza, chicken pox, pertussis, measles, and mumps, and are experienced mostly as “diseases of childhood” (Chongsuvivatwong et al. 2011: 431). Sexually transmitted diseases like venereal syphilis are also a major concern (Chongsuvivatwong et al. 2011: 431; Petney 2009: 927). Rural or peri-urban (mixed rural-urban)
areas, on the other hand, are more likely to see outbreaks of vector-borne diseases, like malaria or dengue, as well as water-borne, gastro-enteric diseases like shigella/dysentery, campylobacter/salmonella, and giardia (Coker et al. 2011: 600). These diseases are more common outside of the core area of cities as access to healthcare, surveillance warnings, and in general, sanitation and food security may be unevenly distributed in the peri-urban and more rural areas (Chongsuvivatwong et al. 2011: 431-2; Coker et al. 2011: 600-601, 604; Petney 2001: 923-25).

In this highly pathogenic environment, Southeast Asia has also been “ground zero” for new diseases like Ross River virus, Japanese Encephalitis, and Nipah virus. These diseases have remained relatively contained to their places of origin (Barnes 2005: 410; Coker et al. 2011: 600; Shetty and Shetty 2009: 20), but types of zoonotic viruses, such as H5N1, or the Swine flu, have had more far-reaching consequences outside of Southeast Asia (Shetty and Shetty 2009: 20). Traditional mores surrounding domestic habitation with livestock and the laxer enforcement of regulations surrounding the meat industries in Southeast Asia ensure close contact with animals like pigs, chickens, and other types of poultry (Chongsuvivatwong, et al. 2011: 434; Coker et al. 2011: 600-601). The proximity with domestic animals is thought to have been the main factor in the emergence of new zoonotic diseases, these being infectious diseases transferred from animals (Chongsuvivatwong, et al. 2011: 435; Coker et al. 2011:603-604; Petney 2001: 22). Furthermore, to supplement subsistence and income, rural communities often rely on wild animal game and products. This practice is also a disease risk since the forested regions where these game animals are procured are also home to arthropod vector species, like mosquitoes and ticks, as well as non-human primate species that act as reservoirs for disease (Coker et al. 2011: 604). Contact with previously unknown forest variants of these diseases has been used to explain the origin of drug-
resistant forms of malaria and tuberculosis (Chongsuvivatwong, et al. 2011: 435; Coker et al. 2011: 604). With these factors considered, international public health organizations like the World Health Organization (WHO) and the Centre for Disease Control (CDC) consider Southeast Asia an area of major concern, only behind sub-Saharan Africa and the Sahel (Gould 2009: 35-36; Shetty and Shetty 2009: 19; WHO, N.D).

If the disease-bearing agent spends part of its lifecycle outside the host’s body, it is much more difficult to predict, monitor, or control (Barnes 2005: 6). Tropical diseases cyclically infect a host population and often cause debilitating injuries—lesions that cause social stigma, blindness, the loss of the use of a limb, hands and/or feet, diarrhea, fever, or other gastro-enteric distress—all of which can affect the ability of a person to perform work and provide for themselves and their family (Shetty and Shetty 2009: 28). Tropical diseases are notable in that they tend to affect populations on an “endemic” basis, that is, they infect populations on a constant, low-level rate of contraction (Barnislaug et al. 2014: 18, 21). Most of these diseases, like bacterial infections, treponematoses, and intestinal parasites cause debilitating symptoms and potentially chronic illness such as blindness or lesions—but not necessarily high mortality, or death rate (Cook 2014: 1-3; Storey 2006: 279-280; WHO 2013; WHO ND). In the case of modern-day Southeast Asia, The WHO cites uneven access to health infrastructure, contaminated water, poor housing, and sanitation, and crowded living conditions as the culprits for endemic levels of disease (Barnislaug et al. 2014: 18, 21; K. Smith 2011: 173).

**THE PROBLEM**

There have been several hypotheses that suggest that Southeast Asia’s high disease burden—and its impact on the quality of life of its population—has not always been so severe (Reid 1990: 55-6, and as disputed by Boomgaard 2007: 119). Several scholars, including
historians and archaeologists, argue that the inhabitants of pre-industrial cities in Southeast Asia adopted specific land-use strategies to protect against the spread of infectious diseases, to the point where widespread disease epidemics—but not necessarily endemic levels of disease—were thought to have not occurred in the region until European contact (Lieberman 2003: 50, 97; Reid 1990: 78,79). This would explain, for example, the generally “happy and healthy” populations of post-contact Southeast Asians encountered by European explorers and colonialists (such as Bontius and Crawfurd, discussed by Reid 1990: 55-6, and as disputed by Boomgaard 2007: 119).

Due to their maritime contact with other major centres in Eurasia, such as China and India, pre-industrial populations in Southeast Asia were believed to have been able to avoid the major mortality crises that marked first contact scenarios between Europeans and America’s First Nations peoples, and between Europeans and the indigenous peoples of Polynesia (Merbs 1992: 4; Warrick 2003: 262; see also McNeil 2010: 126-127).

Nevertheless, it has also been argued that the density of pre-industrial populations in South East Asia was kept relatively low and spread out due to rolling epidemics throughout its pre-industrial past (Andaya and Andaya 2015: 21; Boomgaard 2007: 121). McNeil (2010: 124), for example, argues that infectious disease was a major barrier in population growth for tropical Southeast Asia, and hence, prevented the establishment of dense settlements, and presumably, the development of social complexity that is supposed to accompany such population growth:

“The comparative slowness of civilized expansion in this environment is almost certainly connected with the health consequences of trying to concentrate dense human populations within a well-watered tropical landscape. Intensification of microparasitism—with malaria and dengue fever perhaps in the lead, water-borne infections of the alimentary tract close behind, and an extremely complex series of multicelled parasites available to batten upon what remained—presented formidable obstacles to the growth of population in southeastern Asia toward anything like the densities that sustained Chinese and Indian civilizations.”
Given the above debate, through this thesis I set out to examine the interconnected natural and cultural processes—also known as “socio-ecological” processes—in historical-ecology thinking (Balée 2006: 80-81; Balée and Erickson 2006: 1; Fabinyini et al. 2014), which conditioned the quality of life and human well-being in pre-industrial Southeast Asia, especially in the case of my area of interest: the Southeast Asian state of Angkor (c. 802-1432 CE), arguably the largest pre-industrial centre in the world (Evans et al. 2007: 14278-9; Fletcher 2009: 2, 2012: 301-2).

**Potential Challenges**

There has not been a concerted effort—at least, not until the last six or seven years—to trace back the history of infectious disease and its effects on preindustrial population health and well-being in Southeast Asia (Halcrow et al 2015: 158; King et al. 2017: 28; Lieberman 2003: 97-98; Tayles and H.R. Buckley 2004: 1-2). This knowledge gap was largely due to the dearth of available bioarchaeological material. The ability of both local and non-local archaeologists to excavate archaeological sites in Southeast Asia was marred not only by the presence of dense vegetation, and varying levels of preservation—due to natural processes like periodic flooding—but also political unrest (Clark et al. 2014: 484; Oxenham and Tayles 2006: 3; Pottier 2012: 13, 16; Stark 2006b: 145). Furthermore, with adoption of Hinduism and Buddhism in the Early Iron Age (c. 500 BCE-500 CE) and proto-Classic period (c. 500 CE-800 CE), respectively, changes in mortuary practices involving cremation and exposure (leaving the dead outside in the open)—rather than inhumation—meant that skeletal samples are largely absent from the major urban centers (Oxenham and Buckley 2016: 13; Oxenham and Tayles 2006: 3).

Thus, my research fills an important gap in understanding the disease patterns of Southeast Asia’s pre-industrial past, like Merbs’ (1992) *A New World of Infectious disease* and
the various works of Culbert and Rice (1990; Rice 2006: 252-3). These authors also demonstrated that tropical, complex state societies of Mesoamerica were afflicted by diseases that were different than pre-industrial, temperate Eurasia. A relatively recent inventory of Pre-Columbian infections of the Americas includes staphylococci and streptococci bacteria, intestinal parasites, treponematoses, tuberculosis, some forms of leishmaniasis, trypanosomiasis, some fungal infections, some rickettsial infections, legionellosis, and hydatic disease (Merbs 1992: 9; as discussed in Storey 2006: 279).

Merbs (1992:4) states that the difference between New World and Old World disease regimes is not a lack of infectious diseases, but a lack in the New World of the crowd-type of diseases, such as smallpox, malaria, measles, and scarlet fever. This idea is also echoed by McNeil (1977: 176-180; 2010: 24-5, as cited in R. Storey 1992: 43), who argues that although people suffered from diseases endemically, due to the few types of domesticated animals present, there was less of a disease burden in the New World compared to the Old World (though this does not hold for the inhabitants of pre-industrial Peru, who relied on llama and guinea pigs; R. Storey 1992: 43). In summary, the people of the Pre-Columbian New people certaintly had health problems (see Verano and Ubelaker 1992; Culbert and Rice 1990), but the number of diseases present seems to be fewer than the Old World (Douglas and Pietrusewsky 2007; McNeil 1977: 176-180; Warrick 2002: 263-4).

In conclusion, what remains to be seen is whether the disease patterns of urban sites in pre-industrial Southeast Asia are more comparable to those of temperate Eurasia or of tropical Mesoamerica. Unlike the pre-industrial tropical societies in Central America, the Classical states of Southeast Asia had frequent contact with major centres in the Old World—eventually drawing them into the Eurasian “civilized disease pool” (of the Near East, the Mediterranean, China, and
India; McNeil 2010: 115-116) during the Iron Age (Lieberman 2003: 50-51, 63, 224; McNeil 2010: 125-6, 158). That said, the physical city forms of the complex states of the Maya and Classical Southeast Asia both shared similar material characteristics (Lucero et al. 2015: 1139; Lucero, Gunn and Scarborough 2011: 483-4), and presumably similar disease hazards. Thus, the question of what disease hazards the inhabitants of the complex states of Southeast Asia faced remains to be answered.

**RESEARCH QUESTIONS AND OBJECTIVES**

The complex state-level societies of the tropics successfully adopted a specific land-use strategy—"low-density, dispersed agrarian urbanism" (Fletcher 2012: 285)—to adapt their settlements to the unique environmental challenges of life in their respective geographic regions, such as consistently high temperatures, fragile soils, high plant respiration, and variable water availability and quantity (Sachs 2001: 13-14; Gallup et al. 1998: 18). Low-density urbanism is a term coined by Roland Fletcher (2009: 1; 2012: 286) to describe the unique type of cities that developed in the pre-industrial tropics. Common characteristics of this city-type are 1.) spread-out settlement structure of residential areas; 2.) blurred boundaries between outside/peri-urban zones and the monumental epicentre of the city; 3.) and, patches of agricultural space within the city that allow for subsistence without reliance on a non-urban, hinterland population (Fletcher 2012: 287). Together, these traits reflect a different urban form than the dense, bounded cities that are found in pre-industrial, temperate areas (Isendahl and M.E. Smith 2013: 132-33). The creation of these cities involved heavy landscape modification of wetland resources in making widespread access to water predictable (Scarborough and Burnside 2010: 331). The creation of these “artificial landscapes” is an anthropogenic (human-directed) process known as “ecological-niche building” (Weisz et al. 2001: 126-7). This ecological niche-building has resulted in a
distinct “urban footprint,” or city plan (Iannone 2015a: 9; 2015b: 252) for early complex societies in the tropics, which materially can be identified in the archaeological record by (Iannone 2015a: 8):

- spread-out settlements mapped onto variable patches of resources
- large-scale and localized water management
- large-scale and localized agricultural systems
- Cooperative networks of agriculturalists and other non-elite labourers, linked by “integrative mechanisms.”
- Relatively “hands-off” administrative bodies of temples and landed nobles in the “epicenter” or ceremonial core of the settlement

My research falls under SETS, or the Socio-ecological Entanglements in Tropical Societies Project, which is headed by Dr. Gyles Iannone of the Trent Anthropology Department. Our project’s stated goal is to understand the resiliency and adaptability of past state-level societies’ relationship to their tropical environments (Iannone 2015a: 1; 2014a: 1). These Southeast Asian states are called “Charter States,” because of their legacy as templates for the political, social and economic organization for the succeeding states that came after their collective “collapse,” around the 14th to 15th centuries CE (Lieberman 2003: 23). What these states have in common is that, within their settlement hierarchies, there is often a descending level of autonomy (economically, but also ideologically) on the part of the ruling king and the primary centre, with secondary settlement nodes—in the form of independent temples, craft workshops, or enclaves of independent rice farmers (Stark et al. 2015: 1444)—often exerting control over their own daily affairs (Lieberman 2003: 23; Hall 2011: 13-15; Hawken 2013: 365; Junker 2006: 209).

In the emerging conversation surrounding pre-industrial Southeast Asia’s settlement archaeology, one understudied topic I explore with my thesis research is the health advantages and repercussions that came with the adoption of this low-density, dispersed, and agrarian-focused land-use strategy. While there has been a push for non-elite focused archaeology, few
projects in Southeast Asia have attempted to excavate for secular, residential architecture at Charter-State city sites (Hanus and Evans et al. 2015: 1), due to the perishable nature of the domestic building materials used (Evans 2016: 164; Walker 2015:167). Angkor is the main exception, with remote sensing, survey, and the excavations at this state’s main capital having started a push for a more “people-centered archaeology” (Lucero et al. 2015: 1141; Stark et al. 2015: 1440; Hanus and Evans 2015: 1). Unfortunately, the study of settlements and urban planning for these major urban centres is still in process. Due to varying levels of preservation, and as well as political unrest in the recent past, archaeologists are just starting to understand or the planning and building process behind the Charter era (c. 800-1400 CE) urban sites (Lieberman 2003: 23; Evans et al. 2007: 1295). As such, my main research questions are:

- Did the city-planning practice of dispersed, low-density agrarian urbanism promote resilience against the health hazards and risks associated with tropical, wetland environments?
- Or, does low-density, dispersed urbanism create unique health problems comparable to the population health issues seen in other pre-industrial urban sites?

To answer these questions, I also had to know:

- Which tropical disease hazards were likely to have been present in mainland Southeast Asia during the Charter era?
- What strategies would the inhabitants of Angkor have used to prevent the risk of contracting these diseases?
- How did these patterns of disease risk and vulnerability change over time and space with the transformation of Angkor’s “urban footprint” or city plan?

**CHAPTER SUMMARIES**

To answer these questions, the general plan of this thesis is as follows. **Chapter 1** introduces the major research questions and objectives of this thesis project; explains how this thesis fits into the larger research paradigm of SETS (Socio-Ecological Entanglement in Tropical Societies) project; provides the background information on the impetus of this research project; defines and contextualizes the important terms and concepts used throughout this thesis.
Chapter 2, the Background, introduces the reader to the background information surrounding “urbanism” and “urbanization” in pre-industrial Southeast Asia. I examine the general literature about pre-industrial cities: what makes them different than industrial cities, what draws people to live in them, and what were the potential repercussions—regarding population health and quality of life—that came with humans adopting urbanism (Brooke 2014: 158). However, this literature review also emphasizes that urbanism in pre-industrial Southeast Asia took a very different route than in the more commonly studied regions of the Near East or the Mediterranean (Kealhofer and Grave 2008: 201-202; Stark 2006a: 21.11) and underscores that the available bioarchaeological record emphasizes this difference.

Chapter 3, the Theory and Method chapter, examines the theories and methods I use to analyze human-environment interactions: Resilience Theory and Entanglement Theory. Resilience Theory is an adoption of an ecological sciences concept which examines the adaptability and sustainability of human-environmental interactions and interrelations over the long-term (Holling and Gunderson 2002; Iannone 2015a: 6-8; Redman 2005: 72-73; Redman and Kinzig 2003: 14). Entanglement theory is largely a post-modern archaeological theory which identifies those human-environment interrelationships as material entities that can be observed and identified on or in the ground (Hodder 2012: 88). I then discuss how I will analyze these interrelationships. Together, these theories and methods will allow me to reconstruct the Angkorian inhabitants’ quality of life throughout the development, apogee, and breakdown of the city’s overarching state.

Chapter 4, my data chapter, catalogues and examines the development of urban infrastructure—economic, religious, and social—that constituted the different components of urban space that made up the city of Angkor. Angkor is probably the most extensively studied
urban site of the Charter Era on the in the Southeast Asian mainland, and our understanding of it compares with the Island Southeast Asian center of Trowulan, East Java (Miksic 1999: 178-83). I focus on the development of settlement patterns, water management, agricultural intensification, labour organization, and community projects since these are the major material correlates available in the archaeological record for the Classical-era Charter States (Iannone 2015: 8) which also conditioned the inhabitants of Angkor’s quality of life.

In **Chapter 5**, my analysis examines the resilience and sustainability of Angkor’s urban planning. This includes both the top-down (administrative, elite-driven city-planning) and bottom-up (collectively-driven by the non-elite support population) settlement processes, as well as heterarchical interactions (across demographic strata) which altogether conditioned the inhabitants’ health and quality of life. The result will be an assessment of the numerous strategies used by the urban population of Angkor in the face of the health risks and hazards associated with tropical environments, as well as their determining their success. Success, in this case, will be qualitatively assessed by this settlement strategy’s long-term effects on community-level markers of quality of life: population growth and dynamics, longevity of settlement, participation in community projects, and ability to withstand external shocks.

In **Chapter 6**, I answer my research questions. Firstly, I will answer my main research questions surrounding whether the urban plan of Angkor predisposed or protected its inhabitants against tropical disease risks. Then, I summarize the general successes and challenges of my thesis research, contemplate what I would do if I were to start this study again, and discuss further avenues of research.
CHAPTER 2: BACKGROUND

There has been an increasing number of large-scale, multi-disciplinary research projects in the past fifty years—mainly from present-day Thailand—that have emphasized the low-density, dispersed nature of pre-industrial Southeast Asian agrarian villages and early cities (Halcrow et al. 2016: 158; King et al. 2017: 28; Tayles and Oxenham 2006: 1; Tayles and Buckley 2016: 1). This period between 2500 BCE and 500 CE saw recognizable changes in social complexity, including the intensification of agriculture, changes in social organization, increasing population density, and some evidence for greater contact with centres in China and India, as well between locations in mainland and maritime Southeast Asia (Ross and Steadman 2017: 251).

The cities that emerged in pre-industrial Southeast Asia during the Classical period (c. 600 to 1400 CE) were geographically large, going beyond the traditional confines of enclosure walls and/or moats that were characteristic of the Iron Age (c. 500 BCE-500 CE) (Kealhofer and Grave 2008: 202-203; Stark 2006a: 21.11). Containing large temples or religious monuments, sculpture and inscriptions, early city centers in Southeast Asia have often been interpreted as largely ceremonial, either as cosmological expressions of the “mandala”—an important dravartic symbol that involves several radiating circles (Gaucher 2004; Cambodia Commission for UNESCO 2016: i)—or performative areas for a ruler to express powerplays in the form of the “theatre state” (Fox 1977; Geertz 1960; Tambiah 1976: 102–131). Identifying them as “dispersed, low-density agrarian urban centres” is a relatively new development, as the full extent of these cities based on size and political influence has only recently begun to be realized (Evans et al. 2007: 14277, 2013: 12594, 99; Fletcher 2009: 1-2, 2012: 287; Iannone 2014a: 1-2, 2015a: 1).
Settlement surveys have largely been the preferred method for uncovering cities in the archaeological past (Marcus and Sabloff 2008: 19; M.E. Smith 2016:152), and it is only with the recent advent of aerial survey through LIDAR and ground-penetrating radar techniques that the full extent of ancient cities have been uncovered from underneath dense tropical forest cover (Fletcher 2012: 285; Hanus and Evans 2015: 2; Lucero et al. 2015: 1139). What I want to examine in this chapter is the developmental trajectories towards urbanism that occurred in Southeast Asia, which can be compared to cities in temperate Eurasia and tropical Central America (Kealhofer and Grave 2008: 203; Stark 2006a: 21: 11.; Wrigley 1990: 103).

“The City” in Archaeological Study

The definition of a “city” in the social sciences falls into two categories: the sociological/demographic definition, and the functional definition (M.E. Smith 2016: 153; Isendahl and M.E. Smith 2013: 133). The most influential is the first definition, as coined by the sociologist Louis Wirth who in “Urbanism as a Way of Life” (1938: 8), stated: “For sociological purposes, a city may be defined as a relatively large, dense, and permanent settlement of socially heterogeneous individuals.” Largely influenced by the Chicago School of Urban Geography, and Louis Wirth’s formal definition of the city (1938: 8), Vere Gordon Childe adopted these principles to codify the characteristics of the ancient city. Writing two influential papers in 1936 and 1950, he set down the foundations for urban archaeology (Sabloff and Marcus 2008: 9; M.E. Smith 2016: 154; Yoffee 2009: 265). Gordon Childe’s identifying characteristics of a city included:

“greater community size [than villages or towns], larger populations, higher densities of people, agricultural surpluses, truly monumental public buildings, full-time craft specialization, systems of counting and recordkeeping, a writing system, regular foreign trade and subsidized traders, officials, and priests” (as cited in Sabloff and Marcus 2008: 9).
However, what became apparent over time, as more sites were excavated around the world, was that this strict definition excluded most ancient cities from consideration, since many early urban settlements—while playing a functionally important position in their own contemporary political and economic environments—did not meet these strict sociological criteria (M.E. Smith 2016: 153). Data that are based solely on population size or density are types of data that are very hard to correlate materially in archaeological contexts (Isendahl and M.E. Smith 2013: 132; M.E. Smith 2016: 153-4). Unlike cities in the present, from which there is documentary information in the form of city-plans, construction budgets, census records, and taxation records, ancient cities often only show up fragmentarily through regional surveys and other settlement studies (M.E. Smith 2016: 153). Even if certain disastrous events like volcanic eruptions or landslides can preserve whole cities without much deterioration, such as at Pompeii, these cases are comparatively rare (M.E. Smith 2016:154).

Many investigators have avoided these problems by employing “functional” definitions for cities, basing their identification and analysis of cities in the archaeological record not solely on demographic evidence, but on the nature of activities or institutions that take place within the site (Isendahl and M.E. Smith 2013: 133; Marcus 1983; M.E. Smith 2016: 154; Yoffee 2009: 265). Examples of functional definitions of the city emerged in the 1960s, out of the New Archaeology movement (for example, see Adams and Nissen 1972; Cohen and Service 1978; Cowgill 2004; Fried 1967; Trigger 2003; Wheatley 1983). Out of this functional focus came the trend of casting the city’s purpose as a “central place” that concentrates important societal institutions, with material comparisons often being made about the types of activities that take place in cities versus their surrounding hinterlands (Christaller 1979; Fisher and Creekmore 2014: 14; M.E Smith 2015: 154; Yoffee 2009: 265-66). This functional analysis of cities is
probably best expressed in the arguments surrounding the “city centres” of the Maya and other early complex societies of Mesoamerica. Though previously viewed as “vacant ceremonial centres,” where few people lived, it came to be seen that these urban hubs filled important administrative and religious roles in the context of their surrounding social and political environment. Yet, their population sizes and densities were far below that of most cities today (Chase et al. 1990; Sanders and Webster 1998; M.E. Smith 2016: 155; Wiley 1962) as the residential settlements were far more spread out (Isendahl and M.E. Smith 2013: 132; Fletcher 2012: 285).

Recent discussions of states and cities emphasize their variability and the cosmopolitan nature of their populations, as well as the nonlinear processes by which cities can grow and change (Marcus and Sabloff 2008: 13; M.L. Smith 2003a: 3–4). The rise of post-processual critiques in the 1980s and 1990s also brought two interrelated developments that have changed how archaeologists look at the past built environment (Fisher and Creekmore 2014: 13). The first was the acknowledgement of the agency of people of the past, especially regarding the non-elite members of society (see Rapoport 1989, 1990), and the second was a “spatial” focus that saw settlements as living spaces (see Bordieu 1977; Fisher and Creekmore 2014: 13). This conceptual shift is a greater movement towards a more “people-centered” focus in archaeology (Fisher and Creekmore 2014: 21). From this perspective emerged the post-processual views of cities, wherein the city is seen as “socially constructed” through the interaction of different social groups in the creation of an “urban experience”: both in terms of hierarchical, top-down processes, and heterarchical, horizontal relationships within and across different groups (Fisher and Creekmore 2014: 13; M.L. Smith 2003c: 2, 4).
Rather than seeing cities as fundamentally changed by the advent of the Industrial Revolution and the global connections of transoceanic trade, Monica L. Smith (2003a: 2) suggests that both ancient cities (used here to mean pre-modern, pre-industrial cities) and modern cities are the results of a “limited range of configurations that structure human action in concentrated populations” (see also Sabloff and Marcus 2008: 19; Yoffee 2009: 266).

Taken together, these perspectives can provide a model for the construction of a city. A city, both materially and socially, appears to be a “by-product” of the centralization of leadership (Marcus and Sabloff 2008: 21). Leaders provide protection, opportunities for work, materials acquired through trade, and locales for worship that would allow many people of different places and backgrounds to interact with one another (Marcus and Sabloff 2008: 21; Ross and Steadman 2017: 45-6; Yoffee 2005: 54). Archaeologically, material evidence of a city may be marked by dense settlements, fortifications, and evidence for economic activities beyond self-sufficient subsistence (M.E. Smith 2016: 160). These often include spaces for storage facilities and granaries, exotic goods, craft workshops producing prestige goods, market spaces, and both public and exclusive areas for feasting and gift-giving (Ross and Steadman 2017: 45). As such, the physical grouping of institutions within an urban centre is demonstrative of increased efficiency and control over the movement of resources and people by some authority (Marcus and Sabloff 2008: 21; Ross and Steadman 2017: 45-6; M.E. Smith 2016: 160-161). In Fisher and Creekmore’s opinion (2014: 21), the motivation for people to move into cities “…may have been the sheer concentration of diverse functions, services, and activities in the new urban centers.”

Taking these factors into consideration, we can also create a “general” model of pre-industrial cities and how they operate. They are settlements that concentrate large populations; the settlement is distinct from a rural hinterland, which acts as a resource base in regards to both
raw materials as well as people and their labour; and, the settlement functions as a centralizing and integrating hub to draw in non-agricultural specialists (Kealhofer and Grave 2008:201-2; Marcus and Sabloff 2008: 19-21; M.E. Smith 2016: 154; Fisher and Creekmore 2014: 3). But was the development of urbanism a positive development for the human experience overall, or for only a select few? One answer may lie in historical and archaeological evidence for the living conditions and quality of life for the inhabitants of pre-industrial cities.

**MAJOR EPIDEMIOLOGICAL TRANSITIONS IN THE PRE-INDUSTRIAL WORLD**

Before the 1990s, much of the study of human remains focused on descriptive studies and the cataloging of pathologies (Tayles and Oxenham 2006: 1; Waldron 2007: 2). The major shift came—in the form of bioarchaeology—with the study of the people behind those bones. Correspondingly, discussions of preindustrial cities frequently focus on health issues (R. Storey 2006: 277). It has long been argued that the ancient cities suffered high levels of epidemic disease and mortality (Cohen 1989; de Vries 1984; McNeil 1976: 75-76; Scheidel 2001, 2003; R. Storey 1992: 35-37).

The traditional model of prehistoric health change, or the sequence of epidemiological transitions, is often applied across regions (Clark et al. 2014: 484). It posits that the transition from hunting and foraging to agricultural and/or pastoral subsistence systems (the Neolithic Demographic Transition) had major implications for diet, weaning, and therefore fertility, with a related increase in infectious disease and posited decrease in general quality of life (Bocquet-Appel and Naji 2006; Clark et al. 2014: 484; Gage and Dewitte 2009: 650; Larsen 1995). Although agriculture developed independently in several places around the world, this model of prehistoric health change is based mainly on research in Europe and North America (Brooke 2014: 158; see Larsen 1995; Pinhasi and Stock 2011; Cohen and Armelagos 1984). There are
two established models used to describe the impact of the Neolithic Demographic Transition (NDT) on the overall human condition (Brooke 2014: 158).

The Fertility model argues that as foraging populations settled into villages, the stress associated with migrating from place to place during hunting and gathering excursions was alleviated, and as such, women had shorter birth intervals and more children who could be put to work during the routines of the Neolithic farming village life (Brooke 2014: 220). The corresponding population growth was aided by the introduction of starch-based weaning foods, which led to a shorter breastfeeding period and earlier return of regular ovulation after birth (Brooke 2014: 220; Clark et al. 2014: 484; R. Storey 1992: 12). In this model, a population would have grown rapidly until this high fertility balanced out an equal increase in mortality: new diseases developed in response to these higher population densities and “mortality crises” (severe depopulation events) grew in frequency as human populations “outgrew” their environment. This new fertility-high mortality regime would have settled into place with the emergence of cities and early states and was thought to last until the modern demographic transition (Brooke 2014: 99, 220, 229; Clark et al. 2014: 484-5).

The Fertility model is informed by a Neo-Malthusian perspective, where increasing population growth and density (also known as “population pressure”) is the sole driver of human suffering (Gage and DeWitte 2009: 649). In this rather dire view of life in the pre-industrial past, as a population grew in numbers and density, communities would eventually reach an environmental threshold that could not be circumvented by new technologies (Chamberlain 2006: 5).

According to Chamberlain (2005: 5), opposing this Neo-Malthusian viewpoint were processual archaeologists like Binford (1968); Cairmero (1970); and Renfew (1973), as inspired
by Boserup (1965) and Dumond (1965) (see also Gage and Dewitte 2009: 659). New Archaeologists saw the Neolithic Demographic Transition as a “consequence” of population growth, rather than population growth being its cause, and this shift in thinking is articulated in the concept of the second model, the “Food Control” model (Brooke 2014: 124). The Food Control model argues that the size and density of populations were managed through food production and increased food security (Brooke 2014: 124). While relying on a more restricted spectrum of foods in favour of staple cereal crops may have reduced nutrient density, the storage of food—whether in the form of grains or livestock and their secondary products—buffered the impact of subsistence crises (Brooke 2014: 124). This food security allowed individuals, families, and communities to survive through periods of droughts, famines, and other environmental adversity (Brooke 2014: 124-5; McMichael, Woodward and Muir 2014: 39). As the frequency of such mortality crises faded, larger numbers of people survived—including the very young and very old—to the point where they would have lived long enough for the effect of those diseases to be observed on their bones (Brooke 2014: 106-107; McMichael, Woodward and Muir 2014: 39-40). This is probably best illustrated in the ground-breaking concept of the “osteological paradox” (Wood et al. 1992), whereby evidence of poor health inscribed in skeletal bone may suggest that the affected individuals were living long enough to suffer these manifestations of disease, rather than dying earlier in life. Thus, the appearance of these skeletal pathologies would, paradoxically, suggest a healthier population on average, rather than a dire Neo-Malthusian vision of unchecked population growth eventually leading to mass deaths (Brooke 2014: 225). Nevertheless, as new diseases evolved in the dense settlements of Neolithic and Bronze Age settlements, they would have varied in their impact, but it is agreed that they did
not become epidemic until the rise of urban populations (Brooke 2014: 234, 279-80; Barnes 2005; 192-196; Wolfe et al. 2007: 251).

THE DISEASES OF PRE-INDUSTRIAL CITIES

The pre-industrial city has a rather negative reputation when it comes to their internal population’s health and well-being. Ancient cities, especially those of Medieval Europe or other temperate areas were, “cesspools…full of diseases” (R. Storey 1992: 160, 266), “glittering palaces of death” (Brooke 2014: 80), and places where the “…surplus rural populations were hived off to die quickly” (Lieberman 2003: 76).

Across these descriptions, what becomes apparent is that ancient cities are popularly conceived as crowded, dense places to live in, and easy places to die—especially for the non-elite populations that make up the largest share of any ancient population (Cohen 1992; 1998; Cohen and Service 1978, see also Haberl 2011: Table 1). With the increasing environmental awareness of the 1960s and 1970s, cities were also viewed as having a “disastrous” impact on human health (Brooke 2014: 80). According to M.L. Smith (2003:3), a common theme amongst publications on urbanism warned that cities were “doomed, dying, and dysfunctional” and that city life was “inherently damaging, inefficient, and wasteful”. One prominent finding was the link between urbanization and the increased incidence of nutritional deficiencies and contraction of infectious diseases in city-dwelling populations (Armelagos et al. 1996: 1-2).

Thus, in popular opinion, infectious diseases are thought to run rampant in ancient cities, and the non-elite inhabitants living within these cities are thought to be incredibly vulnerable in comparison to those of higher social standing (R. Storey 2006: 280). The reason that mortality is elevated in pre-modern cities is because of denser populations, which allow for the easy and

In pre-modern Europe, for example, there were major epidemics like the Black Death of the 14th century CE, but also the cholera and influenza pandemics of the 18th and 19th centuries CE that are associated with re-occurring seasonal epidemics (Barnes 2005: 280, 337). Childhood killers—such as measles, smallpox, chickenpox, and diphtheria—also caused regular mortality crises in cities (Brooke 2014: 120-121; McNeil 2010: 79-81). In rapidly urbanizing and industrial areas, infectious diseases incurred an “urban penalty;” diseases like cholera, typhoid, and tuberculosis created a high mortality regime throughout the eighteenth and nineteenth centuries for populations living in the crowded cities of Europe, to the point where their hinterland populations were comparatively healthier (Brooke 2014: 120-121; Gould 2014: 99; McMichael, Woodward and Muir 2014: 122-123).

Even the earliest urban studies, like that of the Chicago School, had negative views of the quality of life within cities. Louis Wirth argued that cities are places where the individual is disconnected from former family and other kinship connections; and, where ‘human contacts are “impersonal, superficial, transitory and segmented”’ (1938: 12). Due to the increase in population numbers in urban settlements, it was impossible to know everyone there as intimately, as was possible in village-based societies. Urban living was more impersonal, creating an easily divided, alienated populace (M.L. Smith 2003: 3; Ross and Steadman 2017: 42-43; R. Storey 2006: 277). Marxist critiques, working in the same vein, saw cities as the “physical locus of alternating rejections of, and acquiescence to, capitalist domination” (Marcus and Sabloff 2008: 9).

Mark Cohen (see Cohen 1992, 1998) and George Armelagos (see Armelagos 1990) were the pioneers to link the epidemiology of pre-industrial cities to an overall lower quality of life for
their inhabitants. Cohen and Armelagos’ epidemiological models of the city requires a large heterogeneous population that is stratified into classes. Social organization within the city does not rely on kinship markers and family ties, but the grouping of people based on their contributing labour to the overarching ruling power (Cohen 1998: 252). Inherent in this model is the idea that urbanization is spurred on through social stratification, as the elite classes of this type of pre-industrial, urban society rely on the surpluses of non-elite labour to maintain their power and prestige (Ross and Steadman 2017: 16; Yoffee 2005: 54). Consequently, social stratification and its relationship to the management of human labour led to the creation of populously-dense, compact settlements. As such, dense, compact settlements would allow for the critical mass of population required by the pathogens of acute, crowd-based diseases to spread continuously throughout the urban environment (Armelagos et al. 1996: 3-4; Cohen 1992: 56; Brooke 2014: 279).

In this epidemiological model, as Neolithic village societies turned into Bronze and Iron Age urban hubs, the first of a series of disease complexes developed (Brooke 2014: 158, 281). People brought together from different places in early cities carried with them their local diseases that spread accordingly, until the rise of the modern public health movement in the late nineteenth century provided a means to deal with the issue (Brooke 2014: 158, 281). Probably the most important effect of the development of a populously-dense city on human health is the interaction of a wide diversity of individuals in a single settlement, including those with different economic specializations and levels of wealth, different ethnic backgrounds, and different social standings (R. Storey 2006: 277; R. Storey 1992: 42). Consequently, the intermixing of these populations within the urban space—with each group having its own history of immunity and disease exposure—created a “disease pool” from which local infections emerged and spread
(Boomgaard 2007: 121; McNeil 2010: 76-77; R. Storey 2006: 277). For example, cases of endemic tuberculosis that cyclically infected human populations are thought to have emerged in these early urban environments (Barnes 2005: 160; Wolfe et al. 2007: 46). A second urban disease complex evolved along the lines of overland and maritime trade, as first contacts between previously isolated societies merged disease pools with devastating results in “virgin-soil” epidemics that eventually sublimated into “childhood diseases” as populations acquired immunity (Brooke 2014: 280; McNeil 2010: 76-77).

In this rather dire epidemiological model of city life, the rulers of a city are not concerned with the health or well-being of the non-elite population, but competition with other social elites. In this perspective, it is the introduction of more complex forms of social stratification that gives a reason for why humanity’s quality of life so drastically changed when people moved into cities in the age of pre-industry (Cohen 1992: 51, 67). However, more recent post-processual perspectives on the city have emphasized the positive factors that would draw populations to live in cities. According to Fisher and Creekmore:

“Anthropologists had to reconcile a philosophical understanding of the autocratic role of leadership and the rootlessness of city life with the observations showing that residents actively view cities as places of ‘community and opportunity.’” (Fisher and Creekmore 2014: 21).

Though negative views of the pre-industrial city are still prevalent, there are also more positive readings. There is increasing evidence that cities are also places where kinship ties are reaffirmed, rather than destroyed, and furthermore, they are places where social contacts with new groups can be diversified (M.L. Smith 2003b: 3). Neighbourhoods become the principle “anchor” of social interaction and mutual co-operation, rather than just being a place of alienation, acting as a focus for new communities to form (M.L. Smith 2003b: 3). More recently, environmental analysis is starting to see the city form as a potentially efficient “locus” to manage
the landscape (Fischer and Creekmore 2014: 21), and as a place for communities to exercise positive change without involving the hand of the state (Fisher and Creekmore 2014: 14,21; M.L. Smith 2003b: 3-4; Yoffee 2009: 282). What remains to be seen is if the same issues with the development of agriculture, social stratification, and urbanism had the same associated health impacts in Pre-historic and Classical Southeast Asia. For this, we must turn to the available literature on pre-industrial Southeast Asia’s demographic trends and patterns.

**POPULATION NUMBERS AND DENSITY IN PRE-INDUSTRIAL SOUTHEAST ASIA**

Ethnographic data, historical records, and assumptions based on changing agricultural strategies have been used to explain pre-industrial Southeast Asia’s famously low population densities (Bray 1986: 176-77; Kealhofer and Grave 2008: 205; Reid 1983: 59, 70). In one view, Southeast Asia remained relatively sparsely populated until recently (compared to India, China, Japan, or even Europe; Kealhofer and Grave 2008: 205; Junker 2006: 206). In the seventeenth century (c. 1600 CE), during the initial period of European contact, Southeast Asia’s overall population density was estimated to be 5.5 persons per square kilometer, only one-fifth in comparison to the 32 people per square kilometer in the Indian subcontinent, and the 37 people per square kilometer for China (not including Tibet; Junker 2006: 206, 207 (see also Junker’s Table 11.1); Reid 1990: 15). Even further away, Europe had about double the population density of Southeast Asia (Junker 2006: 207 [see also Junker’s Table 11.1]). Southeast Asia also had less than one-tenth of Japan, less than one-third of Polynesia, and approximately two-thirds of the population density of the West African kingdoms of Mali and Benin (Junker 2006: 206, 207 [see also Junker’s Table 11.1]; Reid 1990: 49). New World civilizations, such as those centered in Peru (the Inca) and the Valley of Mexico (the Aztecs) also had significantly higher population
densities than those of contact-era Southeast Asia, but probably would have been the most similar (Junker 2006: 206, 207 (see Junker’s Table 11.1)).

The reason for these comparatively low population densities in Southeast Asia before European colonization have continued to be debated by historians, anthropologists, and demographers. Although resources varied in their distribution according to topography, geology (such as soil quality), monsoonal conditions, and other factors, ecologists have generally described the region as resource-rich for farmers, foragers, and exploiters of marine resources (Kealhofer and Grave 2008: 204, 207). The tropical rainforests of the interior yield abundant edible wild plants and potential domesticates (e.g., yams, taro, sago palm, banana, coconuts, breadfruit and rice) and a variety of both wild and husbanded protein sources (e.g., pigs, chickens, elephants, tigers, monkeys, and deer) in addition to rich marine and coastal sources (Bellwood: 1997, 2011; Hall 2011: 4; Junker 2006: 208; O’Connor: 1995). In fact, Southeast Asia was described by both Indian and Chinese sources as the “Golden Lands” or “Golden Islands” because of the richness of its environment (Andaya and Andaya 2015: 23-25; Bellwood 1997; O’Connor: 1995; Hall 2011: 4, 40)

Given the bounty of both land and marine resources and soaring post-colonial population levels sustained primarily through traditional agricultural practices, researchers recognize that low pre-colonial population densities in Southeast Asia cannot be attributed to ecological limitations on subsistence alone (see Boomgaard 2007:122-127; Junker 2006: 208; Kealhofer and Grave 2008: 204-5, 207). Reid (1992: 461-2, as cited by Junker 2006: 208), using historical data, suggests a fertility-based explanation for the low population densities of pre-industrial Southeast Asia. Factors inhibiting fertility there included cultural mores surrounding the extended breastfeeding of children, the high agricultural workloads of mothers, the widespread
cultural practice of abortion, and the ubiquity of fertility-reducing diseases such as malaria (Junker 2006: 208). Nevertheless, Southeast Asia was not sparsely populated due to ecological constraints, subsistence practices, or fertility rates, but frequently had sizable regional populations overall—they were just dispersed throughout the landscape (Junker 2009: 208-9). For those populations to congregate in one place, there had to be an adequate number of resources, goods and services, that the state could provide which would draw people into city centres (Scarborough 2003; Scarborough and Burnside 2010: 345-6).

The Maritime Trade Immunity model suggests that the early urbanized population centers of Eurasia, India, the Middle East, and north China were the first to develop limited immunities to certain diseases, such as measles, smallpox, and enteric fevers associated with diarrheal diseases like dysentery or cholera (McNeil 2010: 141-142; See Fig. 2.1 to see mainland Southeast Asia’s position in the “Maritime Silk Road”). The smaller, more isolated, and less densely populated centers in western and northern Europe (McNeil 2010: 154-155), Japan (McNeil 2010: 151, 155), and South China (McNeil 2010: 149), and mainland Southeast Asia (McNeil 2010: 125-6) were not yet able to gain regular exposure or population densities.
that would support comparable disease resistances (Lieberman 2003: 97; McNeil 2010: 158-9).

When exposed to these pathogens during the first millennium BCE, these rimland locations of Southeast Asia and Southern China were hypothesized to have suffered similar mortality rates to First Nations and Polynesian populations during first contact scenarios with Europeans (Boomgaard 2007: 121; Lieberman 2003: 50-51, 63, 97). During the first millennium CE, nevertheless, the eventual strengthening of overland and maritime trade networks increased exposure to these pathogens. So, by the start of the second millennium, epidemic diseases in Southeast Asia had become endemic, killing pre-adolescents and seniors rather than working adults, which in turn increased population numbers and agricultural productivity (McNeil 2010: 158-9). It has been argued that trade between the core civilizations and the rimland areas was more important for its “immunizing effects” rather than its economic benefits (Boomgaard 2007: 121; McNeil 1976: 124-7; Lieberman 2003: 63,224; Reid 1990: 56-57). With these demographic models in mind, it is now pertinent to review the available bioarchaeological evidence to determine the role that disease played in settlement formation in pre-industrial Southeast Asia, before Angkor (See Fig. 2.2).
Southeast Asian bioarchaeological research has focused on the Neolithic and Bronze Age, as most of the skeletal samples in this world region are from these time periods. The bioarchaeological sample is largely restricted to northern Vietnam and Thailand, however, due to environmental considerations (like soil acidity). Since analysis of these bioarchaeological samples involved varying methods, sampling, and demographic groups, only general temporal trends, and not statistically different analytic results can be discussed (Halcrow et al. 2016: 158; Newton et al. 2013: 6). It should be also be noted that there are limitations to bioarchaeological lines of evidence (in that, there are only a limited number of diseases—most notably, smallpox and leprosy—that can leave lines of potential evidence in the skeleton [Roberts and Manchester 2005: 27-28]) and other infectious diseases do not present themselves in the archaeological record. Furthermore, it should be noted that the review of Southeast Asian bioarchaeology is a general summary and is not comprehensive or up-to-date.
Incipient Agricultural Communities in the Neolithic (c. 2500-1500 BCE)

Early perspectives influenced bioarchaeological analyses to conclude that the prehistoric inhabitants of Southeast Asia were an exception to the general model of declining health over time, a process starting with the Neolithic Demographic Transition (Domett 2001; Domett and Tayles 2007; Douglas 1996; Douglas and Pietrusewsky 2007; Oxenham 2006; Pietrusewsky and Douglas 2002, 2002a; Tayles et al. 2000, as cited in Clark et al. 2014: 484-485). Instead, these studies suggested that stable population health levels, or even an improvement with the introduction and intensification of rice-based agriculture (Clark et al. 2014: 484-485).

In agricultural societies dependant on maize and wheat, it has been frequently reported that with the intensification of agriculture there was a deterioration of general population health (e.g., various in Cohen and Armelagos 1984; Clark et al. 2014: 484; Cohen and Crane-Kramer 2007; Larsen 2006; Steckel and Rose 2002). The most common reason suggested for this deterioration in health is the dietary shift from a nutritionally rich and diverse hunting and gathering subsistence base, towards a nutritionally restricted diet consisting mostly of complex carbohydrates (Clark et al. 2014: 484; Brooke 2014: 298-99; McMichael, Woodward and Muir 2014: 39).

In many Southeast Asian population studies, however, these early agricultural populations continued to exploit the abundant natural resources in this rich tropical environment, including wild-caught fish, animals, and gathered plants (Domett and Tayles 2006; Kealhofer and Penny 1998; Pietrusewsky and Douglas 2001, 2002; Tayles and Oxenham 2006; White 1995). It is argued, therefore, that these populations had access to a relatively nutritious diet during and after the adoption of rice agriculture compared with other world regions (Clark et al. 2014: 485). Rice itself is high in nutritional value, and when even small amounts of meat or fish
and vegetables are added, the diet remains nutritionally balanced (Bray 1986: 13; Junker 2006: 205; Tayles and Oxenham 2006:15).

The retention of a varied subsistence base at these sites following the introduction of rice agriculture would have thus presumably aided immunity from pathogens and recovery from infections, and potentially protected people from nutritional deficiencies (Clark et al. 2014: 485). However, it must also be acknowledged that metabolic disease can occur in an environment with adequate nutritional resources if the population is experiencing high rates of infection from parasites (Wood et al. 1992: 34). There also appears to be a movement of parasites that came along with the movement of incipient rice agriculturalists into Southeast Asia (Lieberman 2003: 50). The evidence derived from genetic research indicates that, although indigenous hunter-gatherers contributed significantly to the present gene pool in Southeast Asia, the expansion of Neolithic rice and millet farmers had a major impact on demography and population structure. Gignoux et al. (2011: 6046) found that there is a period of exceptional population growth in Southeast Asia, five times faster than in the preceding period of hunter-gather occupation. This period of population growth took place from about 2700 BCE, precisely the period when we can trace, archaeologically, the expansion of rice farmers into the Red River basin of Vietnam, taking the expected riverine and coastal routes (Piper et al. 2017: 252). There, numerous Neolithic settlements are associated with the Phung Nguyen sites culture. The most important of the Phung Nguyen sites are Man Bac and An Son (Higham 2014: 110-112; Piper et al. 2017: 252; Willis and Oxenham 2011). The initial distribution of Neolithic settlement from the Red River to the Mekong was along the coast. In the interior, there was a parallel movement south by way of river valleys (Higham 2014: 112-3). Out of the many Neolithic sites, the best for understanding the
impact of incipient rice agriculture on population health is Khok Phandom Di, on the southern coast of Thailand (Higham 2014: 112).

Khok Phanom Di’s inhabitants were adapted to coastal, malarial conditions. The population consisted of indigenous hunter-gatherers who interacted with rice farmers, eventually admitting some non-local women into their community (Boomgaard 2007: 38; Higham 2014: 91). At Khok Phanom Di, the increased prevalence of ill-health over five mortuary phases can be explained by assessing localized factors, rather than just the adoption of agriculture. These include increased contact with farming communities, a shifting estuary climate regime with the alteration in layout of a nearby river, evidence for changing marital residence patterns, and most importantly, the exposure to malaria, which is evidenced by markers for thalassemia in the skeletal sample (Halcrow et al. 2016: 173; Higham 2014: 96; Tayles 1996: 13). The immune response to malaria is anaemia. A physical response to malaria can be traced in the skull by the thickening of the cranial vault (porotic hyperostosis) and upper part of the eye sockets (criba orbitalia; Tayles 1996: 11). For example, the high infant mortality at the coastal site of Khok Phanom Di is believed to be due to malaria-induced anemia for fifty percent of all individuals in the earlier mortuary phases (Higham 2014: 180-1; King et al. 2017: 29). Yaws is also presented as a hypothesis for the lesions seen on some of the burials (Tayles 1996: 16). Parasites of the intestinal tract, such as the hookworm, roundworm, liver, and intestinal flukes would have also been encountered at this site (Tayles 1994: 23-4). In comparison with this site, the Bronze Age sites of Thailand’s Khorat plateau see an improvement in population health (Clark et al. 2014: 490-491; Higham 2014: 180-181).
Bronze Age Village Settlements and Cemeteries (c. 1500-500 BCE)

In the mainland river deltas, the Bronze Age is characterized by the improvement of technology for agriculture, more durable vessels, and warfare. Knowledge of bronze-casting diffused into Southeast Asia through trade with China (Boomgaard 2007: 40-41). The introduction of bronze and iron is associated with the concentration of wealth and status among a small number of people and therefore increasing political, social, and economic differences between different lineages, individual families, and people (Boomgaard 2007: 41). These innovations increased the productivity of land and labour and intensified the populations’ ability to modify the natural environment (Boomgaard 2007: 41). The people of the Bronze Age lived in relatively small settlements. They selected slightly elevated terrain to plant their rice and millet. J.C. White (1982) has shown that the slightly elevated locations were optimal for settlements since access to swampy land that regularly flooded would allow for the incipient cultivation of wild rice. Proximity to water was also important for the maintenance of domesticated animals (Higham 2014: 176). Communities also maintained domesticated dogs, pig, chickens, and cattle, with pigs, chickens, and dogs being adopted from settlers from South China who had immigrated into the region (Piper et al. 2017: 264). But the remains of many sources of food are invisible in the archaeological record, as are the wooden and bamboo traps used for hunting or gathering. Stone axes or adzes are present in numerous sites for clearing unwanted vegetation, which created conditions for feeding cattle and enhanced rice production (Higham 2014: 179-180; Higham 1989:138). Most agricultural sites found in Southeast Asia and dating between 1000 BCE to 1000 CE are in areas of strong seasonal rainfall; this implies that precipitation-based irrigation was likely practiced (Boomgaard 2007: 51). Lower areas were probably too wet, and higher areas were probably too steep for effective crop growth (Ross and Steadman 2017: 241).
The investment in permanent, sedentary settlements is evidenced by the appearance of wooden houses (the main evidence of which is preserved at the Neolithic/Early Bronze Age site of Co Con Ngua) and the maintenance of cemeteries over centuries, such as at Ban Non Wat, Ban Lum Khao, Nong Nor, Ban Na Di, Ban Chiang and Non Nok Tha on the Khorat plateau in Thailand (Higham 2014: 176, 180). As argued by Higham (2014: 180), the cemeteries of Non Nok Tha (Douglass 1996), Ban Lum Khao (Domett 1999), Nong Nor (Tayles et al. 1998), and Ban Na Di (Houghton and Wiriyaromp 1984) are the only cemeteries that span the Bronze Age in full, and they can provide us with evidence about the health and lifestyles of the inhabitants of Southeast Asia at this time. The human remains from Ban Chiang can also be considered, as they span the late Neolithic to the Iron Age (Douglas 1996; Higham 2014: 180). Ban Non Wat, also on the Khorat plateau, is also an important case since its cemetery’s mortuary phases span the Late Neolithic to the early Iron Age (Higham 2014: 180).

Unlike the Neolithic site of Khok Phanom Di, the age profiles for the Bronze age reveal far fewer infant deaths. The figures for the death of infants under one year of age range from 11% (Nong Nor) to 19% (Ban Na Di, Ban Khum Lao) (Higham 2014: 181). There is also evidence of dental conditions which originate in poor childhood health (such as enamel hypoplasia, or the thinning of dental enamel due to caloric and nutritional deficiencies). About one-quarter of all adults had this condition at Khok Phanom Di, but this figure fell to 11-12.6 % for the females of Ban Na Di, Ban Lum Khao, and Nong Nor, with 11-15.6 % for the men (Higham 2014: 181). Bone mass and stature at Ban Na Di, Nong Nor, and Ban Lum Khao had similar levels which indicate the presence of good nutrition; only 2.8 percent of the adults at Non Nok Tha had caries, a figure that varied between 5.2 and 6.5 % at the other sites (Higham 2014: 181).
Comparatively, the Bronze age samples provide a picture of health, stature, and life expectancy that was better than the Neolithic sites. The people of Ban Khum Lao seemed to suffer more than other Bronze Age sites, however. The women died younger (presumably from childbirth complications) and men had smaller stature (Higham 2014: 181). This site’s poorer mortuary offerings might also reflect upon their poorer quality of life in comparison with other Bronze age sites (Domett 1999; Higham 2014: 181-2).

Alongside this comparison, some broader conclusions can be made about the population health of the people living in Bronze Age Southeast Asia. Settlement density increases in the Late Bronze Age in the Mun River Valley of northeast Thailand around the area of Ban Non Wat, which set the stage for greater social and political complexity in the Iron Age (Higham 2011; King et al. 2017: 30; Welch and McNeil 1991). While a nutritional and calorically-sufficient diet was maintained, greater settlement density and increased zoonoses from domesticated animals, among other factors, increased the risk of exposure to infectious pathogens (Clark et al. 2014: 490-1). The increase in population density and potentially greater prevalence of infectious diseases, combined with a shift in subsistence practices related to the deterioration in the physical environment (e.g., fire-cleared swidden agriculture), likely resulted in a decline in female stature and an increase in linear enamel hypoplasia. This change in population health can be observed in skeletal samples dating to the middle to late Bronze Age, as women took on the primary role in rice farming (Clark et al. 2014: 491). Regarding external forces at work, it also appears that a major climate shift occurred as the Mun Valley turned drier and colder during the end of the Bronze Age. This climate shift could explain the worsening population health patterns that are seen at the end of this period, as these Bronze age peoples
may have had problems adapting to climate conditions that were not as conducive to their 

The Iron Age Moated Sites (c. 500 BCE-500 CE)

Whatever the social and political structure of the Bronze Age settlements, by the late first 
millennium they had coalesced into larger unified polities that can be termed “early chiefdoms” 
(Ross and Steadman 2017; Higham 2014: 239). During the early Iron Age (ca 500 BCE to 200 
CE), some sites show evidence for agricultural intensification, social stratification, and hence, 
corresponding changes to population dynamics. These changes have been best-documented in 
the Upper Mun River valley of Northeast Thailand (Higham 2011; O'Reilly 2014: 298) and 
northwest Cambodia (O'Reilly 2004; Newton et al. 2013), with a particular focus on the 
moated settlements in both these region (Boyd et al.1999; McGrath and Boyd 2001; O'Reilly 
2014). These moat systems were used for agricultural purposes such as irrigation, the penning of 
animals, and as a water source during drought (King et al. 2017: 29; O'Reilly 2014: 302), rather 
than just defence (as argued by Malleret 1959: 402, and disputed by King et al. 2017: 29).

Settlements in the Mun River Valley allow us to understand the impact of the burgeoning 
maritime trade system as it moved inland (Higham 2014: 239). Like bronze smelting, iron 
smelting may have diffused from China, but by the sixth century CE, it was firmly in place and a 
part of the various metallurgical traditions of local communities (Ross and Steadman 2017: 243). 
There was more variation in iron tools than in bronze ones in Southeast Asia, which suggests that 
iron-working could be carried out by small local workshops, making such tools more abundant 
and available (and thus, cheaper) (Boomgaard 2007: 51). One outcome of the new iron-working 
tradition was the Southeast Asian adoption of the iron plough (Higham 2014: 209; Kealhofer and 
The iron plough and water-buffalo represented a radical change during the Iron Age, allowing much more land to be cultivated than by a person and hoe alone, and allowing for surplus rice production beyond basic subsistence (Higham 2014:209; Kealhofer and Grave 2008: 205; King et al. 2017: 30). Material infrastructure and artefacts, like moats for the management of water, extensive field systems, iron ploughs, water shovels—a type of tool used for digging into inundated soils—and sickles also start to appear during this time (Boyd and Habberfield-Short 2007; Boyd and Chang 2010; Higham and Rispoli 2012; Halcrow et al. 2016: 159; Moore 1988). The trade-off for higher food yields, however, is that this more intensive Iron Age farming requires a larger labour input. Production steps included the construction of fields during the early part of the rainy season, the preparation of soil, the transplantation of seedlings, and the time to thresh, harvest, and transport crops for storage. According to numerous scholars, the surpluses generated by this rice farming system underwrote the development of more complex social organization in Southeast Asia (Delvert 1961; Higham 2014: 210; Kealhofer and Grave 2008: 206; Stark 2004: 100).

Moated sites are found in the Khorat plateau, as well as in Cambodia (see Phum Snay and Sophy; Newton 2013), and the Pyu sites of Myanmar (Gutman & Hudson 2004: 158–69; Hudson et al. 2001: 59–61; Moore 2004b, Stargardt 1990, as cited in Stark 2006a: 21.6). The largest, found in Vietnam, is known as Coa La (Nam Kim 2013). These are a series of circular or rectangular areas surrounded by mounded earth that may have orginated in the late Bronze age, or perhaps even in the Neolithic, but they did not establish a true foothold as a prominent settlement form until the Iron Age (E. Moore 1988: 115-116, 1997; Stark 2004: 91; Nam Kim 2013). Preservation of organic remains is generally poor. It is thought, however, that it is likely that raised houses on platforms may have once stood inside these walled and moated areas (Ross
In general, there is a single opening in the embankment that allows for entrance into the interior mound, past a water-filled channel. The use of these features is widely hypothesized, but it is now thought that they probably played multiple roles: for defence against human invaders and raiders, and to keep livestock penned and to block wild animals (Higham 2014: 204; Ross and Steadman 2017: 242-3). They could have also been used for water management and sanitation, to prevent flooding of the home during the rainy season, as well as to store water during the dry season (King et al. 2017: 30; Ross and Steadman 2017: 242-3). These moated configurations with houses on stilts would also carry into the residential practices of the subsequent Classical period (Higham 2014: 204).

Several of these moated sites, such as Noen-U-Loke and Prohear had associated cemeteries, while the site of Lovea and Non Ban Jak show how new developments in rice agriculture took place (Higham 2014: 205). At Prohear, in the lower Mekong Valley (Pietrusewsky and Ikehara-Quebral 2006), we find evidence of a relatively healthy population. Men had an average height of 160.5 centimeters, and women were around 156.6 centimeters, and their bones showed little to no signs of dietary stress, and little evidence of illness or disrupted growth (Higham 2014: 222). At the site of Lovea, in the valley of the Puok river (what would later become the Angkorian heartland) in Northwest Cambodia, Hawken (2011) has analyzed the prehistoric rice fields that radiate from the moats in a fan-like pattern (see Figure 2.6). The change in rice field structure implies the establishment of a rice farming practice that would have greatly improved productivity and crop yields. By harnessing a plough to draft animals like water-buffalo, groups of rice farmers were able to cultivate more land together (hence the fan-like pattern of rice fields which radiated from a central point) than through hand and hoe alone (Higham 2014: 235). Wet-rice farming of all types tends to be a collaborative effort across
various times and countries (Bray 1984: 33), so Lovea would be a particularly early example. This interpretation is also supported from the evidence of finds at Noen U-Loke and Non Ban Jak, both located in the Upper Mun Valley of Northern Thailand, where we find socketed iron ploughshares (Higham 2014: 235). Lovea’s rice field forms were precursors to those we see in the Classical Angkor period, where we see rice fields organized in grids and on a coaxial basis (Hawken 2011; Higham 2014: 235; O’Reilly and Shewan 2015: 470).

Noen U-Loke is in a swampy, low-lying habitat on the Khorat Plateau in Thailand (Boyd et al. 1999). Its Iron age occupants invested much energy in constructing earthworks to control water flows. The moats may have been multi-purpose: defence, providing water during the dry season, and a source of fish (Higham 2014: 247; Ross and Steadman: 244). The human remains of Noen U-Loke provided the first opportunity in Southeast Asia to assess the health and demography of an Iron Age population that spans the entire period (Domett and Tayles 2006; Tayles et al. 2007). Additionally, the inhabitants were all local individuals, not immigrants new to the area, based on isotope analysis (carbon and oxygen) of their teeth (Cox et al. 2011). The intensification of rice agriculture at this site shows no relationship with worsening dental health over time, a trend that is also consistent throughout mainland Southeast Asia during this period (Douglas 1996; Newton et al. 2013; Oxenham et al. 2006; Tayles et al. 2000; Willis and Oxenham 2013; Halcrow et al. 2016: 159).

In summary of the basic trends of population health found throughout this period (Domett and Tayles 2006; Oxenham et al. 2006; Tayles et al. 2007), the assessment of Iron Age samples provides evidence for a deterioration in population health due to a number of environmental and social factors, rather than just nutritional deficiencies (Domett and Tayles 2007; Halcrow et al. 2016: 159; Tayles and H.R. Buckley 2004). The lack of an observed decline in oral health (such
as enamel hypoplasia and dental wear) during the intensification of agriculture during the Iron age implies that a broad-based subsistence regime was retained into the Iron-age (Newton et al. 2013: 7-9). Willis and Oxenham (2013), in their assessment of adult oral health in the Neolithic Vietnamese sites of An Son and from the Thai sites thereafter argue that there was in fact an improvement of dental health after the Neolithic period (Halcrow et al. 2016:175).

The implications of this are the deterioration in overall health was not caused by the intensification of agriculture per se, but other changes entangled with this development. This includes growth in population density, changes in fertility patterns, large-scale human alterations to the environment, and increased contact with the populations outside of Southeast Asia (Halcrow et al. 2016: 160; 171; King et al. 2017: 28-9). External changes like climate fluctuations must also be considered (Halcrow et al. 2016: 160; 171; King et al. 2017: 28-9). A gradual reduction in rainfall and the drying of the land at this time has been argued to have led to the construction of water-management systems in the Upper Mun Valley and intensifying rice agriculture. O’Reilly (2014) has assessed the development of the Iron Age moats from a socio-economic perspective and he argues that they functioned as water storage channels to irrigate rice fields during times of environmental stress, such as drought, and thus they were instrumental in the development of surpluses to support a transition to more hierarchal social organization (O’ Reilly 2014: 305-306; Halcrow et al. 2016: 171; King et al. 2017: 30; J.C. White 1995: 112).

THE DEVELOPMENT OF THE STATE IN SOUTHEAST ASIA

In many areas of Southeast Asia, the transition from the Iron Age chiefdoms to early states was signaled by the introduction of Sanskrit inscriptions written in Indic script. Kings, states, and cities were known by their Sanskrit names, and Hinduism and Buddhism, as imports from India and China, became state-religions for the early polities (Hall 2011: 8). Today,
scholars no longer accept the idea that the spread of culture and religion from China and India was the cause of state formation in Southeast Asia (Lieberman 2003: 7). Indian statecraft was adopted by the rulers of the Proto-Historic or Proto-Classical states of Southeast Asia to boost their status to that of a divine monarch, with the king as a link between the human society and the cosmic order of things (Boomgaard 2007: 65; Hall 2011:8-9; Lieberman 2003: 63).

Despite the ruler’s position, it has been argued that the Southeast Asian premodern state was “structurally weak,” since as one moved further away from the core area, the less physical control the state had (Hall 2011: 2; Junker 2006: 205). Thus, rulers kept their power through a combination of the supernatural fear, a regular show of force (see Figure 2.3), and large ceremonies that kept the people in awe (Boomgaard 2007: 61). Statecraft was also stimulated by things other than the establishment of a ruling, hierarchical power. These included: 1.) the switch from swidden to sawah (wet-rice) that increased food production and hence, population numbers (Boomgaard 2007: 74; O’Connor 1995); 2.) the introduction of new irrigation technologies (from immigrating farmers coming from what is now Thailand and Myanmar) that redirected fast-moving perennial streams (Boomgaard 2007: 74; O’Connor 1995, Lieberman 2003: 50); 3.) the growth of international trade, which boosted both the policies of the

![Figure 2.3. War Scene Showing Jayavarman VII’s Enemies Thrown into Tonle Sap, Bayon Temple, c. 12th century CE (Personal Photo taken May 2016).](image_url)
state and the Hindu and Buddhist monkhood by providing incentives for cooperation in the form of exotic goods, alongside local rewards like titles and land (Boomgaard 2007: 75); and, 4.) and increased reliance on livestock and bonded labour as means of production (Boomgaard 2007: 75). In the Khmer realm, the latter were known as “Khum,” a demographic group who had less autonomy or the limited ability to move away in times of crisis, and which provided a steady pool of labour for the Classical temple economy (Boomgaard 2007: 75; Hawken 2013: 357). The class of Khum was likely to have been generally comprised of war prisoners, criminals, and captured tribespeople from the surrounding Cambodian highlands (E. Lustig 2009: 75). The impact of these innovations on population health and well-being is visible in the archaeological record at the sites associated with the proto-historic polities of Funan (c. 200 CE-600 CE) and Chenla (c. 600-800 CE), precursors to the state of Angkor which are also located in Cambodia (see Figure 2.4).
THE FUNAN SITES OF ANGKOR BOREI AND O’C EO (c. 200-600 CE)

In the Mekong river valley, between 500 BCE-600 CE, there is a rapid transformation from chiefdoms to kingdom-like polities, with the rise of the proto-states of Funan and Chenla (Vickery 1998: 390-393). The Funan capital appears to be Angkor Borei, located slightly inland, but connected to the Gulf of Siam by canals leading to the port city of O’c Eo. Its inland position is somewhat puzzling given the importance of maritime trade to Funan, but Angkor Borei is in an ideal area for rice production. Over the last two decades, archaeological work has begun to document some of the remains of this large Funan center (Stark et al. 1998, Stark 2003). Ancient Angkor Borei stretched across roughly 300 hectares and was encircled by a substantial masonry wall; the city housed as many as 20,000 inhabitants (Stark 2006a: 21.11). The historic occupation, between the 1st -6th centuries CE, is characterized by features like brick temples, walls, and water reservoirs or baray, one of which was 20,000 square meters in size. Funan’s rise had two supports: the productivity of its agrarian system and the area’s strategic location opposite the Isthmus of Kra, an important maritime passage (Hall 2011: 48-9; Liere: 1980; Malleret: 1959–1963; Stark et al. 1998, 2003, 2006: 21.7).

Flood recession farming was likely utilized when deep flooding ruled out wet season farming (Fox and Ledgerwood 1999; Higham 2014: 282). In this type of farming, the flood water is trapped behind bunds, or in reservoirs, and released into fields as the annual flood recedes at the beginning of the dry season (Bray 1986: 28). Yields are high because the fields are covered in a new layer of silt with each flood, so ploughing is not necessary (Bray 1986: 19). Fox and Ledgerwood (1999), alongside Delvert (1961) and Stark (2004:100), indicate that this agricultural system was well capable of supporting large populations, noting its potential for supporting later inland states (Higham 2014: 282). Favourable water resources, the good soil
condition, and seasonal weather allowed Funan’s agriculturalists in the upper delta and lower Mekong River basin to produce multiple rice harvests each year, supplying a surplus large enough to feed foreign merchants residing in Funan ports easily and to provision their ships (Hall 2011: 47-48; Higham 2014: 279; Vickery: 1998: 300–1).

In addition to Angkor Borei and its port city O’c Eo, archaeological survey has identified twelve other urban centers that likely belonged to the Funan proto-state (Ross and Steadman 2017: 247). As many as 200 kilometers worth of canals connected these settlements (Khai 2003; Stark 2003). Though most of the brick masonry structures at Angkor Borei have yet to be investigated, there are some hints as to the Funan religion, which likely included aspects of Hinduism and Buddhism intertwined with indigenous beliefs. Indeed, in the 6th century CE, both Hindu and Buddhist statuary became more common here (Ross and Steadman 2017: 247).

**The Vat Komnou Cemetery**

The inhabitants of Angkor Borei were buried at the cemetery of Vat Komnou, and this is the only Proto-Historic cemetery site in Cambodia (Ikehara-Quebral and Pietrusewsky 2006:90). The population sample was relatively healthy, comparable to the previous Bronze and Iron age sites that have been discussed. Adult Vat Komnou males, on average, were approximately 5.5 cm taller than modern Cambodian and other Southeast Asian males, for example (Ikehara-Quebral and Pietrusewsky 2006:88). The relatively low frequencies of dental enamel hypoplasia in the Vat Komnou skeletal remains suggest that these early inhabitants did not suffer nutritional deficiencies (Ikehara-Quebral and Pietrusewsky 2006: 89-90). The frequency of *cribri orbitalia* observed in these remains, although based on few observations, suggests that some of the people buried at Vat Komnou may have been subjected to parasitic diseases, iron-deficient diets, and other chronic stressors in their environment (Ikehara-Quebral and Pietrusewsky 2006:90;
Ikehara-Quebral et al. 2017: 37-38). The low frequencies of dental infections suggest a broad-spectrum diet (Ikehara-Quebral and Pietrusewsky 2006: 90), alongside teeth-preserving betel nut chewing (see Reid 1990: 57-9 for a discussion on the health benefits of the betel; Ikehara-Quebral and Pietrusewsky 2006:90). The very high frequency of advanced dental attrition in female skeletons may suggest sex-differentiated labour patterns and diet (Ikehara-Quebral et al. 2017: 37). With the occurrence of least one healed skull lesion and a possible healed broken humerus, the evidence indicates that this population was not immune to trauma, or even violence (Ikehara-Quebral et al. 2017: 38). The relatively high frequency of *spondylolysis* (stress in the lumbar vertebrae of the spine) in this small sample indicates that females of Angkor Borei experienced heavy loads on their backs, due to their role as the primary rice harvesters (Ikehara-Quebral and Pietrusewsky 2006:90). The low levels of pathologies associated with old age—osteoarthritis and osteophytosis—in these remains is also consistent with the young age at death demonstrated across the skeletal sample of the preceding Bronze and Iron Age sites, though length of life is better than the even earlier Khok Phanom Di (Iquehara-Quebral and Pietrusewsky 2006: 91; Ikehara-Quebral et al. 2017: 37-8). Together, there is only limited evidence in these remains for skeletal changes suggestive of infectious diseases (Ikehara-Quebral and Pietrusewsky 2006: 87). The available bioarchaeological evidence at these sites suggests human well-being and a good quality of life were being maintained at the community level through something, think later, and in combination with new socio-economic innovations, this likely contributed to the success of Funan as a proto-state. Stark (2003: 90-1) notes that in mainland Southeast Asia, the Funan culture demonstrated the first characteristics of social complexity in the region:

“…1.) high population and urban centers 2.) the production of surplus food supply through intensive rice cultivation 3.) sociopolitical stratification legitimized by Indic
religion ideologies 4.) a system of writing by the end of the early historic period 5) a vigorous network of long-distance trade.”

However, these adjustments were not enough to prevent Angkor Borei and O’c Eo from being abandoned. Improvements in navigation made it possible for ships sailing from distant ports to bypass Funan and deal directly with Chinese traders (Stark 2006b: 166). Chinese records make it clear that by the fifth century, Holotan in western Java and Koying in the Sunda Strait were trading directly with China, rather than through Funan (Stark 2006b: 166). Funan was thus being cut out of the India-to-China trade route (Hall 2011: 61). Funan was abandoned, its canals silted up, and its temples were taken over by forest, eventually setting the stage for the next Mekong delta state—Chenla—to fill the power vacuum (Hall 2011:60-61; Manguin 2004: 300; Ross and Steadman 2017: 249; Stark 2006b: 152).

THE CHENLA SITE OF SAMBOR PREI KUK (c. 600-802 CE)

Located in the valley of Stung Sen, a tributary of the Tonle Sap river, is the site of Sambor Prei Kuk. The four hundred-hectare site with over two hundred brick and stone sanctuaries was first excavated by Aymonier (1900-03) and Parmentier (1927) (Higham 2014: 288-9; O’Reilly 2007: 113-14; Stark 2004: 100). Sambor Prei Kuk is thought to be Ishanapura, which according to Chinese documents was the name of the Chenla capital (Stark 2006b: 153). Within the capital, a fraction of the temples have been excavated: their brick platforms elevated them above ground, their brick walls were decorated with reliefs and inscriptions of temple founders, and they often give vital information about donations and family relationships (O’Reilly 2007: 113-14).

Van Liere (1980: 270-71) has examined the hydraulic system at Ishanapura. One problem is that the site was occupied into the Classical era, which makes dating its construction difficult (Hendrickson 2010: 488). Ishanapura/ Sambor Prei Kuk continued to be a centre of learning and
culture into the Angkorian period when it was linked by the state road network (Hendrickson 2010: 488, Kubo et al. 2012). Reservoirs likely constructed in the 7th century CE supplied the moats, religious foundations, and urban population with water, and aided in the irrigation of rice fields. Shinoda (2010) has noted that there are traces of rice fields beyond the urban centre; they are likely to be a precursor to the agricultural systems used at Angkor (Higham 2014: 291).

Given the lack of domestic architecture and other residential material, our understanding of daily life is limited to documentary sources. But we do know that the people of Chenla followed a matrilineal kinship system, with property and titles passing from male to male on the female side (the matrilineal nephew; Ross and Steadman 2017: 250; Vickery 1998: 260-270)—something that would remain consistent into Angkorian times (Hall 2011: 6).

The titles mratan and pon marked men who might have ruled territories, held positions in the king’s court, or served in a religious capacity. These titles are associated with significant wealth and appear to hold the leadership position associated with chiefs (Vickery 1998: 271). Thus, early in the Chela state, and probably in Funan before it, and carrying into Angkor, there was a significant dispersal of authority that corresponded with the spread of resources across the region. The pon and temples controlled the production of food and luxury items, as well as their distribution (Higham 2014: 297; Ross and Steadman 2017: 250).

Sambor Prei Kuk is also notable for the physical evidence for Southeast Asia’s entrance into the Maritime Silk Road (two Roman coins, as well as architectural reliefs showing Persian, Central...
Asian, and Indian visitors; see Figure 2.5). These artefacts support the idea that the inhabitants of the Cambodia basin were interacting with other complex societies of Eurasia, and presumably, their “disease pools” (Cambodian National Commission for UNESCO 2016: 50; Ross and Steadman 2007: 250-251). At the end of the period of Chenla, two major centres were flourishing, resulting in a smooth transition into the Classical era. The first is located at Angkor itself: the site of Prei Khmeng with the temple of Ak Yum. In the area beyond Ak Yum, Goloubew (1936) identified a series of temples and rectangular features that belong to the seventh and eighth centuries. At Iuhanapura, these seem to be related to fan-shaped rice fields (Hawken 2012, 2013: 351; see Figure 2.6). The orientation of the linear banks north of these temples and fields may have served to hold and direct water into the irrigated rice fields for flooded rice farming (Higham 2014: 295). The second centre was established east of the Mekong, at Banteay Pre Nokor. It is a huge site, the moats and ramparts dominating the flat landscape, and it was hypothesized to be the court from which Jayavarman II came to establish the kingdom of Angkor (Higham 2014: 295).

CONCLUSIONS

In conclusion, this background chapter examined several interconnecting topics: pre-industrial urbanism, the health impacts of early urbanism, and Southeast Asia’s unique path to urbanism. From these discussions, several conclusions can be made. Most of our information
from the Southeast Asian prehistoric sites comes from mortuary contexts, and from these, we have bioarchaeological information that allows us to understand general trends surrounding population growth and dynamics, as well as the patterns of population health across pre-historic Southeast Asia. In contrast, in the proto-state period (c. 500-802 CE), we have a much better understanding of settlement patterns. The Cambodian sites of Angkor Borei and its cemetery, Vat Komnou, provide information on population health during this transitional period (Pietrusewsky and Iquehara-Quebral 2006: 90-91; Ikehara-Quebral et al. 2017: 2; Newton et al. 2013: 5). Meanwhile, the establishment of Chenla as a Maritime Silk Road trading node also marked an inroad for new diseases to enter the mainland (McNeil 1977: 124-7).

A review of these Pre-Angkorian sites is important, since they provide information on the disease risks and hazards that likely carried into the Classical period, and emphasize that the developments of social complexity in Southeast Asia—the origins and intensification of agriculture, sedentism, proto-state formation, and regional entrance into long-distance, maritime trade—did not follow along the same epidemiological transitions as the more commonly studied areas of temperate Eurasia or North America. What remains to be seen, however, is whether the rise of the complex state, which is associated with major health changes for urban populations, was also unique for pre-industrial Southeast Asia, and for Angkor in particular.
CHAPTER 3: THEORY AND METHOD

There has not been a concerted effort to trace back the history of infectious disease and its effects on social complexity and resultant state formation patterns—in terms of origins, efflorescence, and collapse—in pre-industrial Southeast Asia (Clark et al. 2014: 484; Halcrow et al. 2016: 158; Tayles and Buckley 2006: 1-2). The ability of both local and foreign archaeologists to excavate in Southeast Asia has been hindered not only by the presence of dense vegetation, and varying levels of preservation—due to certain ecological processes, like periodic flooding—but also political unrest (Tayles and H.R. Buckley 2006: 1-2) and the modification of the environment through modern farming (Evans 2016: 164).

Also, with the adoption of Hinduism and Buddhism in the early Iron Age and Proto-historic period, respectively, mortuary practices changed to cremation and exposure (leaving the dead out in the open), rather than burial. Thus, skeletal samples are largely absent from the major Classical capitals, such as Angkor of Cambodia and Bagan of Myanmar (Oxenham and Buckley 2016: 1; Oxenham and Tayles 2006: 5). For this reason, the greatest challenge for my research project is that we do not know what specific disease hazards Angkor’s population faced.

With these limitations in mind, there are normally several datasets one can use when trying to understand the distribution, determinants, and dynamics of disease within past human populations. These include written records such as inscriptions and ethnohistoric accounts, art depicting disease and treatment, archaeological evidence of human behaviours and activities, and direct physical evidence that is preserved in human remains (Barnes 2005: 7-8). For this research project I consulted the following resources:

- Medical literature on the evolutionary trail of infectious diseases in Southeast Asia, based on genetic studies and histories of population movements
• Physical evidence of these diseases from both historical references and osteological material that either place these diseases directly or indirectly in pre-industrial Southeast Asia (see Chapter 2 and Table 2 for the results).
• The archaeological evidence of human behaviours that would modify the environment to create ecological niches for these diseases.

By doing so, I was able to identify thirteen diseases that were likely to be present in mainland Southeast Asia. My reasons for focusing on Angkor as a case study are discussed below.

ANGKOR AS CHOSEN CASE STUDY

While there has been a push for non-elite focused archaeology, few projects in Southeast Asia have attempted to excavate for secular, residential architecture at Classical era city sites, due to the perishable nature of the domestic building materials used (Walker 2015: 166-7; Evans 2016: 165). Angkor is the main exception, with remote sensing, survey, and excavations at this

Figure 3.1. Map of Areas Visited at Angkor Archaeological Park, modified from canbypublications.com
state’s Classic capital starting a push for a more “people-centered” archaeology (Hanus and Evans 2015: 1; Lucero et al. 2015: 1141; Stark et al. 2015: 1440).

But what about the people who inhabited this city? What would their daily life have been like? Was their quality of life objectively “good?” Unlike its monumental architecture, the physical remains of the people of Angkor are much less conspicuous in the city’s archaeological record (Evans 2007: 12595). Thus, it has not been until recently that there has been a call to build Angkor’s household archaeology (Hanus and Evans 2015: 1), beyond what has been described in the 13th century “snapshot” of a declining capital provided by Zhou Daguan in his *A Record of Cambodia and its People* (translated by Harris 2007). The process of urbanization happened differently at Angkor, as compared to the more commonly studied geographical areas of Southwest Asia, the Mediterranean, and the Americas (Armelagos 1996; Cohen 1992; Cohen 1998; R. Storey 1992). Thus, it can be argued that Angkor’s inhabitants would have had different challenges to deal with to maintain health and good quality of life.

But what is quality of life? Quality of life is a subjective measure of standard of living (M.E. Smith 2015: 1). For individuals, it would involve being adequately nourished— in regards to calories and essential nutrients—as well as the ability to avoid premature death (Morgan 2013: 120; M.E. Smith 2015: 7). For individual households, this may be signified in the richness and diversity of domestic goods, as well as household participation with, and access to, social networks (M.E. Smith 2015: 2). On the community level, quality of life is seen in: 1.) population growth and dynamics; 2.) the ability to participate in community projects; 3.) stability and length of settlement; and, 4.) the ability to withstand external shocks (M.E. Smith 2015: 7-9).

Out of all the archaeological data available for Angkor—given a lack of skeletal samples that would allow us to know about individuals’ health and only a partial understanding of its
households—the rich literature on this site’s macro-scale settlement data, or urban archaeology (see Evans et al. 2007, 2013; Evans 2016: 169; Fletcher et al. 2003; Fletcher et al. 2008; Stark et al. 2015) is our best means to understand the inhabitants of Angkor’s quality of life on the community scale (McElroy 290: 250, 253). Several theoretical concepts and methods will help facilitate this assessment. For this, I draw from the Socio-Ecological Entanglement in Tropical Societies (SETS) project’s repertoire of theoretical concepts and methods.

**SETS THEORETICAL CONCEPTS**

Like other theses in the SETS project, my research is built upon a historical-political ecology framework (Iannone 2015a: 7). Historical-political ecology focuses on the historical-political landscape: the material entity from which human intentions, decisions and action over time and space can be inferred, based on the remains of anthropogenic modifications to the environment which illustrate these former human-environment interrelationships (Balée 2006: 76; Balée and Erickson 2006: 1; Fabiyini et al. 2014; Iannone 2015a: 7-8; Winterhalder 1994). Unlike landscape ecology, which generally views humans as just another species in the ecosystem, and which is generally under the purview of environmental scientists, conservationists, and ecologists, historical ecology specifically focuses on the role that humans play as a “keystone species” in their relationships with the environment (Balée 2006: 2). The SETS project specifically uses two theories to frame our analysis of these human-landscape interactions: Resilience Theory and Entanglement theory. We also use the comparison of pre-existing data sets through a method known as “data proximity”, also known as on-site visitations (Drennan and Petersen 2012), to make assessments of data set suitability for answering questions about the socio-ecological entanglements of human societies in the tropics (Iannone 2014b: 1; Iannone
Having these on-site visitations was important, as noted by Drennan and Petersen (2012: 71):

“...no one person or reasonably sized collaborative group can possibly carry out field research in very many regions. It is possible, however, to complement the reconstructions made by regional specialists by carrying out consistent analyses of primary archaeological data sets from many places so as to avoid the impact of incompatible ways of interpreting the evidence that are embedded in the conventional wisdom for different regions.”

**Resilience Theory**

The socio-ecological systems studied by SETS are examples of complex adaptive systems. A complex adaptive system is a system of diverse “agents” that interact, mutually influencing each other in their adaptations to outside stimuli (Walker and Salt 2006: 1-2; Scarborough and Burnside 2010: 329). The relative success of these agents reinforces these adaptive strategies for replication or enhancement, allowing the system to evolve, forming complex patterns that are not easily predictable (K. Smith 2011: 47; Scarborough and Burnside 2010: 329; Walker and Salt 2006: 2).

Systems theory in archaeology originated in the 1960s when archaeology in North America and Britain became more closely aligned with anthropology; often in opposition to the earlier “culture-history”-orientated mode of study (Ross and Steadman 2017: 2-3). Prominent scholars included Kent V. Flannery (1972) and Robert McC. Adams (1966). They and others regarded every society as comprising a unique mixture of interacting systems, modelling them on organs in the body. Systems theory evolved from an equation-based approach adapted from the natural sciences in the 1970s (K. Smith 2011: 46). The basic idea is that any system—a river, the global atmosphere, or a social grouping—acts as a set of components to produce a specific output (K. Smith 2011: 46). Previous attempts to understand such systems tended to simplify key inputs, internal flows, and outputs. In practice, natural or social systems were conceptualized as
“machines” that delivered an expected product (K. Smith 2011: 46; Scarborough and Burnside 2010: 328).

Challenges to early systems models occurred in the 1980s. Archaeologists criticized them for being too “mechanistic” and not flexible enough to account for human behaviours and social relationships (Ross and Steadman 2017: 4). Still, the idea that culture is composed of interrelated and interconnected subsystems continues to generate theories of culture change; this is seen in the recent turn towards the concept of “complexity” in archaeological theory (Ross and Steadman 2017: 4). Complexity theory starts from the premise that systems are best examined by not grouping components together for analysis. Many real-world natural and social systems exhibit “emergent behaviours”: complex-looking patterns and behaviours not easily predictable from the base attributes and actions of their components (Scarborough and Burnside 2010: 327-328; K. Smith 2011: 46-7; Walker and Salt 2006: 31, 35). The turn towards “the complex” in archaeological theory also influenced the adaption of Resilience theory for a type of big-picture analysis that could be used by archaeologists to understand long-term human relationships with the environment (Redman 2007: 71).

Figure 3.2. Adaptive Cycle Diagram, from www.resilience.org, modified from Holling 2002.
Resilience theory comes from the field of ecology (specifically from the works of Holling and Gunderson [2001, 2002]), and it has spread to multiple social sciences, including archaeology, in the late 1990s to early 2000s. Resilience theory is a type of eco-systems theory, but it is quite different from the traditional paradigm in several respects. In the traditional systems theory utilized by Processual archaeologists—the theoretical framework disseminated by the works of David Clarke (1968) and Kent Flannery (1972)—it is assumed that the system’s different components are working towards optimal, homeostatic stability (Armitage and Johnson 2006: 2; Balée and Erickson 2006; Redman and Kinzig 2003:14). In resilience theory, the main theoretical focus is on the ability of a system to react to, work with, and work around perturbances (Walker and Salt 2006: 3).

In the archaeological interpretation of resilience theory, as conceptualized by Redman (2005: 70; Redman and Kinzig: 14), human societies accumulate environmental capital (biomass and energy), conserve, and eventually release it, depending on their interactions with the surrounding environment (Iannone 2014b: 6). In socio-ecological theory, this is encapsulated in the concept of the “metabolic profile,” which describes how a human society gathers energy to sustain itself (Weisz et al. 2001: 126). For example, foraging societies rely on the direct harvesting of biological material, while agrarian societies, which contain larger and denser populations, are supported by modifying natural ecosystems to meet that population’s need for greater amounts of biomass. Often, this requires technological innovations (Iannone 2014b: 6; Weisz et al. 2001: 126-7). The stages of this environmental capital acquisition are represented by the “Adaptive Cycle” (see Figure 3.2). The first is exploitation (r); the second is conservation (k); third is release (omega); and, the fourth is reorganization (a). The fourth stage accounts for
the human ability to revert or reorganize to different forms of social organization in the face of change (Redman 2005: 73-74).

**Applicability**

Resilience theory is concerned with both stability and change. Resilience itself is defined as the ability of a system to adapt to changes without changing its fundamental organizational structure (Walker and Salt 2006: 3); nevertheless, resilience is not just about not “not changing,” but rather the ability to focus and direct things and actions to create the most desirable circumstances envisioned by a particular group, community, or social organization (Iannone 2015a: 4; Walker and Salt 2012:24). In an increasingly globalized world, where disasters in one world region can have a “domino effect” on others, it makes sense that Resilience theory would resonate with scholars who are trying to understand the repercussions of a rapidly transforming environment and climate due to the actions of humans (Walker and Salt 2006: 1-2). Disasters, for this thesis, are defined as:

“…Often rapid-onset, events that directly threaten human life, property, and other assets by means of acute physical or chemical trauma on a relatively large scale. Such losses follow the sudden release of energy or materials in concentrations greatly in excess of normal background levels (K. Smith 2011: 5).

It used to be thought that environmental disasters, like plagues, volcanic eruptions, or earthquakes sprung from vengeful gods or an “actively hostile” environment (K. Smith 2011: 9; Barnes 2005: 4). The Black Plague in the fourteenth century, for example, was conceptualized by Christians in Europe to have been caused by “the sins of men” and the abandonment of the church rather than—as we know today—the spread of the bacterium *Yersinia pestis* as facilitated through the population migrations of rats (Barnes 2005: 9, 238; Brooke 2014: 349-50).

Now, however, much of disaster theory considers the environment to be “neutral” (K. Smith 2013: 4, 9). It is the human use of and perception of the environment that determines
whether an ecological process is a *resource* (as something useful) or a *hazard* (something that threatens human life well-being or property; K. Smith 2011: 11). On the practical level, however, a human population’s sensitivity to environmental hazards is determined by the “exposure” of “people and their assets to potentially damaging events and by the degree of human vulnerability (or resilience) to such damaging events” (United Nations International Strategy for Disaster Reduction 2009, as cited in K. Smith 2011: 4). Exposure itself is predicated on the ability of a human population to tolerate or adapt to changing circumstances, which will determine whether the presence of an environmental hazard will become a disaster (K. Smith 2011: 9; Redman 2005: 71; Butzer 2012: 3632, 3638).

Archaeologists have a unique perspective on past disasters, working with timescales and data that is complementary to the work of ecologists and other environmental scientists (Redman 2005: 71). Archaeologists make an important contribution to our understanding of human-environment interactions in that their work focuses on long-term socio-ecological cycles (Balée 2006: 76), as well as data sets that allow them to compare multiple case studies (Butzer 2012: 3638; Diamond 2005: 7-8; Redman 2005: 71-72; Redman and Kinzig 2003: 14). Modern studies of the environment, such as by human geographers, climatologists, and ecologists, on the other hand, tend to focus on socio-ecological cycles that have not ended yet, usually in timescales of months, singular years, and decades (Balée and Erickson 2006: 1-2; Redman 2005: 71). Thus, archaeological studies of past human-environment interactions—as carried out with this thesis—often provide insight into the long-term human relationships to environmental hazards and the resulting strategies for risk management.
Entanglement Theory

Entanglement theory is about the mutually constituting relationship, or “dialectic” between humans and “things.” (Hodder 2012: 88). “Things” in this case are defined as material “entities” created through natural forces or through human ideas and hands (Hodder 2011a: 175, 2012:17–18, 88; Iannone 2014b: 6). Entanglement theory is largely a post-processual archaeological theory which identifies those human-thing interrelationships as material objects that can be observed and identified on or in the ground (Hodder 2012: 97, 100). Two important concepts related to entanglement theory are “dependence” and “dependency” (Hodder 2012: 17-18; 97; Iannone 2015a: 7). Dependence is when the mutually constituting relationships between humans and things allow for societal innovation and adaptability against new challenges. Dependency is when the entrenched relationships between humans and things constrain or limit a society’s ability to adapt to new challenges, which entraps the society in prescribed decision-making pathways which are difficult to deviate from (Hodder 2012: 17-18, 100; Iannone 2015a: 7-8).

In other words, humans rely on “things” to survive, creating dependence from previously debilitating problems in the face of challenges of their environment. However, as humans and things become entangled over time, they become “entrapped” in prescribed pathways, creating dependency on those same strategies (Hodder 2011a: 178). This “Path dependency” is a problem because it ultimately limits the ability of a person, group, community, or society to solve new, unexpected problems (Iannone 2014a: 7; van der Leeuw 2007: 215). If an entrenched cultural practice cannot be abandoned, since the human investment—either in time, energy, or labour—is too great (the so-called “sunk-cost fallacy” [Janssen and Scheffer 2004]), this constrains the ability of the human group in question to respond to new challenges with innovative ideas.
Entanglement theory is thus a lens for looking at the material outcome of human-landscape interactions and adaptations, by identifying the problem-solving methods which initially enabled a human population or society to combat environmental challenges, but which had constraining effects on their ability to manage unexpected risks and hazards over time, which correspondingly, culminate in a loss of decision-making flexibility, and therefore, resilience (Iannone 2015a: 8).

**Applicability**

In historical ecology, the anthropogenic landscape is a constructed environment, modified through human agency, with those building actions filtered through specific, culturally contingent human worldviews (Balée and Erickson 2006: 3). By viewing the process of urbanization through the lens of entanglement theory, it can be said there is a “mutually constituting” relationship between the urban landscape of Angkor (the thing) and the actions and interactions of individuals, groups, and institutions (humans), as informed by their own motivations and identities (Fisher and Creekmore 2014: 1; Rapoport 1990: 29, 1989). The city form is socially constructed by, firstly, the top-down actions of socio-political authorities, often manifested in varying degrees of urban planning, achieved through the exercise of hierarchical power structures (Fisher and Creekmore 2014: 1; Rapoport 1988; M.E. Smith 2007: 30-31; Wolf 1990, 1999). Top-down planning can be seen in the ruler-directed and state-maintained water management infrastructure and royal temples that were constructed to act as fail-safes in times of water and food insecurity at Angkor (Fletcher et al. 2008: 668).

Secondly, there are the mid-level actions of socio-economic groups, neighbourhoods, and districts (Fisher and Creekmore 2014: 1; Rapoport 1988; M.E. Smith 2007: 31). This mid-level
planning can be seen in the formation of production enclaves, as well as the actions of non-state temples, which exercised a good degree of independence as these secondary settlements moved away from the core area of Angkor’s regal-ritual, ceremonial complex (E. Lustig 2009: 51)

Finally, there are the “grassroots actions” as seen in the daily actions of households and individuals (Fisher and Creekmore 2014: 1; Rapoport 1988; M.E. Smith 2007: 31). The hygiene, sanitation, and other household planning of the agrarian personnel that made up eighty percent of Angkor’s population (see Haberl 2011, table 1; Iannone 2015b: 258) would have been informed by the cultural memory of labour-tasking techniques used by their prehistoric and proto-historic precursors (Lucero, Gunn, and Scarborough 2011: 484-5; Lucero et al. 2015:1141-2). For this reason, it can be said that the settlement practice of dispersed, low-density agrarian urbanism was constructed at differing levels by all members of Classical Khmer society.

**Summary**

One definition of health is the ability to “perform the activities of daily life” (Gage and Dewitte 2009: 654). Connected to this definition is the implication that communities must be able to adapt to changing circumstances in order to maintain their quality of life, and that the absence of disease does not convey the whole picture when it comes to human well-being (Barnes 2005: 25; Clark et al. 2014: 485). With these considerations, Resilience theory and Entanglement theory are the heuristic devices I am using to frame my analysis of the quality of life conveyed by Angkor’s urban settlement plan. Nevertheless, I also had to narrow down which cultural decision-making practices would be most appropriate to analyze with these tools.
METHODS

Adaption, Complex Adaptive Systems, and Assessing Health in the Past

Biocultural studies are defined as research on questions of human biology and medical ecology that includes social, cultural, or behavioural variables in the research design, and incorporates social and political factors into the study of health, including disease patterns, quality of life, disability, population health, and healthcare systems (McElroy 1990: 244, 246). In the case of infectious disease, for example, socio-cultural responses—or “adaptions” —allow populations to respond faster and with “flexibility” to environmental stressors, unlike the slower process—in terms of tens, hundreds, or even millions of years—of physiological evolution of the human body (McElroy 1990: 248). For example, acquired immunity after infection would be a physiological adaption to an infectious disease (Barnes 2005: 24).

The adaption paradigm continues to serve as an important heuristic and conceptual tool for organizing data on human responses—especially socially-constructed ones—to environmental stressors, such as disease, disability, the feelings of loss, and major life events (McElroy 1990: 245). Furthermore, it can analyze how these adaptions developed within the environmentally and historically contingent trajectories of past societal development (Drennan and Peterson 2012: 71; McElroy 1990:246).

In some writings by biologists, physiological, morphological and cultural characteristics that enhance survival in given habitats are referred to as adaptive strategies. Over time, humans have learned what the limits of their physiological responses are. In response, clothing, fire, shelter, cooperative hunting, horticulture, agriculture, and animal husbandry were innovations that augmented physical limitations (McElroy 1990: 249-50). In function, the concept of the “adaptive strategy” does not necessarily imply that the human behaviour and customs are a result
of conscious planning or trial and error to reduce exposure to disease or increase well-being.

Dietary and traditional medical systems often involve functional and dysfunctional relationships to health (McElroy 1990: 250). Thus, by reconstructing the relationships between social and environmental variables—or in this thesis’ theoretical application, socio-ecological “entanglements”—we can assess the capacity of human adaptive strategies to health stressors, like infectious disease (McElroy 1990: 25).

As discussed in the literature review (Chapter 2), the process of urbanization, in general, could perhaps be considered a maladaptive strategy to overall human population health in the past before the modern Epidemiological transition (see Cohen 1989; Goodman and Armelagos 1989). In the conventional model of pre-industrial urban health, it is argued that the centralizing process of urbanization benefits only a small minority of elite leaders (McNeil 2010: 65), since it allows them to command the labour pools (humans and their physical work) that are the backbone of “organic” economies (Brooke 2014:261; Sjoberg 1960). By concentrating economic resources and labourers in one place to meet the economic and political needs of the social elite, the common people are exposed to the various risks of crowd-dependent diseases (Cohen 1989: R. Storey 2006: 279-280), with the state negatively acting as a “macro-parasite” upon them (McNeil 2010: 65). For an example of how to assess the mutually constituting relationship between urban planning, a state, and human health, we can turn to the well-studied areas of temperate Europe (see Finley 1980 and McKeown 1990 for foundational texts), and in the next section, a review of commonly discussed Imperial Rome.

Creating Assessments of Population Health and Quality of Life: Examples from Temperate Rome

Ancient and Medieval agrarian societies were often thought to be bound in a “rigidity trap” based on the limitations of human and animal power as the backbone to the archaic state
(e.g., their physical work; Brooke 2014: 261). In these “organic economies” (Brooke 2014: 261; Sjoberg 1960), economic growth was limited to territorial expansion, or through the intensification of commerce, labour, and organic technologies. In comparison, modern economies are driven by accelerating cycles of advanced technological innovation in a fossil-fueled, mineral-based economy (Brooke 2014: 261-262; Sjoberg 1960). One major limitation of life in an organic economy, where often only the new economic opportunities could be found in cities, is that newcomers would become exposed to crowd-based diseases, as well as introducing their own to the urban disease pool of their destination (McNeil 1977: 78; R. Storey 2006: 267; R. Storey 1992: 35).

In the case of pre-industrial Europe, people were attracted to the city in hopes of economic opportunity, often only to have themselves and their children become the casualties of poverty in the urban environment (R. Storey 2006: 283; R. Storey 1992: 36; de Vries 1984). In this argument, pre-industrial European cities lost populations internally because deaths outweighed births, and thus, these cities were dependent on migration from rural areas, where mortality was low, for maintaining population numbers and allowing the urban population to grow. This pattern is known as the “Law of Natural Urban Decrease” (de Vries 1984: 179-198; McNeil 2010: 76-77; R. Storey 1992: 36). Cities acted as “demographic sinks” (Wrigley 1967) in this model, and they were thus highly dependent on their urban hinterland for both resources and people as the birth rate within the city could not keep up with the deaths (Wrigley 1967: 96-7).

In Sharlin’s hypothesis (1978), excess urban mortality was due to the mortality of immigrants, who would be in more precarious living conditions and thus less likely to marry. Residents who lived in the city for multiple generations had long-term access to support systems, such as local social connections, better housing due to more established economic circumstances,
and higher-income occupations, and thus, had a more stable quality of life. More established residents were also more likely to acquire immunity and resistance against infectious disease when compared to newcomers, due to their longer occupation in the city and therefore, longer exposure to the city’s own “urban pool of disease” (Lo Cascio 2006: 53; Sharlin 1978: 21; R. Storey 1992: 42).

Ancient Rome, based on size and social connections, is also argued to have acted as a similar demographic sink (Russell 1985: 25). Nevertheless, Roman scholars have been divided on the health conditions of imperial Rome. Scobie (1986) believes that Rome was a “nightmarish landscape” of contagion and death and a “huge death-trap.” Generally, the city of Rome was portrayed as a “dystopia” in the traditional literature because of “overcrowding, general promiscuity, and scarce hygiene of the population” (Lo Cascio 2006: 52; see Scheidel 1994; Sallaress 2002). Evidence for this interpretation includes epigraphical evidence from Christian graves (Russell: 1958: 25-29; Paine and G. Storey 2006: 69; R. Storey 1992: 40-41), which present the mortality patterns in Rome as “catastrophic,” especially due to endemic malaria (Lo Cascio 2006: 52; O’ Sullivan 2008:46).

Lo Cascio (2006) questions this view, however. It has been argued that certain material features of Rome would have had as an imperial city—generous water supply and the careful grain dole by the imperial distribution authority known as Annona—could have possibly offset the effects the “Law of Urban Decrease” as people were drawn into the city for its social and economic opportunities (Lo Cascio 2006: 53). What created the quality of life in Rome were the types of services provided to the inhabitants, independent from status and economic conditions, especially after the urban and administrative re-organization of the city during the Augustan age (Lo Cascio 2006: 53).
An effective drainage system had been developed early on in Rome. The sewers were not intended to collect and dispose of human waste but to prevent the “unhealthy stagnation” of water (Lo Cascio 2006: 61; Soren 2003). The maintenance of the sewers in the imperial age also controlled the seasonal flooding of the Tiber, or at least, made its effects “less destructive” (Lo Cascio 2006: 61). Sets of aqueducts provided water, and although they were largely reserved for the emperor and other elite families, there were also public fountains that provided water for the urban non-elite population. In Lo Cascio’s argument (2006: 61), the average quantity of the water available to the individual inhabitant of Rome was “unparalleled” in other pre-industrial cities and compares well with nineteenth-century standards. *Lacus* (reservoirs) and *salientes* (fountains) allowed one thousand litres per person a day, double the amount available today (Lo Cascio 2006: 61). Nutritional conditions for Roman inhabitants were also presumably better than other pre-industrial cities (Garnsey 1998: 226-252). The diet of the poor of Rome included the corn (grain) dole—which provided the basic caloric intake needed to feed the urban population—alongside the *frumentatione*, the fixed price of wheat for adult male citizens that provided additional food security (Lo Cascio 2006: 61-62).

Nevertheless, as evidenced in the example of industrial London (McKeown 1990), the availability of water, a sanitation system, or the presence of a grain dole do not in themselves indicate that water contamination and the circulation of diseases were not present and harmful to urban dwellers (McKeown 1990; R. Storey 2006: 283; R. Storey 1992: 42). Furthermore, there was still potential for disaster if those services were not maintained or broke down, especially since the population was reliant on those services to maintain a good quality of life. From this example, it can be argued that city planning practices can operate at different social levels (see
Rapoport 1989, 1990) over time and space, and correspondingly, an assessment of inhabitants’ health and subsequent quality of life involves comparisons across groups within the city.

Summary

The classic archaeological approach to understand the social dynamics of change either involves the comparisons of societies across different regions (usually at their “peak”; Isendahl and M.E. Smith 2013: 132; Drennan and Peterson 2012: 80)—this is the approach taken by the majority of the SETS research projects (Iannone 2015a: 6); or, they compare societies at different points of time in the same region (Drennan and Peterson 2012: 80). It is the sequential connectedness of the second approach that answers how and why an adaptive strategy came to be in a particular time and place (Drennan and Petersen 2012: 81). It is also the second, sequential approach that this thesis takes to understand how and why low-density, dispersed agrarian urbanism was utilized by the inhabitants of Angkor, as they faced the challenges of tropical diseases over time and space.

Unlike some of the more well-known cities of pre-industrial cities of temperate Europe, there is a less-than-strict divide between urban and rural boundaries for the Southeast Asian pre-industrial city, with inhabitants of the city expected to move and work seasonally for temples (Hall 2011: 184; E. Lustig 2009: 76). It has become increasingly apparent that settlements in pre-industrial Southeast Asia cannot be solely identified through the traditional means of enclosure walls and moats (Kealhofer and Grave 2008: 201; Stark 2006a: 21.3-21.4). Identifying them as “dispersed, low-density agrarian urban centres” is a relatively new development, as the full extent of these cities in size and political reach have only begun to be realized (Fletcher 2009: 1-2, 2012: 285; Isendahl and Smith 2013: 132-133; Evans et al. 2007:14282, 2013:12599). Thus, the model of health and mortality differences ascribed to newcomers to the pre-industrial city
and its long-term residents (as described in the Rome example) is likely not entirely applicable to the urban dwellers of the Classical states of Southeast Asia. The inherent mobility required for subsistence patterns and labour organization means that the aforementioned model is not a good fit for Southeast Asia during its pre-industrial, Classical period.

Since anthropologists and archaeologists are normally conditioned by the conventional approaches imposed by the traditions of their area study (Drennan and Person 2012: 71; McElroy 1990: 253), new comparative approaches can play an important role, since their research paradigms involve identifying patterns of “data threads” or socio-cultural variables, which can be collected and analyzed in compatible ways. (Drennan and Petersen 2012: 71). SETS, for example, focuses on the material components of the dispersed, low-density city plan—water management, agricultural intensification, settlement patterns, epicenters, and integrative features/infrastructure (Iannone 2015a: 6)—to understand the resilience of the different complex states of the Charter era in South and Southeast Asia (c. 9th to 15th centuries CE). Similarly, (bio-) archaeologists reconstructing bio-cultural models of past population health and well-being within and between different urban demographics often utilize settlement patterns, social structure, and subsistence as their key variables to (McElroy 1990: 253).

With these complementing data “threads” in mind, my assessment will consider several variables (see Figure 3.3). I focus on the development of settlement patterns, water management, agricultural intensification, labour organization, and community projects/integrative mechanisms at the core site of Angkor since these are the major material correlates (Iannone 2015a: 6) of the overarching society’s adaptive strategy to the challenges of the environment. Direct bioarchaeological evidence is not available to illustrate the effect of tropical diseases on the inhabitants of Angkor, but their urban planning strategies can indirectly reveal their ability to
contend with established disease risks and hazards. Thus, the well-being of Angkor’s inhabitants—as a community—in the face of tropical disease risks will be indirectly qualified through the settlement components’ relationships to the material markers of community quality of life (M.E Smith 2015: 7-9). These material markers of community quality of life include:

- Population growth and dynamics
- Ability to participate in community projects
- Length and longevity of settlement
- Ability to withstand external shocks

The relationships between Angkor’s urban settlement components and their corresponding relationship to the physical markers of community quality of life are discussed in depth below.

![Figure 3.3 Assessing Community Quality of Life (Adaptive Cycle)](image)
VARIABLES FOR ANALYSIS: SOME CONSIDERATIONS

Environmental Characteristics

The first variable I will consider for my assessment is the environment. By doing so, I will be able to identify what ecological challenges Angkor’s inhabitants had to contend with. In the tropics, the variable quantity, quality, and availability of water resources throughout the landscape have, and continue to play a major role in the settlement patterns of populations (Marajh 2015; Scarborough and Burnside 2010; Scarborough and Lucero 2010). The temporal and spatial dispersal of these wetland resources, due to changes in precipitation, humidity, ambient heat, and the surrounding landscape, meant humans either had to track down water resources seasonally to survive, or they had to manipulate the surrounding landscape to collect and redistribute water to support larger and more complex socio-ecological systems (Scarborough and Lucero 2010: 188).

Both the humid inner tropics and the outer wet-dry tropics are markedly different from other ecological zones, due to their high plant and animal biodiversity. The diverse and dispersed resources provided by tropical settings demand varying and flexible adaptive strategies (Fig. 3.4).

Although all societies are creative in attempting to concentrate ecological resources and refine their edible or otherwise useful qualities, it has been demonstrated that people in the tropics had to organize the timing of labour for the most productive

Figure 3.4. Examples of variety of aquatic, wetland species in the Greater Angkor region; Bas relief of Banteay Chhmar’s Loksevara gallery, c. 12-13th century CE (Personal photo taken May 2016).
extraction, distribution, and consumption of spread-out resources (Scarborough and Burnside: 332; Scarborough and Lucero: 188). Given the dispersed character of tropical niches, humans living there had to develop different adaptive strategies to locate, allocate, and consume seasonally ephemeral resources (Scarborough and Burnside 2010: 331-2).

Inhabitants of the seasonally wet-dry tropics frequently modified, expanded, and refined wetland environments—such as lake and river floodplains, marsh and swamps, mangrove forests and estuaries—into complex “agro-ecosystems” (McCrae 2014, 2015; Weisz et al. 2001: 123), “cultivated ecosystems,” or “artificial landscapes” (Dearing et al. 2007: 215; Iannone 2015a: 6) that utilized a variety of landscaping and water control techniques to supply water during times of scarcity. Thus, by reconstructing Angkor’s surrounding environment, I will be able to illustrate the biological disease risks and hazards Angkor’s population faced.

**Population Growth and Dynamics**

Population dynamics are defined as growth or decline in population numbers, or segments within the population, over time. They are influenced by the fertility rate, which is the number of births that add to population numbers over a pre-determined period, the mortality rate, which is the number of deaths that subtract from a population over a pre-determined period, and migration, which is the movement of people in or out of a population that does not involve births or deaths (Chamberlain 2006: 1-2; Gage and DeWitte 2009: 652).

There are notable differences in fertility rates among foraging societies, horticultural societies, and intensive agricultural societies. Tropical agro-systems usually involve farming by both men and women, though women may play a larger role in the harvesting stage (Clark et al. 2014: 481), and the men may continue to hunt to supplement their family’s diet (Boone 2002: 17-20). This agro-system flexibility allows for the retention of a broad-spectrum diet (Boone
2002: 20). The result is quite striking because while foraging and horticultural societies have quite similar fertility rates (low mortality, low fertility), agricultural societies whose economies are based on dry cereals have higher fertility and higher mortality rates. The fertility rates of societies that rely on wetland agriculture tend to resemble that of horticultural societies more closely; thus, the low fertility rates of pre-industrial tropical populations in combination with variable nature of tropical resources meant that populations were more likely to spread out over the landscape (Boone 2002: 20; Junker 2006: 208). These are some of the factors that would influence divergent path to urbanism that took place in the tropics (Iannone 2015a: 2; Isendahl and M.E. Smith 2013: 134). Regarding compatibility with the data sets examined by SETS, the growth and dynamics of Angkor’s population could be materially correlated from what we know about the labour practices and related population movements into Angkor’s epicenter.

In much of the discussion of the role of labour in pre-industrial Southeast Asia, one encounters a class of indentured people; for Angkor, they are known as “Khun,” which is often translated as “serfs” or “slaves” (Hawken 2013: 357). However, the meaning of this phenomenon for Southeast Asian economies and societies in this period has been seldom analyzed and is hotly debated (E. Lustig et al. 2007: 21). There were large variations in degrees of freedom for Classical Khmer society, ranging from mild debt bondage to chattel slavery: people whose hereditary status meant that they could be bought, sold, or sacrificed (Boomgaard 2007: 72; Hall 2011: 6; Lieberman 2003: 95-6). Nevertheless, even though agrarian personnel likely made up eighty percent of the population, Khun were likely only a small subset of that population (Haberl et al. 2011, Table 1; Iannone 2015b: 258).
Temples had bondspeople but also took on war captives and migrants who could not provide for themselves by providing food from granaries in exchange for work, as well as seed and land (Boomgaard 2007: 73; Hall 2011: 6; see Fig 3.5). Additionally, rulers occasionally seem to have resettled populations from other areas to their core lands. There are documented examples from Java in the 10th century, Burma/Myanmar in the 11th century, and Vietnam in the 11th century (Hall 2011: 13). Pre-industrial Southeast Asian warfare is thought to devastating in its own particular context: loss of life due to warfare, raids, and the deliberate spoiling of field crops is also well-documented (Boomgaard 2007: 73). One assumes that some initial force must have been used by the state to relocate these people, but it is also hypothesized that they were given advances to put them on equal standing as the local agriculturalists, such as ready-made fields near the king’s temples (Higham 2014: 298).

Altogether, the system of bonded labour suggests that it was a powerful tool in the hands of temples and leaders with an interest in creating large settlements with permanent, irrigated rice fields (Boomgaard 2007: 73; Hall 2011: 6-7; Lieberman 2003: 51). This would be consistent with the idea that early Southeast Asian states derived their power from control over people and their labour rather than from landholding rights since the former was scarcer than the later (Higham 2014: 298; Ricklefs 1967; Wolters: 1979a, 1999). Thus, it is argued here that the available information on population dynamics and movements as related to migration and Angkor’s ceremonial core is important for understanding its population’s quality of life.

Figure 3.5. Bas-relief of prisoners of war from Banteay Chhmar temple’s Loksevara Gallery, c. 12th century CE (Personal Photo taken May 2016).
Ability to Participate in Community Works

For community projects, it must be considered what institutions and economic opportunities were in place that drew populations to live in the city. Was Angkor like Rome, where there were incentives like food and water security (the grain dole or fountains) that would condition the average inhabitant’s quality of life? In the past decade, work by anthropologists and archaeologists have emphasized the novel land-use, water-use, and labour strategies used by pre-industrial populations in the seasonally wet-dry tropics to maintain food security in these so-called “challenging” or “marginal” environments (Lucero, Gunn and Scarborough 2011: 480; Scarborough and Burnside 2010: 327-8; Scarborough and Lucero 2010: 199-201). Materially, the analysis of community works fostering quality of life can complement the comparative research done by the members of the SETS team who examined the pre-existing data sets of Water Management Systems (Marajh 2014, 2015) and Agricultural Intensification (Macrae 2014, 2015).

Regarding analysis, environments defined by high humidity and temperatures will accelerate organic decay, affecting the freshness of food resources (Lucero et al. 2015: 1139-40; Lucero, Gunn and Scarborough 2011: 482). Thus, human societies in the tropics had to develop production, timing, and distributional strategies to combat these limitations (see Figure 3.6).

Figure 3.6. Bas-relief scene of Food Preparation, Bayon temple, c. 12 century CE (Personal Photo taken May 2016).
Ethnographic and archaeological case studies, such as from modern-day Indonesia, the Maya Lowlands, Cambodia, and Western Africa demonstrate a similar repertoire of “labour-tasking” strategies, defined as strategies which rely on the culmination of collective human labour to manage the challenges of the environment, and often, transform the landscape gradually over time to take advantage of the high biodiversity of the tropics as a resource. (Scarborough and Burnside 2010: 334-336; Scarborough and Lucero 2010: 188). Beyond storage practices like salting fish or leaving root vegetables in the ground, landscaping efforts might involve constructing or maintaining ponds or reservoirs of fresh water for fish and mollusks, while cultivating “agricultural corridors” to best accommodate root crops together with more perishable maize or squash (Lucero, Gunn and Scarborough 2011: 482-484; Scarborough and Burnside 2010: 336; Scarborough and Lucero 2010: 188). Larger scale wetland modifications soon came to include irrigation canals, tanks, dams, and water reservoirs (see Figure 3.7), as communities of agriculturalists combined their collective labour to transform the landscape sustainably over the long-term (O’Reilly 2014: 302-303). This collective effort ultimately resulted in sustainable subsistence regimes that could produce multiple crops above and beyond the swidden agriculture (“slash-and burn” farming) that was thought to solely characterize tropical agro-ecosystems (Boserup 1965; Gould 2014: 26).

Fig. 3.7. The large-scale West Baray during the dry season (Personal photo taken May 2016).
Studies have indicated that water quantity is just as important as water quality in affecting the transmission of tropical diseases (Miksic 1999: 174; Dearne et al. 2015: 56, 69). It has been calculated that exercise takes six times more the energy in the tropics than in temperate zones. With water loss of eight to ten liters per day, the need for greater water consumption exposes humans to a higher risk of contracting waterborne disease, and this is a major problem for populations trying to utilize wetland resources (Lucero, Gunn and Scarborough 2011: 482; Miksic 1999: 174). Thus, it is apparent both large-scale and localized water and land management, as community projects, likely played an important role in determining the quality of life of Angkor’s urban inhabitants.

**Ability to Foster Length and Longevity of Settlement**

Having a stable, long-lasting place to live is thought to also be a hallmark of a good quality of life. A stable settlement allows for the establishment of family life and the communal investment in economic opportunities—such as consistent access to basic living resources, medical care, collective maintenance of public works, and socialization opportunities—that foster a high standard of living (Lo Cascio: 61-62; M.E. Smith 2016: 2-7-9; R. Storey 2006: 269-70). It also allows families and groups to create and maintain social links for mutual co-operation and the sharing of resources (Fisher and Creekmore 2014:21).

In the case of general health and disease, one benefit of long-term settlement is the creation of the “urban disease pool” (Lieberman 2003: 50-51; Brooke 2014: 234; Junker 2006: 205). After an initial period of disease outbreaks, when a new disease is introduced to a population, long-term exposure over consequent generations eventually leads to a general immunity for long-term residents (Junker 2006: 205; Lieberman 2003: 50-51), with the disease generally affecting only children, the elderly, or the immune-compromised, rather than working
adults (McMichael, Woodward and Muir 2014: 75). But, this, of course, had its drawbacks, especially for newcomers and other migrants to the city, who lacked this long-term exposure and thus remained vulnerable to the diseases circulating throughout the city (Lieberman 2003: 50-51, 97; de Vries 1984: 179-198; McNeil 2010: 76-77; R. Storey 1992: 36). Materially, an examination of Angkor’s longevity as a settlement can also complement the research of cross-polity comparison settlements done by SETS (Coria 2014; Savage 2015; Walker 2015).

To contend with the unique ecological challenges and barriers, tropical agriculturalists used “labour-tasking” techniques, whereby relatively “higher” densities of semi-tropical farmers rely on each other, not only to maintain water and agricultural systems, but also to exchange goods not available in their immediate residence in a “small-scale economy” (Scarborough et al. 2012: 21; Lucero et al. 2015: 1140-41; see Figure 3.8.). These are different from the industrial, agricultural technologies associated with “techno-tasking” which rely on fast-paced technological breakthroughs to manage the challenges of the environment (Scarborough and Burnside 2010: 330, 331-332; Scarborough and Valdez 2003; 2009). A positive benefit of these labour-tasking techniques is that they foster close-knit communities; potentially circumventing the “worker alienation” that reliance on mineral-based technology propagates (Scarborough and Burnside 2010: 330)
This is particularly true in the case of pre-industrial Southeast Asia, where it was the control of people and their labour, rather than landholdings, which remained the backbone of the economic systems of the Charter states (Hall 2011: 13; E. Lustig 2009: 78). Since low population densities ensured that the control of large pools of labour was a limited resource for Classical-era complex societies, incentivizing people to move to certain areas drove the creation of urban settlements of Southeast Asia (Hall 2011: 13). Agricultural labourers in the tropics are increasingly recognized to have maintained a high degree of autonomy in comparison to those in temperate regions, creating independent settlements, with demonstrable cases in the pre-industrial past where people would “return to the forest” if their governing bodies did not provide enough benefits in return for their work (Lucero et al. 2015: 1148; Scarborough and Lucero 2010: 200-201). Regarding analysis, this section would be complementary to the research on settlement undertaken by other SETS members (Coria 2014; Savage 2015; Walker 2015), as it will determine whether Angkor’s settlement was stable enough for the inhabitants to maintain their quality of life over the long-term.

**Ability to Withstand External Shocks (New Disease Risks?)**

In a broader terms, I also have considered whether the adaptive strategies of low-density, dispersed agrarian urbanism were effective in withstanding new or previously unexposed shocks to such complex, adaptive systems. Since the rise of the environmental movement from the 1970s and onward (Brooke 2014: 99), the new school of environmental history has argued that the intensification of pre-modern, agricultural economies—and their development of social complexity—inevitably lead to degradation, further intensification, and eventual collapse. Constrained by the limits of human and animal biokinetic energy to generate environmental capital would eventually lead to disaster, as is encapsulated in the term “ecocide” (Diamond
Modelling their interpretation of the ancient and medieval past on the environmental critique of modern economies, a dominant school of environmental historians has consistently argued that human populations have always been the fundamental root of their demise (Brooke 2014: 99; Butzer 2012: 3638; Diamond 2005: 6-7).

Theories of civilizational decline due to environmental change or natural disaster (especially volcanic eruption) have also had enormous influence in archaeology and studies of ancient history (Ross and Steadman 2017: 368). Their popularity seems cyclic; common in the early 20th century, they are experiencing another renewal in the 21st century, in part reflecting modern-day concerns about contemporary environmental decline (Brooke 2014: 99; Ross and Steadman 2016: 368). Droughts in particular have become an increasingly dominant part of this conversation, especially as explanations for (and against) the role of extreme environmental actors in the collapse of states (Brooke 2014: 101; Iannone 2014: Gill 2000; Kintigh and Ingram 2018: 26; see Diamond [2005] for discussions on drought in the role of the “collapse” of the societies of the Anasazi of Chaco Canyon [2005:158] and the Maya [2005:173-174]).

Material evidence for the ability of Angkor’s community to withstand external shocks, integrative mechanisms—such as hospitals, rest houses, roads, bridges, and marketplaces – is a complementary data set examined by SETS research (Hills 2015) that can be used to understand Angkor’s resilience as a city. These physical infrastructure and public works provided by the state were a physical representation of the ability of the
ruler to consolidate and stabilize the realm, as he played his (or rarely, her) cosmological role of the divine or semi-divine preventer of disaster (Boomgaard 2007: 70-71; Hills 2015: 201).

Similar arguments have also been made for Angkor’s state-managed, monumental water management system as a public work (Evans 2016: 172; Fletcher et al. 2003, 2008). Marketplaces provided new economic opportunities and enhanced the ability of non-elite members to obtain goods that improved their quality of life (M.E. Smith 2015: 3; see Figure. 3.9). Roads and resthouses provided the ability to travel safely and efficiently through the state (Hendrickson 2010: 490). Finally, the presence of hospitals indicates that the health of the population was a concern of the king (Chhemm 2006:8). The state-managed water management system is also argued to have played a role in the king’s ideological basis of power by providing a water and food- security “fail-safe” in times of unpredictable climate conditions (Fletcher et al. 2008: 668-9). Conversely, the disappearance of these public works in the archaeological record may indicate something had gone wrong with the king’s ability to consolidate his rule and maintain the stability of the realm (Hill 2015: 202).

**CONCLUSIONS**

In conclusion, this chapter has discussed the theories (Resilience and Entanglement) and the methods I will use to assess the capacity of the dispersed, low-density agrarian urbanism, as an adaptive strategy practiced by Angkor’s inhabitants, to maintain a resilient and sustainable quality of life in the face of tropical diseases. The main findings made by this chapter are summarized below.

In resilience theory, the initial adaptive strategies of human societies to their environments are highly flexible and highly resilient. If the population does not select a path or trajectory that provides a degree of predictable structure, however, this can rapidly endanger it,
especially if the “entanglements” with the “things” that support that adaptive strategy become reinforced with their use over time. (Iannone 2015a: 7) Conversely, if an adaptive strategy is not flexible enough, its entrenched nature exposes that human group to external shocks (Penny et al. 2018: 1) since they are not capable of adapting to new circumstances, leading to the eventual breakdown of the system—and presumably, though it has been debated (see Butzer 2012)—a mortality crisis for the population that relies on that system.

In the case of centralized urbanization, it may “solve” some problems, it is also the source of other ones (Yoffee 2005: 16). For Angkor, the centralization of the state is comparatively weak in comparison to states in other world regions (Junker 2006: 209; also see Fox’s 1977 typology), as the state exerts less control over labour pools and land as settlements are established further and further away from the primary centre (Lieberman 2003: 213; Hall 2011: 13-15, 184; Hawken 2013: 365; Junker 2006: 209). The urban population of Angkor—as was with all other pre-industrial urban states of Southeast Asia—was not as a whole beholden to the services offered by a centralized city centre and attendant ruler to maintain their quality of life. Independent communities living in their own rice enclaves or craft workshops protected themselves against ecological risks and hazards of the tropical environment—such as food insecurity—using localized land and water management constructed under their labour-tasking power (Scarborough and Burnside 2010: 331-2; Scarborough and Lucero 2010: 201-2), so rulers had to create incentives to draw people under the sphere of their control (Lieberman 2003:23).

In contrast to other world regions, due to the ecological variety of their environment, pre-industrial southeast Asian labourers would leave for “better pastures” if their ruler or king did not maintain the stability of the realm, as was expected in their cosmological understanding of the world (Andaya and Andaya 2015: 40; Hall 2011: 13, 18-19, 21; Lieberman 2003:23). On the
other hand, there were other demographic groups, such as the *Khum*, whose livelihood was beholden to the state, and who were reliant on state infrastructure to maintain their quality of life (Evans 2016: 172).

With these considerations in mind when creating my assessment, I will determine, on the community level, whether the adaptive strategies developed by Angkor’s population to solve smaller, and more immediate problems in city planning left them vulnerable to unexpected consequences, such as increased exposure to disease—and hence, a reduction in quality of life—over the long-term. I will also be able to determine whether certain segments of that population were more resilient or vulnerable than others throughout Angkor’s Adaptive Cycle.
CHAPTER 4: SOCIAL COMPLEXITY AT ANGKOR AND ITS HEALTH IMPACTS

To collect data for the reconstruction of Angkor’s disease burden and corresponding community quality of life, I synthesized pre-existing data sets. These included archaeological excavation reports, historical syntheses, paleo-ecological reconstructions, and settlement maps based on survey and remote-sensing. Additionally, to get a phenomenological understanding of the physical impact of Angkor on its surrounding environment, I participated in on-site visitations to Angkor Archaeological Park from May 20th to June 2nd 2016, to take photographs, detailed notes, and make observations concerning contemporary and past land use (Figure 4.1).

The results of this data collection are discussed below. These on-site visitations offset some of the limitations that come with relying solely on secondary literature for comparative archaeological reconstructions (Drennan and Petersen 2012: 69-71).

THE “CLASSICAL STATE” OF ANGKOR (c. 802-1432 CE)

Spread over an estimated one thousand square kilometers, Angkor’s large-scale water management system of reservoirs and canals transformed its surrounding wetland landscape to store the annual monsoon rains for rice production, enough to supply an estimated 750,000
people at its largest extent, despite the yearly droughts that are typical for its climate zone (Evans et al. 2013: 12595). Within its low-density, spread-out settlement pattern, archaeologists have found that Angkor boasted an extensive network of around two hundred temples, a tripartite public water management system (Evans et al. 2013: 12595; Fletcher et al. 2008: 663-5; Hall 2011: 160), and a complicated agricultural landscape of both state, temple, and independently-run rice fields that covers its 1000 square kilometers (Hawken 2013: 347).

ANGKOR’S PHYSICAL ENVIRONMENT

Unlike the riverine coastal environments that housed the early states of the Malay Peninsula, the Philippines and the Indonesian Archipelago, Angkor—alongside the other early states of mainland Southeast Asia—was situated within a “lowland, wet-rice environment” (Hall 2011: 11; O’Connor 1995; Lieberman 2003: 50, 100; Figure 3.2). The main physical landmarks that delineated the borders of “Greater Angkor” are the Tonle Sap, or “Great Lake” in the south and the Kulen Hills to the north. The terrain between the Tonle Sap and the Kulen Hills is very flat, with an average slope of 0.1%, trending northeast-southeast with the elevation varying from two to sixty meters above mean sea level (AMSL). The Kulen Hills rise between 300 and 400 meters above mean sea level, with a maximum elevation of 490 meters (Kummu 2009: 1414; Penny 2006: 311) (see Figure 4.2).

Typically, the seasons in Cambodia, as well as the rest of Southeast Asia, can be divided into two phases: a wet season, where it consistently rains from Late May to October, and a dry season covering the rest of the year. The wet season produces eighty-eight percent of the annual rainfall, averaging 1180 centimeters per year over the area of the Tonle Sap floodplain to Phnom Krom, and up to 1850 centimeters in the Kulen hills (Kummu 2009: 1414; Penny 2006: 311).
The lower part of the Mekong River basin features one of the longest existing wetland ecosystems in Southeast Asia, comprised of different rivers, lakes, marshes, and swamp-forest (Penny et al. 2005: 499). The most important wetland component is the Tonle Sap. The Tonle Sap lake is the largest permanent freshwater body in Southeast Asia (see Figure 4.2). This river-fed lake is located on the northeastern edge of the Greater Angkor Region. The three feeder rivers—the Puok, Siem Reap, and Roulos—originate in the Kulen Hills and drain down to the Tonle Sap lake. The average annual runoff for the three catchments is around 500 centimeters per year (Kummu 2009: 1415; Penny 2006: 310-11, 319; Van Liere 1980: 266-67).

The annual average open water evaporation rate in the region is 1690 centimeters, being the highest between March and April and lowest between August and September. Correspondingly, the average temperature in the region is 28.2 degrees Celcius, being lowest in December (25 degrees Celcius) and highest in April (30.6 degrees Celcius) (Kummu 2003, Figure 4.2. Location of Angkor in relation to the Tonle Sap in the Cambodia Basin, modified from Kummu (2009: 1414, figure 1).
During the wet season, the Mekong River double backs on itself, which forces the Tonle Sap to grow more than five times its size, with the seasonal input of around 51,000 million cubic meters of water. The lake consequently floods around 16,000 square kilometers of the surrounding alluvial plain, which would be used for wet rice farming. Since the bottom of the lake has an elevation of around 0.7 meters above sea level, the water becomes very shallow (as little as 1 meter in depth) at the end of the dry season. Nevertheless, the lake, its floodplain, and particularly the swamp-forest at its edge, offer favourable breeding and growing conditions for fish migrating from the Mekong (Dearne et al. 2015: 63; Kummu 2009: 1415; Penny et al. 2005: 499; van Liere 1980: 267). The lake itself supports both the local and national fisheries of Cambodia, providing a significant part of the animal protein intake for the entire country: up to sixty percent (E. Lustig 2009: 60). More than one million people are directly dependent on the lake. Thus, the Tonle Sap was an essential food resource, particularly of fish, for communities during the Angkor era (Kummu 2009: 1415; E. Lustig 2009: 60; Penny et al. 2005: 499; van Liere 1980: 267). There is also the issue of perennial growth of areas of swamp-forest, however, which make parts of the alluvial plain inaccessible during certain times of the year (Penny et al. 2005: 500, Penny 2006: 311-12; Kummu 2009:1413).

Besides providing fish and other food resources, the lake was also a major part of Angkor’s transport network. Goods and people were easily moved between the regional centers and capital by the boats, particularly during the wet season (Kummu 2009: 1415). In relation to the Tonle Sap, the location of Angkor is close to ideal. It is safe from the annual inundation, but at the same time close enough to the lake to collect water during the dry season. Where the city is situated near the floodplain is relatively narrow (on average twelve to fourteen kilometers in
width) compared to the other parts of the lake where it can be four times as large. This flooding cycle made Angkor relatively accessible by boat during the dry season (Kummu 2009: 1415; van Liere 1980: 267).

Groundwater is another important resource in the Greater Angkor region. It is easily accessible, as the water-table lies between the depths of zero and five meters below ground level during the wet and dry seasons, respectively (Kummu 2009: Pottier 2012: 13). This source offers relatively reliable access to potable water during the dry season, since seasonal variation in the groundwater resources appears to match the overarching precipitation pattern (van Liere: 266-67; Penny 2006: 317). The depth of the water table varies greatly around the lake basin of the Tonle Sap, with the distribution of groundwater dependent on how deep the bedrock is alongside the characteristics of the soil (Kummu 2009: 1415). West of Siem Reap, for example, the surface of the Kralanh District’s local aquifer is more than forty meters down, while east of Siem Reap, the local groundwater aquifer of Sotr Nikum lies only about twelve meters deep (T. Lustig et al. 2008: 84). Therefore, Angkor is comparably located on a more easily accessible groundwater source in relation to other areas around the lake basin (Kummu 2009: 1415; van Liere 1980: 266-7).

In summary, the Greater Angkor region is a very heterogeneous landscape, with different micro-environments ranging from sandy lakeshore, to delta areas alongside the Mekong river, to hilly forest; these are in addition to human modifications to the environment like rice paddies for wet rice farming and irrigation ditches. This landscape provided numerous resources, such as fish, coconut, palm products, and rice, which were and continue to be the cornerstones of the Khmer diet, as well as bamboo, laterite and sandstone, which were used for building materials

**ANGKOR: THE CAPITAL CITY OF THE KHMER EMPIRE**

During the rule of its most extolled king, Jayavarman VII (1181-1231 CE), the Khmer empire controlled not only what is now modern-day Cambodia, but also parts of Laos and Thailand. Though some of its rulers strayed from it as their seat of power, the dispersed urban complex that is now designated as “Angkor” was the main capital of the Classical Khmer state from the 7th to 14th centuries CE (Evans et al. 2013: 12595; Hall 2011: 160; Higham 2004: 1-4). Regarding the geographic and temporal limits of this study, the territory that Angkor directly controlled as a capital, or primary epicenter, has been designated as “Greater Medieval Angkor” or the “Greater Angkor Region” (Evans et al. 2013: 14277). This 3000-square kilometer subordinate area was the main catchment area for the resources directed to Angkor and housed the population that would have most closely served the capital. (Evans et al. 2013: 14277; Hawken 2011, 2012, 2013, Higham 2014; Kummu 2000: 1413).

The area also has a long history of habitation, despite early European explorers, after having erroneously “discovered” Angkor’s temples, believing that the remains the city were some non-indigenous development, either Indo-Chinese or even Roman in origin (Hall 2011:1; Higham 2003: 1). As discussed in the Background (Chapter 2), two previous proto-states were present in Cambodia, Funan (c. 200-600 CE) and Chenla (c. 600-800 CE), having set down the indigenous developments for agricultural practices and sedentary life that would be the blueprints for the later Angkor state and empire (Coe 2003: 57; Lieberman 2003: 218). Early Khmer settlements have been found at the sites of Koh Ta Meas (Bronze Age), Prei Khmeng, and Baksei Chamkrong (Iron Age), the early temples of Ak Yum (which, dating to the eighth
century, are found underneath the Western Baray reservoir), as well as Phum Snay and Sophy (Higham 2014: 35; Newton 2013: 5-6). Earlier Khmer settlements in the region, from around the 5th to 6th centuries CE, were situated alongside the Mekong River and Mu-Chi River, to take advantage of flood-derived waters for wet rice farming (Lieberman and Buckley 2012: 1067). The settlement alongside the Tonle Sap lake in the seventh century was made possible by better climatic conditions (Buckley 2010: 6748; Lieberman and Buckley 2012: 1067). Previous settlement attempts around the lakeshore were less than ideal before the Medieval Climate Anomaly (800/850-1300 CE), but the impact of regular monsoons would have made the area less dry and arid (Lieberman and Buckley 2012: 1059, 1067).

Traditionally, the dates for Angkor’s founding and end are 802 CE to 1432 CE, though scholars are now extending the end date to the sixteenth century (Stark et al. 2015: 1440). Within that time, Angkor was the heart of the Khmer state and was the capital city of an empire (Evans et al. 2013: 12594; Fletcher 2009, 2012: 301-2). The Khmer empire was founded by Jayavarman II in 802 CE when he ascended the throne; from this point on the region was called Kambuja, and from this, we get the modern name of Cambodia (Ross and Steadman 2017: 251). Jayavarman II consolidated various small kingdoms into a singular Khmer polity. Jayavarman II established his capital at the site of Indrapura (according to a stele in Southern Thailand) perhaps located in Southern Cambodia near the modern city of Phnom Penh, from which he launched several military campaigns (Stark 2004: 104). He ended up moving his capital several times, probably to ensure that it stayed in a productive and defensible location, eventually settling at the site of Hariharalaya, which is in the area that today houses the temples of the Roulos Group (see Fig. 4.3; Ross and Steadman 2017: 251).
The marshalling of people and resources to construct this massive and powerful empire was aided by several strategies developed by Jayavarman II, and these persisted into later centuries (Vickery 1998: 393). He acquired neighbouring polities militarily, but also ideologically, through the establishment of the installation ceremony, whereby he was enaugurated as the king-of-kings at the mountain site of Phnom Kulen, which symbolized the mountain home of the god Indra. He also was declared the “god-king” or the Deva-raja, literally stated as the kamataten jaat ta raja in Sanskrit, or the “Lord of the World who is King” (Snellgrove 2004: 48-51). This second ceremony was carried out by the king’s purohita, or chief priest. This ceremony linked Jayavarman II with the Shiva-linga in the temple, and with the god himself. The devaraja and the associated Shiva-linga were the imperial symbols of the Khmer, ensuring that the gods would keep the king and the realm safe from disasters, and therefore be prosperous (Boomgaard 2007: 60). From this point forward, the devaraja ceremony constituted the Khmer state religion, with the divine king as its chief representative (Ross and Steadman 2017: 251). As described in Table 1, the accomplishments attributed to Angkor’s various kings are numerous, and run the gamut of urban planning, water management, the conquest of other regions, and the running of and delegation of bureaucracy, all of which were carried out to ensure towards the stability of the realm and to maintain the favour of the gods (Boomgard 2007: 60). We know of these accomplishments from temple inscriptions, which were translated by epigraphical scholars like George Coedes (1935-66; 1941, 1968; Coedes and Dupont 1943-46) and Michael Vickery (1985, 1998).

<table>
<thead>
<tr>
<th>KING NAME</th>
<th>ORIGIN AND ASCENSION</th>
<th>REIGN</th>
<th>CAPITAL NAME AND LOCATION</th>
<th>MILITARY CAMPAIGNS/TERRITORIAL ACQUISITION</th>
<th>END OF REIGN</th>
<th>INSCRIPTION</th>
</tr>
</thead>
</table>

TABLE 1: IMPORTANT CHRONOLOGICAL DATES AND STAGES OF ANGKOR’S DEVELOPMENT (C. 802 CE-1432 CE)
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Jayavarman II</td>
<td>Not a direct descendant of Jayavarman I (Ruler of Ishanapura). Possibly from Java.</td>
<td>(802-835 CE)</td>
<td>First Capital: Harihalaya</td>
<td>Moved his capital several times, while endowing his followers with rice land – along the Tonle Sap from Harihalaya to Amarendh, up to the Kulen hills, then back to Hariharalaya again.</td>
</tr>
<tr>
<td>2. King Indravarman I</td>
<td>Step-cousin of Jayavarman II, once removed. Potentially a usurper, or at least had won the throne by force from Jayavarman III (835-77 CE).</td>
<td>(877-889 CE)</td>
<td>Capital at Harihalaya, which is southeast of Angkor (Yasodharapura).</td>
<td>Possibly won the throne.</td>
</tr>
<tr>
<td>3. Yasovarman I</td>
<td>Indravarman’s son and successor.</td>
<td>(889-910 CE)</td>
<td>Yasodharapura, in Angkor proper (centered at Phnom Bakheng).</td>
<td></td>
</tr>
<tr>
<td>4. Jayavarman IV</td>
<td>Grandson of Indravarman I through the female line, (Yasovarman and his sons were through the male line. Jayavarman IV’s an example of a legitimate claim to inheritance of a daughter’s son despite the presence of cousins—Inshanavarman II and Harshahavarman).</td>
<td>(928-941 CE)</td>
<td>Lingapura., located 120 km away from Angkor Archaeological park at the modern site of Koh Ker.</td>
<td>Took over Battambang (Dan Raek Mountain Range) to Mekong (Lopburi).</td>
</tr>
<tr>
<td>5. Rajendravarman II</td>
<td>Cousin and uncle of his predecessor, traced ancestry to earlier than Jayavarman II (Jayavarman I?) through his mother who he claimed was a goddess.</td>
<td>(948-968 CE)</td>
<td>Yasodharapura</td>
<td>Pre Rup—became the administrative centre temple in the capital, king’s presence/rule is noted at inscriptions at Battambang (west), Lingapura Angkor, and down the lowlands flanking the Mekong river as far as the lower delta. One Pre Rup inscription notes an important administrator, Mahendradhipatavarma (daughter was a royal consort) who was responsible for building reservoirs, canals, and rice field boundaries at Ba Phnom in the far south. Demonstrates the relationship between the capital and the frontiers of the state.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6. Jayavarman V</td>
<td>Regents were two courtiers, Yajnyavaraha and Vishnukumara (sons of Harshavarman I), who was responsible for building the temples complex known as Banteay Srei and were known for healing/caring for the sick and poor.</td>
<td>(968-1001 CE)</td>
<td>Yasodharapura</td>
<td>Inscriptions reflect a state centered on the northwest shore of the Tonle Sap, but which controlled Battambang to the West, and the Mekong Valley from the Dang Raek Range to the Mekong Delta.</td>
</tr>
<tr>
<td>7. Suryavarman I</td>
<td>Competed against two claimants to the throne Udayadityavarman I (most likely the legitimate heir due to the relationship through the sister’s son line) and Jayaviravarman through violence, the uprooting of</td>
<td>(c. 1003-50 CE)</td>
<td>Yasodharapura</td>
<td>Before 1006, all of Suryavarman’s inscriptions were east of Angkor, but then seems to have established himself at Angkor Had nobles pledge allegiance to him in stone, had to claim they would only fight for him, never revere another or be accomplices to an enemy.</td>
</tr>
<tr>
<td>8. Suryavarman II</td>
<td>Grand-nephew of Jayavarman VI, this dynasty shows a complete break with the dynasty established by Jayavarman II. Was a Vishnuite, rather than a Saivate.</td>
<td>(1113-1150 CE)</td>
<td>Yasodharapura</td>
<td>Suryavarman II’s campaign against Jayashinvarman, who led the troops of Lopburi on a war elephant.</td>
</tr>
<tr>
<td>9. Jayavarman VII</td>
<td>Restored the dynasty of Maidharapura at Angkor A Buddhist, soldier, and most prolific builder of all the Khmer kings. Under his reign saw the Angkor we know today built.</td>
<td>(1181-1218 CE)</td>
<td>Yasodharapura/ Angkor Thom</td>
<td>Hendrickson 2007 notes that roads were along already well-known routes; Phimai supplied salt, Banteay Chhimar gold, and Preah Khan iron. The amount consumed by the hospital was great: the 102 hospitals were supplied with 11370 tonnes of rice, provided by 81640 people living in 838</td>
</tr>
</tbody>
</table>
villages in proportion, villages of about 100 people would have had to supply 13.5 tonnes of rice each taxation. This would have been double their requirements. Such figures provide insight into the way in which excess production, as well as corvee labour, was channelled towards the requirements of the state religion which at its apex, the deified king himself.

<table>
<thead>
<tr>
<th>10. Jayavarman VIII</th>
<th>Court was Angkor Built Mangalartha. Zealous Shivaite Jayavarman VIII eradicated Buddhist influences.</th>
<th>(1243-1295 CE)</th>
<th>Yasodharapura</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>11. Indravarman III</th>
<th>1296-1327 CE</th>
<th>Yasodharapura</th>
</tr>
</thead>
</table>

Entertained Chinese (Yunnan) delegation described by Zhou Daguon.

<table>
<thead>
<tr>
<th>12. Jayavarmadiparamesvara (Jayavarman IX)</th>
<th>1327-1352 CE</th>
<th>Yasodharapura</th>
</tr>
</thead>
</table>

Last Sanskrit inscription (c.1327 CE)

13. 1352–1357 Siam Ayutthaya invasion led by Uthong

14. 1393 Siam Ayutthaya invasion led by Ramesuan

15. Abandon Angkor (1431) Last ruler was Barom Reachea II (1405–1431)

Citations
What is important to realize is that what has been attributed to the kings and ruling elite of Angkor may have been the independent product of autonomous farmers and other agriculturalists, who must have played a role in the social construction of the city beyond its ideological and bureaucratic establishments (Hendrickson 2010: 481-83). Furthermore, it should also be emphasized that temple administration also played an important role and was not necessarily reliant on the king to sponsor their public works (E. Lustig 2009: 73; Mabbet 1978: 30-32). Thus, to get a more inclusive picture of Angkor’s city-building process, we must turn to its urban archaeology.

THE URBAN ARCHAEOLOGY OF ANGKOR

Though Angkor is the name used for the current archeological site, its dispersed nature makes it difficult to delineate and describe fully. The term “Angkor” is used to describe the polity of the Khmer rulers, the main core of temples associated with this kingdom’s rulers, as well as the archaeological site found at the Angkor Archaeological Park. A series of different royal court complexes were at the heart of the Angkorian polity—Harihalaya, Yasodharapura, Lingapura and Angkor Thom within Yasodharapura—all of which make up a palimpsest of nodes within the greater Angkor region that is difficult to entangle (Coe 2003: 11-12; Lieberman 2003: 218). It is the main core area of temples within Yasodharapura that have garnered the most attention, however (Evans et al. 2007: 12595).

Angkor means “city” or “Holy City,” in the Khmer language and script (Coe 2003: 12; Hall 2011: 1-2). Angkor itself is not the traditional name of the city, however, but the common Western nomenclature used to refer both to the archaeological site and the historical civilization.
it represents. Its actual name is Yasodharapura (Coe 2003: 11). Angkor, as a city and archaeological site, has been characterized in numerous ways since its “discovery” by European explorers (Coe 2003: 12; Hall 2011: 1-2). The archaeology of Angkor has also had numerous shifts in focus over the past one hundred or so years of study. Early scholarship in Southeast Asia equated the progress of a civilization with the number of temples it left behind, to compare, contrast and even connect these civilizations with the Classic civilizations of the west (Hall 2011: 4-5). The temples of Angkor, such as Angkor Wat, Banteay Srei, the Bayon, the Baphuon, and Ta Phrom existed as a spiritual core for the city, and they were what French archaeologists working in Cambodia, like George Coedes, used to lay down the foundation of Khmer archaeology. This temple-based focus (as informed by a culture-history framework) was the mainstay of Cambodian archaeology between the early 1900s to 1950s and resulted in a thorough knowledge of Khmer artwork, temple architecture, temple inscriptions, and the creation of a chronology based on Angkor’s ruling dynastic rulers (Coe 2003: 137).

The 1950s and 1960s saw a shift away from this temple-based archaeology as new excursions to understand the function of Angkor’s public water management system became a priority. Landscape surveys in the 1960s, led by Bernard-Phillipe Groslier, moved away from the downtown core of temples, towards the south, to map the extent of the water management system. It was Groslier (1979) who first identified Angkor as a “hydraulic city.” He argued that its water management system of canals, channels, huge reservoirs, and spillways were engineered by the state to produce large quantities of rice (Fletcher et al. 2003; Fletcher et al. 2008: 661-2).

Nevertheless, starting in the 1970s and 1980s, new interpretations of Angkor’s water management shifted from its utilitarian use to an interpretation based on its symbolic and
idealogue role, since scholars like van Liere (1980), Acker (1998), and E. Moore (1989) doubted that the water management system had the technological sophistication and capacity to feed a city population estimated to be around a million in number (Acker 1998: 17; van Liere: 274, 279). The English school at Angkor argued that the water management system had ritual significance as a symbol of the king’s orderly rule on earth, echoing the mythology surrounding Mount Meru (E. Moore 1989: 209). Furthermore, they argued that the “hydraulic city” interpretation had implications of Orientalism, as similarly seen in Wittfogel’s (1957) work on the relationship between hydraulic states and “oriental despotism,” which cast negative aspirations on non-European, non-Western states (Fletcher et al. 2008:660). Nevertheless, with the early mapping and survey efforts by Christophe Pottier (1999, 2001) in the 1990s and 2000s, it was proven that the water management system did play an integral role in the statecraft of Angkor, and that the population did have the technical skill to construct a utilitarian water-management system (Fletcher et al. 2003; Fletcher et al. 2008: 660, 662-3). Now it is generally agreed that the public water management system functioned in both an economic and spiritual capacity (Fletcher et al. 2008: 668-9). The new interpretations of Angkor’s water management system also coincided with new surveying and mapping at Angkor during the late 1990s and early 2000s by the Greater Angkor Project (GAP).

The results of GAP’s satellite-based and LIDAR investigations painted a very different picture of Angkor than that of the temple-based and hydraulic-city perspectives (Evans et al. 2007: 14278-9; Evans et al. 2013; Evans 2016; Penny et al. 2018). Before these surveys, there were two prevailing interpretations about Angkor’s urban landscape and morphology. Angkor was either a ceremonial centre surrounded by a residential hinterland (Gaucher 2004: 58; Lombard 1970: 850, as discussed in Pottier 2012: 12), or a low-density urban landscape with a
densely populated centre (Higham 1989, as discussed in Evans et al. 2013: 12596 and Pottier 2012: 12). Like other early states in Southeast Asia, Angkor’s archaeological record showed evidence of monument building and statecraft, but less than discernable evidence of the conventionally accepted urban settlement forms (e.g., the idea of a dense and compact settlement; see Evans et al. 2013: 12595; Miksic 1999; 2000; Pottier 2012: 15-16).

The recent surveys integrate previous cartographical work from other scholars, such as by B.P. Groslier’s survey mid-twentieth century (1979) and Pottier’s maps from the 1980s and 1990s (Pottier 1999). Over fifteen-hundred additional square kilometers of new archaeological sites were found through several survey methods; these include a preliminary air-borne AIR-SAR survey done in 2001 (Evans 2001), a water-shed catchment analysis done in 2003 (Kummu 2003) and a high-resolution topographic survey map created by airborne LIDAR imaging (Evans et al. 2007; see Fig 4.3). The new archaeological map features a more comprehensive picture of the hydraulic infrastructure (such as ponds and canals) spanning multiple temple complexes, mounds, agricultural fields, and residential areas (see. Figure 4.3). Angkor could thus be described as an “organically-shaped” and “poly-nucleated” urban complex over one thousand square kilometers in size (Evans et al. 2007: 14278). From these results, Angkor is argued to be the largest low-density urban settlement of the pre-industrial world, massively dwarfing the next in size, the Maya city of Tikal (Evans et al. 2007: 14278-9; Fletcher 2009: 2, 2012: 301-2).
The interpretations of these new survey results were also informed by concurrent identification of dispersed settlement patterns in the other pre-industrial cities found in Southeast Asia and Mesoamerica (Fletcher 2009: 1, 2012: 285-286). Comparisons with the lowland Maya had already taken place in the 1950s and 1960s by Michael D. Coe (1960). Additional identifications of this type of settlement pattern at the Sri Lankan city of Anuradhapura and Bagan in Myanmar in the 1990s, however, had moved the conversation away from seeing these urban sites as merely as an extension of walled city enclosures—which matched the preconception of past pre-industrial cities as compact and dense—to seeing these low-density settlement patterns as a unique form of urbanization specific to tropical areas like Southeast Asia (Fletcher 2009: 3-4, 11; Fletcher 2012: 301, 314; Smith 2010; Evans et al. 2013: 12595).
**Length and Longevity of Settlement**

The development of Angkor as a city over time and space roughly occurred in the following sequence (Evans et al. 2013: 12597-8; Stark et al. 2015: 1443-44; Pottier 2012: 18-19):

- Between the 8th and 10th centuries CE, Angkor’s main urban settlement plan was comprised of a network of “Temple-cities” with residential features spreading out from temple complexes in an “unstructured manner” along with the irregular distribution of house-mounds and residential ponds of different sizes (Evans et al. 2007: 12597).

- Between the 9th and 11th centuries CE, the settlement plan saw the increasing ordering and regimentation of space, with linear features like roads and canals being introduced to divide areas, and regularly distributed house-mounds, ponds, and other water management features placed in a broader grid-pattern (Evans et al. 2007: 12597).

- Finally, between the 11th and 12th centuries CE, walls were introduced to divide the civic-ceremonial core from the rest of the urban complex, with large concentrations of non-agricultural specialists living in closely spaced residential zones near the temples (Evans 2016: 172). During this period, the largest temple complexes, Angkor Wat and the Bayon, were built. The residential areas surrounding them were gridlocked, and too near to one another to allow room for rice farming. The massive Angkor Thom regal-ritual complex intensified this centralization by walling up the inner city from the rest of the ceremonial core. It is likely that a class of non-agriculturalist administrative personnel were well-established at this time, signalling that efficiency could be increased if people who managed agriculturalist affairs were amalgamated in one place (Evans 2016: 172). Thus, while there was never a strict urban-rural divide that characterizes the city-form of Angkor (as the cardinal rice grids still extended from within the walls to outside it), the
last stage of Angkor’s urban settlement plan saw parts of the ceremonial core resemble
the more compact, bounded cities that are associated with pre-industrial cities in non-

In summary, because of the initial satellite and subsequent LIDAR surveys, the GAP team
saw a general urban transformation, from the 11th to the 12th centuries CE, as more linear
elements in the form of canals and roadways formed orthogonal grids that would define “city
blocks” (Evans 2016: 171-2; Stark et al. 2015: 1444). In the twelfth and thirteen centuries CE,
there was an overflow of orthogonal residential blocks into areas beyond the walls of Angkor
Thom, the city within the city established by King Jayavarman VII (1181-1217 CE) (Evans
2016: 172; Evans et al. 2013: 12597; Pottier 2012: 19; Stark et al. 2015: 1444). Each block had
elevated residential mounds as well as ponds that were likely used by multiple families that were
regularly spaced throughout the blocks (see Fig 4.4). The concentrated central space within the
walls of Angkor Thom can be considered the new urban core of the city. It takes up
35 square kilometers, and it is quite architecturally dense in comparison to the other
parts of the city-scape and the hinterland beyond the walls (Evans et al. 2013:
12598-99; Evans 2016:172; Pottier 2012: 20). It has also been argued that, corresponding with
this urban transformation, the 11th to 13th centuries saw the emergence of large populations of

---

**Figure 4.4** LIDAR evidence of Angkor Thom's settlement patterns, modified from Evans (2016: 173; Fig.7).
non-agrarian inhabitants who would have increasingly relied on the state-sponsored water
management systems for food security (Evans et al. 2016: 172; see Figure 4.4).

**Participation in Community Works: Water Management and Agricultural Intensification**

But how was this city supplied with water? Water management infrastructure was
developed at the household level, village/neighborhood level, and city level (Kummu 2009
1416). Many of the houses were built on the small mounds that raised the house above flooding
waters. Due to the long dry season, the collection and storage of water were very important.

![Figure 4.5 LIDAR evidence of regularly-spaced house mounds near East Baray, modified from Evans (2016: 168, fig. 3g and 3h). Blue arrows show likely direction of water-flow.](image)

At the household level, this was
accomplished by excavating small ponds
which were dug into the water table (Fig
4.5). For village and neighborhood use,
where we see larger residential areas
clustered together, bigger ponds known
as trapeang, or water tanks, were
constructed (Figure 4.6). They were also
associated with the temples (Pottier 2012: 18). Most of the trapeang had a length-width ratio of
2:1 and were generally aligned east-west (Kummu 2009: 1416). Almost every temple had its

![Figure 4.6 Lidar evidence of trapeang of Preah Khan’s “temple city”, modified from Evans (2016: 171; Fig.6d).](image)
moat which was also dug into the water table. The moats were square or rectangular and generally orientated east to west (Pottier 2012: 18-19).

At the city level (Fig 4.7), the principal water management features can be identified as *Barays* (large reservoirs) and linear channels, roads, and embankments. Angkor has four major *Barays*: the Indrataka (*Baray* of Lolei), the Yasodhаратataka (East *Baray*), the West *Baray* (which is normally just referred to as the West *Baray*) and the Jayatataka (North *Baray*) (Kummu 2009: 1415-16). *Barays* were fed directly by the channel network and rainfall. The shallow channels (1-2 meters deep, and 30 to 40 meters wide) crisscrossed the whole landscape, and doubled in purpose as ways to travel across the settlement, both atop the water by boat, as well as by foot on the surrounding embankments, which were about one to two meters high (Mekong River Commission 2005; Evans et al. 2007: 14280; Kummu et al. 2009: 1416; Pottier 2012: 19).

---

**Figure 4.7** Angkor's state-sponsored water management system, modified from Kummu 2009 (Fig 4, pg. 1417) to show suspected direction of water flow (blue arrows).
The lacustrine floodplain of the Tonle Sap was transformed by Angkor’s inhabitants through the re-direction of water from natural rivers through artificial channels to large reservoirs, creating a new cultivated landscape devoted to the use and management of the water (Kummu 2003). As conceptualized by Kummu (2009: 1416), this artificial landscape can be divided into three principal zones (Kummu 2009: 1416):

1.) collector zone
2.) aggregator and holding zone (temple zone)
3.) drainage and dispersal zone

Also according to Kummu (2009: 1417), the 1218 square kilometer collector zone includes the Kulen Hills and the upper floodplain that is found between 28 and 490 meters AMSL (above mean sea level). The zone is divided into two subzones: the upper plain (elevation between 20 and 70 meters above mean sea level) b) and the Kulen Hills (elevation above 70 meters above mean sea level). The Kulen Hills are an important source of water since it is here from which all three main rivers of the Angkor riverine floodplain originate. The precipitation in the upland areas is almost double that of the upland plain. From the 10th or 11th century CE, the water was diverted from the natural rivers to the aggregator, and holding zone by North-South aligned channels, such as the Great North Channel and the Siem Reap Channel (Kummu 2009: 1417; T. Lustig et al. 2008: 83-4).

The 465 square kilometer square aggregator and holding zones include the main temple area, excluding the Roulos group. The constituent channels and the barays were composed of earthen ramparts. Both rain and groundwater were stored in the large barays, temple moats, and smaller reservoirs (trapeang) of this collector zone (Fletcher et al. 2008: 662-3; Kummu 2009, Kummu 2003: 1416-17; T. Lustig et al. 2008: 81).
The 1202 square kilometer drainage and dispersal zone includes the area below 18 meters AMSL and is divided into two sub-zones: the Tonle Sap floodplain (10-18 AMSL) and upper drainage area (10-18m AMSL; Kummu 2009: 1417). Orientated on a Northeast-Southwest, basis, the former Siem Reap Channel, Angkor Wat Channel, and Southeast Channel are the main means of transporting water from the aggregator and holding zone towards the Tonle Sap. Due to their orientation, they flowed faster down the steeper slope, whereas those canals orientated Northwest-Southeast, being perpendicular to the slope, were relatively slow-flowing channels. Human actions during the Angkor era, such as diverting water from natural rivers to storage features through artificial channels, altered the natural hydrology of the Angkor area significantly. Building the channels across the natural slope of the terrain, however, also created problems with erosion and sedimentation, as shall be discussed later (Kummu 2009: 1417-18; T. Lustig et al. 2008: 83-84, 93). Nevertheless, by exploiting the regular monsoon rains through this state-sponsored water public work, the inhabitants of Angkor could ostensibly maintain their food security in times of trouble (Buckley et al. 2010: 6748; Lieberman and Buckley 2012: 1053).

**Population Growth and Dynamics: Temple Administration and Labour**

Temples controlled land, the labour on the land, and the land’s productive output (E. Lustig et al. 2007: 24; E. Lustig 2009: 58-9; Hall 2011: 190). But it was not until the 10th and 11th centuries that temples were created as nodes for the state’s outreach. Rich temples funded construction projects, and irrigation works for rice that were out of the central area of Angkor (Hendrickson 2010: 487). By developing peripheral temples, such as at Battambang or Lopburi (under the rule of Survyvarman I), the king could tie himself to those outreach nodes and legitimize his rule on the kingdom’s boundaries (Hendrickson et al. 2010: 485). According to
Hall (2011: 190), the development of the temple economy was directly linked to the development of the state.

Khmer temples fulfilled three economic functions in the state apparatus, according to Hall (2011: 184). First, they were like “banks” where capital in the form of donation gifts and agricultural surplus were redistributed to individuals or groups of peasant and bondsman cultivators; they also loaned out land, seed, and livestock (Hall 2011: 184). Second, temples acted as “libraries” of technological information and knowledge, supporting scholars, astrologers, and artisans who would determine the best times to plant, supplementing the local knowledge of agriculturalists with the best times and new methods to produce maximum crop yields (Hall 2011: 184). Finally, Khmer temples acted in a supervisory role, providing physical and spiritual incentives to draw populations to work on their land (Hall 2011: 184).

Lands assigned to temples for development were often unpopulated, requiring the assignment of a labor force (the men, women, and children numbered in the inscriptions) with no previous land-owning experience (Hall 2011: 184; E. Lustig et al. 2008: 25-26). These people might be war captives, or they might be moved from elsewhere into the state’s core domain (Ricklefs 1967: 411–20). For instance, at the beginning of Jayavarman VII’s reign, he is noted in inscriptions to have been lenient with his former usurpers (not the Chams, as previously thought), and thus resettled their bonds-people on new lands (E. Lustig et al. 2007: 25-26; Hall 2011: 196). It is thought that the temples co-ordinated both long-term landed peasants and newly relocated labourers, investing in new farmlands so the landless agriculturalists would not have to shoulder the burden of landscaping, as well as teaching newcomers the specific nuances of wet-rice farming in that environment niche (Coedes 1937:180–92, 1953:143–46, 7:104–19; Hall 2011: 185; E. Lustig et al. 2008: 25-26).
Across the temple inscriptions, there is a consistent ratio of 60% females: 40% males working for the temples as rice farmers (E. Lustig et al. 2007: 21; E. Lustig 2009: 53; Vickery 1998: 310). This likely reflects the continuity of gendered labour patterns (as women since in the Neolithic were the primary rice farmers) and supports the notion that labourers working for the temples were there on a “part-time basis” to donate their labour for spiritual merit (E. Lustig 2009: 76; Stark et al. 2015: 1451). Even though this also supports the idea that local communities were often incorporated into state temples—perhaps through force or coercion—in the 10th and 11th centuries CE, it appears that the organization of corvée labour did not necessarily involve despotic interruption of local agricultural, residential, and settlement practices (E. Lustig 2009: 45, 51-53; Vickery 1998: 310). In an inscription describing the reign of Jayavarman IV, temple estate workers were divided into two groups, one that worked during the two weeks of the full moon, and one that worked during the darker weeks of the month; presumably, this cycling would allow these workers to work their plots of rice when not working for the temples (Hawken 2013: 362-363). Lands assigned to family temples were in some cases divided among the temple personnel or in other instances were considered communal “fields of the cult” as the temple personnel received “sacrificial rice” (Hall 2011: 185). According to the Daun Onn inscription, the land of the Neam Rup estate was divided between the “common field of the cult” for the temple, a “field of the servants of the cult,” and a “field of the chief priest” to supply the temple’s leaders and administrative personnel (Hawken 2013: 363). Finally, there were “sustenance fields” to supply the Khum (Coedes 1937: 180–92; 5:143–46; 7:104–19, Hall 2011: 185; Hawken 2013: 363; Figure. 4.8).
Of course, there was worker dissatisfaction and exploitation, and penalties were documented in the written record. During the reign of Jayavarman VI, workers who shirked their taxes were “caged” by the village elders and sent to the king for sentencing (Higham 2014:367). In the temple inscription of Battambang (built during the reign of Suryvarman II), we find the tale of the *Khum* Viruna, who had his eyes removed and nose cut off for trying to run away during the movement of workers to the temple (Higham 2014: 367). It can thus be assumed that threats of violence were also used to keep indentured labourers in line, even if the social and spiritual capital, as well as a portion of the harvest gained by working for the temple, was supposed to circumvent worker alienation (Hall 2011: 185).

On the other hand, we also see rice agriculture that is practiced independently, not under the aegis of royal lands or a temple (Pottier 2012: 20; 2001: 112). Hawken (2011, 2012, 2013) has examined the relic rice fields that are visible from air survey in the Greater Angkor region and has noted that it is likely that some

---

**Figure 4.8.** Location of important inscriptions that describe and illustrate the processes of Angkor’s, “cultivated,” or “artificial” landscape/agro-eco-system, modified after Hawken 2013: 356, Fig.3). Arrows indicate orientation of fields.
paddy systems were independent of the state and temples and were likely organized on the local level (Hawken 2013: 347; Pottier 2012: 20; 2001: 112). Covering over 1000 km² of rice fields, and 22,000 square kilometers of rice bunds, the Greater Angkor region appears to be divided between coaxial-orientated (meaning the fields share a common axis, like a fan) and cardinal-orientated field systems (meaning the fields intersect at right angles in a grid), which has important implications for the socio-economic development of both local and state agro-ecosystems (Hawken 2013: 347; see Figure 4.8).

Cardinal/orthogonal rice fields were more likely to be found near major temples, in the spiritual core of Angkor (see Figure 4.9.), while coaxial fields are more likely to be found on the outskirts of the Angkorian heartland (Hawken 2013: 352). Cardinal rice-field grids are also strongly associated with local temples, so it is likely that this was institutional land; additionally, their common alignment along more manageable streams also indicates that temple authorities and other elites attempted to claim better land for themselves (Hawken 2013: 355; see Fig 4.8). From dated examples, there are clusters of 10th century CE temples associated with very defined grids; either as isolated sections surrounded by coaxial fields or near scrubland. Sometimes these temple fields would intersect with each other, such as with the 6500-acre cardinal matrix stretching between the Eastern Baray and the Tonle Sap (Hawken 2013: 355). Just like the state-level water management infrastructure, cardinal rice fields appear to have been constructed in stages by a centralized leadership and funded by royal endowments to the administrative personnel of temples (Hawken 2013: 355-57, 365).
Unlike the core area of Greater Angkor, there appears to be evidence that the coaxial fields were products of independent rice farming enclaves, who worked the land on a collective basis without state oversight (Fletcher 2012: 307; Hawken 2013: 351). Established before the construction of the West *Baray* (since the temple fields cut through them), these coaxial fields stretch from the periphery of Angkor’s core to along the Tonle Sap floodplain (Pottier 2012: 20; 2001: 112). This area has a relatively small number of temples, but a dense number of household ponds, suggesting independent domestic areas, rather than state residential housing. The similarity of the orientation of the fields and their interdependence also suggests a gradual, collective build-up of these fields over time (Hawken 2013: 355-57, 365; see Figure 4.10).

In summary, unlike the massive infrastructure and consistent division that characterizes
the temple core area within Greater Angkor, the development of the coaxial rice-field system (and associated homes) near the Western Baray seems to have been gradually built up over time, (Fletcher 2012: 307; Hawken 2013: 366). It therefore can be concluded that the city-building process of Angkor is very different than the modern-day process of urban sprawl (Iannone 2015b: 269). Since, rather than new settlements radiating out from an established urban core, the urban core of Angkor was built up after the major settlements in the greater Angkor region were in place to draw in people whose residential settlements were already spread out (Iannone 2015b: 254, 269).

THE END OF ANGKOR (AND ITS PUBLIC WORKS)? ABILITY TO WITHSTAND EXTERNAL SHOCKS

Angkor’s regional pre-eminence was not to last. A startling change in climate emerged in the late 14th and 15th centuries CE, coinciding with the end of the Medieval Climate Anomaly (a period of warm stable climate, with more stable predictable monsoons) and the transition into the Little Ice Age (a colder and drier period). The Little Ice Age saw heavy monsoons interspersed with a lingering series of droughts (Buckley and Lieberman 2012: 1067). This interpretation is based on tree-ring data (Buckley et al. 2010, 2014), as well as other climate proxies like deep-sea cores, Himalayan ice cores, peat bog cores, loess deposits (as summarized in Moberg 2005: 2), and cave speleothems from Dandak Cave in Thailand (Sinha et al. 2011) and Waxiang cave in China (Zhang et al. 2008). These paleoclimate proxies appear to show extreme changes in monsoon patterns that would have affected Southeast Asia, Northern China, and other parts of Eurasia (Buckley et al. 2014: 2).

The Angkor droughts not only have physical, paleoclimate proxies, but also descriptions from written sources, such as the chronicles of Hanoi and Hue from Vietnam, texts from Lanna in Thailand, and temple records from Chiang Mai in Thailand, whose monks were recalled from
Sri Lanka due to the severity of the droughts (Buckley et al. 2014: 3). The Hanoi Chronicles describe drought in Tonkin (in northern Vietnam) with unusual regularity in this period: in 1343, 1345, 1348, 1358, 1362, 1374, 1379, 1392, and 1393, with famines occurring 1392, 1393, and 1437. It is also assumed that similar famines were occurring at Angkor at the same time (Buckley et al. 2014: 11). Epidemics and hunger are described in 1407 and 1409, with harvests lost to pests in 1393 and 1434 and 1446, and with drought again in 1434 and 1446; floods were described in 1333, 1336, 1338, 1351 and 1352, 1355, 1359, 1360, 1378, 1382, 1421, and 1422 (Buckley et al. 2010: 6752; Buckley et al. 2014: 11). This information suggests that the same climate instability that hit Angkor had also affected the Red River delta in Vietnam (Buckley et al. 2014: 11; Buckley and Lieberman 2012: 1077).

Wrongthes ([2009], cited in Buckley et al. 2014: 10) argues that the Siamese movement from La Wo (now known as Lopburi) to Ayutthaya (the rivals of the Classical Khmer [see figure 2.4]) was due to an epidemic in 1350, but it is unclear what this disease was. Malaria is one suggestion for a pan-regional epidemic, being hypothesized as early as 1640 with the writings of European visitor van Vliet (1640: 57-58), and again in 1979 with B.P. Groslier’s characterization of Angkor as a citie hydraulique (1979), and thus, there was the hypothesis that the inhabitants were susceptible to the disease. During these tumultuous years, much of the residential population migrated from Angkor’s heartland and established smaller towns in a wide arc along the southern side of the Tonle Sap, up and along the Mekong River, and up to the province of Isan in the north-eastern part of Cambodia (Lunet de Lajonquiere 1911, as cited in Lucero et al. 2015: 1148). The number of village sites in the state’s heartland declined from 292 in the Angkorian fluorescence of the early Medieval period (8-10th centuries) to only eighteen by its end (Lucero et al. 2015: 1148). Khmer elites moved towards the coast, switching between
several capitals there before settling on Phnom Penh in the mid-15th century, perhaps between 1423 and 1440 CE (B.P. Groslier 2006: 118-20). This settlement abandonment was also accompanied by the abandonment of much of the urban core, and most of the temple complexes in the central and outer areas—recent excavations around Angkor Wat indicate that there was some continued habitation, however (Stark et al. 2015: 1451). The greater Angkor region was not entirely abandoned, however, as small communities continued to practice swidden agriculture until the resettlement of the Dry Zone in the nineteenth century (Lucero et al. 2015: 1148), but only eight small villages were observed during this time (Lunet de Lajonquiere 1911, as cited in Lucero et al. 2015: 1148).

**CONCLUSIONS**

In conclusion, this data chapter describes the path that the inhabitants of Angkor took to urbanism. This was done by cataloguing the cultural, ideological, and social institutions that informed Angkor’s settlement plan, as “things” developed from human traditions derived from both the proto-historic and prehistoric period. The Angkorian investment in a “tropical urban footprint”—such as dispersed residential settlements, heterarchical and hierarchical organization of land and water management, and bonded labour (Iannone 2015b: 251)—was used to combat the ecological challenges of life in the tropics. These developments shaped the Angkorian quality of life. The next step of the thesis is to analyze how successful these strategies were, as Angkor’s dispersed, low-density settlement plan changed over time and space, and as its inhabitants had to contend with the specific problem of tropical disease.
Angkor’s development as a city utilized adaptive strategies for risk management against malnutrition and seasonal drought, conditions that influence and intensify the effects of infectious disease (Acuna-Soto 2005: 405-6; Soren 2005: 193-4; McMichael, Woodward and Muir 2014: 38-9). These resulting adaptive strategies were developed over hundreds, if not thousands of years by the Neolithic, Bronze Age, Iron Age, and Proto-historic populations, Angkor’s predecessors, as described in Chapter 2. In resilience theory, this would be known as the $r$-phase, or exploitation phase, where new adaptive strategies are developed and tested against the ecological challenges (Aimers and Iannone 2014: 24-5). These adaptive strategies, in the form of the key entanglements of dispersed settlement patterns, water management, collective labour projects, and heterarchical administrative systems of the temples allowed for the effective timing and directed movement of people and their labour, allowed populations to manage the health risks associated with the hazardous monsoon (Iannone 2015b: 251). One outcome of these strategies being used involved the transformation of the monsoon-forest environment of mainland Southeast Asia into a more productive ecological niche, or “cultivated” or “artificial” landscape (Iannone 2015a: 6; Weisz et al. 2001: 123), comparable to that of the Maya (Isendahl and M.E. Smith 2013: 132).

Classical Angkor worked in the tradition of and intensified these strategies, eventually drawing a population into its heartland of up to 750,000 people to support an economy that relied on the institutionalized and regimented production of rice through the apparatus of the temple (Fletcher et al. 2008: 662). In resilience theory, this would be known as the $k$-phase, or conservation phase, where chosen adaptive strategies are locked in a dependent path (Aimers and Iannone 2014: 24-5; Redman 2005: 73-4). The success of the city and state eventually lead to a
modification of the settlement pattern within parts of Angkor’s ceremonial core, resulting in a denser urban plan resembling the pre-industrial cities of temperate areas, and with large parts of its non-agriculturalist administrative class concentrated in the inner city of Angkor Thom (Evans 2016: 172). On the other end of the socio-economic spectrum, there were also people whose livelihood was completely beholden to the temples (the Khum) (Hawken 2013: 365), whose settlement concentration around the ceremonial core also transformed the urban plan of Yasodharapura away from earlier dispersed, low-density roots.

What remains to be analyzed is if and how the population of Angkor (or more likely, segments of it) dealt with the health consequences when a series of climatic events—and likely a corresponding rise in infectious disease—tested the resilience of the infrastructure that had developed in the more predictable monsoon regime of the Medieval Climate Anomaly.

**THE GROWTH/ EXPLOITATION, OR R- PHASE**

I identified thirteen disease hazards that were most likely to be present at Angkor during the Classical period. These include the categories of endemic, water-borne, and vector-borne diseases, as well as acute, direct human-to-human diseases.

We know of the presence of some diseases in pre-industrial Southeast Asia because of the evolutionary trail they left behind in their DNA. This information is either derived from genetic studies of the disease pathogen, which allow us to place the disease’s geographic origin in this region or genetic studies of modern-day populations, which provide evidence of migrations based the geographic distribution of immunities (Barnes 2005: 82; 204, 307). For instance, dengue fever and vivax malaria are both thought to have origins in South and Southeast Asia (Barnes 2005: 82; 204, 307), possibly dating back to when populations first settled into a sedentary lifestyle in the Neolithic, around 2500 hundred years ago. Changes to parts of the skull
(porotic hyperstosis and criba orbitalia) may have indicated the presence of endemic malaria (Barnes 2006: 82). This type of skeletal pathology is found in the skeletal series at Khok Phanom Di, an early Neolithic village site (c. 2500 BCE) on the coast of southern Thailand (Tayles 1996). It is also thought that Thai and Laotian peoples, the original inhabitants of South China, were pushed into present-day Thailand and Laos by Han Chinese coming into the region from the north around 2000 years ago (Boomgaard 2007: 74; O’Connor 1995, Lieberman 2003: 50). They likely carried the schistosome, the fluke known for causing schistosomiasis, with them into mainland Southeast Asia (Barnes 2005: 111; Southgate and Rollingston 1987).

In the Neolithic, there was a major shift in nutritional health that came with the introduction of rice agriculture (and accompanying rice farmers). Nevertheless, it also appears that underlying environmental conditions, such as in a shifting estuary environment with malaria risk factors—like at Khok Phanom Di—also created a platform for contracting vector-based infectious diseases that this improvement in nutrition was not quite able to circumvent (King et al. 2017: 29).

Settlement density increased in the Late Bronze Age in the Mun River Valley, as documented in the Khorat Plateau (Welch and McNeil 1991; Higham et al. 2011). Greater settlement density and increased zoonoses from domesticated animals, among other factors, enhanced the risk of exposure to infectious pathogens, resulting in a greater prevalence of infectious disease (Clark et al. 2014: 490-1). The increase in population density and potentially greater prevalence of infectious diseases, combined with a shift in subsistence practices, contributed to the deterioration in the physical environment (e.g., fire-cleared swidden agriculture). Gendered changes in labour and diet likely caused the decline in female stature and
an increase in linear enamel hypoplasia observed in skeletal series in the Middle to Late Bronze age, as women took on the primary role in rice farming (Clark et al. 2014: 491).

Other diseases are associated with the long-term development of rice agriculture in the region were likely to have been present in the wet-rice agro-ecosystems of Angkor. Intensified wet rice agriculture from the Bronze Age to the Iron Age in mainland Southeast Asia is associated with the appearance of large encircling moats for the management of water, extensive field systems, and ploughshares and sickles (Higham 2014: 204, 209). Iron Age skeletal samples, in turn, have demonstrated evidence for a deterioration in health, including an increase in evidence for infectious disease (Domett and Tayles 2007; Halcrow et al. 2016: 168; Tayles and Buckley 2004). Likely diseases associated with this intensifying rice agriculture include schistosomiasis, melioidosis, and typhoid, since these pathogens were thought to have co-evolved alongside the establishment of farming systems in Southeast Asia, in ecological niches like rice paddies and irrigation canals (see Figure 5.1 for a visual re-creation; Barnes 2006: 111, 122, 293; Dearne et al. 2015: 47, 49).

It has also been proposed that the increase in iron smelting in the late Iron Age would have also caused dramatic changes to the environment. The high fuel requirements for iron production would have led to a significant increase in the clearance of trees (Higham 2004;
Palynological research suggests that there was a wide-ranging and large-scale burning of forests in areas of Thailand and Cambodia during the Bronze and Iron Age (Kealhofer and Penny 1998; Boomgaard 2007: 80). The partial destruction of forest areas and the intentional flooding of areas for rice cultivation produced standing ponds that may have created more suitable breeding grounds for Anopheles mosquitoes, resulting in an increase in malaria risks. Although this is not directly measurable from skeletal remains, it would have affected mortality and general health. The construction of canals and reservoirs filled with stagnant water, which, along with a rise in the number of individuals living more densely together, would have resulted in water contamination, and hence, exposure to water-borne pathogens. In combination with fire-based forest-clearance for intensified rice agriculture, these new agricultural practices would have created new platforms for the emergence and spread of disease (Halcrow et al. 2016: 168-171).

With increased settlement size in the Iron Age, there would have been a higher rate of parasite transmission, increasing the prevalence of infectious diseases. Also, with the growing density of settlement, human faecal waste would have accidentally passed into water and food, thereby enhancing the rate of transmission of gastrointestinal diseases. For example, in Northeast Thailand, the many ponds and lakes are sources of invertebrate, fish, and amphibian sources of food and these water sources are also used for washing and swimming (Petney 2001: 927). Fish obtained from domestic pools, ponds, and neighbourhood water tanks (trapeang) are a major source of contamination via the fecal-oral route, with many foods acting as intermediate hosts for human pathogens (King et al. 2017: 31; Petney 2001: 928).

At the site of Noen-U-Loke, in northern central Thailand in the catchment of Mu and Chi River valleys, we also have evidence of tuberculosis and leprosy physically present in its Bronze
Lesions are present in three skeletal samples, making these particular skeletons some of the oldest evidence of these diseases on record, not only in Southeast Asia but the world in general (Tayles and H.R. Buckley 2004; Barnes 2006: 86). The identifiable evidence of leprosy and tuberculosis at Noen-U-Loke likely indicates there is a long continuity in the region if it is present at this Iron Age site (Tayles and H.R. Buckley 2004).

Additionally, the Iron Age would have also seen an increase in population contact, and therefore exposure to foreign pathogens brought through contacts across the wider region, as evidenced by the appearance of exotic artifacts (Cambodian National Commission for UNESCO 2016: 50; Ross and Steadman 2007: 250-251; see Figure 2.5), as well as trade contacts within Southeast Asia, and between highland and lowland populations who were building a trade economy based on the foraging of “forest” products (Boomgaard 2007: 79). These first contacts would have possibly wiped out previously isolated highland populations and introduced new wild or “sylvatic” strains to the urban disease pool of lowland centres (Lieberman 2003: 50-51, 97; Lieberman and Buckley 2012: 1068).

Smallpox and cholera are also both thought to have been brought to the area through maritime trade routes, as Iron Age settlements and early state societies in Southeast Asia established intensified trade contacts with China and India around the century 5th century BCE to the 5th century CE (McNeil 1977: 124-7; Lieberman 2003: 63, 224; Reid 1990: 56-57). The Maritime Trade Immunity model (as discussed in Chapter 2) suggests that the early urbanized population centers of Eurasia, such as in India, the Levant, and north China, were the first to develop limited immunities to certain diseases, such as measles, smallpox, and enteric fevers associated with diarrheal diseases like dysentery or cholera (McNeil 2010: 126, 142, 151). The smaller, more isolated, and less densely populated centers in western and northern Europe,
Japan, and South China, and mainland Southeast Asia were not yet able to gain regular exposure or population densities that would support comparable disease resistances (Lieberman 2003: 50-51, 97; McNeil 2010: 126, 142, 151). When exposed to these pathogens during the first millennium CE, the “rimland” locations of Southeast Asia and Southern China suffered similar mortality rates to First Nations and Polynesian populations during first contact scenarios with Europeans (McNeil 2010: 124-5, 141-142), but later developed immunities that sublimated their effects to that of childhood diseases after prolonged exposure (McNeil 2010: 70-72; 142-143). This has stimulated some scholars to state that rather than material goods, it was this conveyance of immunities between long-distance centres that was the most positive development that came from Southeast Asia’s introduction to the Iron Age maritime trade network between India and China (Lieberman 200: 50-51, 63; McNeil 1977: 124-127; McNeil 2010: 126). A summary of the evidence of emergence of disease hazards in pre-Angkorian Southeast Asia is described in Table 2. What should be noted is that my conclusions are based on inferences made from the available archaeological information, and unless specified (as a direct conclusion), are not conclusions made by the main excavators themselves.

<table>
<thead>
<tr>
<th>SITE/LOCATION/MAIN EXCAVATOR</th>
<th>TIME PERIOD</th>
<th>DISEASE (BOTH DIRECT AND INDIRECT CONCLUSIONS)</th>
<th>RELEVANT ENVIRONMENTAL CONDITIONS</th>
<th>ARCHAEOLOGICAL INFORMATION THAT PROVIDES INFERENTIAL EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>An Son/ Red River Delta/ Willis and Oxenham 2011; Willis and Oxenham 2013</td>
<td>2000-1050 BCE</td>
<td>Indirect; Dengue Fever, filariae, and other helminths. Indirect: Malaria, schistosomiasis.</td>
<td>Incipient agriculture; Contact with immigrating Chinese farmers; Domesticated animals (pigs, chickens, dogs).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical Lesions, Ante-mortem tooth loss); Dental modification; Cranial pathologies (criba orbitalia, periostitis, endocranial lesions); Joint wear and trauma; Paleopathological evidence of infection; Genetic research on migrations.</td>
</tr>
<tr>
<td>Site/Region</td>
<td>Time Period</td>
<td>Indirect Pathologies</td>
<td>Direct Pathologies</td>
<td>Age and sex distribution</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>----------------------</td>
<td>--------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Khok Phanom Di/ Southern Coast of Thailand/ Tayles 1999, Tayles 1996</td>
<td>2000 BCE–1500 BCE</td>
<td>Indirect; Malaria</td>
<td>Incipient agriculture, flooded rice; Contact with migrating Chinese farmers; Domesticated animals (pigs, chickens, dogs).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Cranial pathologies (crib anterior, periostitis, endocranial lesions); Joint wear and trauma; Paleopathology (thalassemia); Diet analysis (fluke egg ingestion); Genetic research on migration.</td>
</tr>
<tr>
<td>Ban Non Wat/Khorat Plateau/ Higham, T.F.G 2004; Higham and Kijngam 2012</td>
<td>1050 BCE-450 BCE</td>
<td>Indirect; Leprosy and tuberculosis (domestication of cattle and village lifestyle); Typhoid, melioidosis, schistosomiasis, irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Dry Rice agriculture, broadcast rice, flooded rice; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Cranial pathologies (crib anterior, periostitis, endocranial lesions); Joint wear and trauma; Paleopathological evidence of infection.</td>
</tr>
<tr>
<td>Ban Chiang/ Khorat Plateau/ Pietrusewsky and Douglas 2002, 2002a</td>
<td>(early: ~2100–900 BCE), (late: ~900 BCE–200 BC)</td>
<td>Indirect; Leprosy and tuberculosis (domestication of cattle and village lifestyle); Typhoid, melioidosis, schistosomiasis (from rice agriculture development), irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Dry Rice agriculture, broadcast rice, flooded rice; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical Lesions, Ante-mortem tooth loss); Dental modification; Cranial pathologies (crib anterior, periostitis, endocranial lesions); Joint wear and trauma; Paleopathological evidence of infection.</td>
</tr>
<tr>
<td>Nong Noi/ Khorat Plateau/ Tayles et al. 1998</td>
<td>1100 BCE-700 BCE</td>
<td>Indirect; Leprosy and tuberculosis (domestication of cattle and village lifestyle); Typhoid, melioidosis, schistosomiasis (from rice agriculture development) irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Dry Rice Agriculture, Broadcast rice, flooded rice; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical Lesions, Ante-mortem tooth loss); Joint wear and trauma.</td>
</tr>
<tr>
<td>Ban Lum Kao/ Chao Praya/ Plain Domett 1999, 2004</td>
<td>1000 BCE–500 BC</td>
<td>Indirect; Leprosy and tuberculosis (domestication of cattle and village lifestyle); Typhoid, melioidosis, schistosomiasis (from rice agriculture development), irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Dry rice agriculture, broadcast rice, flooded rice; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Dental modification; Cranial pathologies (crib anterior, periostitis, endocranial lesions); Joint wear and trauma.</td>
</tr>
<tr>
<td>Non Nok Tha/ Khorat Plateau/</td>
<td>(early: 2800)</td>
<td>Indirect; Leprosy and tuberculosis (domestication of cattle and village lifestyle); Typhoid, melioidosis, schistosomiasis (from rice agriculture development), irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Dry rice agriculture, broadcast rice, flooded rice;</td>
<td>Age and sex distribution; Stature;</td>
</tr>
<tr>
<td>Site</td>
<td>Date Range</td>
<td>Evidence of Activities</td>
<td>Pathological Indicators</td>
<td>Notes</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Douglass 1996</td>
<td>BCE–1400 BC (late: ~1400 BCE–200 BCE)</td>
<td>of cattle and village lifestyle; Indirect, typhoid, melioidosis, schistosomiasis (from rice agriculture development); irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Domesticated animals (pigs, chickens, dogs, cattle, water buffalo); Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss) Cranial pathologies (cribra orbitalia, periostitis, endocranial lesions); Joint wear and trauma.</td>
<td></td>
</tr>
<tr>
<td>Ban Na Di/ Khorat Plateau/ Houghton and Wiriyaromp 1984</td>
<td>600 BCE–400 BC</td>
<td>Indirect; Typhoid, melioidosis, schistosomiasis (from rice agriculture development); Indirect, Leprosy and tuberculosis (domestication of cattle and village lifestyle); Likely that mosquito-based and other parasites remained endemic.</td>
<td>Dry rice agriculture, broadcast rice; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo).</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Cranial pathologies (cribra orbitalia, periostitis, endocranial lesions); Joint wear and trauma.</td>
</tr>
<tr>
<td>Prohear/ Mekong Delta/ Pietruesewsky and Ikehara-Quebral 2006</td>
<td>500 BCE–100 BCE</td>
<td>Indirect; Typhoid, melioidosis, schistosomiasis (from rice agriculture development)—irrespective of good dental health and nutrition; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Wet rice agriculture (other methods used in specific niches); Moated mounds; Iron smelting Clearing of forest for rice bunds Increased Trade Contact</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Cranial pathologies (cribra orbitalia, periostitis, endocranial lesions); Joint wear and trauma.</td>
</tr>
<tr>
<td>Noen U-Loke/ Khorat Plateau/ Tayles and HR Buckley 2004</td>
<td>300 BCE–200 CE</td>
<td>Direct; Tuberculosis Leprosy; Indirect; Typhoid, melioidosis, schistosomiasis (from rice agriculture development); irrespective of good dental health and nutrition (slightly worsening dental health though); Likely that mosquito-based and other parasites remained endemic.</td>
<td>Moated mounds; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo); Wet-rice agriculture (other methods used in specific niches); Iron smelting; Clearing of forest for rice bunds; Increased in-land trade contact.</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Cranial pathologies (cribra orbitalia, periostitis, endocranial lesions); Joint wear and trauma; Paleopathological evidence of infection (skeletal lesions); Maritime Trade Immunity Model.</td>
</tr>
<tr>
<td>Phum Snay / Mekong River Delta/ Newton 2013</td>
<td>350 BCE–200 CE</td>
<td>Indirect, Cholera, Smallpox (Maritime Trade Immunity Model); Indirect; Typhoid, melioidosis, schistosomiasis (from rice agriculture development); Skeletal evidence shows slightly worsening dental health though; Likely that mosquito-based and other parasites remained endemic.</td>
<td>Wet-rice agriculture; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo); Moated mounds; Iron Smelting; Clearing of forest for rice bunds; Increased in-land trade contact.</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical lesions, Ante-mortem tooth loss); Joint wear and trauma; Maritime Trade Immunity Model.</td>
</tr>
<tr>
<td>Phum Sophy/ Mekong River Delta/ Newton 2013</td>
<td>100 CE–600 CE</td>
<td>Indirect, Cholera, Smallpox (based on the Maritime Trade Immunity Model); Indirect, Typhoid, melioidosis, schistosomiasis</td>
<td>Wet-rice agriculture; Domesticated animals (pigs, chickens, dogs, cattle, water buffalo); Iron Smelting; Moated Mounds;</td>
<td>Age and sex distribution; Stature; Dental pathologies (caries, wear, Periapical Lesions, Ante-mortem tooth loss); Joint wear and trauma;</td>
</tr>
</tbody>
</table>
In Cambodia, the seventh and eighth centuries saw a population increase, and movement from Chenla and the Mekong Delta to lowland sites conveyed disease immunities inland (Lieberman and Buckley 2012: 1059, 1067). If immunities did increase, they probably did so in combination with agricultural changes that permitted self-sufficient regional populations to cross the size threshold needed to convert epidemic diseases like smallpox and measles to epidemic levels (Lieberman 2003: 97-8, 224).

Thus, having established which diseases that were likely to present in Pre-Angkorian Southeast Asia, the next step is to figure out how they impacted Angkor’s population over time and space. Regarding resilience theory, this would be during the intensification phase that comes with the conservation/intensification phase of the adaptive cycle, when adaptive strategies are put to the test (Redman 2005: 74-75).

**CONSERVATION, OR $K$-PHASE**

The $K$-phase is related to increasing costs of labour and material resources in the process known as “intensification” (Aimers and Iannone 2014: 24-5; Redman et al. 2007: 122). In this phase, we see greater state integration across the Angkorian realm, as more amenities were put in place to draw people to the ceremonial core, or epicentre of Angkor, as well as a greater emphasis on the institutionalization of part-time
(as taxation) and bonded labour to maintain this attracting infrastructure (E. Lustig 2009: 76; Stark et al. 2015: 1451). This was done through the “apparatus” of the state temple and belief in the institution of the ruler’s divine kingship, both of which compelled debt-bonded and free people to contribute their labour to the state’s public works through the promise of spiritual “merit” (Iannone 2014a: 7). The result is that the city of Angkor and its overarching state was wealthy, yet highly entangled with a human resource base as the source of its economic and ideological power (Hall 2011: 13; E. Lustig 2009: 78).

The methods used by elites and rulers to accumulate power often involve organizing risk management practices and strategies. These decision-making strategies ostensibly benefit the whole of society, such as protection against invasion and disasters, warfare to accumulate new land and resources, and the creation of public works (Peterson and Drennan 2012: 75, 76); as such, their role in risk management is part of the justification for the elite classes’ control of the non-elite classes’ labour (Ross and Steadman 2017: 44). The creation of “urban hubs”, which centralize administrative institutions, and concentrate public works and services for the well-being of the population, is also a part of this risk management strategy (Yoffee 2005: 16, 54).

With the creation of its own urban hub, the Angkorian state’s reliance on urban infrastructure which was employed to attract, control, and maintain this human labour base—like large-scale water management, temples and state-controlled rice fields—diminished potential and diversity in adaptive capacity when these institutions and public works were compromised (Penny et al. 2018: 4-5). This is a phenomenon known as a “path dependency” (see Hodder 2012: 105, 6; Holling 2001: 400; Walker and Salt 2006: 87)
Materially, this path-dependency is also reflected in new types of settlement forms. Angkorian-period urbanization produced new settlement “configurations” beyond the typical mound, moat, and pond combinations used by people before the establishment of the state (Evans 2007: 24–26; Stark 2006a: 21.13). These include the orthogonal grid for both residences and rice fields, and linear settlement along rivers, canal embankments, and roads (M.E. Smith 2010: 231; Stark et al. 2015: 1444). Some relatively early temples in the Angkor region (e.g., Prei Monti, Preah Ko, and Bakong; see Figure 5.2) were largely monastic (not residential) during their initial usage, with residential mound clusters distributed for some distance outside their moats in a low-density, dispersed pattern (Penny et al. 2006: 601; Stark et al. 2015: 1443).

Other key ninth- to mid-eleventh-century temples that may have had associated residential areas lacked “city” enclosures (e.g., Bakheng, Ta Keo, and Baphuon; see Figures. 5.3 and 5.4) (Pottier 2000, 2012: 21; Penny et al. 2006: 599-600). Twelfth-century Angkorian kings
constructed a series of temple enclosures on large-scale orthogonal grids (e.g., Gaucher 2003, 2004; Pottier 2012; Evans et al. 2013: 12596). Within its moated and walled enclosure, the Angkor Wat orthogonal grid pattern divides the space into blocks, each of which is further systematically divided into mounds and ponds (Hanus and Evans 2015: 3-4; Stark et al. 2015: 1442-3). A summary of Angkor’s large-scale, and state-sanctioned monumental construction is provided in Table 3.

<table>
<thead>
<tr>
<th>KING’S NAME</th>
<th>PALACE CENTRE</th>
<th>LAND MANAGEMENT/TREATMENT OF LABOURERS</th>
<th>WATER MANAGEMENT</th>
<th>TEMPLE BUILDING PROGRAM</th>
<th>OTHER KINGLEY WORKS</th>
<th>AREAS OF DEBATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Jayavarman II</td>
<td>Multiple</td>
<td>Endowed followers with rice fields.</td>
<td>N/A</td>
<td>N/A</td>
<td>Established State of Angkor.</td>
<td>Depending on the translation, may have been from Java, or Champa (Vietnam).</td>
</tr>
<tr>
<td>2. King Indravarman I (877-889 CE)</td>
<td>Harihalaya: a complex of moated temples, linked to the Bakong temple. Prei Monti (800x530 m moat, raised platform of 230x400 m) further south—possibly his new palace, had Chinese pottery dating to the Tang dynasty and from the Middle East (turbquoise glaze). These are apart of the “Roulos group,” on the southeast end of</td>
<td>Indrataka baray (3.8 km long on an east-west axis, with retaining banks). Had diverted Roulos river to create this reservoir. A series of stone human-made inlets and outlets were used for directing and controlling the flow of water rice fields from the Indrataka. Indrataka was used to fill the sacred moats at the temple complex, but also most likely the</td>
<td>Major temples include Preah Ko (royal chapel named after bull), Bakong (possibly earlier though), and Prei Monti; these were made of brick on raised platforms, and were surrounded by moats. Six shrines at Preah ko were dedicated to Indravarman I’s father and grandfather, one to Jayavarman II (and Shiva for each); other temples were dedicated to their wives.</td>
<td>Temple Inscriptions demonstrate how control of labour in construction programs, craftwork, and agriculture was used to provide practical goods (rice) and opulent luxuries to the shrines, by gifting land to elite working for him.</td>
<td>Bakong may have been established before his reign: pollen evidence showed land-use around the temple a century before Indravarman. This pollen evidence also shows that this court was abandoned after the eighth century CE.</td>
<td></td>
</tr>
<tr>
<td>3. Yasovarman I (889-910 CE)</td>
<td>Moved the capital from Harihalaya to Angkor (Yasodharapura) on Bakheng hill (65 m); was to be a stand-in for Mount Meru. Inscriptions state that a series of towers (108) including a central one housing a Shiva known as Yasodharesvara. There were to be 33 towers to be seen from any part of the plain, and seven heavens.</td>
<td>Founded and endowed temples; needed an administrative body to control the districts (praman) beyond the capital, who were taxed for accumulated surpluses (of rice) that would have sustained the court and the workforce that constructed the temples at the Bakheng.</td>
<td>Created the Eastern Baray (7120 by 1700 m), the Yasodharataka, which holds about 60 million m^3^ of water. Increased the state's power to control and deploy water, during the dry season, but also avoid flooding in the rainy season, and avoid the failure of the crops in the middle of the rainy season, which they tend to do even today if the rain faltered (May to October). Outlet/stone channel at Krol Romeas is thought to have controlled the flow of water, but was later modified to bring water into the reservoir; would have allowed for more than one annual crop of rice. A second later outflow structure must have been constructed on the opposite south side, but the date is uncertain.</td>
<td>Bakheng</td>
<td>Created a series of ashrams, or rest houses; their inscriptions show the extent of Yasovarman’s control, from Wat Phu in the North, to the Mekong Delta, to the Gulf of Siam. Constructed raised highway between Harihalaya and the new capital.</td>
<td></td>
</tr>
<tr>
<td>4. Jayavarman IV (928-941 CE)</td>
<td>Constructed Lingapura, palace center located near the modern town of Koh Ker, about 120 Km from the main Angkorian state temple complex. Many workers were described by the subsidiary temples as coming from many districts (praman) and were sustained through the rice tax from the provincial temple estates. Inscriptions state that flouting royal taxation</td>
<td>Indrataka (Lolei); also known as the North baray.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
demands would get one caged by the village elders and sent to the king for sentences. Another inscription states that the king filled his enemies with arrows, another stated that estate workers were divided into two groups, one that worked during the two weeks of the full moon, and one that worked during the darker weeks of the month—presumably, this cycling would allow these workers to work their plots of rice when not working for the temples.

| 5. Rajendravarman II (948-968 CE) | Yasodharapura | One inscription (site of Basak) describes a group of 30 men and women role of caring for a sacred group of cows who were designated for creating holy oil/butter. At Battambang, we have inscription describing Viruna, an unfortunate worker who escaped from rice production from his and had his eyes cut out and nose cut off. | Eventually built a canal that redirected the Puok river, which would feed into the Eastern Baray, later creating the Siem Reap river. | Created the East Mebon and Pre Rup, to the centre and south of the Yasodharatataka, which both housed Shiva lingas (Rajendravarmesvara and Rajendressvara). Created subsidiary temples to aunt and predecessor. |
| 6. Jayavarman V (968-1001 CE) | Yasodharapura (Takeo) | Jayavarman V built the Takeo (alternately, Hemasringagiri, which means Mountain of Golden Summits) temple, which was struck by lightning, which was seen as a bad omen. Had his court with Takeo and a palace, in a complex known as Jayendrenagari. | A large number of inscriptions from this reign indicate the titles and duties of office-bearers and the duties of the agricultural workers employed in fields rigorously defined by boundary markers. This included naming the chief of corvee labour, inspectors of quality and defaults, chief of the warehouse, the vrah guru (guardian of the bedchamber). Another inscription discusses that four princes were gifted land grants by the king, after that they founded temples, endowed land, increased rural production. Transactions in land and personnel involved measures of silver and gold (though there was no official currency). |
| 7. Suryavarman I (c. 1003-50 CE) | Yasodharapura | The Sdok Kak Thom inscription is the most important for understanding how the roles and function of a noble family—it describes lineage of Sadashiva, his family land holdings, boundaries. | Built the Western baray (8X 2.1 km, which was able to store 70 million meters cubed of water). It was meshed into the existing system by the canal (e.g., The Western Mebon was constructed by Udayadityavarman II, which had a bronze Vishnu. | Built the Phimeankas, a steeply rising temple just north of Yasodharapura and the Khleangs—an elegant row of buildings with unknown function. |
and layout, how reservoirs were built, and that family property devastated in the war were restored, justifying their continuing loyalty to the king.

| 8. Suryavarman II (1113-115 CE) | Built Angkor Wat, a radical change from the pattern of temple mausolea in Yasodharapura. | Had “raised corvee labour and dug towers and basins.” | Angkor Wat: Outer moat encircles the area of 195 ha; the moat itself is 200 m wide and the structures within open spaces, walls, and a courtyard which culminates with five central towers with carved lotus flowers on top, made of sandstone meant to represent the ancestral temple of Phimai; it was 340m350m. The stone quarries were 30 km away; it was thought that a huge amount of labour would be needed to build this. Bas-relief images carved onto the stone walls show extensive images from Indian epics, as well as images of Suryavarman II’s campaign against Jayashinvarman, who led the troops of Lopburi on a war elephant. |

| 9. Jayavarman VII (1181-1218 CE) | Angkor Thom, his new urban centre, was built on the cardinal points of the compass; its walls were 3.3 km squared. Access involved crossing through five gateways, then over a moat. Gauchier (2004) was able to reconstruct interior roads and canals that were later confirmed by LIDAR | Ta Prohm Temple (Figure 5.8) (Rajavihara): From its inscription, we know that 18 high priests administered it, alongside 2740 officials. There were 2202 assistants and 615 dancers. 12640 are listed as serving the temple, with 1000-2000 entitled to live within its Jayavarman VII created own reservoir, the Jayatataka, which was linked with the water temple known as Neak Pean. | Two major new temples were Ta Phrom (dedicated to his mother) and Preah Khan (also known as Nagara Jayasri dedicated to his father), Banteay Chhmar—engravings show battle scenes against the chams. Neak Pean was also built as a water temple meant to invoke the sacred lake of the Himalayas. Also built Ta Som. | Jayavarman VII created own reservoir, the Jayatataka, which was linked with the water temple known as Neak Pean. Jayavarman VII was known for building hospitals and rest houses throughout this territory. Built rest houses, seventeen a day each between to the king’s ancestral homeland of Phimai. En route was the sanctuary of Banteay Chhmar, the temple dedicated to the crown prince Srindakumarapura. Works may be misattributed to him from earlier kings (Hendricks 2010: 481-3.) Chhem (2006: 12) reviews the evidence provided by Coedes (1941: 408) who argues that Jayavarman VII was not the sole builder of the temple.
imaging; the royal court was centered just north of the Bayon temple, which was surrounded by over 330 rectangular precincts containing the houses of the population together with pools in (which, according to Zhou Daguo, where the populace regularly bathed).

walls. Additionally, over 66625 people from rural villages were tasked with supplying the temple with mosquito nets, fine cloth, rice honey, molasses, millet, beans, butter, milk, salt, and vegetables. Ta Phrom was also the administrative centre for the 102 hospitals spread across Jayavarman VII's territory. Workers were also expected to send in supplies of medicine like camphor, coriander, pepper, mustard, cardamom, molasses, cumin, pine resin, ginger, and onions. Preah Khan (Figure 5.19): 5324 villages incorporating 97840 people, including the staff and support of the numerous establishments managed by Preah Khan were assigned to this establishment. They were to supply resin to light tapers, goats, pigeon, 645 lengths of red and white cloth to clothe the gods; silk mosquito nets were used to protect the images, a sacred cow with gilded horns roamed the premises.

hospitals attributed to him.
There have been several paleodemographic analyses that estimate the number of people that lived in Angkor during its peak. There is Coe’s (2003:3,12) estimate of 1 million, based on B.P. Groslier’s (1979) rough modelling of the Baray system’s rice output. Cross-referencing Fekri Hassan’s anthropological estimates of pre-industrial family groups (e.g., about five people per household), Hanus and Evans (2015: 2,7) argue that the complex of Angkor Thom alone likely had a population of around 35,000. Stark et al. (2015: 1443) estimate that the Angkor Wat enclosure contained approximately 283 mounds and 250 to 300 ponds. Field-based investigations during 2010 and 2013 examined the nature and time-depth of this Khmer grid-structured settlement configuration from the twelfth century onwards (Stark et al. 2015: 1443-44). There would have been around 1500 people residing near this temple. Ta Phrom and Preah Khan were supposed to have around 1000 people in residence, and villages in the tens of thousands supported them, likely from further afield in the Greater Angkor region (Hall 192-199; Higham 2014: 390; see Table 3). Altogether, conservative estimates put Angkor’s population at around 140,000.
750,000 in an estimated 1000 square kilometers, and we see an increasing push towards a dense settlement pattern, likely to accommodate the residential housing around temples for bonded Khum and administrative personnel (Hanus and Evans 2015: 7). These denser settlements would be the prime conditions for crowd-based diseases like smallpox and measles, as Southeast Asia is likely to have joined the main Eurasian disease pool at this time (and was likely to have been exposed long enough to have sublimated these diseases into childhood diseases [see McNeil 2010: 125-6]). This hypothesized change in disease patterns could also explain the explosion of hospital building near the end of Angkor’s fluorescence.

Much has been written about the Jayavarman VII’s sponsorship of hospitals during his reign in early 13th century Angkor (Chhem 2000, 2005, 2006). Jayavarman VII’s hospitals by routine had two doctors for treating ailments, alongside a staff that numbered in the hundreds, including orderlies, assistants, guards, cooks, and temple pilgrims, all of which are noted on these inscriptions, such as at Ta Phrom Kel, a subsidiary chapel located near Angkor Wat (Higham 2014: 388-389). It has been argued that these hospitals could be comparable to the Medieval almshouses—medical resthouses run by Christian monks—which existed throughout Europe during roughly the same time (Au 2011: 23-24; Hall 2011: 163; Hendrickson 2010: 487; see Figure 5.10). The Ta Prohm inscription (1186 CE) reports that Jayavarman VII instituted a healthcare network that consisted of 102 ‘‘hospitals’’ that were dedicated to Bhaishajyaguru, the Indic god of healing (Chhem 2006: 8).
The Ta Phrom inscription, as the administrative centre of both the rest houses and hospitals, also describes the road network that Jayavarman VII improved to allow pilgrims easy travel to different temples. This construction of public works had a networking advantage as well, cementing Angkor’s connections to the regions annexed by Suryavarman I in the eleventh century, like Vijaya (a former Cham territory) in the west, Phimai in the northwest, and south to Suryaparvata, home of the Mountain of Sun God (Phnom Chisor) (Hall 2011: 196; Hendrickson 2010: 487, 490). Along these roads, Jayavarman VII built 121 rest houses spaced every sixteen kilometers (Coedes 1941, Hall 2011:196; Hendrickson 2010: 487, 490), and in doing so, he gave Angkor access to important resources like salt and forest products such as exotic animal parts and healing plants. Outside the realm, Angkor was also important as a market centre, and a major destination for Chinese traders (Hall 2011: 196; Harris 2007: Introduction V-VI). But despite these urban benefits, Jayarvaman VII—as written in this Ta Phrom inscription—found the empire in a poor state, as it was “plunged into a sea of misfortune” and “heavy in crime” (Coedes 1940a: 344; Hall 2011: 195). There was also apparently high incidence of disease since Jayavarman VII was said to have: “…suffered from the illness of his subjects more than his own; the pain that afflicted men’s bodies was for him a spiritual pain, and thus more piercing” (Coedes 1940a: 344; Hall 2011: 195). However, Jayavarman VII was working in a long tradition of kings providing medical care for the realm’s subjects. Yasovarman I (the founder of Angkor) had created a series of ashrams or rest houses;
the inscriptions show the extent of Yashovarman’s control, from Wat Phu in the North, to the Mekong Delta, to the Gulf of Siam (Hendrickson 2010: 487). Jayavarman V’s regent courtiers, Yajnyavaraha and Vishnukumara (sons of Harshavarman I), were responsible for building the temple complex known as Banteay Srei (Figure 5.8) and were known for caring for the sick and poor (Higham 2014: 367).

During the Iron age and into the Classical Angkorian period, nevertheless, the eventual strengthening of overland and maritime trade networks increased exposure to pathogens (McNeil 1977: 124-127; 2010: 125-126). By the start of the second millennium CE, epidemic diseases in Southeast Asia had become endemic, killing pre-adolescents and seniors rather than working adults, which in turn increased population numbers and agricultural productivity (Lieberman 2003: 97). It has been argued that trade between the core civilizations and the rimland areas was more important for its “immunizing effects” rather than its economic benefits (Lieberman 2003: 50-51, 97). For example, McNeil argues that Bagan/Pagans’ import of Indian slaves to Upper Burma (now Myanmar) had immunizing effects in the state (McNeil 1977: 124-127; 2010: 125-126). By 1350, it appears that smallpox had become endemic in Upper Burma (as discussed in Lieberman 2003: 97), affecting children more than child-bearing economically productive adults. Here, as in other outlying sectors of Eurasia, the transition may have intensified demographic growth. This immunizing effect would have aided the mainland populations, especially those living in the lowland cores, where both foreign contacts and population densities needed to sustain endemic disease were greatest (Lieberman 2003: 50-51, 97).

In summary, the permanent settling of people in the core of Angkor made it more like a compact city, as exemplified by the temple and residential complex of Angkor Thom. This settlement pattern likely resulted in the urban complex reaching the population threshold where crowd-based diseases like smallpox
could have circulated, alongside the endemic conditions of already present vector-based and water-borne diseases. These circumstances would have primed the permanent population at Angkor for potential epidemics (Buckley and Lieberman 2012: 1068).

**COLLAPSE OR RELEASE (OMEGA) PHASE**

When Zhou Daguan visited Angkor under the Chinese Yunnan dynasty, the city was described as a once great capital city gone to seed (Harris 2007: Introduction iii-iv). The omega phase of the adaptive cycle is associated with a sudden, extreme perturbation which causes the disentanglement of important material and human relations in a release of energy and resources (Aimers and Iannone 2014: 26). These can also be considered “tipping points” or “critical transitions” in lieu of the term “collapse” (Aimers and Iannone 2014: 26; Penny et al. 2018: 1; Redman 2005: 73).

Today, Angkor is situated within the catchments of three different rivers, the Puok, Siem Reap, and Roluos. However, before the Angkor kingdom emerged in the 9th century, the region probably only had two major rivers: the Puok and the Roluos (Kummu 2009: 1418). During the Angkorian period, the creation of the Siem Reap river involved breaking up the Puok watershed into two (Kummu 2009: 1415-16; T. Lustig et. al. 2008: 83; Penny 2018: 4). Kummu (2009; 1418), building upon Groslier (1979), suggests that this redirection of natural watercourses happened as early as the 10th century CE. This dating estimate is based on the type of masonry at Bam Pehn Reach (Fletcher et al. 2008: 666-668; Kummu 2009:1418; T. Lustig et al. 2008: 84).

The extensive modifications of the natural rivers would have led to severe problems with erosion and sedimentation in the artificial channels (T. Lustig et al. 2008: 94). Straight channels have higher flow velocities and higher potential to erode (Buckley et al. 2014: 2; T. Lustig et al. 2008: 83; Penny et al. 2018: 6). When a channel is built across the natural slope, the channel more
quickly erodes its bed and banks, as was the case for Angkor’s large-scale water channels. The extensive forest clearance over the entire Angkor plain, up into the lower altitudes of the Kulen and Khor hills, would have expedited this process since the tree roots were not in place to anchor the sediments that would fill up the channels (Buckley et al. 2014: 5).

The river plain and the lower slopes of the Kulen and Khor hills had been converted to banded rice fields by at least the twelfth century (Fletcher et al. 2008: 662; Hawken 2013: 365). Forest clearance had accelerated by the fourteenth century, to extend rice production from the lowlands to higher up on the hills (Hawken 2013: 365). The heavy forest cover had been fragmented by “anthropogenic woodlands” clustered around residential house mounds, fields, channel embankments, and roads. This modification of the environment resulted in spread out, sparse forests and minimal, nutritionally-deficient soils, the remnants of which can still be seen in the Greater Angkor region today (Buckley et al. 2014: 5; T. Lustig et al. 2008: 93).

High magnitude rainfall events would have also caused flooding and erosion of soils, and this would have had detrimental effects on the embankments and channels of Angkor’s water management system (Buckley et al. 2014: 5). There were also a series of changes to the barays that impeded their function as a risk management system and hindered their ability to mitigate the water shortages associated with both routine and extreme drought. These changes are best seen from the cores taken from the West Baray (Buckley et al. 2014: 6; Day et al. 2012: 1048-50). The cores show that an increase in sand deposited in the early fifteenth century, which is consistent with evidence that shows climate conditions had changed towards drought conditions, consistent with the speleothem records from Dendak Cave and Waxiang Cave (Sinha et al. 2010; Zhang et al. 2008), as well as the dendro-chronological record from northern Vietnam (Buckley et al. 2014: 2). Deposits of sand that now fill the Siem Reap canal are thought to have affected
the Siem Reap river floodplain near the Kulen Hills, where the canal is cut eight meters into the ground (T. Lustig et al. 2008: 83). The substantial damage to the waterways is thought to be due to periodic, but severe storms, which caused significant erosion and silting in the aftermath of so-called “mega-droughts” (Fletcher et al. 2012: 313). This damage cut off the inlet and outlet connections from the old canal to the eastern and western parts of the monumental water management system (Buckley et al. 2014: 5; Fletcher et al. 2008: 667-8). It was believed that the West Baray was built by royal mandate as a response to droughts punctuated by severe storms; causing severe erosion and silting between 1050 and 1100 CE (Buckley 2014: 9). However, with the prolonged drought between 1200 CE and 1250 CE, the Western Baray was reconstructed as its exit, which was previously used to channel water into the irrigation system, was closed off by the construction of Angkor Thom (Buckley et al. 2014: 9). The Jayataka Baray’s exit was similarly blocked by the construction of Ta Som (Figure 5.9) in the late 12th and 13th century, outside of the east bank of the Baray (Buckley et al. 2014: 9). The East Baray, which was built in the 9th century CE, had its exit, the giant Krol Romeas channel, blocked partially by a giant masonry wall in the 12th to 13th century CE (Penny et al. 2018: 5; see also Sonneman 2013 for the full discussion). Thus, former outflow points associated with the various barays were not in place
when the mega-droughts of the 13th and 14th came (Buckley et al. 2014: 9; Fletcher et al. 2008: 667-8).

Between the 12th and 13th centuries CE, the East Baray had been modified into a holding tank for water (Buckley et al. 2014: 9). Some water may have flowed through new gaps in the southern banks of the Baray, but these gaps have not yet been dated. A relatively new channel had been built for the East Baray, but it brought water to the same point as the old channel, indicating that what changed was not the source of water, but its quantity, since the baray could only be filled half-way (Buckley et al. 2014: 9).

The West Baray had been deteriorating from a lack of water since the 13th century (Penny et al. 2006: 7). It could not do its former job of directing water into the southern canals. The southern canals connected to the Tonle Sap were filled with “cross-bedded sand of medium to coarse-grain size” (Day et al. 2012: 1048-50). This fill is the result of the large quantity of water that was rapidly halted as it reached the southern floodplain of Angkor. Sand also filled the western disposal channels of Angkor, such as the “Angkor Wat canal” (Day et al. 2012: 1050), as well as the former Siem Reap canal at Kar Krahn and Thnal Putrea (Buckley et al. 2014: 10; Fletcher et al. 2008: 667).

Since a large part of its construction was built during a time of stable climate and rain events, the complex and deteriorating water management system—as infrastructure created by the state—could not keep up with the extreme shifts between dessication and inundation (Fletcher 2012: 313; Penny et al. 2018: 4). While the droughts had serious consequences for the populace’s food security, it was the high-energy flood events that created the most structural damage to the water management network (Buckley et al. 2014: 11; Fletcher et al. 2008: 668; Penny et al. 2018: 5). The damage was either irreparable or was not worth the time and effort to
rebuild. The damaged structures caused disruption, inconvenience, and risk, and would not have allowed the agricultural system to produce the former yields expected of this state-controlled irrigation system (Buckley et al. 2014: 11; Fletcher et al. 2008: 668-9; Fletcher 2012: 313).

According to Buckley et al. (2014: 11):

“The Khmer had built a more manageable and less-risk prone environment, but by the 13th century, some critical components of the water management infrastructure were at least between 300 and 500 years old, were profoundly complex, and filled with redundancies. While the system had coped with drought since the 9th century… we posit that the network and the way that the water management system was managed could not simply facilitate adjustments to the increasingly unpredictable impacts of extreme monsoons, and its complexity and age produced a breakdown.”

As noted in Table 1, the last Sanskrit inscriptions describing events at Angkor date to the early 14th century CE, with no new inscriptions between 1327 to 1546 CE (Buckley et al. 2014: 4). Angkor Thom was still thought to be inhabited in the 1540s and 1580s (Groslier 2006), but by the modern period, roughly between the dates of 1423-1440 CE, the capital had moved to Phnom Pehn (Buckley et al. 2014: 4; Groslier 2006: 118-20).

Increased incidence of disease due to the end of the Medieval Climate Anomaly and the stagnation of the water management system could have also made Angkor a less favourable place to live. Reduced size and availability of water bodies cause crowding of both reservoir species and humans, and in general, lead to the consequence of increased pathogen load in water through the fecal-oral route (McMichael, Woodward and Muir 2014: 77).

Furthermore, the search for more water can lead to more contact between humans, and greater opportunities for disease transmission. Pathogen transmission can also be higher when water levels are low. Rapid shifts in and out of drought and flood conditions often create the ideal ecological niches for vector populations, like mosquitoes (Acuna Soto et al. 2005: 407-408; Carver et al. 2015: 109; Dearne et al. 2015: 56; K. Smith 2011: 202). As with flooding of
important wetlands and water sources, the drying of wetlands during drought can also cause the forced displacement of human populations. Such environments provide favourable conditions for the proliferation and transmission of pathogens (Dearne et al. 2015: 56-7).

For some diseases, such as leprosy, yaws, and syphilis, we also know of their presence in mainland Southeast Asia and Angkor from historical records (Chhem 2005, 2006), beyond osteological sources. The only outsider account of daily life Angkor dates to 1296 and is by the Chinese diplomatic Zhou Daguan (Harris 2007). When the topic of health and disease does come up at Angkor, researchers tend to be heavily reliant on the account of Zhou Daguan. For instance, we know from his account that dysentery and leprosy (see Figure 5.10) are diseases present at Angkor (Harris 2007: 67). Mosquitoes, a known disease vector, are specifically mentioned in-text to have been a major nuisance in the city at night, with common practice being to put up mosquito nets (Harris 2007: 49). Three medical texts found at the hospital chapel sites of Ta Prohm also provide a selection of diseases that Khmer doctors were treating (Figure 5.11), using a combination of Chinese traditional medicine, Ayurvedic medicine, and indigenous Khmer medical practices (Chhem 2005, 2006). These
indicate the presence of diseases that caused lesions, or large open sores, as well as fevers, and diarrheal infections (Chhem 2005: 36-37). Syphilis and Leprosy are interesting cases because unlike their reputation in the west, they are considered “royal” diseases that only kings were thought to contract because only they could have had many wives (Reid 1990: 56).

Gunderson (2015: 63) posits that the shift out of the Medieval Climate Anomaly created the ideal environmental conditions for increased occurrences of infectious disease at Angkor, including an outbreak of the Black Death. He argues that the rise in infectious disease would be a main factor for the decline of the state after the reign of Jayavarman VII (2015: 65-66). We do know that the Black Death hit China and India around 1330 and in Europe in 1340, but there does not seem to be convincing evidence for its spread into Southeast Asia at the same time (Boomgaard 2007: 120). The purported absence of the plague from Southeast Asia in the 14th century and its alleged presence in the 17th century might suggest that Southeast Asia joined the Eurasian disease pool between those dates. Due to the low population densities in the region, however, it may have been present on an endemic level, not growing to epidemic levels until population density grew in the fifteen and sixteenth centuries (Boomgaard 2007: 121; McNeil 1976: 78-140, 2010: 125l). But even if the plague did not reach Angkor, the breakdown of important urban services would have exposed Angkor’s population—or at least some segments of it—to the risks of infectious, tropical diseases.

First, there would be the issue of food security. Crop yields and sources of freshwater are highly dependent on ecological factors like temperature and rainfall, and these, in turn, affect the success of water flow, and consequently whether irrigation systems collect enough water for the crops to grow and harvest (see Figure 5.12 for an example). This is complicated by the fact that food yields are affected by many other factors, including soil degradation, groundwater shortage,
pest infestations, and the diversion of harvests into biofuel production (McMichael, Woodward and Muir 2014: 58). Food insecurity would have affected the physiological ability of the population to fight off infections, as well as maintain the remaining infrastructure that conditioned their quality of life.

Water access would have also been an issue. Water is essential for safe drinking, basic personal hygiene, sanitation, and wastewater management. The presence of water in excess, however, as with flooding, will contaminate local drinking water and vegetable gardens and exacerbate outbreaks of cholera, dysentery, and other diarrheal diseases (Dearne et al. 2015: 56). Diarrheal diseases are also exacerbated by climate change since diarrheal risk increases with lack of adequate drinking water, and generally, the breakdown of sanitation as efforts are directed towards basic subsistence and survival (Kummu 2009: 1413; Lucero et al. 2015: 1148; McMichael, Woodward and Muir 2014: 59).

Some of the diseases, like cholera, schistosomiasis, melioidosis, and typhoid, as bacterial diseases, can enter the host population through ingestion of contaminated drinking water and seafood—known as the fecal-oral route—and these are major risk factors (Dearne et al. 2015: Figure 5.12 View from Phnom Bakheng showing bunded rice fields during the dry to wet season transition (Personal Photo taken May 2016).
Cholera, for example, is associated with saltwater estuaries but can be spread to inland populations through the floods of monsoon rains that wash contaminated water into household pools and tanks that are used for washing and drinking water (Barnes 2006: 280). Schistosomiasis, a type of large parasitic fluke or worm, as well melioidosis, and typhoid, both types of enteric bacteria, are often contracted during the wet planting season, as rice paddies and irrigation canals can be contaminated if human waste is flooded in (Dearne et al. 2015: 48-49). According to King et al. (2017: 31), water management systems that incorporate moats and canals are a particularly efficient route of transmission if fecal-laden waters are washed into stagnant reservoirs during torrential downpours (Brooke 2014: 155; Dearne et al. 2015:49; King et al. 2017: 31; see Figure 5.12). The disease lifecycles of malaria, a protozoan disease, and dengue, an arbovirus, both rely on insect vectors—mosquitoes—that find their ideal breeding and resting areas in wetland environments (Barnes 2005: 69). Their ability of mosquitoes to breed and find safe places for their eggs also relies on the presence of ideal wetland ecological features, such as floodplains, stagnant pools, or even human-made containers and tanks, depending on the species (Carver et al. 2015: 104). While healthy wetlands with high biodiversity tend to maintain a good balance of mosquito numbers to species that regulate their population numbers, wetlands that are degraded through draining or siltation expose humans to increased mosquito-borne diseases (Carver et al. 2015: 105). Mosquitoes are quicker to thrive in these degraded environmental circumstances compared to competitor or predatory species that eat mosquito larva and eggs (Barnes 2005: 69-70; Carver et al. 2015: 104-5).

Deforestation around Angkor would have also removed the potential habitats of shade-loving mosquitoes (such as the *Aedes*, or woodland mosquito), but the creation of moats and paddies would have formed new ecological niches for mosquito species that prefer standing
water (such as the *Anopheles* mosquito). Furthermore, moats, the hallmarks of increasing social complexity and population density in Southeast Asia, were likely to have increased malarial incidence in comparison to rice paddies, since they would have provided an easier route of transmission to human households (Carver et al. 2014: 98).

Finally, there is the issue of the moats of urban centres and temples, given their proximity to residential areas would have provided mosquitoes easier access to human hosts during the nighttime feeding hours (Carver et al. 2015: 98-99; Lambin et al. 2010; King et al. 2017: 30-31). As a general phenomenon, impermanent or seasonal wetlands are better ecological niches for mosquitoes compared to permanent wetlands because their predators or competitor species are not as fast at establishing breeding colonies there as mosquitoes (Carver et al. 2015: 103). Thus, the standing water created by the siltation of Angkor's canals, the abandonment of temples (and hence, their moats), and the closing of the *barays* could have also been a risk factor for mosquito-based diseases as they inhabited these ideal ecological niches (Carver et al. 2015: 104).

Smallpox, a type of variola virus, and yaws and syphilis, both treponemal bacterial diseases, can also be included among these vector-borne diseases, if only on a secondary basis. While direct human to human contact—through the breathing in of infected nasal fluid, sputum, or physical contact with other infected bodily fluids—is the main mode of transmission, these diseases can also be transferred from place to place if flies get in contact with the open sores and land on an uninfected host. The biggest deciding factor in the spread of these diseases, however, is the number of people concentrated in one space. Dark and enclosed places away from direct sunlight are the environments where these pathogens survive, even outside a host
(Barnes 2005: 204, 207, 224), and in combination with the hypothesized crowding, could have created conditions for smallpox to take hold.

Tuberculosis and leprosy are both mycobacterial diseases that are passed on directly from human to human. Leprosy can be passed on indirectly, however, if as discussed with yaws and syphilis, a flying insect gets into an open sore and lands on an uninfected human. Tuberculosis is a zoonotic disease that can be transferred from humans to cows, and vice-versa if they breathe in infected aerosols. As observed during fieldwork, cattle are often free-roaming the rice paddies in Southeast Asia, and dried dung, a fertilizer that is often used in the paddies (see Figure 5.13), can also transfer the disease if a cow is infected (Barnes 2005 160-162; 176). Thus, the presence and reliance on cows as a livestock animal could have also exposed Angkor’s inhabitants to the disease.

In conclusion, the lack of potable water during the 13th and 14th-century mega-droughts and deluges, as well as the concentration of non-agricultural personnel and Khum around the ceremonial core, likely created an ideal platform for disease transmission during this tumultuous time, either through:

1) the sharing of fewer and fewer water resources as the climate became drier and colder
2) increased contact between people, creating more incidences of direct contact diseases, as they shared reduced water resources
3) A reliance on the compromised constructed wetland biospheres in the form of dried-out temple moats and canals, and closed off barays, with less running water

Figure 5.13 Free-wandering cow at Neak Pean water temple, temple dated to the c. 12th century CE (Personal Photo taken May 2016).
Similarities can also be seen in other ancient cases. In the case of imperial Rome, while it had been afflicted by endemic cases of *P. malariae* and *P. vivax* throughout its history, a new strain of malaria hit the city in the 2nd century CE (Bruce-Chwatt and de Zulueta 1980: 89-90). An unusually hot and long summer caused the Tiber to stagnate around the port areas. The Tiber’s function as an important transportation artery and water source made it a risk area in these ideal conditions for the proliferation of the mosquito population, causing the consequence of an unusually long and severe period of malaria infections (Bruce-Chwatt and de Zulueta 1980: 89-90; Soren 2003: 199). In the case of the Classic Maya, there are arguments—based on similarities with a similar depopulation event in the 16th century—that the Terminal Classic transition (750-950 BCE) was partly spurred on by an epidemic of hemorrhagic (severe-bleeding) fever called cocxihuactual (Acuna-Soto et al. 2005: 406). Similar to the consequences of 16th century CE mega-droughts, the population growth and movements of this disease’s vector species (rodents) could have also been propagated by the mega-droughts of the eighth, ninth and tenth centuries (Acuna-Soto et al. 2005: 407; Brooke 2014: 432), as these rodents’ population grew with their takeover of ecological niches abandoned by other species (Acuna-Soto et al. 2005: 407). What these cases emphasize is that rather than a short-term disaster, the full effects of a drought on a community’s quality of life are complex and dynamic, and the full effects can often take place over a long period (Penny et al. 2018: 1). Climate change is often a risk “amplifier” or “multiplier” (McMichael, Woodward and Muir 2014: 53), and rather than being the sole cause of a “collapse” (Aimers and Iannone 2014: 28; Butzer 2012: 3639; Kintigh and Ingram 2018: 30), it exposes the inherent structural weaknesses of a socio-ecological system. The same can be said for the 14th and 15th century CE “mega-droughts” and their effects on the population of Angkor.
A shift in economic circumstances towards greater investment in maritime trade, greater disease transmission, and outside invasion, would have undermined the control the ruling families of Angkor had over the agrarian population, which eventually caused them (the elite members of the state capital) to migrate (Buckley et al. 2014: 11). Recent archaeological excavations from 2015 (Stark et al. 2015: 1451) have also revealed that Angkor had remained inhabited after these major droughts and floods, but at a smaller village scale without state oversight. Furthermore, this social reorganization coincided with the movement of the elite population to the new capital of Phnom Penh, where they took advantage of the growing long-distance maritime trade economy (Buckley et al. 2014: 11). The ability to migrate in times of trouble, such as during the breakdown of a state, does not necessarily indicate a mortality crisis. In fact, the people who were most likely to be at risk from these external shocks were those who could not leave without repercussions, such as the Khum and other landless temple workers: their livelihood was reliant on the now entrenched, and less flexible state-maintained urban infrastructure (Hall 2011: 60-61; Ross and Steadman 2017: 249).

**REORGANIZATION, OR A-PHASE.**

Researchers are now accepting of the fact that environmental circumstances do not determine the nature of the human response, but stimulate multiple responses, or adaptive strategies (Iannone 2014a: 8). There may be varying, often contradictory responses to the same environmental crisis. Different groups in a community may be impacted—both negatively and positively—due to varying perceptions or ability to cope with changing environmental circumstances (Iannone 2014a: 9; Rosen 2007). Furthermore, different segments of a community are not isolated so that these responses will influence one another in a mutually constituting entanglement (Constanza, Graumlich, and Steffen 2007b: 17; Iannone 2014a: 9). During the
reorganization or alpha-phase of the adaptive cycle, this is normally associated with increased diversity in decision-making choices, often in the form of migrations (mobility), new technological innovations, and the rapid restructuring of society (Aimers and Iannone 2014: 26-7). Potential pathways include a movement into a new form of social organization or “regime shift,” or regression into a former mode of living, which can be associated with a reduction in quality of life but may also prove for the better (Aimers and Iannone 2014: 23, 26-7).

For example, the correlation between the decline of erecting monuments inscribed with written texts, and the descriptions of famine in historical records have been used as evidence for the deleterious impacts of droughts for the Classic Maya (for a summary of this discussion, see Diamond 2005: 174). Richardson Gill famously hypothesized that the Maya of the southern lowlands died from an apocalyptic episode of thirst and starvation, and corresponding disease due to these mega-droughts (Gill 1994: 476; 2000: 387; compare the opposing arguments made by Iannone, Yaeger Hodell 2014: 64; McMichael, Woodward and Muir 2014: 163). But according to Iannone (2007: 60-61), the discontinuation of monument erection and the construction of monumental architecture at the end of the Classic Maya period should not be used as a proxy for community or regional abandonment (Iannone 2007: 60-61; see also Aimers and Iannone 2014: 26; Yaeger and Hodell 2008: 192; Demarest 2013: 3). At most centers, the last dated monuments dates were erected well before the city center’s abandonment (Iannone, Yaeger and Hodell 2014: 63). Though there was a significant population decline in the Late Classic to Terminal Classic transition (ca. 800-900 CE)—especially in terms of smaller households that had little control over arable land—considerable populations continued to live on after the collapse of royal authority, both within and around former palace centres (Aimers 2007; Aimers and Iannone 2014: 26; A. Chase and D. Chase 2004b; Demarest 2013: 3; Iannone,

The rapid abandonment of a city, or “urban diaspora,” appears to be a common adaptive strategy to long-term climate instability—and the health consequences thereof—by low-density, urban societies in the tropics (Fletcher 2012: 308-9; Lucero et al. 2015: 1139). In the case of Angkor, segments of the non-elite population had their own autonomous, small-scale economy—as evidenced by coaxial fields and settlements that literally remained off the temple “grid,” supplying staples, local goods, labour and services via tribute and exchange—that operated parallel to that of the temple-focused, state economy (Fletcher 2012: 307; Hawken 2013: 365). Throughout Angkor’s development, however, people became entangled with a centralized political elite for access to water via the baray during the dry season. In the rainy season, farmers worked their fields throughout the urban landscape (Lucero et al. 2015: 1141), working part-time for the temples as a part of tax obligations and for religious merit (E. Lustig 2009: 76; Stark et al. 2015: 1451). Throughout South and Southeast Asia (see Marajh 2015: 77-78), including Angkor (see Fletcher et al. 2003, 2008), rulers maintained the large-scale water management system through varying modes and degrees of control in return for goods, labour, and services (O’Reilly 2014: 305-6). But long-term and drastic climate change, resulting in flooding, prolonged droughts, and as described in this thesis, increased incidence of infectious disease, disrupted the seasonal scheduling and management of labour, eventually eroding the maintenance of the monumental water network (Buckley et al. 2014: 21; Buckley and Lieberman 2012: 1067-68; Fletcher et al. 2008: 668-9; Fletcher 2012: 307).

The migrations of the elite members of the population to Phnom Pehn do not appear to coordinate with the movement of agrarian support personnel during the so-called abandonment
of Angkor, and likely represent divergent adaptive strategies (Lucero et al. 2015: 1151). The end of the 13th and 14th centuries CE also saw migrations of Vietnamese and Thai peoples into the east and western parts of Angkor’s former territory (Buckley et al. 2014: 9; Buckley and Lieberman 2012: 1068). Theravada Buddhism diffused into the Khmer world from the west, altering the relationships between the state, Hindu and Mahayana Buddhist temples, taxation, and the support population (Buckley et al. 2014: 9; Dagens 2003; Groslier 2006: 3; Harris 2007: Introduction, ix). Finally, increased contact with other trading nodes (Arab, Indian, and Chinese shipborne trade) began to be more began an economic shift away from the inland-focused, agrarian economy that had supported Classical Angkor and many of its Charter-era contemporaries (e.g., Bagan/ Pagan). Ships from Europe, looking to circumvent Arab trade entrepots, began to go directly to the source of different commodities—to Southeast Asia itself. Lombard (1970) and Vickery (2004: 48-49) argue that this “globalization” would have undermined the power of the Angkorian state (Buckley et al. 2014: 9).

**CONCLUSIONS**

The collective “collapse” of the Classical Southeast Asian states around the 15th century CE seems to indicate that something had gone broadly wrong, with the hypotheses ranging from warfare, climate change, or environmental degradation (Buckley et al. 2010: 6751; Buckley and Lieberman 2012: 1067-8; Fletcher et al. 2008: 668-9, Fletcher 2012: 310, 314; Higham 2014: 402; Lieberman 2003: 51). The topic I examine is whether tropical disease played a role in the adaptation of dispersed, low-density, agrarian urbanism for the populations that lived in the humid, wet-dry environment of mainland Southeast Asia.

Humidity and seasonality intensify the threat of agricultural pests and waterborne disease unless agricultural strategies and water-management strategies are co-ordinated (Lansing 1991;
Miksic 1999: 182-3). Initially, water features required centralized management to engineer and build. Once in place, however, a large labour force was the key resource required to expand and maintain these risk management features (Scarborough and Burnside 2010: 346-7; Lucero et al. 2015: 1142). A distinct feature of tropical, pre-industrial societies in South and Southeast Asia is their growing reliance on water management systems (Marajh 2015: 77-78). Dependency on these systems could continue if the external circumstances did not radically change. But they did change, via climatic instability, weakening water networks to the extent that they failed.

Consequently, people “…from all walks of life left the dispersed urban landscape and central nodes in search of more reliable sources of water and economic opportunities” (Lucero et al. 2015: 1147). Former subjects continued farming but did so in different areas within smaller community networks (Lucero et al. 2015: 1148). As a conscious risk-management strategy, they returned to the settlement patterns, water management systems, and heterarchical labour organization that served their prehistoric precursors well, as the collectively built-up infrastructure of local ponds, coaxial fields, and independent enclaves focused on the farming of rice continued after the state’s collapse (Fletcher 2012: 312, 314)
CHAPTER 6: DISCUSSION AND CONCLUSIONS

The main topic this thesis explored is the relationship of Angkor’s urban space and its potential facilitation of tropical diseases. Cities, both in the present and the pre-industrial past, embed into the landscape physical evidence of the collective choices humans make to adapt their settlements to the challenges of their socio-ecological environments (Balée and Erickson 2006: 1-2; Yoffee 2009: 2). To understand what health challenges Angkor’s population faced, and the corresponding decisions made by that community considering those challenges, I had to use several pre-existing data sets reflected in the urban landscape—since direct skeletal information was not available as a corroborating source. Based on my review of available literature, it appears possible the following diseases discussed here may have been present in Southeast Asia at the time. Secondly, I assessed the urban archaeology of Angkor to identify the settlement components—both materially and socially constructed—that would expose or protect its population to these disease risks. The result is an assessment that illustrates what adaptive strategies were used by Angkor’s population (and communities within that population) to adapt to these disease risks and hazards over time and space, as well as their success. I used Resilience theory and Entanglement theory—theories that can be used to assess sustainability and flexibility, respectively, of past human-environmental interrelationships at Angkor (Iannone 2015a: 7-8). This allowed me to determine if certain segments of the population were more successful than others when facing changing health circumstances. By doing so, I was able to create a discussion surrounding the role of low-density, dispersed urbanism as a strategy used by pre-industrial populations in the tropics to adapt their settlements to a challenging environment, especially when it came to the risks and hazards of tropical disease.
My thesis is significant because it illustrates the long-term development of different groups’ decision-making processes as they related to both everyday environmental challenges and extreme events (Redman 2005: 77; M.E. Smith 2015: 10). Modern studies of the environment, such as by human geographers, climatologists, and ecologists tend to focus on the cycles of short-term adaptive strategies, usually in timescales of months, singular years, and decades (Redman 2005: 77). In comparison, archaeological studies of past human-environment interactions—as carried out with this thesis—often provide insight into the long-term human relationships to environmental hazards (Redman 2005: 72). My thesis ultimately examines how humans adapted to changing circumstances, and how different groups within a society deal with these changes, with success based on their ability to problem-solve. Through this thesis, I was also able to answer the following research questions.

**RESEARCH QUESTIONS**

1. **Did the city-planning practice of dispersed, low-density agrarian urbanism promote resilience against the health hazards and risks associated with tropical, wetland environments?**

   Based on the available literature and evidence to-date, it can be said that the dispersed, low-density urban plan of Angkor was at its core, a land-use strategy developed over the long-term—centuries at least—to meet the agricultural challenges of the tropical environment, especially when facing the ever-shifting dynamics of the yearly monsoon (Iannone 2015a: 4; Isendahl and M.E. Smith 2013: 132-33). This risk-management strategy, in turn, provided the food and water security that is such a large component (Morgan 2013: 120, 125-126) for maintaining bodily health when faced with the risk of infectious diseases. To make Angkor an attractive place to live and to maintain large population numbers within their sphere of control, the top-down city planning of its rulers had to incentivize people to integrate and centralize in the
face of an environment which predisposes a dispersed settlement pattern (Iannone 2015b: 252). They had to provide large-scale physical irrigation infrastructure and other integrating features, such as roads, marketplaces, and even hospitals, which would act as a failsafe in times when local agroeconomic systems were not as fruitful (Fletcher et al. 2008: 68-69; E. Lustig 2009: 61; Iannone 2015b: 256). And, they had to maintain reciprocal relationships with potential usurpers or political rivals, through gift-giving, title-bestowing, and allocation of land, which would prevent potential civil wars and resultant casualties (Hall 2011: 19, 21, 164; Iannone 2015b: 256). They also created state temples, which created ideological ties to the capital, given to the importance of gaining merit through labour donations, which are integral to the Dvaratic religious systems of Hinduism and Buddhism, which most of the population followed (Boomgaard 2007: 60-61; Hall 2011: 19-21).

In terms of population structure, apart from the precious metals and other rare objects, raids probably yielded war captives that could be kept as serfs or sold as slaves; warfare could also lead to the forced migration of populations of invaded territories to the winning rulers, who absorbed them as bonds-people (Boomgaard 2007: 60; Hall 2011: 19, 21; Lieberman 2003:51).

It was only until the last stages of Angkor’s urban development that concentration of the population—and the shift away from a dispersed settlement pattern—may have increased the city’s inhabitants’ vulnerability to the risks of infectious disease. At this time the city took on a more compact urban character that was not as compatible as the earlier dispersed pattern for dealing with not only the disease dynamics of the surrounding wetland environment but also certain political and economic changes. A shift in economic circumstances towards greater investment in maritime trade, greater disease transmission, and outside invasion, would have
undermined the control of agrarian personnel on the part of ruling family of Angkor, which eventually caused the latter to migrate.

2.) **Or, does low-density, dispersed urbanism create its unique health problems comparable to the population health issues seen in other pre-industrial urban sites?**

From what the available evidence presents, I argue that the low-density, dispersed adaptive strategy was utilized by the local agrarian support population, who remained more resilient in the face of climatic changes, and that the elite royal family, whose power relied on the large-scale temple economy system and monumental water management infrastructure, was less flexible (Isendahl and M.E. Smith 2013: 133). Adaptive strategies for Southeast Asian inhabitants throughout the prehistoric period often involved a component of mobility, such the retention of wild food foraging up into the Classical period, which circumvented nutritional deficiencies that come with reliance on a staple cereal crop (Clark et al. 2014: 484).

As pre-modern Southeast Asian populations grew to hundreds of thousands in the Greater Angkor region during the Classical era, the population density of their settlements continued to be dispersed over the landscape to meet the resource-demands of the tropical environment (Lieberman 2003: 224, 97-8). These populations were nevertheless integrated through ideas and urban infrastructures, such as ideological ties to the ruler (and through his perceived role to maintain the stability of the realm; see Iannone 2015b: 256) through state religion, the temples, and their economic services—especially in terms of water management—and the social interactions and relationships provided by local communities (Hall 2011: 184-5; E. Lustig et al. 2007: 22-24). The attempt on the part of the Angkorian state, however, to centralize large segments of the population in a more concentrated urban area aided in undermining the power of the ruling families (Lucero et al. 2015: 1451). The state-maintained urban infrastructure of Angkor could not withstand changing climate circumstances (and their transformation of the
health risks faced by Angkor’s population), making the societal elite seek a new powerbase focused on long-distance trade, as the agrarian support people—who saw that the king was not able to maintain his heavenly-ordained role of maintaining realm—disengaged from the classical power-structure and its fundamental ideas and infrastructure.

3. Which tropical disease hazards were likely to have been present in mainland Southeast Asia during the Classical era?

The tropical diseases I identified that were likely to be present at Angkor throughout its existence, include diseases like those thought to develop independently in Southeast Asia during the Paleolithic and Early Neolithic, such as (vivax) malaria and dengue fever, diseases that are associated with the development of rice agriculture in the region, such as schistosomiasis and melioidosis, diseases that associated with the control and collection of water, such as typhoid and dysentery, diseases that were associated with the development of sedentary village life, such as yaws, syphilis, leprosy, and tuberculosis, and diseases that were brought to the region through trade of the Iron Age, such as smallpox and cholera. Nevertheless, though water-borne and vector-borne diseases likely affected the population on an endemic basis, it wasn’t until attempts on the part on the state to concentrate large segments of its agrarian personnel, in combination with ageing, inflexible large-scale water management system, that an ideal platform for density-dependent, crowd-based diseases took hold.

4. What adaptive strategies would the inhabitants of Angkor have used to prevent the risk of contracting these diseases?

The need for fresh, uncontaminated water, is a foremost concern for all human societies, for hydration, subsistence, and hygiene, as well as the resources supplied by wetland environments, which serve to buffer the effects of droughts, floods, and help regulate the populations of organisms that can spread diseases (Horwitz et al. 2012: 1; McMichael,
Not having access to water resources, consequently, is a major environmental “hazard” or “challenge” for human health and well-being, but it can turn into a disaster if the human responses to those challenges are unsuitable.

Large-scale water management infrastructure was developed by the Angkorian state to act as a “failsafe” during unusually long dry seasons or to manage excess water during increased rains (Fletcher 2008: 668). This large-scale risk management infrastructure acted as a centripetal force for the settlement of 750,000 people in Angkor’s heartland, as a conservative estimate, during Angkor’s apogee (Fletcher et al. 2003, 2008: 668-9). The water management system would have circumvented some of the worst sanitation issues that propagate the spread of water-borne disease, by ensuring there was just enough water, but not too much (Miksic 1994: 174). Household pools and neighbourhood ponds would have provided water on a per-family basis, ensuring that people had an adequate water supply to meet their hydration needs in the hot and humid climate (Kummu 2009: 1416; Pottier 2012: 18). Domestic architecture in the form of houses on stilts or piles—a form that has precedent to the Neolithic—would allow for easy waste removal where it would fall through a hole in the floor, towards the domesticated animals that were separated from the household (Reid 1990: 51). The royal family and other elite families, working in tandem with the Hindu and Buddhist temples, also provided economic opportunities in the form of temple complexes (Hall 2011: 184). Clean and abundant water, along with food security, would have been the main deterrents against the contraction of tropical diseases. This is because the main risk factors behind tropical diseases are a lack of clean water or nutritional deficiencies, things that leave people vulnerable to contact with vector species and parasites (Shetty and Shetty 2009: 24; K. Smith 2011: 280).
5. How did these patterns of disease risk and vulnerability change over time with the transformation of Angkor’s “urban footprint?” or city plan over time and space.

Like the Maya during the Late Classic to Terminal Classic transition (c.800-950 CE), it is likely that the breakdown of Angkor’s state infrastructure created conditions that made certain social groups and communities more vulnerable to infectious disease. The first social class likely to be affected were divine leaders and other elites whose power base was firmly grounded in large-scale water management and the state temple economy (Iannone, Yaeger, Hodell 2014: 64; Lucero et al. 2015: 1148). I argue that non-agrarian personnel’s proximity to each other in the dense neighbourhoods of the administrative districts and palace complexes made them more likely to contract crowd-based diseases that were common on the mainland (see McNeil 2010: 124-7). Khmer sharecroppers (Khum) whose livelihoods were beholden to the temple and monkhood (Higham 2014: 298) were also likely to more vulnerable to the risks of water-borne and agricultural diseases, since their reliance on state temples and their associated city-wide water management features made them vulnerable to famine (and its associated health risks) when those social systems failed. Furthermore, their social status made it more difficult to move away when the health consequences of infrastructural breakdown made themselves known, which also increased their susceptibility to disease.

On the other hand, it was likely that households who inhabited the independent rice enclaves, and whose subsistence investment was in gradually built-up, collective agro-systems, weathered the more unpredictable climate changes (see Scarborough and Burnside 2010 and Scarborough and Lucero 2010 for comparison) and their associated disease risks. These farmers were more flexible, relying on access to perennial sources of water and other ephemeral natural resources (Lucero et al. 2015: 1150). They presumably had the option to disperse when the disease load grew, as “labour-tasking” farming techniques allow for the establishment of
communities that do not have to be dense in number (preventing the population threshold for an epidemic to take hold) in order to meet food and water requirements.

Thus, the social return to the heterarchical settlement strategies put in place by populations in the time before the rise of the Classical state (comparable to the Maya: see Longstaffe and Iannone 2011: 54; Iannone, Yaeger, and Hodell 2014: 64) likely protected more autonomous communities from the contraction of diseases on the larger scale, as the dispersal of communities into a less populously-dense settlement strategy (as seen at the end of Angkor’s habitation; Lucero et al. 2015: 1150; Stark 2015: 1449, 1451) prevented the establishment of a population threshold where crowd-diseases could circulate.

**CHALLENGES**

Without skeletal evidence, it cannot be said for sure if there was a mortality crisis during the political collapse of Angkor, even if we can identify the stages where the state as a system broke down. Comparison with the Classical Maya indicates that it is likely that the people who made their living on royal lands who bore the brunt of the breakdown of infrastructure, like the large-scale water management and cardinal rice fields (see Lucero et al. 2015; Lucero, Gunn and Scarborough 2011). For those living in independent rice-growing enclaves, the adaptive strategy of migration (emigration) when the king did not live up to his ability to maintain the stability of the realm meant that it is likely that people moved away when times got “tough.” This echoed the ability of their ancestors, like in the case of Funan (the precursors of the Angkorian Khmer, who lived in Southern Cambodia), to move away in times of crisis (Hall 2011:60-61; Ross and Steadman 2017: 249; Stark 2006b: 166-7).

Chronic disease infections are most likely to occur in populations with endemic malnutrition, and correspondingly, a case of famine is often hard to separate materially—at least
archaeologically—from an epidemic (Morgan 2013: 122). A human’s physiological system, having been weakened by malnutrition or undernutrition, is simply more susceptible to disease and parasitic infection than a healthy one (Barnes 2005: 3-5; McMichael, Woodward and Muir 2014: 39-40). According to Morgan, the deaths associated with a specific famine are often more from the subsequent epidemics than the starvation itself (Morgan 2013: 122). Severe caloric deprivation is often accompanied by opportunistic epidemics which may themselves produce osteological reactions; unfortunately, the most common of these (like dysentery and malaria) are invisible in the osteological record (Roberts and Manchester 2005: 27; Scrimshaw 1987; Morgan 2013: 120). Disease itself can cause an acute famine event if it weakens the workforce responsible for food acquisition and processing: this instigates a self-reinforcing downward spiral, as there is less food for the labourers with the highest caloric needs (McMichael, Woodward and Muir 2014: 39; Morgan 2013: 123-4) who focus the biokinetic energy and biomass that underpin the “organic economies” of a pre-industrial state (Brooke 2014: 127, 261).

The result is that deaths from starvation appear remarkably like those from widespread infection because that is often the actual cause of death (Morgan 2013: 125). As such, there is no efficient way to distinguish the former from the latter. The most significant problem regarding dating, even with the perfect methods, is that deaths directly related to starvation may not take place during the period associated with it. A population socially and biologically affected by a famine severely enough to be visibly identifiable in the bioarchaeological record is unlikely to completely recover to pre-famine health, fertility, and practices in less than several years, and thus the effects will be felt by the population years after the instigating event (McMichael, Woodward and Muir 2014: 77; Morgan 2013: 125-126; Scrimshaw 1987).
With these limitations in mind, if I was to complete this thesis research again, one avenue I would take is making cross-polity comparisons a bigger part of my research design. While frequent references are made to the city-planning practices of the Classic Maya and Imperial-era Romans throughout this thesis, making these a more formal part of my analysis method could fill in some of the gaps that the data involving Angkorian settlement strategies is not available to fill. These study areas also have publically available information on population health from skeletal series (see Culbert and Rice 1990; Rice 2006 for discussions on the Maya; see Lo Cascio 2006; Scheidel 1994; Scobie 1986; G. Storey and Paine 2006 for discussions on Rome) that Angkor does not. Specifically, I would compare and contrast the disease risks that I expected the Classical Khmer would have faced to those demonstrably present in skeletal series of the Classical Maya—such as at the capital of Tikal—as a society that practiced a similar form of urbanism in a similar, wet-dry tropical environment (Fletcher 2009, 2012; Isendahl and M.E. Smith 2013), versus that of Rome, the development of which took place in a more temperate climate zone, but still with distinct differences between its wet and dry seasons (O’Sullivan et al. 2008). This would also follow in the line of other scholars who made comparisons between these study areas (for the Maya and Classic Rome, see [Tainter 2014] and [R. Storey and G. Storey: 2017]) while for the Khmer and the Maya, see [Coe 1960]; [Fletcher 2009, 2012] and [Scarborough and Lucero 2010]).

**FUTURE RESEARCH**

With the aid of my thesis’ findings, research others could pursue would be a comparison between population health of the Classical Maya and the Khmer, now that this thesis provides a catalogue of the diseases that likely afflicted the inhabitants of pre-modern, pre-industrial Southeast Asia. Like the Khmer, Maya society depended critically on the annual monsoon rains
(Isendahl and M.E. Smith 2013: 132). The inland reach and strength of the summer monsoon varied as the position of the Intertropical Convergence Zone (ITCZ) meandered north or south of the equator. The further south it went, the more the monsoon rain fell offshore into the Pacific Ocean. Building on earlier palynology in the Yucatan peninsula, the reconstruction of regional drying trends and major droughts during the period of the Maya civic decline was also enhanced by paleo-climate reconstructions of rainfall and temperature variations. Between 700-900 CE, there was a reduction of rainfall, during which decade-long droughts occurred, starting in 770 CE, 825, and 910 CE. Rainfall then stabilized until the end of the 10th century CE, before plummeting into a century-long drought that coincided with the collapse of the several surviving centres of the more water-secure northern Yucatan (Acuna-Soto et al. 2005: 407; McMichael 2017: 164-5; Yaeger, Iannone, and Hoddel 2014: 63-4).

Unlike Angkor, we have a much clearer picture of the biological health of Maya inhabitants during the Maya droughts (Culbert and Rice 1990; Rice 2006: 252). Skeletal remains from Maya burial sites from the late 8th century and onwards show an increased proportion of infant, child, and adult female deaths. From Copan, in the eastern Maya lowlands (modern-day Honduras), the hundreds of bone samples show signs of undernutrition: weakened porous bones, Harris lines in long bones, enamel hypoplasia indicating arrested growth as signs of non-specific, general stress (Diamond 2005: 170; McMichael, Woodward and Muir 2014: 163). Thus, it would be possible to identify similarities and differences in the adaptive strategies, as they related to diet and disease prevention, used by the Maya and the Khmer as they both felt the effects of their respective “Mega-droughts”? After all, unlike the Maya, the Khmer had been exposed to the Eurasian disease pool for hundreds of years, since the Iron Age. Consequently, there are
differences in their disease profiles, even if their settlement structures (dispersed, low-density urbanism) are similar.

Another point of comparison would be with the populations that came after Angkor, who came under the aegis of European colonialists during the so-called period of modernization (Andaya and Andaya 2015: 8-9). Some seventeenth-century Europeans observers and writers thought Southeast Asia was altogether free from the epidemics (Bontius 1629: 104; Crawfurd 1820 I: 31-32, as described in Reid 1990: 55). Or, at the very least, most diseases routinely were experienced by its populations as a mild endemic cycle, rather than the sharp punctuations of epidemics that would devastate large groups of people (Reid 1990: 55-6). Reid, following McNeil (1976: 124-7), argues that the position of Southeast Asia as a major land and maritime crossroads in Eurasia conveyed immunities to most of the serious urban diseases before the European contact (Reid 1990: 57).

There are local traditions about terrible epidemics in a “vague past, several centuries before the time of recording” (Reid 1990: 57). This is the difficult part of trying to identify the presence of diseases from historical records since writers of the past were often not medical doctors, and they would not be able to diagnose diseases as we see them today. The references in the indigenous literature come from a later date, and these suggest that smallpox and other disfiguring diseases—such as leprosy, yaws, and syphilis—were the most feared by the local populations. In the seventeenth century CE, smallpox was the most feared epidemic in most parts of Southeast Asia (Reid 1990: 58):

“There are some contagious diseases, but the real plague of the country [Siam] is the smallpox; it sometimes makes a dreadful ravage, and then they inter the bodies without burning them; but because their piety always makes them render this last respect, they do afterwards dig them up again and...they are not to do it till three years later, or longer.”
A seventeenth-century story about the founding of the Thai city of Ayutthaya in the fourteenth century discusses that the city-centre would be free from smallpox since there were epidemics that killed everyone who tried to live there until the surrounding marsh was filled in (suggesting malaria; van Vliet 1640: 57-58). Wrongthes (2009) describes disease as the reason for the Siamese population movements from La Wo (present-day Lopburi) to its new location in Ayutthaya because of an outbreak in disease in 1350. But it is not clear what this disease was. The Tonklin dynastic chronicle also describes epidemics in what is now northern Vietnam in 1407 and 1409 CE (Buckley et al. 2014: 4).

With European contact and the records of public health instituted by colonial enterprises, we have a better record in the seventeenth century for epidemics. Examples include smallpox in “Siam” (1621-22, 22-23), a Pneumonic plague in Java from 1625-26, and a plague of unspecified etiology in Banten, Mataram, and Makassar (all located in Indonesia) in 1665. The historical record about plagues is scant before the sixteenth century, with only a few references made to epidemics in law-codes, founding stones, and stories (Reid 1990: 58-59). Of the pre-modern cities that were present in Southeast Asia, such as at Baten and Batavia, we also have accounts of the worsening of population health that came with the imposition of European-style infrastructure during the colonial era. The Dutch construction of wider canals in place of the indigenous canal system of Batavia (Jakarta), caused high incidences of dysentery for the indigenous population (causing a mortality rate of up to fifty percent [Lansing 1991: 38-40; Miksic 1999: 173; Reid 1990: 60]). Thus, a path to future research would be to examine how population health changed with the imposition of colonial-era technology and settlement structure in Southeast Asia and to compare their effectiveness as risk management strategies.
KEY FINDINGS AND CONCLUSIONS

Societies, and groups and communities within those societies, will respond to environmental challenges as filtered through their specific ideologies and cosmologies: their culturally constructed view of the world (Iannone 2014a: 8; McIntosh et al. 2000b; Ostrom 2010; Rosen 2007). Thus, what can appear to be a maladaptive strategy for human health may be entirely “rational” in its historically-contingent context (Iannone 2014a: 8). This thesis, which examined how the Classical Khmer dealt with the risks and hazards of tropical disease, has found that it is possible to make inferences about the health afflictions that Angkor’s population faced throughout the city’s history, based on the indirect data source of their urban-planning strategies.

Challengingly, however, without the addition of skeletal evidence, it is difficult to tell how severely overall population health was affected by the breakdown of major infrastructure that supported the city’s development. Thus, my theoretical methods involved making inferences about the Angkorian inhabitants’ quality of life, based on the sustainability of their urban planning on the community level (M.E Smith 2015: 2). Quality of life of past communities can be assessed based on: baseline environmental conditions; population structure and dynamics (especially regarding immigration and emigration); participation in community projects; length and longevity of settlement; and finally, the ability of that population to withstand external shocks (M.E. Smith 2015: 7-9). These entangled socio-ecological factors were used to assess the picture of Angkor’s inhabitants health and well-being throughout the city’s (and overarching state’s) Adaptive cycle.

Regarding findings, not all segments of Angkor’s population were equally reliant on the community projects that propped Angkor up as a state, as expressed through the large-scale water management systems, the cardinal-orientated rice fields, and the concentrated
“neighbourhoods” of permanently settled administrative personnel and bondspeople around its temple complexes (Penny et al. 2018: 4-5; Lucero et al. 2015: 1151). The members of the population who depended on state institutions were more likely to be affected by external shocks to the state, including drought, floods, warfare and changes in economic opportunities. In turn, these communities within Angkor were exposed to a greater risk of contracting the diseases that these perturbations generally foster. The major finding of my thesis is that we cannot correlate the end of one form of social complexity—the pre-modern, pre-industrial state—with an automatic mortality crisis of famine, disease, and destruction that afflicted all members of a population equally (as argued in Gill 1994: 476; 2000: 387). As noted with both the Maya and the Khmer, even after the socio-political and economic breakdown of the state, most of the agriculturalist population—a group, like in other complex agrarian state societies, that made up eighty percent of Angkor’s class hierarchy (Haberl 2011: Table 1; Iannone 2015b: 258; Lucero et al. 2015: 1141; Stark et al. 2015: 1451)—continued to thrive, even in these disease-promoting circumstances. Agriculturalists reorganized and emigrated on their own terms, settling in smaller, more spread-out communities that outlasted the last inscriptions and monumental architecture of the great state temples (Lucero, Gunn and Scarborough 2011: 491; Lucero et al. 2015: 1150), thus returning to the more resilient, heterarchical settlement strategies that served their pre-historic and proto-Classical predecessors well.

Generally, this thesis aimed to look at the sustainability of urban planning practices utilized by pre-industrial Southeast Asian state populations in response to their highly pathogenic, tropical environments. To put this into context, the model of the “hydraulic state,” as first conceptualized by Wittfogel (1957), posited that without top-down control of irrigation technology in “challenging” environments, the common people in pre-industrial, complex
societies would not be able to flourish (Scarborough and Lucero 2010: 197-8), thus beholding them to despotic leaders who did not care about their quality of life or general well-being (Wittfogel 1957: 45). The examined case study of the Khmer of Classical Angkor demonstrates that this is not true and that non-elite population retained the adaptive strategy of labour-based, gradually constructed urban infrastructure—in the form of neighbourhood ponds, independent rice enclaves of coaxial fields, and “poly-nucleated” settlement nodes (Lucero et al. 2015: 1148, 1150)—as a response to both the routine and more extreme health challenges present in the highly variable environment of the wet-dry monsoonal tropics.

Ultimately, this thesis found that the agrarian population’s collective retention of a dispersed settlement strategy was more successful than that of the top-down urban planning practices utilized by the state—in the form of centralizing, monumental infrastructure—to prevent disease risks over the long-term. This is because the state’s reliance on these larger-scale “fail-safes” entrapped and constrained the ability of its non-agrarian population to respond to new, unexperienced challenges to their health and well-being (Buckley et al. 2014: 11). The flexibility of agrarian “labour-tasking” strategies, on the other hand (Lucero et al. 2015: 1148), had a protective capacity against the contraction of disease (see Scarborough and Lucero 2010) allowing for adaptive decision-making in the face of previously unexperienced challenges.

Overall, my thesis has important implications for how different communities in the past managed the problem of infectious disease over the long-term, and correspondingly, weathered potential epidemic disasters when these strategies were tested. Furthermore, this project provides insights into the sustainability of settlement planning for urban and peri-urban areas in Southeast Asia today, as the cyclical relationship between epidemics and climate change, in particular (Shetty and Shetty 2009: 19; K. Smith 2011: 14, 273), have trans-continental consequences.
REFERENCES CITED

Acuna-Soto, Rodolfo, David W. Stahle, Matthew D. Therrell, Sergio Gomez Chavez, and Malcolm K. Caveland

Acker, R.

Adams, Robert McC. and Nissen, Hans J.

Adams, Robert McC.

Aimers, James and Iannone, Gyles

Aimers, James J. and Hodell, David

Aimers, James J.

Armitage, Derek and Johnson, Derek

Andaya, Barbara W., and Andaya, Leonard Y.

Armelagos, George J.
Armelagos, George J., Kathleen C. Barnes, and James Lin

Au, Sokieng

Aymonier, E.

Balée, William

Balée, William and Erikson, Clarke L.

Barnes, Ethne
2005  *Diseases and Human Evolution.* University of New Mexico Press, New Mexico.

Baron, Natalie

Bellwood, Peter S.
1997  *Prehistory of the Indo-Malaysian Archipelago.* University of Hawai‘i Press, Hawai‘i.

Bellwood, Peter S.

Barnislaug, Till, David E. Bloom, Sala Humair

Binford, Lewis
1968  *New Perspectives in Archaeology.* Aldine, Chicago.
Bloom, David E., and Gunther Fink

Bocquet-Appel, Jean-Pierre and Naji, Stephan.

Boone, James L.

Boomgaard, Peter
2007  Southeast Asia: An Environmental History. ABC-CLIO, Inc, Santa-Barbara, California.

Bontius, James

Bordieu, Pierre

Boserup, Ester

Boyd, W.E. and Habberfield-Short, J.

Boyd, W.E. and Chang, N.

Boyd, W.E., Higham, Charles F.W. and McGrath, R.

Bray, Francesca
Brooke, John L.  
2014  *Climate Change and the Course of Global History: A Rough journey.* Cambridge University Press. Cambridge UK.

Bruce-Chwatt, Leonard and de Zulueta, Jan  

Buckley, Brendan M., Anchukaitis, Kevin J., Penny, Daniel, Fletcher, Roland, Cooka, Edward R., Masaki Sano, Le Canh Nam, Wichienkeeo, Aroonrut, Ton That Minh, and Truong Mai Hong  

Buckley, Brendan M., Fletcher, Roland, Shi-Yu Simon Wang, Zottoli, Brian, Pottier, Christophe  


Butzer, Karl  

Cairnero, Robert L.  

Carver, Scott, Slaney, David P., Leisenham, Paul. T., and Weinstein, Philip.  

Cambodian National Commission for UNESCO.  

Chamberlain, Andrew T.  
2006  *Demography in Archaeology.* Cambridge University Press

Chase, Dianne. Z., Chase, Arlen, F., Haviland, W.A.  
Chase, Arlen F., and Chase, Dianne, Z.

Chhem, Rethy K.

Chhem, Rethy K.

Chhem, Rethy K.

Childe, Vere G.

Childe, Vere G.

Christaller, W.

Chongsuvivatwong, Virasakdi, Kai Hong Phua, Mui Teng Yap, Pocock, Nicola S., Hashim, Jamal H., and Chhem, Rethy K.

Clark, Alice L., Nancy Tayles and Sian E. Halcrow

Clarke, David

Coe, Michael D.

Coe, Michael D.
Cœdès George  

Cœdès George  

Cœdès George  

Cœdès George  

Cœdès George  

Cœdès George  

Coedes, George  
1968 *The Indianised States of Southeast Asia*. Honolulu: East-West Centre Press.

Cohen, Mark N., and Armelagos, George J.  

Cohen, Mark N.  

Cohen, Mark N.  

Cohen, Mark N.  

Cohen, Mark N. and Crane-Kramer, Gillian M. M.  
Cohen, Mark, N., and Service, Elmer  

Coker, Richard J, Hunter, B.M., Rudge, J.W., Liverani, M., and Hanvoravongchai, P.  

Constanza, Robert, Graumlich, Lisa and Steffen, Will.  

Cook, Gordon C.  

Coria, Melissa Joe  

Cowgill, George L.  

Cox, K.J., Bentley, R. Alexander, Tayles, Nancy, and Cooper, Matthew J.  

Crawfurd, John  

Crumley, Carol L.  

Culbert, T. Patrick, and Don Rice  

Daguan, Zhou
2007  A Record of Cambodia and its People. Translated by Peter Harris. Silkworm Books, Bangkok, Thailand.

Dearne, Bonnie T., Weinstein, Philip, and L. Lau, Collen


De Vries, Jan

Delvert, J.

Demarest, Arthur A.

Diamond, Jared

Domett, Katrina

Domett, Katrina.

Domett, Katrina M.
Domett, Katrina M., and Tayles, Nancy G.

Domett, Katrina M., Tayles, N

Domett, Katrina M. and Tayles, Nancy G.

Douglas Michele, T

Douglas, Michele T.

Douglas, Michele T. and Pietrusewsky, Michael.

Drennan, Robert D., and Christian E. Peterson

Dumond, D.E.

Evans, Damien H.


Gill, Richardson B.  

Gill, Richardson  
1994  *The Great Maya Droughts.* Unpublished Ph.D. dissertation. Department of Anthropology, University of Texas, Austin

Gignoux, Christopher R., Henn, Brenna M. and Mountain, Joanna, L.  

Glantz, Donald A. and Wilhite, Michael H.  

Goloubew, V.  

Goodman, Alan and Armelagos, George J.  

Gould, W.T.S  

Gould, W.T.S  

Groslier, Bernard-Philippe  

Groslier, Bernard-Philippe  

Gunderson, Lance L., and C.S. Holling, eds.  

Gutman, Pamela, Hudson, Bob A.  
Gunderson, Lawrence  

Haberl, Helmut, Fischer-Kowalski, Marina, Krausmann, Fridolin, Martine-Alier, Joan and Winiwarter, Verena  

Halcrow, Sian, Tayles, Nancy, King, Charlotte L.  

Hall, Kenneth R.  

Hanus, Kasper and Evans, Damian H.  

Hawken, Scott  

Hawken, Scott  

Hawken, Scott  

Hendrickson, Mitch J.  

Hendrickson, Mitch J.  
2010  Historic routes to Angkor: Development of the Khmer road system (ninth to thirteenth centuries AD) in mainland Southeast Asia. *Antiquity*, 84(324): 480-496.

Higham, Charles F.W.  
Higham, Charles F.W.

Higham, Charles, F.W.

Higham, Charles F.W.

Higham, Charles, F.W.
2014 Early Southeast Asia: From the First Humans to the Civilization of Angkor. River Books, Bangkok.

Higham, Charles, F.W. and F. Rispoli.

Higham, Charles, F.W. and A. Kijngam (eds).

Higham, Charles, F.W., Higham, Ciarla R, and Kijngam, T.F.G

Higham Charles F.W., and Thosarat R.

Higham, Charles F.W., and Kijngam, A.

Higham, T.F.G.

Hills, Kendall, B.
Hodder, Ian

Hodder, Ian

Holling, Crawford S., and Gunderson, Lance H.

Horwitz, Pierre, Finlayson, C. Max, and Weinstein, Philip

Houghton, P. and Wiriyaromp, W.

Hudson, Bob A., Nyein, Lwin, Win, Maung

Iannone, Gyles
2005 The Rise and Fall of an Ancient Maya Petty Royal Court. *Latin American Antiquity* 16:26-44.

Iannone, Gyles

Iannone, Gyles (ed).

Iannone, Gyles
Iannone, Gyles

Iannone, Gyles

Iannone, Gyles

Iannone, Gyles, Yaeger, Jason and Hodell, David A.


Isendahl, Christian, and Smith, Michael E.

Janssen, Marco A. and Scheffer, Marten

Junker, Laura
Kealhofer, Lisa and Grave, Peter

Kealhofer, Lisa and Penny, Dan D.

Keesing, Felicia, and Ostfeld, Richard

King, Charlotte L., Halcrow, Siân E., Tayles, Nancy, and Shkrum, Stephanie

Kim, Nam C.

Kintigh, Keith W., and Ingram, Scott E.

Kubo, S., Shimamoto, S., Nagumo, N., Yamagata, M., Him, S., SO, S., Chang, V., Lun, V., Shinoda, I, and Nakagawa, T.

Kummu, Matti

Kummu, Matti

Kummu, Matti and Sarkkula, J.,
Lambin, Eric F., Tran, Annelise, Vanwambeke, Sophie O, Linard, Catherine, and Soti, Valérie

Lansing, J. S.

Larsen, Clark S.

Larsen, Clark S.

Larsen, Clark S.

Lieberman, Victor B., and Buckley, Brendan

Lieberman, Victor B.

Lo Cascio, Elio

Lombard, Denys

Longstaffe, Matthew, and Iannone, Gyles

Lucero, Lisa J., Fletcher, Roland, and Coningham, Robin
Lucero, Lisa J. Gunn, Joel D. Scarborough, Vernon

Lunet de Lajonquière, E. E.

Lustig, Eileen

Lustig, Terry, Fletcher, Roland, Kummu, Matti, Pottier, Christophe, and Penny, Dan.

Lustig, Eileen, Evans, Damien, and Richards, Ngaire

Mabbett, I.W.

Malleret, L.

Manguin, P. Y.

Manguin, P Y. and Vo Si Khai

Marajh, Leah
Marajh, Leah

Marcus, Joyce R.

Marcus, Joyce R., and Sabloff, Jeremy A.

McCrae, Scott

McCrae, Scott

McElroy, Anne

McGrath, R. J., and Boyd, W. E.

McIntosh, Roderick J., Tainter, Joseph A. and McIntosh, Susan. K. (eds)

McKeown, Thomas

McMichael, A. J., Woodward, Alistair, and Muir, Cameron
McNeil, William H.

McNeil, William H.

Peel, M.C., Finlayson, B.L. and McMahon, T.A.

Meggers, Betty T.

Mekong River Commission,

Merbs, C. F., and Miller, R. J.

Merbs, C. F.

Miksic, John N.

Miksic, John N.

Moberg, A., Sonechkin, D.M., Holmgren, K., Datsenko, N.M., Karlen, W.,

Moore, Elizabeth

Moore, Elizabeth
Moore, Elizabeth

Moore, Elizabeth

Morgan, Johanna

Newton Jennifer S., Domett, Katrina M., O'Reilly, Douglas, J.W., and Shewan, Louise

O'Connor, Richard

O'Connor, Richard A.

O'Reilly, Douglas J.W.

O'Reilly, Douglas, J.W.

O'Reilly, Douglas, J.W.,

O'Reilly, Douglas, J.W. and Shewan, Louise

O’Sullivan, Lara, Jardine, Andrew, Cook, Angus, and Weinstein, Philip
Ostrom, Elinor

Oxenham, Marc, and Buckley, Hallie

Oxenham, Marc F., and Tayles, Nancy

Oxenham, Marc F.
2000 Health and Behaviour During the Mid-Holocene and Metal Period in Northern Vietnam, Ph.D. Dissertation, Department of Anthropology, Northern Territory University, Darwin.

Paine, Richard R. and Glenn R. Storey

Parmentier, Henri.

Peel, M.C., Finlayson, B.L., McMahon, T.A.

Penny, Dan
2006 The Holocene history and development of the Tonle Sap, Cambodia. *Quaternary Science Reviews* 25: 310–322.

Penny, Dan, Zachreson, Cameron, Fletcher, Roland, Lau, David, Lizier, Joseph T., Fischer, Nicholas, Evans, Pottier, Christophe, and Mikhail Prokopenko

Penny, Dan, Chevance, Jean-Baptiste, Tang, David, De Greef, Stephane

Penny, Dan, Cook, G., Im, S.S.,


Pottier, Christophe

Rapoport, Amos

Rapoport, Amos


Redman, Charles L.

Redman, Charles L., and Kinzig, Anne P.

Reid, Anthony (assisted by Jennifer Brewster)

Reid, Anthony

Reid, Anthony

Renfrew, Colin A.
Rice, Don S.  

Ricklefs, M.  

Rimmer, Peter J. and Dick, Howard  

Roberts, Charlotte, and Manchester, Keith  

Rollingson, David and Southgate, Vaughn R.  

Rosen, A.M.  

Ross, Jennifer C., and Steadman, Sharon R.  

Russell, J.C.  

Sachs, Jeffrey D.  

Sallares, Robert  

Sanders, W.T. and Webster, D.  

Savage, Dan.  
Scarborough, Vernon L., Chase, Arlen F. and Chase, Dianne Z.

Scarborough, Vernon L., and Lucero, Lisa J.

Scarborough, Vernon L., and Burnside, William R.

Scarborough, Vernon and Valdez, Fred Jr.

Scarborough, Vernon and Valdez, Fred Jr.

Scheidel, Walter

Scheidel, Walter

Scheidel, Walter

Scheidel, Walter

Scobie, Alex

Scrimshaw, N. S.
Sharlin, Allan

Shetty, Nandini P., and Shetty, Prakash S.

Ichita Shinoda

Sinha, A., Stott, L., Berkelhammer, M., Cheng, H., Edwards, R.L., Buckley, B.M., Aldenderfer, M., Mudelsee, M.,

Sinopoli, Carla M.

Sjoberg, Gideon

Smith, Keith

Smith, Michael E.

Smith, Michael E.

Smith, Michael E.

Smith, Michael E.

Smith, Monica L.
Smith, Monica L.

Snellgrove, David L.

Sonneman, T.

Stargardt, Janice
1990 *The Ancient Pyu of Burma, Volume One: Early Pyu Cities in a Man-Made Landscape* PACSEA. Cambridge, UK.

Soren, David

Stark, Miriam T.

Stark Miriam T.

Stark, Miriam T.

Stark, Miriam T.

Stark, Miriam T., Evans, Damien, Chhay Rachna, Heng Piphal and Carter, Alison

Stark, Miriam T., Griffin, P. Bion, Phoeurn, Chuch, Ledgerwood, Judy, Dega, Michael, Mortland, Carol, Dowling, Nancy, Bayman M., Sovathan, Bong, Van, Tea, Chamrouen, Chhan, and Latinish, Kyle
Steckel, R. H., and Rose, Jeremy. C. 

Storey, Rebecca, and Storey, Glenn R. 

Storey, Rebecca. 

Storey, Rebecca. 

Tainter, Joseph A. 

Tayles, Nancy. 

Tayles, Nancy G. 

Tayles, Nancy E., Halcrow, Sian E. and Livingstone, V. 

Tayles, Nancy G., Halcrow, Sian, and Domett, K. 

Tayles, Nancy E. and Buckley, Hallie R. 

Tayles, Nancy G., Domett, K., and Nelsen, K. 


Van Vliet, Jeremias 1640 The Short History of the Kings of Siam. Translated by David K. Wyatt and Leonard Andaya. Siam Society, Bangkok.


Vo Si Khai

Waldron, Tony
2007 Palaeoepidemiology: The Measure of Disease in the Human Past. Left Coast Press, Walnut Creek, CA.

Walker, Brian, and Salt, David
Washington Island Press.

http://www.ecologyandsociety.org/vol11/iss1/art13/

Walker, Samantha

Warrick, Gary

Welch, David J., and McNeil, Judith

Weisz, Helga, Fischer-Kowalski, Marina, Grunbuhel, Clemens M., Haberl, Helmut, Krausmann, Fridolin, and Winiwarter, Verena

Wheatley, R
White, J.C.

White, J.C.

Winterhalder, Bruce

Wiley, G. R.

Willig, M.R., Kaufman, D.M. and Stevens, R.D.

Willis Anna, and Oxenham, Marc F.

Willis, Anna, and Oxenham, Marc F.

Winzeler, Robert L.

Wirth, Louis

Wittfogel, Karl A.

World Health Organization
World Health Organization

Wolf, Eric

Wolf, Eric

Wolfe, Nathan D., Panosian Dunavan, Claire, and Diamond, Jared

Wolfe, Nathan D., Panosian Dunavan, Claire, and Diamond, Jared

Wolters, O.W.

Wolters, O.W.
1999  *History, Culture, and Region in Southeast Asian Perspectives*. Cornell University, Ithaca, New York


Wrigley, E.A.

Wrigley, E. A.

Wrongthes, S.
Yaeger, Jason, and Hodell, David. A.
2008  *Climate-culture-environment interactions and the collapse of Classic Maya civilization.*
In *El Nino, Catastrophism, and Culture Change in Ancient America* edited by Daniel H.
Sandweiss and Jeffrey Quilter, pp. 187-242. Harvard University Press, Dumbarton Oaks,
Washington, D.C.

Yoffee, Norman

Yoffee, Norman

Yuen, Belinda, and Kong, Leon
2009  *Climate Change and Urban Planning in Southeast Asia.* *S.A.P.I.E.N.S*
[Online], 2.3. Online since 18 December 2009, connection on 30 September 2016. URL:
http://sapiens.revues.org/881

Liu, J.
2008  *A test of climate, sun, and culture relationships from an 1810-year Chinese cave record.*