




## Research Article

# Three thousand years of farming strategies in central Thailand

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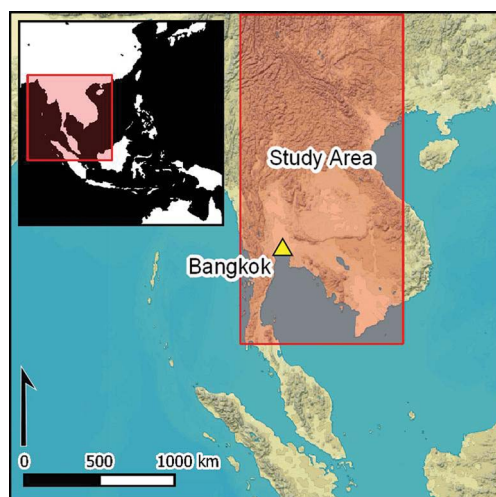
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In prehistoric coastal and western-central Thailand, rice was the dominant cultivar. In eastern-central Thailand, however, the first known farmers cultivated millet. Using one of the largest collections of archaeobotanical material in Southeast Asia, this article examines how cropping systems were adapted as domesticates were introduced into eastern-central Thailand. The authors argue that millet reached the region first, to be progressively replaced by rice, possibly due to climatic pressures. But despite the increasing importance of rice, dryland, rain-fed cultivation persisted throughout ancient central Thailand, a result that contributes to refining understanding of the development of farming in Southeast Asia.

Keywords: Thailand, Southeast Asia, prehistory, millet, rice, spread of agriculture

## Introduction

The ‘Two Layer Hypothesis’ in Southeast Asia describes the expansion of farming communities southward from East Asian centres of rice and millet domestication into a region occupied for millennia by foragers (Higham *et al.* 2015). Foragers formed the first layer of

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occupation in Southeast Asia, whereas farmers from China, who are presumed to have cultivated rice as the dominant domesticate, moved south into territories occupied by these foragers as a second layer of occupation *c.* 2000 BC. Initial archaeobotanical research in eastern-central Thailand, however, has revealed that the earliest farming in Southeast Asia involved millet (Weber *et al.* 2010). Employing data from one of the largest collections of archaeobotanical material in Southeast Asia, we examine over 3000 years of changing farming practices in eastern-central Thailand, a region that played an important role in the development of metallurgy and social complexity in Southeast Asia (see Higham *et al.* 2020). Our research focuses on four sites: Non Pa Wai, Nil Kham Haeng and Non Mak La, located in the Khao Wong Prachan Valley, and Phromtin Tai to the north-west, on the Lopburi Plain (Figure 1).

Following a number of scholars (Mudar 1995; Mudar & Pigott 2003; Pigott *et al.* 2006; Weber *et al.* 2010), we argue that the first farming communities in the Khao Wong Prachan Valley practised dryland/upland millet-based agriculture, supplemented by a substantial element of wild plant foraging. Mudar and Pigott (2003) and Pigott *et al.* (2006) have postulated that this strategy was employed only during the earliest phases of occupation in the Khao Wong Prachan Valley sites, and that the later higher productivity of wet rice agriculture (*i.e.* planting seeds on dryland and transferring the seedlings to a flooded field) was necessary to meet increasing population pressure. Furthermore, they argued that, from *c.* 1100 BC, the inhabitants of the Khao Wong Prachan Valley began to mine, smelt and cast copper to exchange agricultural products with those living in areas more suited to wet rice agriculture.

Our results concur with previous phytolith studies in the Khao Wong Prachan Valley that demonstrate the existence of upland farming regimes (Kealhofer 2002). We argue that sufficient agricultural production of upland (dryland) rice cultivation and small amounts of millet were integrated into local systems of foraging, and later combined with swiddening in ancient central Thailand. These non-irrigated systems of farming continued to play an important part in subsistence for millennia, persisting into the present day.

While the Two Layer Hypothesis is now widely accepted, based on archaeological, linguistic and human biological evidence (Bellwood & Renfrew 2003; Bellwood 2006; Rispoli 2007; McColl *et al.* 2018; *cf.* White 2011), the finer details of the migratory routes taken by the first millet and rice farmers in Southeast Asia are only now being identified. Some scholars have highlighted coastal routes starting in Taiwan and Fujian (*e.g.* Bellwood 1991; Bellwood & Dizon 2008), while others have suggested routes from the Middle Yangtze to Lingnan, Guangdong and Guangxi, with populations entering Southeast Asia through Vietnam (*e.g.* Rispoli 2007; Fuller *et al.* 2011). Still others have highlighted the role played by higher-altitude areas to the west, such as the Yunnan Guizhou Plateau (*e.g.* Higham 2002). A similar debate has involved the direction of transmission of copper/bronze metallurgy, with some authors viewing the ultimate origin of this technology in the Seima-Turbino horizon of the Altai region, which then travelled along the Eastern Himalayas via Gansu, Sichuan and Yunnan (White & Hamilton 2014). The alternative mode sees the Steppic technology reaching the Chinese Central Plain and being transmitted south along lowland routes in the Central Yangtze region into Lingnan and Yunnan and then on to Southeast Asia (Pigott & Ciarla 2007; Higham *et al.* 2011, 2015). Here, we apply a computational model to examine how the agricultural niche was affected by changes in ancient climate

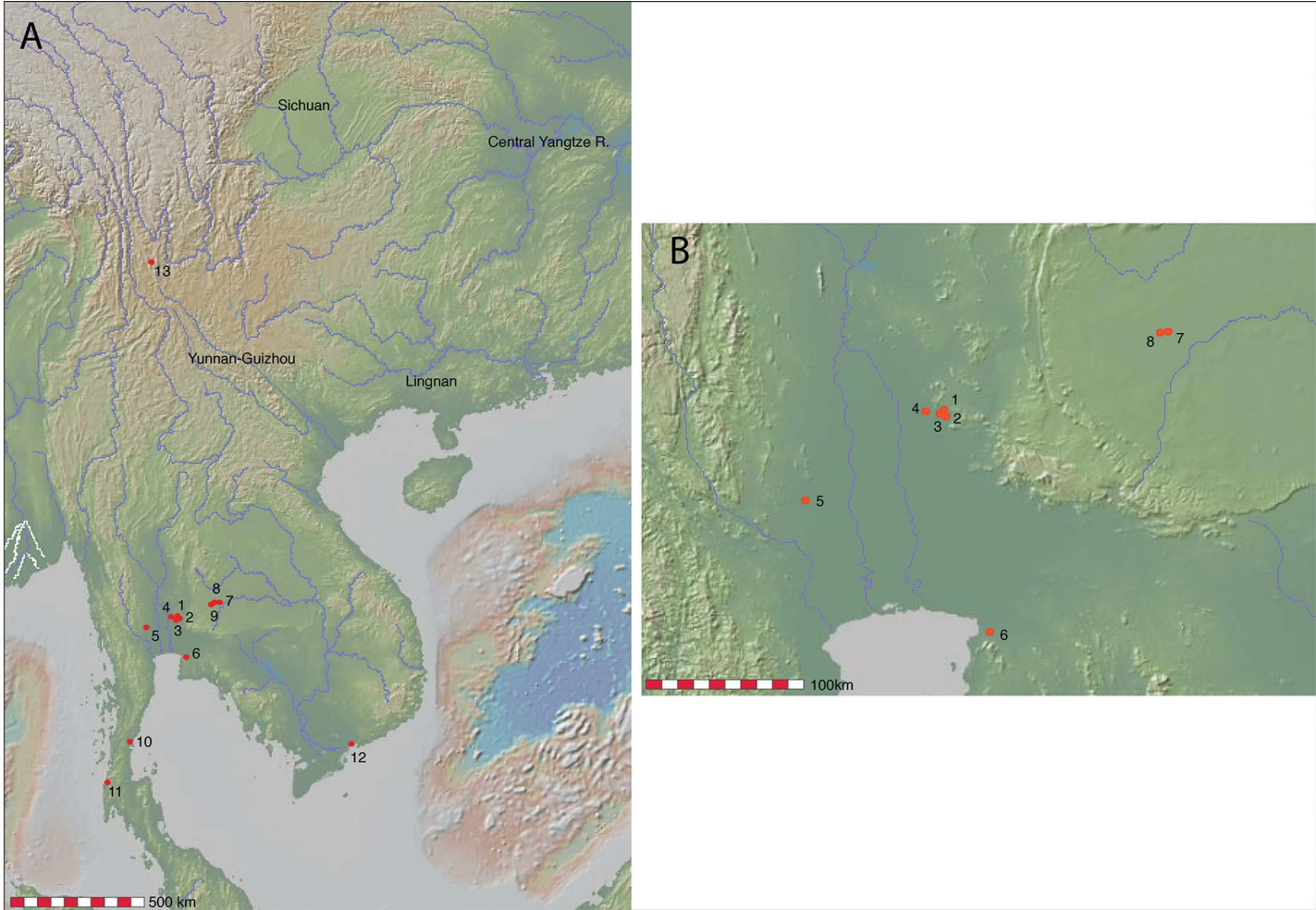


Figure 1. Location of sites mentioned in the text. A: 1) Non Pa Wa; 2) Nil Kham Haeng; 3) Non Mak La; 4) Phromtin Tai; 5) Nong Ratchawat; 6) Khok Phanom Di 7) Ban Non Wat; 8) Noen U-Loke; 9) Non Ban Jak; 10) Khao Sam Kaeo; 11) Phu Khao Tong; 12) Rach Nui; 13) Haimenkou. B: 1) Non Pa Wai; 2) Nil Kham Haeng; 3) Non Mak La; 4) Phromtin Tai; 5) Nong Ratchawat; 6) Khok Phanom Di; 7) Ban Non Wat; 8) Noen U-Loke (figure made by C.F.W. Higham using GeoMapApp ([https://urldefense.com/v3/\\_http://www.geomapapp.org\\_!!Mih3wA!QFNtjNA\\_zEWfMv4616kXxCuTgH\\_PRNyh\\_Y8I6Gxe0Vg\\_SopNyrzjTNbCJHmsVvg\\$](https://urldefense.com/v3/_http://www.geomapapp.org_!!Mih3wA!QFNtjNA_zEWfMv4616kXxCuTgH_PRNyh_Y8I6Gxe0Vg_SopNyrzjTNbCJHmsVvg$)); CC BY (Ryan et al. 2009)).

and to determine which areas of early agricultural systems may have come under adaptive stress.

## Sites and excavations

Data from Non Pa Wai, Non Mak La and Nil Kham Haeng were obtained by the Thailand Archaeometallurgy Project, and those from Phromtin Tai were acquired during excavations by Thanik Lertcharnrit. We combined these data to evaluate how farming strategies were modified from the earliest Neolithic to the late historic period.

Phromtin Tai, a moated settlement and burial site with evidence for copper production occupied from the Iron Age to the Dvaravati period (*c.* 500 BC to tenth century AD), is located close to the floodbanks of the Chao Phraya River (d'Alpoim Guedes *et al.* 2019). Non Pa Wai, Non Mak La and Nil Kham Haeng are located in the Khao Wong Prachan Valley in Lopburi Province on the eastern margin of the Chao Phraya River Valley (Figure 1) (Pigott *et al.* 1997; Rispoli *et al.* 2013; Pigott 2019). They all lie close to valley copper ore sources, and have yielded evidence for settlement and copper smelting. Non Pa Wai and Nil Kham Haeng, both approximately 5ha in size, are among the largest known prehistoric copper-smelting sites in Asia. Non Mak La, an even larger multi-purpose settlement and burial site, has yielded only modest copper-smelting evidence. Our current understanding is that the earliest occupation in the Khao Wong Prachan Valley dates to the late third millennium BC. Copper-base metallurgy began towards the end of second millennium BC, with intensive production in the following millennium. Together, these sites are one of only two major prehistoric copper-production centres known in Southeast Asia (Pigott 2019; Higham *et al.* 2020). Although the final reports of these sites remain unpublished, significant research is in print (see Pigott *et al.* 1997; Weber *et al.* 2010; Rispoli *et al.* 2013; Higham *et al.* 2020).

We report here the results of the analysis of 247 samples containing charred seeds for which we have contextual information. Seeds were found in approximately 30 per cent of floated samples (see the online supplementary material (OSM)). We focus our analysis on the temporal distribution of these remains over several phases (Table 1; full results in the OSM, Table S1).

## Results

Although we recovered only small quantities of archaeobotanical remains from Neolithic phase 1, no rice caryopses, husks or spikelets were found. Remains from phase 1 consist entirely of foxtail millet (*Setaria italica*), confirming patterns previously noted by Weber *et al.* (2010). Only a few samples from the later Neolithic (phase 2) components of Non Pa Wai and Non Mak La contained seeds. While rice remains are present, foxtail millet remains the numerically dominant crop throughout the Early Bronze Age (phases 3 and 4). Rice progressively increases throughout the assemblage. By phase 5 (the Late Bronze Age), rice comprises half the raw seed count, and by the Iron Age (phase 6) and following the Dvaravati phase (phase 7), it dominates the raw count at Phromtin Tai (Figure 2).

Table 1. Phases present at the sites discussed.

Phase	Sites for which phase is present	Dates (cal BC/AD)
Phase 1 (Early Neolithic)	Non Pa Wai	2300–1600
Phase 2 (Late Neolithic)	Non Pa Wai/Non Mak La	1500–1200
Phases 3–5 (Bronze Age)	Non Pa Wai/Non Mak La/Nil Kham Haeng	1100–500
Phase 6 (Iron Age)	Non Pa Wai/Non Mak La/Nil Kham Haeng/Phromtin Tai	500 BC–AD 500
Phase 7 (Dvaravati)	Phromtin Tai	AD 500–900

Rice spikelets from assemblages in China after 4000 BP show high proportions of domesticated spikelet bases. At Neolithic Baiyangcun in Yunnan (third millennium BC), for example, 76 per cent of spikelet bases were from domesticated rice (Dal Martello *et al.* 2018). In our samples, domesticated spikelets account for only 20 per cent of the total assemblage, suggesting that local varieties of wild rice (*Oryza rufipogon*) were gathered alongside introduced and domesticated rice. Although the numbers of rice spikelets are too low in phases 2–4 for meaningful statistical analyses, large quantities of wild spikelets are present

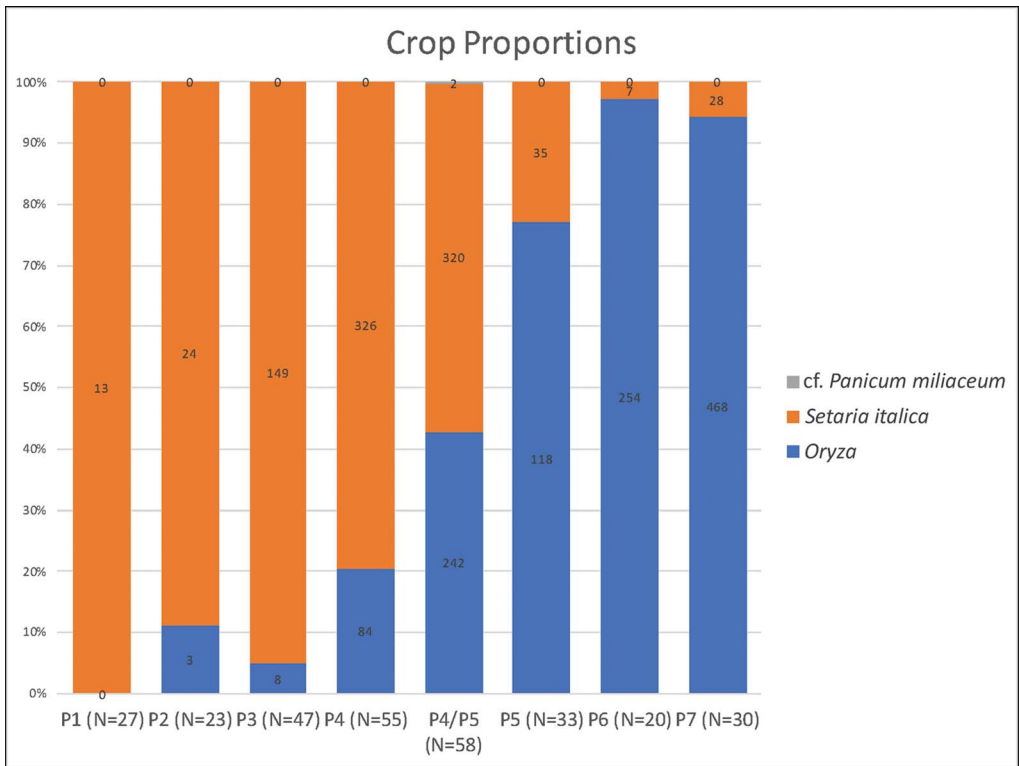


Figure 2. Grain-crop proportions by phase from Non Pa Wai, Non Mak La, Nil Kham Haeng and Phromtin Tai. Note that phase 6 represents a combination of samples from both Phromtin Tai and the Thailand Archaeometallurgy Project sites; N = number of samples; numbers on histogram are numbers of charred seeds (figure by J. d'Alpoim Guedes).

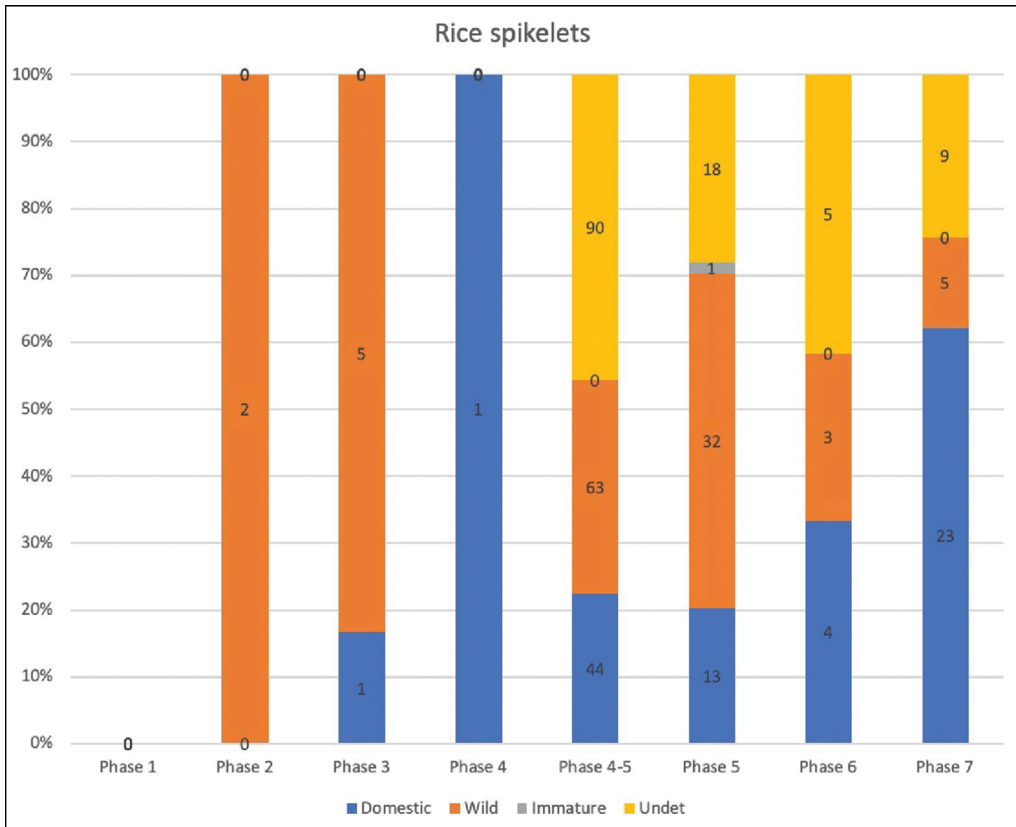


Figure 3. Proportions of rice spikelets by phase at Non Pa Wai, Non Mak La, Nil Kham Haeng and Phromtin Tai; N = number of samples; numbers on histogram are numbers of seeds (figure by J. d’Alpoim Guedes).

in phases 4/5–6 (Figure 3). An increase in the number of domesticated spikelets in the Dvaravati phase (phase 7) is only seen at Phromtin Tai. Many spikelets in our assemblage, however, were poorly preserved, and it is possible that this has skewed our results.

One specimen of pigeon pea (*Cajanus cajan*) appears during phase 3 at Non Pa Wai (Figure 4). The natural range of *Cajanus* sp. is in South Asia, where some of the earliest domesticated examples date to c. 1500 BC (Fuller *et al.* 2019). Pigeon pea has been found at other sites in Southeast Asia, including Khao Sam Kaeo and Phu Khao Tong (Figure 1), although its chronological context is unclear (Castillo *et al.* 2016a). Depending on the age of these specimens, the pigeon pea at Non Pa Wai may be one of the earliest in Southeast Asia. Several fragments of another unidentified Fabaceae, possibly *Vigna* sp., appear in phases 4–5 at Non Pa Wai. The presence of cotton (*Gossypium* sp.) at Phromtin Tai in phase 7 also suggests contact with South Asia (Figure 4) (see d’Alpoim Guedes *et al.* 2019).

Fruit remains were also present at our sites. Citrus rind begins to appear in phase 1 of Non Pa Wai. Taxa include *Citrus medica* (lemon or lime), potentially native to the southern flanks of the Himalayas and *Citrus reticulata* (oranges or mandarins), also possibly native to South

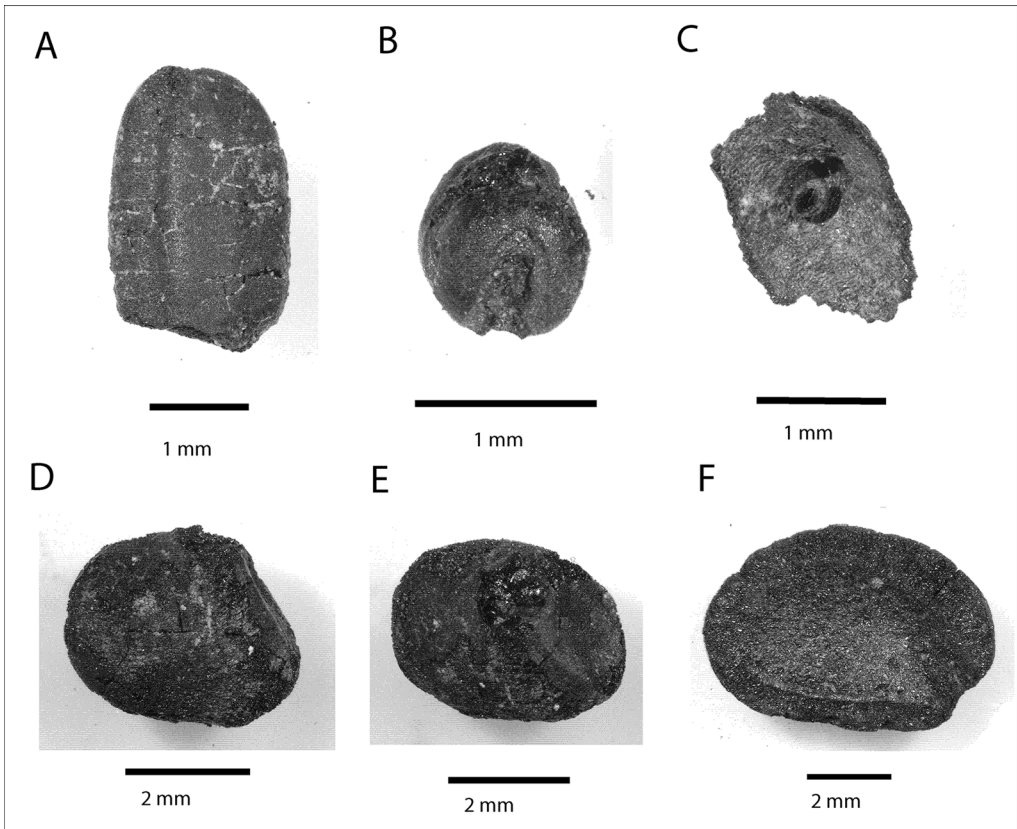


Figure 4. Key domestic pulse and grain taxa from Non Pa Wai, Non Mak La, Nil Kham Haeng and Phromtin Tai: A) rice (*Oryza sativa*); B) foxtail millet (*Setaria italica*); C) cotton (*Gossypium* sp.) funicular cap; D–E) pigeon pea (*Cajanus cajan*); F) unidentified Fabaceae (figure by J. d'Alpoim Guedes).

Asia. The rind of *Citrus maxima* (pomelo), whose potential centre of domestication may be in Southeast Asia, has been identified at Khao Sam Kaeo and Phu Khao Tong (Castillo *et al.* 2016a & b). *Citrus maxima* has marked raised *pusticulae* (warts) on the rind's surface (Fuller *et al.* 2017), a feature not visible on the specimen we recovered in phase 4 at Non Mak La. This specimen appears to conform most closely to *C. medica*, which has fewer visible oil glands that are angular and squarish in appearance (Fuller *et al.* 2017) (Figure 5). This may show further connections with South Asia (Rispoli *et al.* 2013: 150–57). Two additional, tiny and unidentifiable citrus rind fragments were found; one in phase 2 of Non Mak La, and one in phase 3 of Nil Kham Haeng.

Several other wild foraged fruit remains were also found in our assemblage. The number of seeds of a wild date palm fruit, probably of the genus *Phoenix* because of its oval shape and large groove running along the ventral side (Figure 5), increased over time in the assemblage. While some *Phoenix* species are native to the Indian subcontinent, *Phoenix roebelenii* is native to south China and Southeast Asia, and its fruits are edible (Barrow 1994; Frodin & Govaerts 2002). At 5mm in length, our specimens are smaller than examples reported in the literature

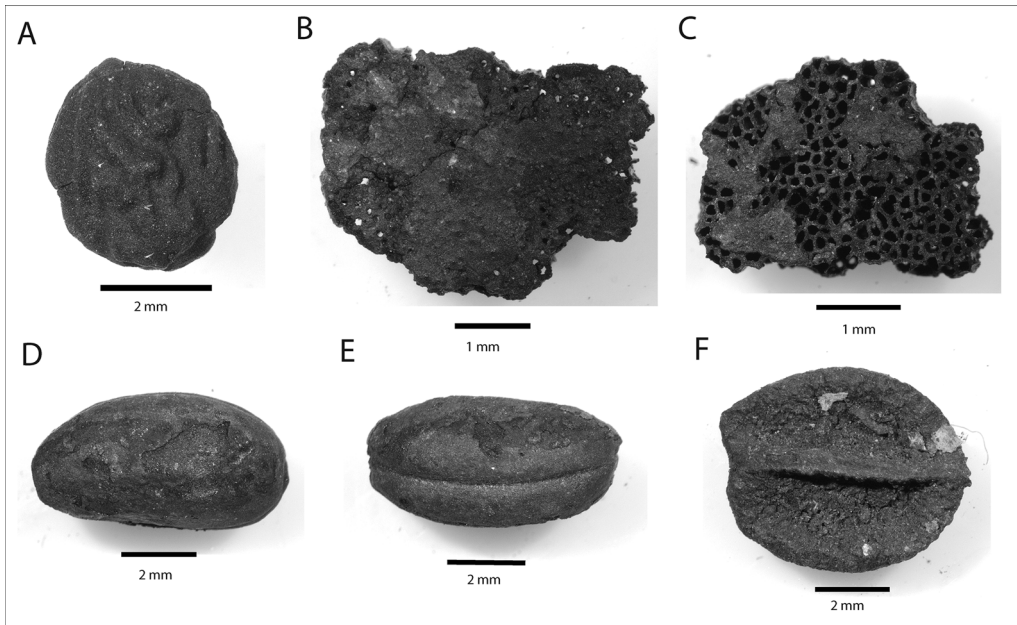


Figure 5. Key fruit taxa unearthed at Non Pa Wai, Non Mak La, Nil Kham Haeng and Phromtin Tai: A) Indian jujube (*Ziziphus mauritiana*); B–C) cf. *Citrus maxima* (pomelo) rind; D–E) pygmy date palm (*Phoenix roebelenii*); F) *Cassia* sp. (figure by J. d’Alpoim Guedes).

(Frodin & Govaerts 2002). Palm leaf epidermis phytoliths were also recovered at Non Mak La, suggesting that palm trees were encouraged to grow near the site, or that palm leaves were regularly employed for economic purposes (Kealhofer 2002).

Other fruits in the assemblage include one specimen of the Indian jujube (*Ziziphus mauritiana*) in phases 4–5 at Nil Kham Haeng, and a single specimen of *Cassia* (*Cassia* sp.) from phase 4 at Non Pa Wai (Figure 5). Both species are probably native to Southeast Asia. Indian jujube is an important economic fruit; as for *Cassia* sp., its leaves and flowers are edible, and its wood may have also been used.

Seeds traditionally considered to be weeds were identified in substantial numbers, including aster (*Acmella paniculata*), *Chenopodium*-amaranth perisperms, *Trianthema* sp. and a wild member of the Aveneae tribe (Figure 6). All these ‘weedy’ taxa are found primarily in dryland habitats (Caton *et al.* 2004). Despite the increasing importance of rice, these dryland weeds form the majority of the assemblage, suggesting that the rice at these central Thailand sites was grown in a rain-fed upland and not in an irrigated paddy environment. *Acmella paniculata* was identified in Bronze Age contexts at Ban Non Wat, where it was considered as evidence for dryland (i.e. rain-fed) rice cultivation (Castillo *et al.* 2018a).

A few wetland weeds such as *Fimbristylis* sp. (sedge) are present, but in small amounts (Figure 7), a result that is consistent with previous research showing very low numbers of sedges but high numbers of panicoid and bambusoid grasses and members of the *Asteraceae* family (Kealhofer 2002). All these weeds are common in open woodlands maintained by regular burning regimes (Kealhofer 2002; Pigott *et al.* 2006). Many of these ‘weedy’ taxa also serve



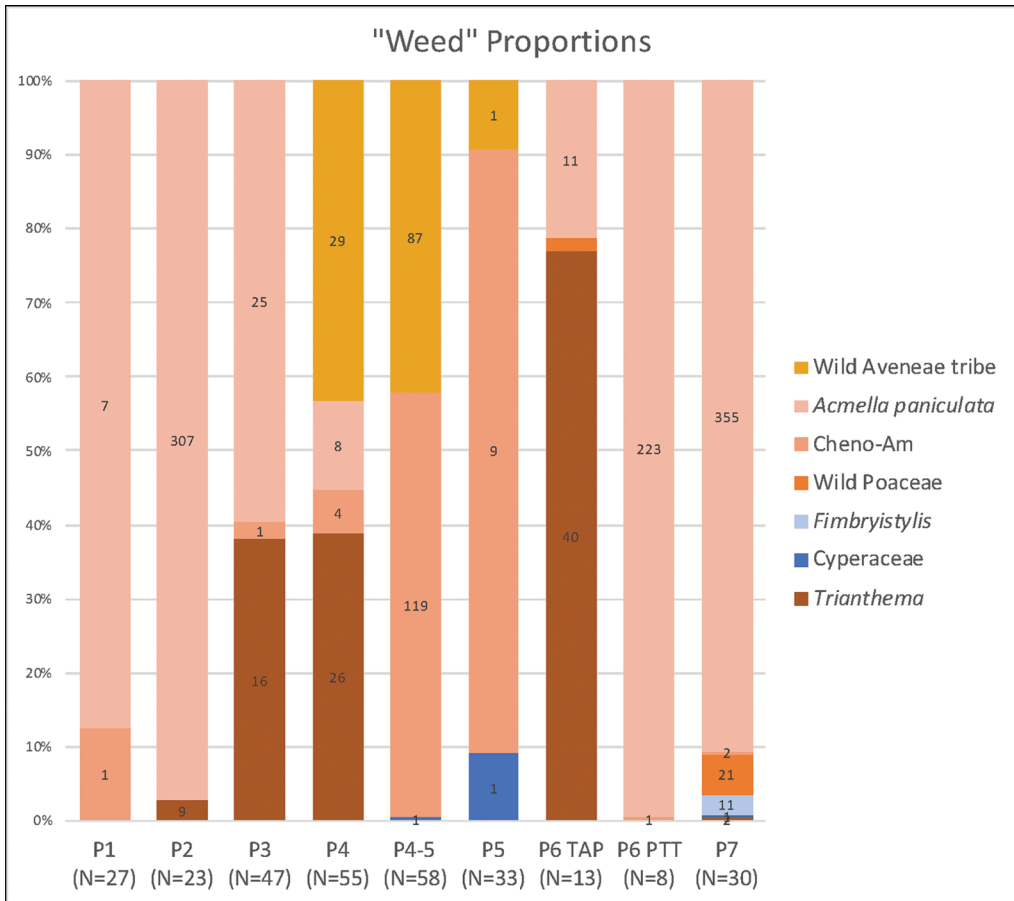


Figure 6. Weed seed proportions at Non Pa Wai, Non Mak La, Nil Kham Haeng and Phromtin Tai by phase (figure by J. d'Alpoim Guedes).

important functions in modern Thai cuisine: leaves of *Acmeella* and *Chenopodium* (goosefoot), for example, are important greens in stir-fries, and hence mechanisms other than land management could explain their presence in our assemblages (see d'Alpoim Guedes et al. 2019).

### Field ecology and cultivation practices in central Thailand

The weedy taxa in our assemblage come from a primarily upland (or rain-fed) environment. As foxtail millet is a rain-fed crop, it is possible that some of the weedy taxa from these sites came from millet fields. Rice can be grown in both upland (rain-fed) and lowland (irrigated, or paddy) habitats (Fuller & Weisskopf 2011). Despite an increasing proportion of rice in our assemblage, the high proportion of upland weeds and almost negligible amount of wetland weeds suggests that rice may have been cultivated as a dryland, rain-fed crop. Irrigated rice requires plants to be in water during the establishment of shoots, and dry at the time of flowering and grain production (Fuller & Weisskopf 2011). This demands either an artificial or

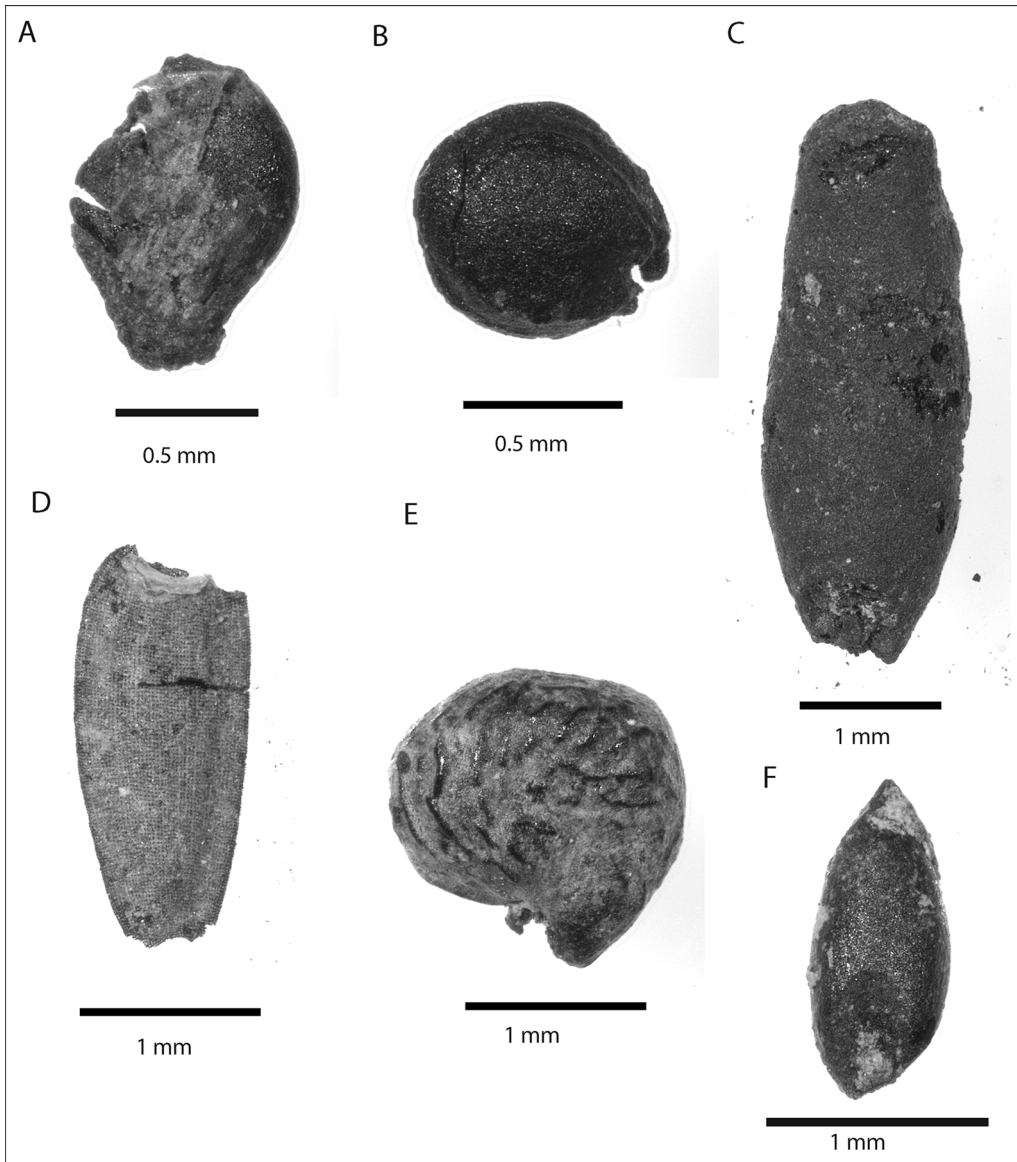


Figure 7. Key weedy taxa recovered at Non Pa Wai, Non Mak La, Nil Kham Haeng and Phromtin Tai: A) sedge (*Cyperaceae*); B) *Chenopodium-amaranth perisperm*; C) *Aveneae* tribe; D) aster (*Acnema paniculata*); E) *Trianthema* sp.; F) *Panicoid* grass (figure by J. d'Alpoim Guedes).

natural paddy environment: one that can maintain stands of water around plants, but also allows for this water to be drained at specific times of the crop growth cycle. Rain-fed rice, particularly wild varieties, rely on monsoonal flooding of lake edges, followed by drying (White 1995).

The large quantity of silicified (i.e. turned to silica) rice husks in our samples suggest that rice-crop-processing probably took place onsite, the rice being cultivated nearby and

transported to the site in sheaths. It is therefore unlikely that this rice was imported in exchange for metal goods (Mudar & Pigott 2003).

Rain-fed (upland) varieties of rice generally grow only in areas where annual rainfall exceeds 800–1000mm (Yoshida 1981; Jacquot & Courtois 1987). Today, the Lopburi Plain has sufficient rainfall (averaging 1200–1300mm annually) to support both rain-fed millet and rice. A reduction in rainfall of between 200 and 300mm would render the cultivation of rain-fed rice marginal. Frequent droughts occur in the area today and may have made rice cultivation less reliable than millets in the past. This may explain the continued presence of foxtail millet in our assemblage, until at least the Iron Age (Figure 4). Millets may have been attractive crops for Southeast Asian foragers, who had begun to interact with shifting cultivators, because millets have short growing seasons (as little as 60–90 days) and do not require investment in irrigation (d'Alpoim Guedes 2011; d'Alpoim Guedes & Butler 2014).

The high proportion of wild-type spikelets in our samples may indicate that a significant number of wild plants (*O. rufipogon*) were growing in the fields. This may have reduced the yield of rice, reinforcing the importance of millet for consistently reliable yields. Indeed, White's (1995) ethnographic work in north-east Thailand has demonstrated that wild varieties of rice still grow along streams and lake edges during the rainy season. It is possible that this wild rice was gathered by local foragers prior to the arrival of domesticated rice into the Khao Wong Prachan Valley. The inhabitants of the sites discussed here may have continued this tradition.

Compared to other sites in Southeast Asia and China, both our weed flora data and previous phytolith work (Pigott *et al.* 2006) from central Thailand suggest that the inhabitants invested less labour in the construction and maintenance of irrigated paddy fields. Instead, they continued to focus on less intensive dryland rice and millet cultivation systems. Pigott *et al.* (2006) and Rispoli *et al.* (2013) have noted that plough animals, such as cattle and water buffalo, are rare in the Non Pa Wai faunal assemblages well into the Iron Age, suggesting that local agriculture did not involve much use of animal traction or ploughs. This is particularly evident when compared to other Iron Age sites in Thailand, such as Noen U-Loke, where an iron ploughshare was found as a funerary offering, and a palimpsest of cattle and water buffalo hoof prints have been interpreted as draught animal enclosures (Castillo *et al.* 2018b). The presence of sickles and hoes at Tha Kae near the Khao Wong Prachan Valley (Rispoli *et al.* 2013) and at Phromtin Tai suggests less intensive modification of the local landscape. We argue that rice-cultivation practices in early central Thailand mimicked the habitat and intensity with which indigenous wild rices were probably gathered.

This pattern of low-intensity gathering and upland farming is also reflected in our sites' faunal records, which show high proportions of wild animals compared to domesticated taxa, such as pigs and dogs (Pigott *et al.* 2006), suggesting a continuation of traditions begun by local foragers.

## Climatic factors and the spread of agriculture to central Thailand

The direction from which both early farming and metallurgy spread from East Asia into central Thailand has long been unclear, although certain pottery styles in the earliest layers at sites in central Thailand (e.g. Non Pa Wai and Tha Kae) suggest strong connections with sites such as Baiyangcun and Dadunzi in Yunnan (Rispoli 2007; Rispoli *et al.* 2013)—connections that

continued into the Bronze Age. A deep-socketed axe from a burial at Non Pa Wai, for example, shares similarities with axe moulds from Haimenkou in Yunnan Province (Higham *et al.* 2011; Chiou-Peng 2018).

Our analysis confirms that millets were probably the earliest crops introduced to the Khao Wong Prachan Valley, arriving by *c.* 2300 cal BC (following Weber *et al.* 2010). Foxtail millet cultivation was practised along the margins of the Tibetan Plateau in China as early as *c.* 3500 BC (d'Alpoim Guedes 2011; d'Alpoim Guedes *et al.* 2016). Millets appear in our samples by *c.* 2300 cal BC, shortly after appearing on the Chengdu Plain (*c.* 2700 BC) and in Yunnan Province (*c.* 2600 cal BC), where they are coupled with finds of rice (d'Alpoim Guedes *et al.* 2013; Jin *et al.* 2014; Dal Martello *et al.* 2018). Both crops also appear together in archaeobotanical assemblages in south-eastern China, *c.* 2200 BC (Deng *et al.* 2017). The initial introduction of millets without rice into the Khao Wong Prachan Valley suggests that millets may have been part of an early spread of domesticates transmitted via the Eastern Himalayas through the Yunnan-Guizhou Plateau, a transmission that took place before that of rice farming.

It has been argued that early rice in Thailand was primarily *Oryza sativa*, subspecies *japonica*, which moved into Southeast Asia from East Asia (Castillo & Fuller 2010; Castillo *et al.* 2016b). Recent genetic data on rice from Khao Sam Kaeo, Phu Khao Tong, Ban Non Wat and Noen U-Loke show that early archaeobotanical rice in Thailand conforms to a *japonica* cultivar (Castillo *et al.* 2016b), rather than *Oryza sativa* subspecies *indica*. The latter was probably domesticated in South Asia following introgression with *japonica* species (Fuller *et al.* 2010). Our samples contain too few measurable grains to confirm this for the earliest examples of rice at the sites examined here. Following Castillo and Fuller (2010), however, we presume that the rice found in central Thailand was a *japonica* rather than an *indica* cultivar. Both tropical and temperate varieties of *O. japonica* exist, and genetic evidence reveals that tropical *O. japonica* is probably ancestral to temperate *O. japonica* (Garris *et al.* 2005; Sweeney & McCouch 2007). Today, the range of tropical *O. japonica* is limited to Southeast Asia and far southern China. In the warmer Early Holocene (before 2000 cal BC), however, this crop may have ranged as far as north-eastern China (d'Alpoim Guedes & Bocinsky 2018).

After 2000 cal BC, increasingly cooler temperatures led to a retreat of the area available for cultivating tropical varieties of *O. japonica* to south-eastern China and Southeast Asia (Figure 8). By 1590 cal BC, farmers of tropical rice varieties in both Yunnan and the Central Yangtze region would have already begun to experience difficulties in cultivating this crop (d'Alpoim Guedes & Bocinsky 2018; Gutaker *et al.* 2020) (Figure 8). While large parts of Zhejiang and Hunan lost their suitability for tropical *O. japonica*, the higher-altitude Yunnan-Guizhou Plateau suffered the largest loss of area suitable for this type of rice. Temperate varieties of *O. japonica* appear to have fared better, even if their range was compromised, particularly in Yunnan and Guizhou (Figure 8).

It is possible that the reduced territory suited to rice farming may have led Yunnan farmers who practised metallurgy in the later second millennium BC to either intensify their trade relationships, or to seek warmer areas in which to cultivate tropical *O. japonica*. Wild varieties of tropical *japonica* rice could also have spread south as their range was affected at higher altitude and latitude. Rice falls out of the diet at sites such as Haimenkou *c.* 1590 BC to be replaced by cold-hardy Western Eurasian domesticates, such as wheat and barley (Jin *et al.* 2014).

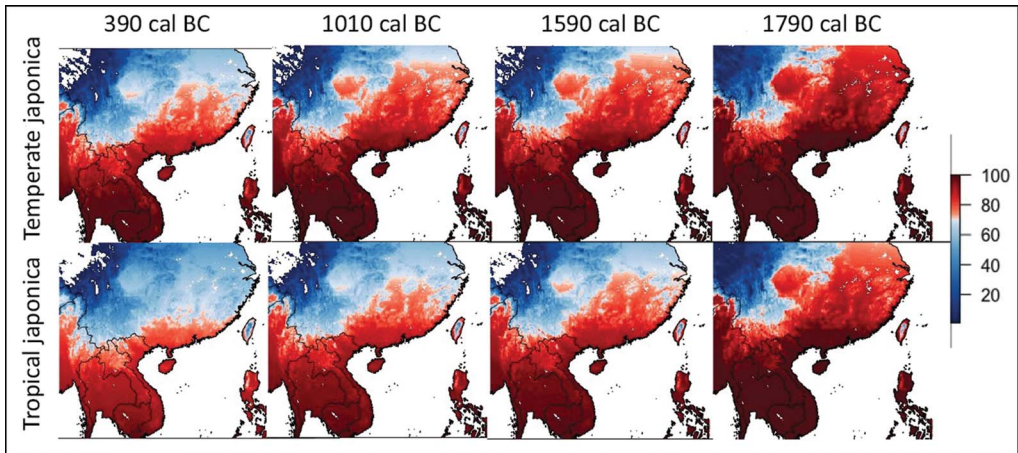


Figure 8. Changes in the probability of rice being in the thermal niche at key time intervals throughout the Late Holocene: blue) areas where growing rice is below the 70 per cent threshold of being in the niche; red) areas where rice is above this threshold (map created using methodology published in d'Alpoim Guedes and Bocinsky (2018); figure by Jade d'Alpoim Guedes).

The substantial decrease in the thermal niche for tropical rice following the second millennium BC on the Yunnan-Guizhou Plateau may have contributed to the intensification of trade networks or influenced farmers to migrate south in search of more suitable environments to grow their crops. The timing of this climatic downturn may explain the intensified connections between Yunnan and Southeast Asia, and possibly also the spread of people, rice and tin-bronze technology. This was not, however, the only factor that contributed to the spread of crops into Southeast Asia. Millet, for example, spread earlier in ways unrelated to climatic factors, and the initial spread of rice by 2000 cal BC to sites such as Rach Nui in southern Vietnam does not appear to have been precipitated in this way (Castillo *et al.* 2018b), perhaps indicating the existence of coastal routes into Southeast Asia.

## Conclusion

In this article, we have documented an early arrival of millet into the Khao Wong Prachan Valley of central Thailand (Weber *et al.* 2010). The presence of millet, initially without rice, suggests that it may have formed part of an early transmission of domesticates via the Eastern Himalayas through the Yunnan-Guizhou Plateau highlands. Over the 3000 years of occupation recorded at the sites examined here, rice replaced millet as the dominant crop, but, up to and including the historic Dvaravati period, there is no evidence for intensifying rice production through ploughing or irrigation. Rather, dryland, rain-fed cultivation dominated, representing a continuation of local forager subsistence practices. This contrasts sharply with the sequence at Khok Phanom Di, where a coastal saline environment generally militated against rice cultivation (Thompson 1992). It also contrasts with the sequences in the Upper Mun Valley occupation sites of Ban Non Wat, Noen U-Loke and Non Ban Jak, which have not yielded a single grain of millet, despite intensive flotation. There, rice dominated from initial settlement in the seventeenth century BC until the end of the

prehistoric period. Moreover, a sharp increase in aridity from *c.* AD 200 stimulated an agricultural revolution involving the construction of reservoirs and the reticulation of water into permanent, ploughed rice fields (Wohlfarth *et al.* 2016; Castillo *et al.* 2018b).

Ongoing research in the Khao Wong Prachan Valley, and more generally in Southeast Asia, continues to reveal the story of its human past. The analysis of further data may provide a clearer understanding of the development of the cultivated landscape of Southeast Asia and add detail to the ‘Two Layer Hypothesis’ about the expansion of millet- and rice-farming communities into a region occupied for millennia by foragers.

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## Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.15184/aqy.2020.8>.

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