Understanding the Role of Climate in the Decline of Angkor
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Introduction & Definitions

In contemporary narratives, Angkor is often depicted as a lost city engulfed by the relentless encroachment of tropical vegetation, perpetuating the notion of a majestic civilization succumbing to the overpowering forces of nature. While some theories propose that political forces caused the downfall of Angkor, the empirical evidence supports the idea that a changing climate may have been linked to changing use of Angkor over time. To address this, I use paleoclimate proxies, derived from a diverse array of sources including tree rings, speleothems, and pollen samples. These proxies serve as invaluable tools to understand the environmental conditions prevailing during the height and decline of the Angkorian Empire. I hope to unravel the intricate interplay between climatic fluctuations and the changes characterizing Angkorian society in the fourteenth century. By comparing insights gleaned from historical records, archaeological excavations, and climatic reconstructions, my objective is to find patterns indicative of either vulnerability or resilience in the face of environmental challenges. This multidisciplinary approach allows us to contextualize the impact of climate variability within the broader framework of Angkor's landscape, thereby shedding light on the complex factors contributing to its eventual demise.

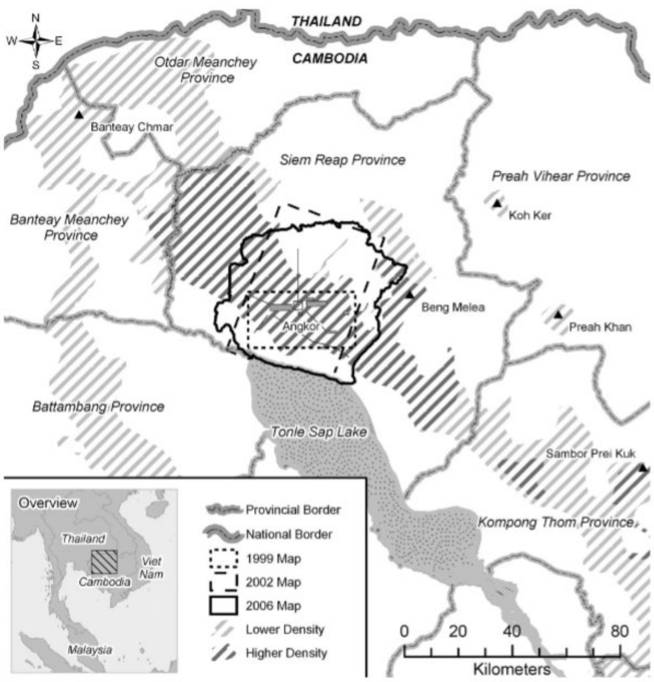

Figure 1. Core region of Angkor (Evans et al. 2007)

Definitions & Brief Historical Background

In this section, the term Angkor is defined as the urban region situated to the north of the Tonle Sap, encompassing the inhabitants residing within, as well as the political institutions governing them. Traditionally recognized as the Angkorian Empire, this entity is commonly believed to have endured from 802 to 1431. However, it is imperative to differentiate between the Angkorian Empire and the Khmer Empire, a distinction often overlooked. While Khmer denotes the ethnic identity of the populace inhabiting Angkor, it is crucial to note that the Khmer people's existence predates and postdates the Angkorian era. The term Khmer Empire predominantly denotes the period during which Khmer culture held sway over the region, extending beyond the confines of the Angkorian epoch into a more decentralized era. Hence, to avoid potential confusion, the term Khmer Empire is not used in this paper.

The main source of knowledge about Angkor comes from the art and inscriptions preserved on buildings around the region, which depict religious scenes and political events. However, in Angkor, only religious structures were constructed from stone, with everything else being built from perishable materials (Evans et al., 2013). This poses challenges for understanding the daily life of ordinary people and reconstructing population dynamics. There is only one written account from an outsider from the Angkorian period, that of Zhou Dugan's visit to Angkor Thom (Higham, 2001). This account is an invaluable resource for understanding Angkor through the lens of Chinese culture at the time, but the issue remains that we don't have any long texts from the Angkorians themselves. During its existence, Angkor achieved notable feats, including the establishment of a healthcare system, advancements in astronomy, and the coexistence of multiple religious groups, such as Buddhist monks, Brahmans, and Shivaites (Higham, 2001). Unfortunately, the last inscriptions in Angkor are from 1327, limiting our direct knowledge of history after that time (Vickery, 1977). Later Cambodian chronicles were long relied upon for historical knowledge, but Michael Vickery's 1977 doctoral dissertation showed that these accounts were likely entirely a product of later dynasties attempting to secure their legitimacy by constructing history that supported them, and therefore should not be relied upon.

Angkor is best known in the modern world for its monumental architecture, especially Angkor Wat, which Miksic and Yian (2016) consider to be the world's largest religious complex (Miksic and Yian, 2016). Despite lacking surviving inscriptions referencing its construction, Angkor Wat's grandeur was unmistakable, characterized by gilded adornments, a 200-meter-wide moat, and a towering 4.5-meter wall (Higham, 2001). Concurrently while Angkor Wat was under construction, numerous other temples were being erected, indicating a period of intense building activity across the Angkorian landscape (Higham, 2001). By the twelfth century, Angkor boasted over three thousand temples, attesting to its status as a vibrant center of religious and cultural life (Lieberman and Buckley, 2012).

Climate & The Rise of Angkor

Geography

Angkor is defined as the region of cities and monuments between the Tonle Sap and the Kulen Hills in modern-day Cambodia (Higham, 2001). This region is unique in Southeast Asia because of the manner in which it developed centralized power, territorial identity, and military culture (Miksic and Yian, 2016). Central to Angkor's geography is the Tonle Sap, the largest body of water in Southeast Asia (Miksic and Yian, 2016). Nestled within the Lower Mekong River Basin, the Tonle Sap plays a pivotal role in the region's ecology and agriculture. This region is unique because every June, the river reverses directions and flows into the lake, flooding a large area around the lake. Because of this phenomenon, the region's seasonal rhythms of rainfall patterns driven by monsoons significantly impacted agricultural practices which sustained the Angkorian civilization (Lieberman and Buckley, 2012). They developed an intricate network of irrigation systems designed to utilize and moderate the waters of the Tonle

Sap (Penny and Hall, 2023). The region of Angkor is contained entirely within the borders of modern-day Cambodia, but their empire extended far beyond at its height. There are over 300 Khmer sites outside of Cambodia that are dated to the Angkorian period (Miksic and Yian, 2016). This paper does not focus on those sites, but it is important to remember that they existed.

Climate of Angkor

The climate of modern Cambodia is predominantly influenced by the seasonal monsoons. Angkor lies within the sphere of influence of both the East Asian and Indian monsoons (Delgado et al., 2012). This results in distinct wet and dry seasons characterized by extreme different in precipitation levels (Miksic and Yian, 2016). The wet season, typically occurring from May to October, is marked by heavy rainfall brought about by the monsoons (Miksic and Yian, 2016). This period sustains the region's lush vegetation and supports agricultural activities both today and in the past. Conversely, the dry season spans approximately seven months during the winter months (Miksic and Yian, 2016). Despite the prevalence of tropical forests in much of the uncultivated land, human activities such as deforestation and urbanization have altered the landscape over time (Miksic and Yian, 2016). However, the remnants of these forests continue to play a crucial role in maintaining biodiversity and regulating local weather patterns. Temperature variations in the Angkor region remain relatively steady throughout the year (Miksic and Yian, 2016).. This stability contributes to the suitability of the climate for agriculture and other socio-economic activities. Furthermore, historical climate data indicates a correlation between strong El Niño events and drought conditions in the region (Miksic and Yian, 2016). These periods of extended dryness pose challenges to agricultural production and water resources management, highlighting the vulnerability of the region to climate variability and change.

Most authors assume that the climate during the Angkorian period was subject to the same general dynamics as today. The medieval climate anomaly, characterized by wetter monsoons in Southeast Asia than the preceding period, coincided with Angkor's ascent, potentially influencing its societal and agricultural dynamics (Lieberman, 2011). This is often compared with the conditions experienced today. Additionally, during this time the region boasted a remarkable agricultural productivity, with records indicating three to four harvests of rice per year (Higham, 2001). Some of this was due to the efficient water management system, but climate conditions also played a role.

Water Management

Because of the large monsoon water intake, Angkor was vulnerable to flooding and erosion (Higham, 2001). In response to these climatic pressures, large-scale water management practices began in the ninth century (Fletcher et al., 2008). There were two major forms of water management: *barays* and *trapeangs*. *Barays* were large, shallow reservoirs that collected the massive amounts of rainfall from the monsoons and kept the water table stable throughout the year (Miksic and Yian, 2016). The largest was the Western Baray, which began construction under Suryavarman I in the mid-eleventh century (Higham, 2001). By the twelfth century, these reservoirs had assumed their final forms, serving as enduring testaments to Angkorian engineering prowess that are still visible on the landscape today (Fletcher et al., 2008). Curiously, *barays* are not referenced in any surviving inscriptions (Miksic and Yian, 2016). *Trapeangs* were smaller pools of water, directly used for irrigation by a few households each (Miksic and Yian, 2016). These are also still detectable in the landscape, but due to overgrowth of vegetation, require remote sensing techniques to be analyzed (Evans et al., 2013). Two competing theories regarding irrigation methods persist, one centralized and controlled by the king, enabling multiple harvests per year, and the other dispersed rain-fed systems (Higham, 2001). Current evidence of the *trapeangs* points more towards the latter theory, but there were fields arranged in square grids, which suggest at least some centralized authority (Miksic and Yian, 2016). Moreover, evidence suggests that similar water management practices extended beyond the core of Angkor, underscoring the expansive reach of Angkorian hydraulic engineering (Evans et al., 2013). However, the continued construction of reservoirs proved unsustainable for the Angkorian Empire, highlighting the challenges of maintaining such extensive hydraulic infrastructures (Evans et al., 2013).

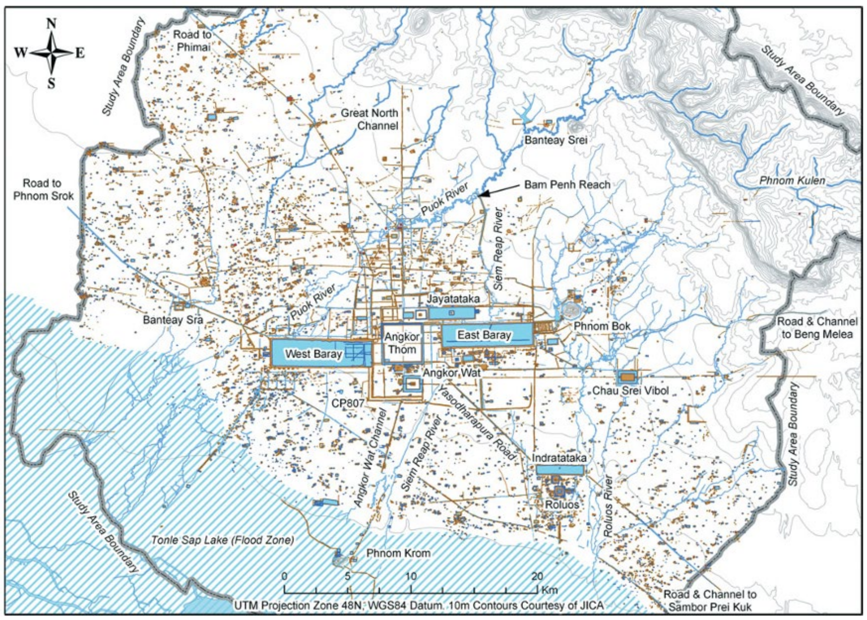

Figure 2 (Evans et al. 2007). Water management system of Angkor.

The Decline of Angkor

Climate and Collapse

The collapse of ancient civilizations due to drought is a phenomenon observed across various historical contexts. Weiss (2017) argues that many societal collapses, such as those of the Akkadians, sixth-century Moche, eighth-century Maya, and twelfth-century Tiwanaku, have been linked to drought events. Moreover, he suggests that megadroughts not only directly impact societies by causing water scarcity but also generate other contributing factors that facilitate societal collapse (Weiss, 2017). This perspective underscores the interconnectedness of environmental and societal dynamics, highlighting the complex web of factors that can lead to the downfall of civilizations like Angkor.

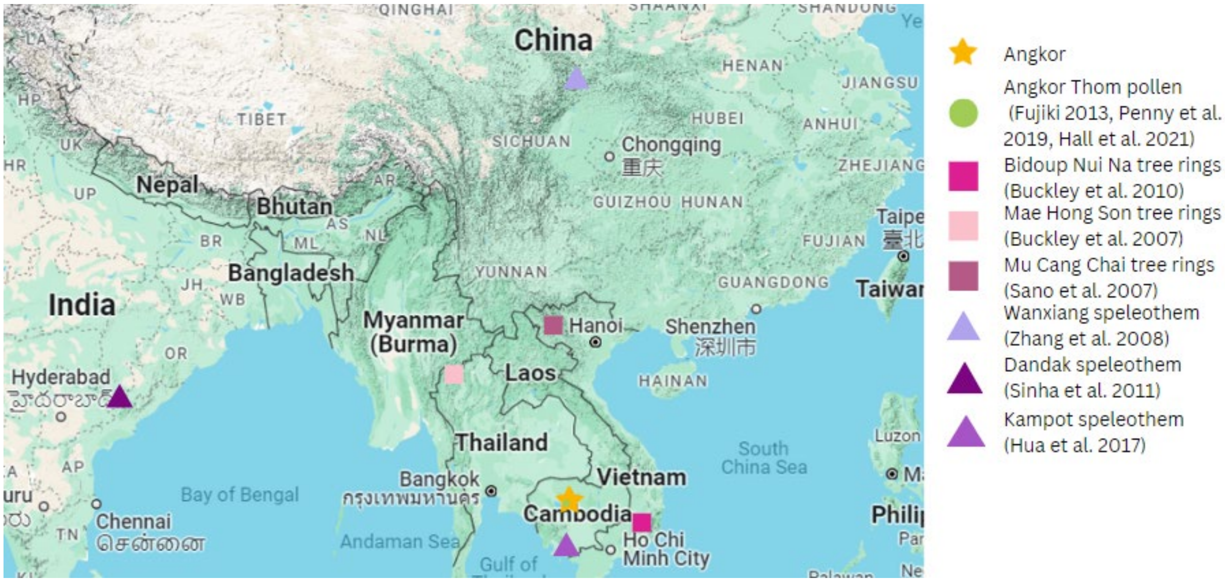

Figure 3. Map of climate proxies used in this paper

Drought

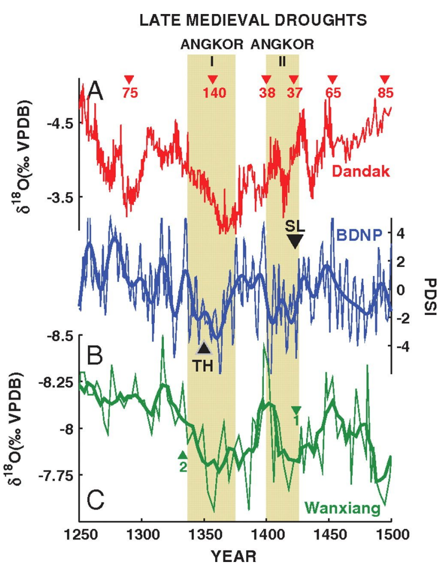

Figure 4 (Buckley et al. 2010). Indicators of Late Medieval Megadroughts in the region surrounding Angkor. Red: Dandak Cave speleothem, Blue: Vietnam tree rings, Green: Wanxiang speleothem.

The transition from the Medieval Climate Anomaly to the Little Ice Age was accompanied by a megadrought, a period of prolonged and severe drought, which posed significant challenges to societies like Angkor (Fletcher et al., 2017). Using tree ring data from Bidoup Nui Ba National Park in Vietnam, Buckley et al. (2010) identified a weakened monsoon in the mid-to-late fourteenth century, with the early fifteenth century experiencing severe droughts, including the driest year in 1403. Interestingly, they note that the reversals from drought to monsoon were rapid, likely resulting in flooding events (Buckley et al., 2010). Sinha et al. (2011) also found evidence for megadroughts in the mid-14th to 15th centuries, with these droughts extending across a large region encompassing Sri Lanka, India, and central China. Importantly, there is no modern equivalent for the scale and intensity of these megadroughts in the instrumental record (Sinha et al., 2011). Following 1450, climate fluctuations decreased, indicating a shift in environmental conditions (Lieberman and Buckley, 2012). The teak record of Thailand correlates closely with the Vietnam cypresses used in Buckley et al. (2010) suggesting that areas like Angkor experienced similar climatic patterns during this period (Lieberman and Buckley, 2012). Furthermore, Hall et al. (2021) notes a peak in fire activity coinciding with the droughts identified by Buckley et al., highlighting the environmental stress experienced by the region. Hua et al. (2017) studied a speleothem covering the last 4300 years and found a growth hiatus between 1250-1670, further corroborating the evidence for sustained environmental challenges during this period. These findings underscore the significant impact of megadroughts on Angkor's ecosystem and provide crucial insights into the environmental factors contributing to its decline.

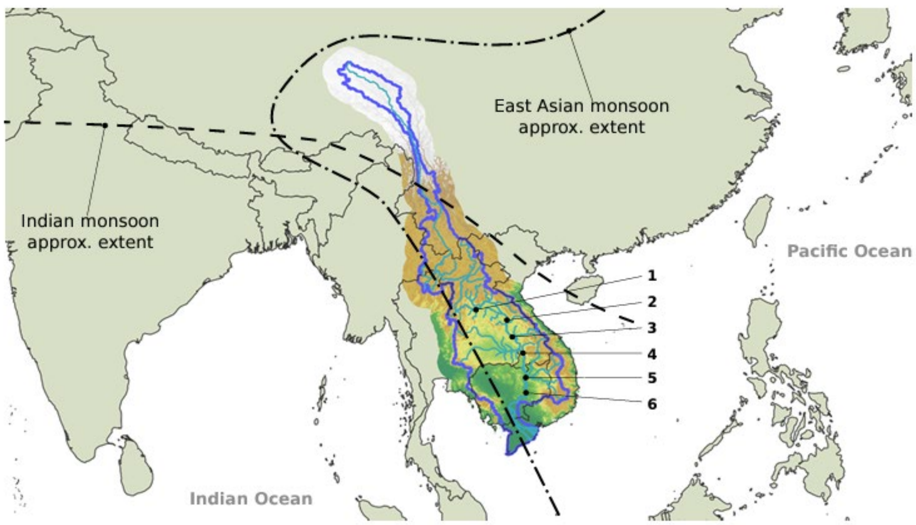

Figure 5. Delgado et al. 2012. Map of Asian monsoons. Angkor lies right on the western border of the East Asian monsoon, and wholly within the extent of the Indian monsoon.

Monsoon & Flooding

The Angkorian empire's agricultural productivity and water management system were intricately linked to the seasonal monsoon flooding (Buckley et al., 2010). Currently, the flooding of the Mekong River is more closely tied to the strength of the East Asian monsoon rather than the Indian monsoon (Delgado et al., 2012). It is well-established that major volcanic eruptions can influence the strength and variability of monsoon seasons (Penny and Hall, 2023). Moreover, studies have found that the El Niño-Southern Oscillation (ENSO) phenomenon has a significant impact on the occurrence of megadroughts (Fallah and Cubasch, 2015). In addition to ENSO, researchers have suggested that major volcanic eruptions, such as the Mt. Pinatubo eruption that occurred sometime between 1400-1500 (Gaillard et al., 2016), may have influenced the later phase of the megadrought in the region (Fallah and Cubasch, 2015). However, the reliability of this finding remains uncertain. These insights underscore the complex interplay between natural phenomena, such as volcanic eruptions and climatic patterns like ENSO, and their impact on the stability and sustainability of civilizations like Angkor.

The rapid reversals from drought to strong monsoon, which involved higher-than-normal precipitation concentrated in smaller time periods, as observed by Buckley et al. (2013), likely contributed to flooding events in the Angkor region. Buckley et al., 2010 also notes the rapid filling of an important canal that linked Angkor Thom, Angkor Wat, and Phnom Krom at the end of the fourteenth century, suggesting a sudden onset of water-related challenges. This phenomenon is further supported by Fujiki (2013)'s identification of a flood layer, the first concrete example of flood in the fifteenth century, which is the century corresponding to the historical time of collapse of Angkor. Modeling studies by Penny et al. (2018) have demonstrated the potential damage to infrastructure from flooding in Angkor, highlighting the vulnerability of the region to such events. Penny et al. (2018) describes the region as "prone to cascading failure," indicating the interconnectedness of infrastructure systems and the likelihood of widespread damage resulting from flooding incidents. These findings underscore the importance of understanding the dynamics of flooding and its impacts on the built environment in Angkor's history.

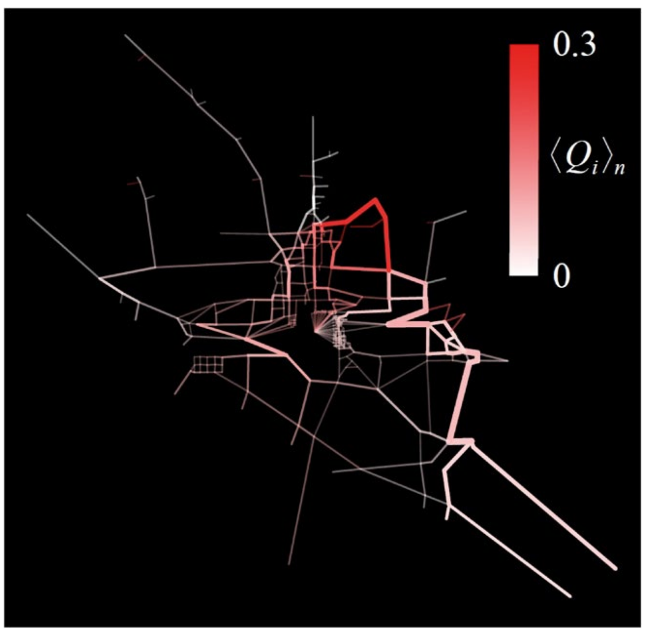

Figure 6. Penny et al. 2018. Modeled damage to water management infrastructure due to rapid drought/flood cycles (darker red indicates more damage).

The Conventional Conventional Narrative

The popular narrative of Angkor is that it suddenly collapsed and disappeared in the mid-fifteenth century. This is present in many media made for non-specialists today, and persisted even in professional historical works until the mid-2010s. This narrative largely comes from texts outside of Angkor, which are of varying reliability, but some of this can be reconciled with the climate-focused narrative presented above. As previously mentioned, the last inscription from the Angkorian period is dated to 1327, and it has been suggested that the rulers of Angkor left the area for brief periods in the mid-fourteenth century (Lieberman and Buckley, 2012). Contrary to notions of a sudden collapse, some scholars perceive a gradual shift in power towards emerging centers like Ayutthaya and Phnom Penh-Lovek by the mid-fifteenth century (Vickery, 1977). This transition coincided with Angkor's continued importation of ceramics from Tai, Vietnamese, and Chinese sources well into the fifteenth century (Miksic and Yian, 2016). One hypothesis suggests that increased Chinese interest in trade spurred this shift, with southern cities like Phnom Penh becoming more strategically positioned for commerce (Vickery, 1977). Although it has not really been discussed in the literature, this shift possibly could've occurred because of the megadrought making land trade routes more risky.

Despite Angkor's decline as a place of political importance, Angkor Wat remained a significant religious site, transitioning into a fully Buddhist temple by 1600 (Carter et al., 2019). Although "rediscovered" in the early sixteenth century, it was left alone for a while, with limited restoration efforts being ordered by the political leaders farther south between 1546 and 1579 (Miksic and Yian, 2016). However, politically, the center of Khmer authority shifted southeast of Angkor Wat (Miksic and Yian, 2016). Nevertheless, Angkor Wat retained its religious importance, evidenced by continued pilgrimages by Khmer rulers until as late as 1658 (Miksic and Yian, 2016). This was likely possible because it requires significantly less people to run a religious site than a whole city.

However, the most prominent theory of collapse before 2010 was that of invasion. The arrival of the Buddhist Tai people to the highlands just east of Angkor has long been suggested as a source of pressure on the political system, especially since they brought higher-output strains of rice than the Angkorians had (Lieberman and Buckley, 2012). In 1431, Tai people from Ayutthaya invaded and supposedly sacked the city (Higham, 2001). There are indications that Ayutthaya installed a puppet ruler in Angkor for approximately twelve years, leading to a period of unrest (Vickery, 1977). While historical accounts attribute the downfall of Angkor to warfare (Higham, 2001), recent scholarship suggests a more nuanced understanding of the events. Evidence suggests that the Ayutthayan invasion of 1431, while it did likely occur, was not a straightforward foreign incursion but involved complex dynamics of Khmer cultural exchange with the Tai and influence (Carter et al., 2019). In fact, high-status people from Angkor lived within the Tai courts, although the extent to which this "invasion" was facilitated by former Angkorians is unknown (Carter et al., 2019). There are also no records from this time that suggest that this political change was a big issue, due to the gap in records in general. This nuanced perspective challenges simplistic narratives of foreign aggression as the sole cause of Angkor's demise, highlighting the intricacies of political and social dynamics in the region. Invasion may have had something to do with the political change in Angkor, but the reasons fo this invasion are not well-known. The political downfall of Angkor reflects not only external pressures but also internal complexities and shifting power dynamics within Southeast Asia.

Resource Overexploitation

It has been established that climate change and political change both occurred during the time labeled as the collapse of Angkor, but did anything actually change for the people living there? The clearest way to estimate this is using pollen data sets from canals in Angkor, collected by Fujiki in 2013, Penny et al. in 2019, and Hall et al. in 2021. The moat surrounding Angkor Thom, dug around 1125, provides a timeline for land use data, showing increased disturbance until around 1300, followed by a decline (Penny et al., 2019). From the late thirteenth to mid-fourteenth centuries, significant ecological shifts occurred in the Angkor region, as evidenced by pollen and insect data. Fujiki (2013) notes a decrease in arboreal pollen and an increase in rice husks and rice-associated insects, indicating an expansion of rice cultivation during this period.

This corresponds with the most dense phase of occupation suggested by the building records. Agrarian land use is supported until the first half of the 14th century, but a gradual decline in intensity is noted thereafter (Hall et al. 2019; Penny et al., 2019). The canal that Penny et al. (2019) studied was overgrown with vegetation by 1400, indicating a lack of management. Above Fujiki (2013)'s flood layer, rice husks, insects, and arboreal pollen are absent, indicating non-functional irrigation systems. Instead, the presence of pottery sherds suggests possible use as a dumping ground (Fujiki, 2013). The late 15th and 16th centuries witnessed a dramatic increase in forest pollen, suggesting reforestation or abandonment of agricultural land (Hall et al., 2021). So it appears that the notion of collapse has merit.

Clearly, at some point in the fourteenth century, at least some water management and irrigation systems were abandoned. The entanglement of the two major food sources, rice and fish, which both depended on water management, further compounded the issue (Fletcher et al., 2017). Upland deforestation, aimed at expanding agricultural land, only exacerbated erosion, intensifying soil degradation and runoff into water bodies (Fletcher et al., 2017). This implies that population decline occurred in this area, as the previous population was only sustainable because of the sophisticated water management systems. Various models have been proposed to explain the population decline in Angkor, but without further evidence, it remains challenging to ascertain whether the decline was gradual or abrupt (Fletcher et al., 2017). One such model suggests a gradual decline in population, leading to a significantly lower population compared to its peak when climatic instability and megadroughts began (Fletcher et al., 2017). In this scenario, the dwindling population would have resulted in fewer people available to repair and maintain the intricate water management system, exacerbating environmental challenges and contributing to societal decline (Fletcher et al., 2017).

Conclusions

Causality

Based on this evidence, I think there is clear evidence for a link between climate fluctuations and the political and demographic decline of Angkor. The dwindling population directly impacted the ability of Angkor's inhabitants to repair and maintain the intricate water management infrastructure upon which their livelihoods depended. With fewer hands available for labor and dwindling resources allocated to infrastructure upkeep, the resilience of these systems gradually eroded. Consequently, as the capacity to mitigate flooding and manage water resources diminished, the propensity for catastrophic failures increased. This precipitated a spiral of abandonment, wherein the remaining population found themselves increasingly vulnerable to environmental pressures, compelling migration to more hospitable regions, notably towards the southeast. The question of causality regarding the collapse of Angkor revolves around whether flooding-induced water management failure prompted people to leave in the first place, or if the lack of repair was a consequence of people already vacating the area.

Comparisons

Sinha et al. (2011) suggests that similar environmental challenges may have impacted the collapse of other civilizations, such as the Yuan in China and the Rajarata in Sri Lanka, highlighting the broader implications of environmental stressors on societal stability. Lieberman draws comparisons between the collapse of Angkor and other contemporaneous civilizations, such as Pagan and Dai Viet, all of which flourished during the same period. This comparative analysis underscores the complexity of societal responses to environmental pressures and the varied outcomes observed across different regions. Furthermore, Lieberman and Buckley (2012) note the decentralization of power after 1431, which made subsequent societies less susceptible to climate influences. This observation suggests that changes in governance structures and power dynamics may have played a role in shaping societal resilience to environmental challenges in the aftermath of Angkor's collapse.

Limitations

Several common issues have emerged in scholarly discussions regarding Angkor. Firstly, there is a tendency to oversimplify the water management system by treating *barays* as direct irrigation sources, overlooking the nuanced complexities of the system. Incorporating the entire water management system into models would give a more realistic perspective on the dynamics of system failure. Additionally, there is a notable absence of household archaeology in research efforts, which could provide valuable insights into everyday life and societal dynamics within Angkorian society. Furthermore, the lack of a comprehensive El Niño-Southern Oscillation (ENSO) model hinders our understanding of the climatic factors influencing Angkor's history. A robust ENSO model could help elucidate the relationship between climatic variability and societal responses, shedding light on the role of environmental factors in shaping the trajectory of Angkorian civilization. Addressing these issues is crucial for advancing our understanding of Angkor's history and unraveling the complexities of its societal dynamics. Finally, as always in science, more data would be helpful. As dendrochronology advances, more trees become dateable, and getting data from within Angkor itself would be extremely useful for understanding local weather and climate patterns. By adopting a more nuanced approach to water management, incorporating household archaeology, and developing improved climate models, research can gain deeper insights into the factors driving the rise and fall of Angkor.

Collapse and Angkor

In conclusion, the investigation into the decline of Angkor reveals a multifaceted interplay between climatic fluctuations, environmental dynamics, and societal responses. Through the integration of diverse sources such as historical records, archaeological findings, and paleoclimate proxies, a nuanced understanding of the decline of Angkor emerges. The evidence presented suggests a strong correlation between climate variability and the trajectory of Angkorian civilization. Megadroughts, characterized by prolonged and severe drought conditions, exerted significant pressure on Angkor's water management systems and agricultural practices. The dwindling population, exacerbated by environmental stressors and possibly compounded by political shifts, diminished the capacity to maintain crucial infrastructure, leading to a spiral of abandonment and societal decline.

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