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RESEARCH ARTICLE

# Zooarchaeology of Ban Chiang and the rise of early farming communities in mainland Southeast Asia

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## Abstract

Ban Chiang is a prehistoric settlement located in the northeast Khorat Plateau in Thailand. Excavations in 1974–1975 identified a cultural sequence that spanned the arrival of the first rice farmers in ca. 1500 BC until the end of the Iron Age two millennia later. The large faunal sample includes the remains of mammals, fish, birds, and shellfish that illuminate aspects of the economy and environment. Domestic cattle, water buffaloes, pigs, and dogs, all domesticated in southern China, were introduced and maintained in an economy that incorporated hunting, fishing and collecting shellfish. The jungle fowl, *Gallus gallus*, was probably locally domesticated. When considered in its broader context, the faunal remains from Neolithic coastal Vietnamese and Thai sites present a very different picture. In the coastal sites, pigs and dogs dominate, but domestic cattle and chickens are virtually absent. The incoming farmers placed much reliance on marine hunting and fishing. Recent multidisciplinary research has identified an agricultural revolution involving animal traction and plowing in irrigated rice fields that occurred as the monsoon rains faltered from ca. AD 200. This took place in the relatively dry Mun River Valley in the southern part of the Khorat Plateau and rapidly led to the foundation of early states. Ban Chiang, however, enjoys higher natural rainfall and evidence for the agricultural revolution there appears muted or absent.

KEYWORDS
Ban Chiang, domestication, fauna, irrigation, plowing, prehistory, subsistence, Thailand

## 1 | INTRODUCTION

Ban Chiang is a prehistoric settlement in the northeastern part of the Khorat Plateau of Thailand (Figure 1). It has been a controversial site since claims were made, following the excavations of 1974–1975, for remarkably early bronze casting and iron forging (Gorman & Charoenwongsa, 1976). The faunal remains from the 1975 excavation of Ban Chiang were analyzed by Amphan Kijngam and Charles Higham in the British Museum (Natural History), where an unrivaled comparative collection of skeletal remains was available The results were fully described in Kijngam's Masters dissertation (Kijngam, 1979), but only a preliminary summary has been published (Higham & Kijngam, 1979). That summary has been overtaken by further research, and in this review, we incorporate the new evidence for the site's chronology and cultural sequence. In 1978/1979, the chronology as proposed on the basis of the first set of radiocarbon determinations had the initial settlement in at least the midfourth millennium BC and the transition into the Iron Age in the midsecond millennium BC (Gorman & Charoenwongsa, 1976). By dating the human bones, the chronology has now been radically revised. The initial Neolithic settlement took place in ca 1500 BC, the transition into the Bronze age ca. 1000 BC, and the first iron has been dated to the 5th century BC (Higham et al., 2015). Shortening of the chronology directly affects the interpretation of the faunal remains both as a reflection of subsistence, the evidence for radical changes in rice cultivation, and for the reconstruction of the environment.

### 1.1 | The excavation of Ban Chiang

There have been several excavation campaigns at Ban Chiang (Figure 1). Those involved in this assessment took place in 1975. The former season yielded a few Neolithic burials, followed by Bronze and Iron Age occupation and burials. None of the 1974 faunal remains have been analyzed, but the initial Neolithic settlement in that part of the site has been dated to ca. 1500 BC. This paper deals only with the 1975 season. The area opened measured 3.5 by 17 m. Both authors participated, CH for a month and AK throughout. With the exception of one Neolithic burial dated to 1415–1230 cal. BC, the lower cultural contexts contained three rows of Bronze Age burials, dated within the span ca 1100–800 BC (Figure 2; Higham et al., 2015). This was followed by a second phase of Bronze Age burials dating ca. 800–450 BC. Twenty early Iron Age and 10 late Iron Age burials complete the sequence. The stratigraphic sequence at this site has been very hard to interpret due to bioturbation and disturbances as in the digging of pits and graves. By relating the depth of the individual graves below datum with the cultural levels as recorded for each bone analyzed, we can divide the sample into two major groups. The first belongs to the Bronze Age occupation, the second to the Iron Age. This is the basis of the following discussion.

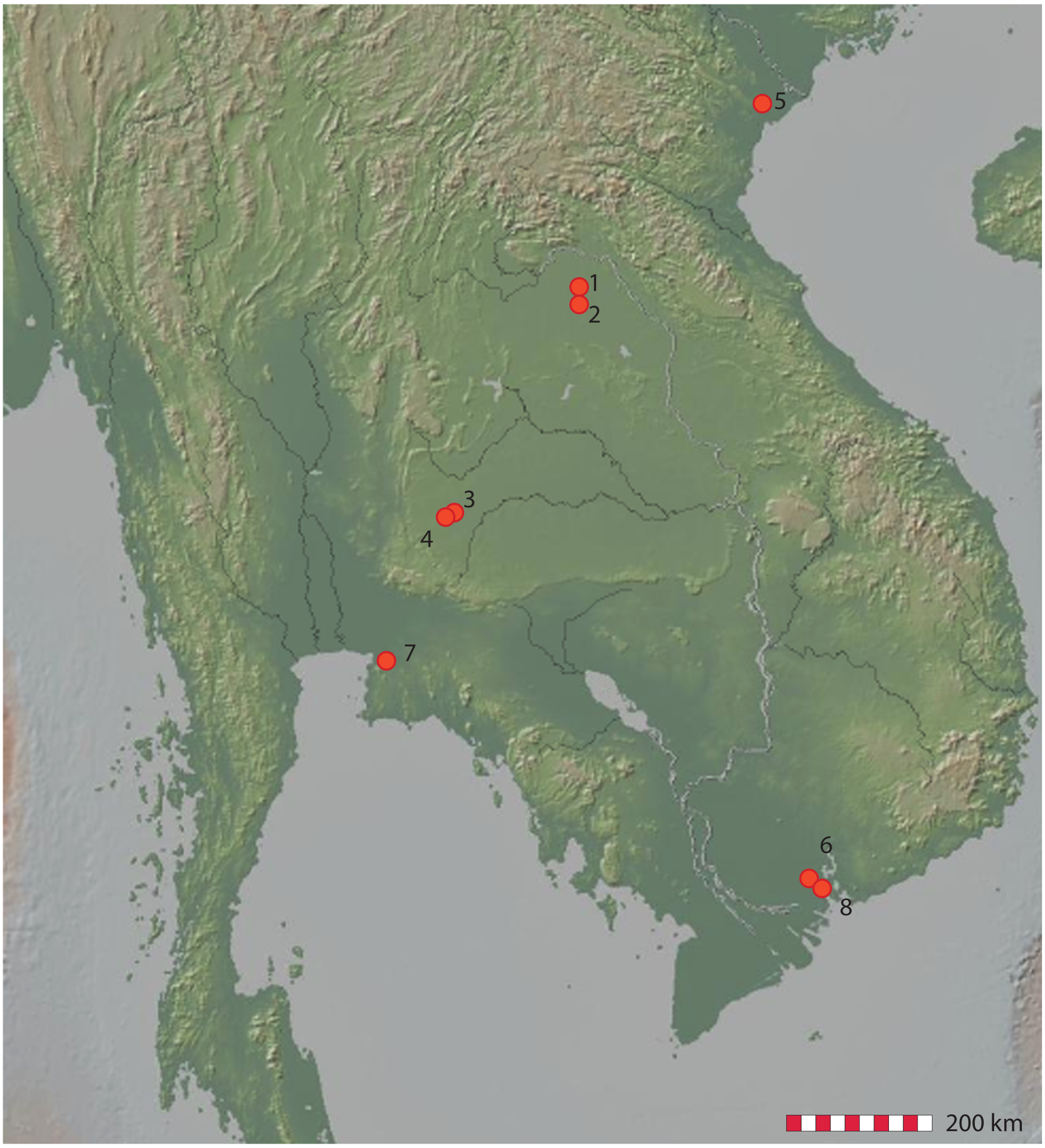


FIGURE 1 Map showing the location of the sites mentioned in the text. 1. Ban Chiang, 2. Ban Na Di, 3. Ban Non Wat, 4. Noen U-Loke, Non Ban Jak, 5. Man Bac, 6. An Son, 7. Khok Phanom Di, 8. Rach Nui [Colour figure can be viewed at wileyonlinelibrary.com]

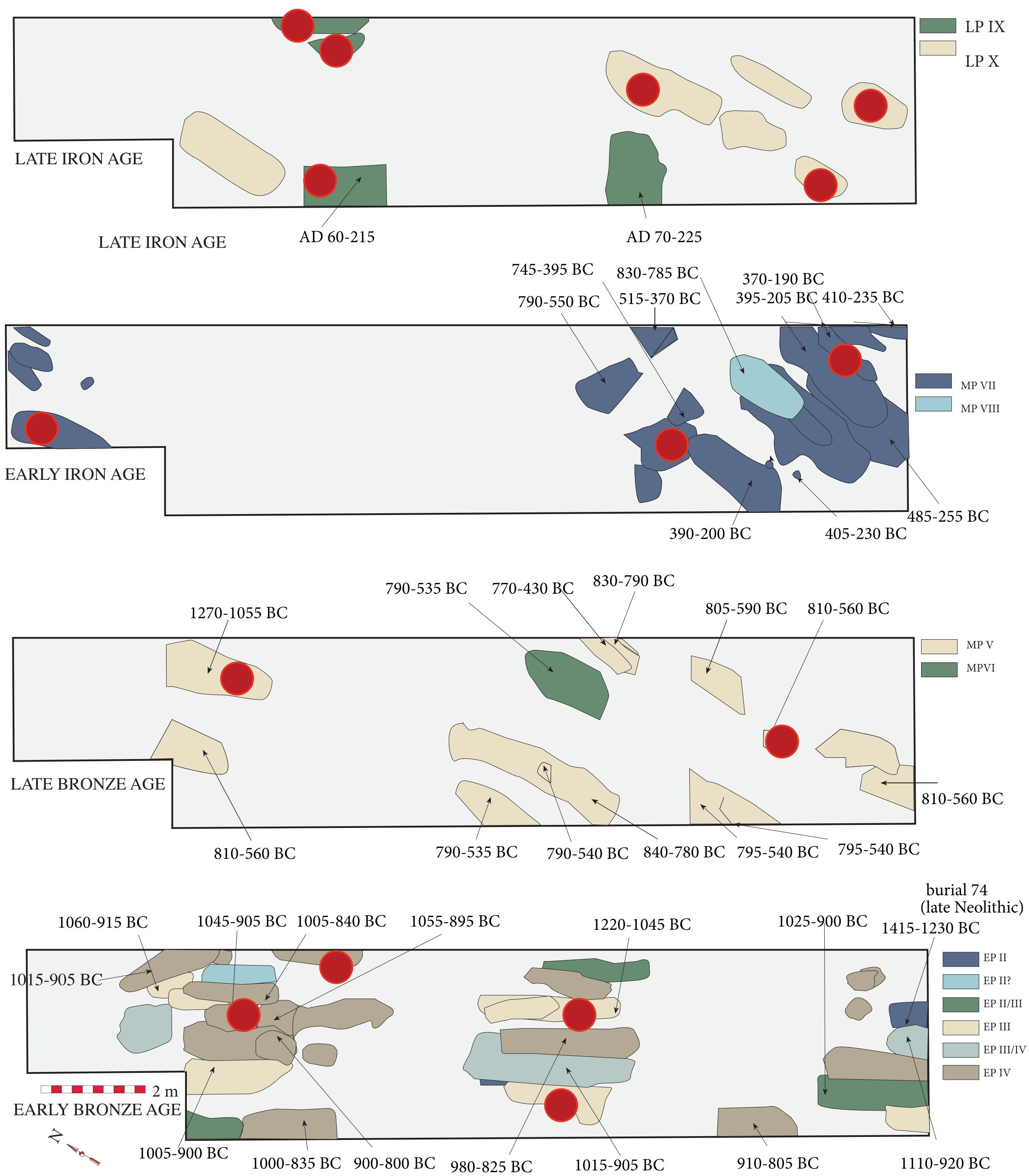


**FIGURE 2** The four phases of the mortuary sequence at Ban Chiang 1975, showing the graves with animal bone offerings (circles) [Colour figure can be viewed at wileyonlinelibrary.com]

## 1.2 | The species identified

### 1.2.1 | Family Bovidae, genus *Bos* sp., species *Bos taurus*, *Bos javanicus*, *Bos gaurus*, *Bos nauveli*

In order to distinguish between cattle and water buffalo, modern comparative limb bones were collected from Ban Chiang and the Bangkok municipal abattoir. These comprised the distal bones of both fore and rear limbs, from the metapodials to the third phalanges. This a significant procedure, because the water buffalo is widely employed for pulling a plow due to its strength and suitability to traction in wet fields. We identified a series of consistent differences between the two genera, on the basis of both size and form, summarized in Figure 3 with the scatter plot for the metacarpal. This allowed us to distinguish between the two for a reasonable number of anatomical bones.

There has been a long-standing inability to identify whether the early domestic cattle of Southeast Asia were introduced, as was

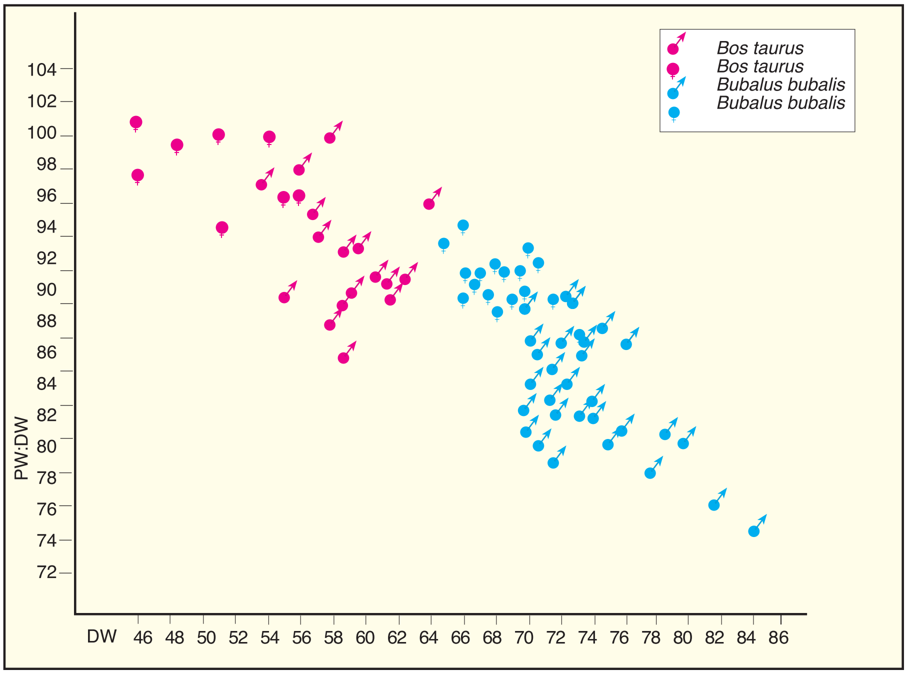


**FIGURE 3** The modern metacarpals from *Bos taurus* and *Bubalus bubalis*, on the basis of the distal width and the ratio of proximal width to distal width [Colour figure can be viewed at wileyonlinelibrary.com]

rice, with the expansion of Neolithic farmers from the north. This issue has now largely been resolved, with the analysis of mitochondrial DNA from cattle bones sourced at Ban Chiang and Ban Non Wat. The results identify the origins of the prehistoric Thai cattle in Chinese *B. taurus* (Siripan et al., 2019). There is no evidence for domestication of the indigenous gaur, banteng, or kouprey. The modern Thai cattle, however, are found to be exotic imports from South Asia.

In analyzing the sample of bovid bones from Ban Chiang, we concentrated on anatomical bones that meet three criteria: to be sexually dimorphic, compact and therefore likely to survive intact and be distinguishable between domestic cattle, the wild gaur or banteng, and the water buffalo. We assembled, as far as possible, bones from the two principal wild cattle of Southeast Asia, the gaur (*B. gaurus*) and the banteng (*B. javanicus*). No comparative bones for the kouprey (*Bos nauveli*) are available. This made it possible to make a reasonable ascription of bones on the basis of size, to a wild or a domestic animal. As may be seen in Figure 4, the majority of the first fore phalanges match in size the modern domestic sample. There are, however, three that fall into the size range of the male gaur, suggesting that some hunting was undertaken. The magnum is a compact bone that is distinguishable between the water buffalo and cattle. Those from Ban Chiang fall within the size range of modern domestic animals and are markedly smaller than the few bones available for the gaur. The same situation is found for the equally compact second phalanges, those from Ban Chiang being similar in size to those from modern Thai cattle.

The age at death is an important indicator when interpreting how domestic cattle were raised and exploited. The eruption and wear on the dentition is one way of approaching this variable; the fusion of epiphyses on the long bones is another. The Ban Chiang sample contained very few deciduous teeth. Of the 165 upper teeth, just 14 were deciduous, and all were well worn. The same is true for the lower dentition, the majority (65/92) displaying advanced wear reflecting an animal that attained between 5 and 10 years of age. The rarity of unfused epiphyses on the long bones confirms that most bovids were of adult body size at death. This raises the issue of how the cattle were exploited. An examination of the fracture patterns reveals that animals throughout the sequence were systematically butchered to remove the meat and bone marrow.

### 1.2.2 | Family Bovidae, genus *Bubalus*, species *Bubalus bubalis*, the water buffalo

In Southeast Asia today, the water buffalo is almost universally preferred as a draft animal to haul a plow and harrow. With the application of the analysis of mtDNA variation and Y-chromosomal sequences, Zhang et al. (2007, 2016, 2020) have identified the most likely geographic origin of domestication in the borderlands between Southern China and Southeast Asia by about 2000 BC. From there, they have mapped the spread of the water buffalo further into Southeast Asia and north into the rest of China. With one exception at Ban Chiang, they are restricted to contexts ascribed to the Iron Age. On the basis of complete second fore phalanges, the size of the bones match the variation seen in the modern domestic breed, thus making it unlikely that the wild *Bubalus arnee* was hunted (Figure 5). The bones reveal extensive evidence for butchering with consistent cut marks and breakage. Even the compact calcanea, a bone with little meat value, and the second phalanges were fractured with powerful blows. Seven of the 20 terminal phalanges were also broken; Charred

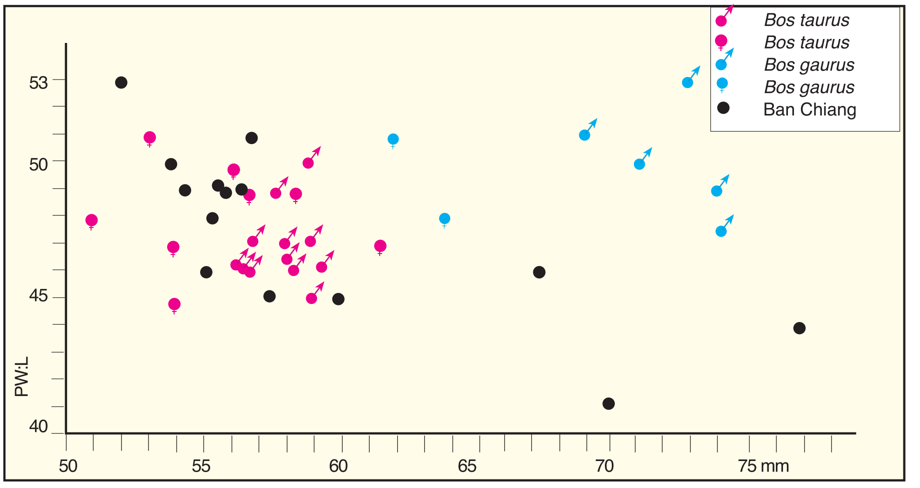


**FIGURE 4** Scatter plot of Ban Chiang and modern bovid first fore phalanges on the basis of the length and ratio of proximal width to length [Colour figure can be viewed at wileyonlinelibrary.com]

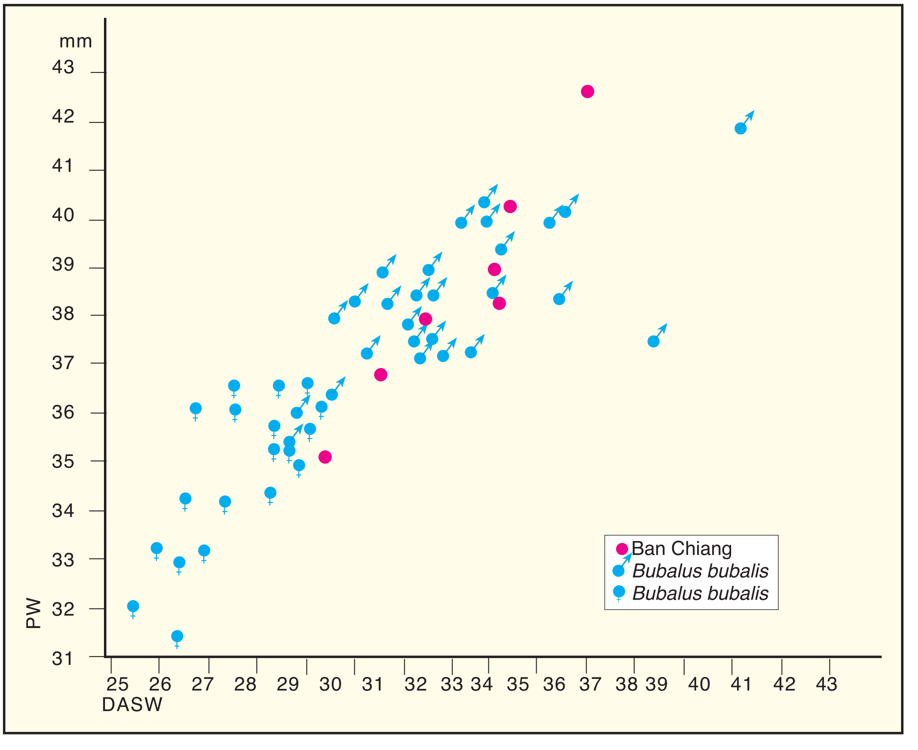


**FIGURE 5** Scatter plot of Ban Chiang and modern *Bubalus bubalis* second fore phalanges on the basis of the proximal width and the width of the distal articular surface [Colour figure can be viewed at wileyonlinelibrary.com]

water buffalo bones were not uncommon. Young water buffalo were rare; there are no second phalanges with unfused epiphyses, and one of the 11 first phalanges was immature.

### 1.2.3 | Family Suidae, genus *Sus*, species *Sus scrofa*, the pig

There may well have been several instances of domesticating the Asian pig in China and Southeast Asia, given the widespread distribution of this species in the wild (Larsen et al., 2010). Distinguishing between fragmentary wild and domestic pig bones is not straightforward, particularly given the possibility of interbreeding. It is, however, assumed that there is a strong possibility that the Ban Chiang sample includes a high proportion of the latter. The majority of the pig bones come from young animals, just over 10% of the mandibles being adult. Fourteen of the 42 jaw bones come from animals under approximately 6 months of age. This is strikingly seen in the mortuary offerings, where just one of the 20 pigs placed with the dead was fully grown. Young pigs were clearly preferred for ritual purposes. This predominance of young pigs is also seen at the South Vietnamese Neolithic settlement of An Son (Piper et al., 2014). From the earliest contexts at Ban Chiang, the suid limb bones bear abundant traces of butchering and burning.

### 1.2.4 | Family Canidae, genus *Canis*, species *Canis familiaris*, the dog

Traditionally, and largely based on archeological evidence, the origins of the domestic dog have been identified in Europe or Southwest Asia (Clutton-Brock, 1995). However, this issue has recently responded to the analysis of mtDNA and Y-chromosome DNA on the world-wide scale (Ding et al., 2012). The results reveal that the greatest genetic diversity is located in China south of the Yangtze River. Domestication from the indigenous wolf there took place ca. 16,000 years ago. In our analysis of the canid remains from Ban Chiang, we assembled a sample of crania from modern village dogs and compared them, and the prehistoric specimens, with the corresponding bones from the wolf (*Canis lupus*), the golden jackal (*Canis aureus*), and the cuon (*Cuon alpinus*) in the collections at the British Museum of Natural History (Higham et al., 1980). The jackal and the cuon are indigenous to Southeast Asia, the wolf is not. We took multiple measurements from the crania of the modern village dog, the cuon, jackal, and wolf and compared them on the basis of a discriminant function analysis with the single complete cranium recovered from Iron Age burial 13 at Ban Chiang. This excluded the cuon and jackal as possible ancestors and placed the specimen among the modern village dog (Higham et al., 1980). The same conclusion is drawn when comparing the canid species on the basis of nine dimensions from the mandible (Figure 6). We conclude that the dog bones from Ban Chiang represent a domestic breed descended from the southern Chinese wolf.

With the exception of two very young dogs with fully articulating skeletons, there is an overwhelming predominance of animals that had attained full body size at death. One of these had been placed as a mortuary offering with an Iron Age infant. The bones had been subjected to butchering and charring, suggesting that they had been cooked and the flesh consumed. This continued throughout the occupation of the site and, indeed, continues to this day in certain parts of Southeast Asia. It is concluded that the dogs were descended from the South Chinese wolf. It is not unusual to find that dogs were placed in human burials or even given their own burials as at Bronze Age Ban Non Wat. Dogs might have fulfilled at least three functions: raised for food, to participate in hunting, and as valued company.

### 1.2.5 | Family Phasianidae, genus *Gallus*, species *Gallus gallus*, chicken

The red jungle fowl, *G. gallus*, is native to Southeast Asia. The earliest known domestic chickens come from Neolithic Ban Non Wat, dating to ca. 1650 BC (Peters et al., 2022). Later specimens from that site have yielded DNA (Storey et al., 2012). Chicken bones were found from the earliest Bronze Age contexts at Ban Chiang but never frequently. Peters et al. (2022) have proposed that the jungle fowl was domesticated in Thailand when attracted to early Neolithic rice fields, thereby entering the orbit of the first farmers.

### 1.2.6 | Family Cervidae

There are several species of deer likely to have been exploited at Ban Chiang. In descending order of size, they are the sambar (*Cervus unicolor*), Schomburg's deer (*Cervus schomburgki*), Eld's deer (*Rucervus eldii*), the pig deer (*Axis porcinus*), and the muntjac (*Muntiacus muntjak*). Each has its favored habitat. Schomburg's deer, now extinct, favored the swamp grasslands of the Chao Phraya flood plain. Eld's deer prefers an open, swampy habitat. The sambar inhabits woodland, with a diet including leaves and grasses, while the pig deer occupies grassy terrain near permanent rivers, streams and marshland. The muntjac prefers to feed along forest margins. Distinguishing between these species on the basis of fragmentary limb bones is not straightforward,

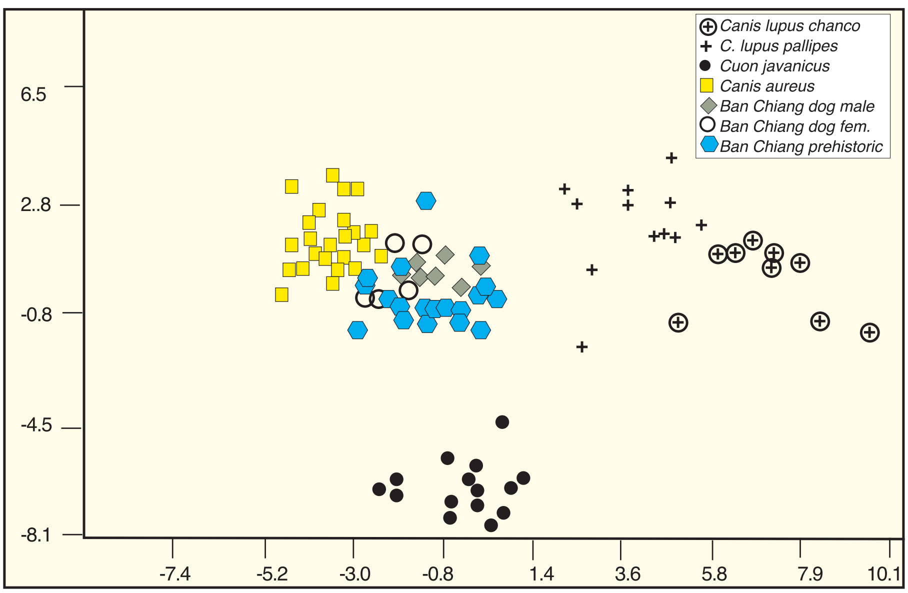


**FIGURE 6** Results of a discriminant function analysis in nine mandible measurements from modern canids and prehistoric Ban Chiang [Colour figure can be viewed at wileyonlinelibrary.com]

given the overlap in size between, for example, the muntjac and pig deer, while Schomburg's deer is extinct and comparative data are inaccessible. There are, at Ban Chiang, three groups on the basis of the size of the radius. The largest corresponds to modern sambar, the middle to Eld's deer, and the smaller either to the muntjac or pig deer. Antlers are more easily identified, and there is no doubting the presence of predated sambar and muntjac.

Sambar bones occur throughout the sequence, though not with the same frequency as bovids and pigs. Both the dentition and the post cranial bones evidence the hunting of adult animals. There are 28 phalanges, none of which displays an unfused epiphysis. There is consistent evidence for the butchering of this animal. Several metapodial bones were charred. Meticulous attention was given to the cutting of antler, 20 of the 179 specimens having been treated in this manner for the manufacture of artifacts.

Eld's deer is as abundant as the sambar. All but one of the 21 individuals died when fully adult. Most bones were butchered and charred, and only one animal comes from a subadult. The sizes of the limb bones of pig deer and muntjac are similar, but most of the antlers come from the latter. Although not as abundant as Eld's deer, the same pattern of utilization is observed: Most animals were adult when hunted, and they were butchered and consumed.

### 1.2.7 | Felidae, the cat

Six small cat species are indigenous to Thailand, two medium in size and one large. All but one, *Prionailurus planiceps*, the flat-headed cat, would have been adaptive to the habitat of the Khorat Plateau. The fishing cat, *Felis viverrinus*, lives near water, while the jungle cat, *Felis chaus* prefers deciduous forest or tall grasses. *Pardofelis marmorata*, the marbled cat, occupies dense forest. One of the problems facing the archaeozoologist is that some of these cats are similar in size, and complete crania are the best means of distinguishing between them. The leopard (*Panthera pardus*) and clouded leopard (*Neofelis nebulosa*) are medium in size, and the tiger is the one large species. *Prionailurus bengalensis*, the leopard cat, and *F. viverrinus* have been identified at Ban Chiang, together with the tiger, *Panthera tigris*.

### 1.2.8 | Family Hystricidae, genus *Hystrix*, species *Hystrix hodgsonii*, the porcupine

The single tooth of a porcupine probably comes from *Hystrix hodgsonii*.

### 1.2.9 | Family Leporidae, genus *Lepus*, species *Lepus peguensis* the Siamese hare

The Siamese Hare is typically found in areas cleared of forest. Being herbivores, they prefer open, grassy habitats. Twenty bones have been identified from both Bronze and Iron Age layers. None shows signs of butchering, but one mandible had cut marks across the ramus.

### 1.2.10 | Family Manidae, genus *Manis*, the pangolin

The modern range of the Chinese pangolin *Manis pentadactyla* and the Malayan pangolin *Manis javanica* are complementary and Ban Chiang lies where the distributions meet. They are adapted to primary and secondary forests. Four humeri were identified from Ban Chiang divided between Bronze and Iron Age contexts.

### 1.2.11 | Family Muridae, genus *Rattus*, the rat

The concentration of rat bones in early layers of the site, allied with the fact that at least some of the 23 species of rat are adapted to different environments, makes the task of assigning limb bones to species as difficult as it is important. No attempt has been made and the sample is divided into large and small specimens. The former contains bones of about the same size as *Rattus edwardsi and R. sabanus* and the latter is the same size as *R. r. koratensis*.

### 1.2.12 | Family Mustelidae, genus *Melogale*, species *Melogale personata*, the Burmese ferret badger

This animal is distributed through several habitats today, from forest to rice fields. Two adult mandibles were identified, one early and the other late in the cultural sequence.

### 1.2.13 | Family Mustelidae, the otter

The absence of comparative otter specimens in the British Museum made it difficult to place the three bones to species. The possibilities include *Lutra lutra*, the common otter; *Lutra perspicillata*, the smooth coated otter; and *Aonyx cinera*, the small-clawed otter. *L. perspicillata* is the most likely of the three; it prefers low-lying terrain and is adapted to moving between suitable aquatic habitats during the dry season. The common otter by contrast is said to prefer upland streams and lakes (Lekagul & McNeely, 1977). Three bones were identified, all from early contexts.

### 1.2.14 | Family Rhinocerotidae, genus *Rhinoceros*, species *Rhinoceros sondaicus*, the Javan rhinoceros

The Javan Rhinoceros is extremely rare in Northeast Thai archeological contexts. Currently, its habitat is restricted to dense forests, but this may be due to intense predation. Indeed, the stomach contents of one Javan rhino contained the remains of 150 plant species characteristic of secondary forest (Hoogerwerf, 1970; Schenkel, 1969). One cuneiform bone was identified, from late layer D5 3.

### 1.2.15 | Family Sciuridae, the squirrel

When it is considered that there are 13 genera and 26 species of squirrels indigenous to Thailand, the rarity of bones at Ban Chiang is notable. There is a large and a small species at this site, the former identified as *Ratufa* sp. and the latter as *Callosciurus* sp.

### 1.2.16 | Family Herpestidae, genus *Herpestes*, species *Herpestes javanicus/Urva urva*, the mongoose

The mongoose has a catholic diet, preferring open grassy terrain to thick woodland. Five mandibles, three humeri, two ulnas and two tibias were identified as *H. javanicus*. Two bones were ascribed to *Urva urva*, the crab-eating mongoose that prefers an aquatic diet of shellfish, frogs, fish, and crabs. Both come from Bronze Age layers.

### 1.2.17 | Family Viverridae, genus *Viverricula*, species *Viverricula malaccensis*, the small Indian civet

The small Indian civet prefers open grassland and regenerating secondary forest. Twelve bones were found, all but two in Bronze Age layers. Two humeri were identified as *Hemigalus derbyanus*, the banded palm civet. This species prefers to live in tall trees and feeds in trees and stream margins. Both tibias come from early layers.

### 1.2.18 | Family Varanidae, genus *Varanus*, species *Varanus nebulosus*, the clouded monitor lizard

Two mandibles come from *V. nebulosus*, the clouded monitor lizard. This is a large, tree climbing species. One bone is Bronze Age, the other Iron Age in date.

## 1.3 | Family Emydidae/Testudinidae

Many fragments of carapace and plastron were recovered. On the basis of the frontal section of the carapace, two species have been identified. *Malayemys subtrijuga* is a water turtle that inhabits streams and rice fields today, and *Testudo elongata* is a tortoise that lives in woodland by preference. They are well adapted to burned-off forest.

### 1.3.1 | Family Trionychidae, the soft-shelled turtle

Several fragments of soft-shelled turtles come from *Trionyx cartilagineus* and *Chitra indica*.

### 1.3.2 | Family Microhylidae, genus *Glyphoglossus*, species *Glyphoglossus mollussus*, the balloon frog

A pelvis from D5 12 comes from *Glyphoglossus mollussus*, the balloon frog that is found today in both rice fields and deciduous woodland. It comes from an Iron Age layer. It is widely consumed in Thailand today.

### 1.3.3 | Family Bufonidae, the toad

A single toad tibia was identified in D5 17.

### 1.3.4 | Family Ranidae, genus *Rana*, species *Rana tigrina*, the frog

Two complete frog's crania have been identified as coming from *R. tigrina*. This frog is adapted to flood plain habitats and is common today in rice fields. There are also many limb bones from Ranidae, the most likely species in question again being *R. tigrina*.

### 1.3.5 | Family Crocodylidae, genus *Crocodylus*, species *Crocodylus siamensis*, the freshwater crocodile

A small number of bony scutes come from *C. siamensis*, the Siamese freshwater crocodile. They were found in layers 12, 18, and 22. It lives in rivers, streams, and lakes. At nearby Ban Na Di, an infant was interred under a crocodile skin shroud, and a woman wore a pendant made from a crocodile skull. In living memory (1981), crocodiles were still to be found in Lake Kumphawapi.

## 1.4 | Fish

The cultural material from Ban Chiang was put through a screening, but no flotation was undertaken. Subsequently, flotation has recovered the vast majority of fish bones at other sites. Therefore, the actual numbers of fish bones at Ban Chiang is likely to be severely under-represented. Only 35 bones have been ascribed to the bagrid catfish genus *Mystus* for example. This Asian red-tailed catfish is found in slow-moving rivers with a muddy bottom, but it also inhabits large lakes. There are also four cyprinid fish and one *Mastacembelus*. The latter is a widespread genus adapted to a wide range of freshwater habitats including lakes, rivers and swamps. It can reach a length of 70 cm and is consumed today but not in great numbers.

*Channa* is the most commonly identified genus. It is probably the most popular and widely consumed fish in Thailand. It has been known to reach a length in the vicinity of a meter. It can be secured by trap or line and survives for long periods without access to water. During the dry season, it can be cut out of the mud in which is takes refuge in dry lake beds.

## 1.5 | Animal bones in human burials

Eighty-two burials were opened during the 1975 excavation season (Figure 2). Of these, 35 are early Bronze Age, 14 late Bronze Age, 20 early Iron Age, and 10 late Iron Age. The rest could not be assigned a phase. The placement of animal bones, presumed to represent food for the deceased, was very limited in the early Bronze Age to just three of the 35 burials. Moreover, few items were involved—two pigs' forelimbs, a single dog bone, and a tortoise carapace. The same situation is found for the late Bronze Age: two of 14 burials contained pig jaw bones. During the early Iron Age, the 20 burials included four with animal bone offerings: pig and cattle jaw bones and a few fish bones. Only with the 10 late Iron Age burials did the number rise, to include a dog skeleton, two chicken skeletons, the first water buffalo bone, a cattle mandible, and two graves with pig jawbones. The following bones have been interpretated as mortuary offerings placed with the dead, listed in chronological order.

## 1.6 | Early Bronze Age

1. Burial 52, D5 28. EP III.? Male aged 6–7 years. Five pots placed beyond the feet of this individual, one of which contained the calcanium of a dog and 39 carapace fragments from *Testudo elongata*.
2. Burial 47, D5 28. EP III. Male, 45–50 years. Radiocarbon date OxA-22381 2786 ± 26, cal. 1222–1047 BC. Male 45–50 years. A young pig fore limb from the humerus to the metacarpals, all bones with unfused epiphyses.
3. Burial 54, D6 30. EP IV. Radiocarbon date OxA-22383 2819 ± 26, cal. 1047–905 BC.? female 3–4 years. The right fore limb of a pig were associated.
4. Burial 37, D6 27. EP IV. Partially excavated. Adult. A cord-marked pot above the skull contained a fragment of pelvis from *Urva urva*, a mongoose, and the coracoid of a bird. Both were probably there fortuitously.

## 1.7 | Late Bronze Age

5. Burial 59, D4 27. EP V. Female aged 45–50 years. A complete skeleton. One cord-marked pot below the feet contained a fragment of pig mandible and a broken fragment of a muntjac mandible.
6. Burial 29, D6 23. EP V. OxA-22378 2965 ± 29, cal. 1271–1055 BC. Female 18–20 years. The complete jaw of a pig was found beyond the feet.

## 1.8 | Early Iron Age

7. Burial 71, D4/D5 15/16. MP VII.? Male young adult. Completely excavated. The mandible of a pig placed above the chest.
8. Burial 10, D7 19. Male, 17–19 years. An open bowl contained fragmentary fish bones from *Channa*, an air-breathing fish known as a snakehead.
9. Burial 20. D4 17/18. MP VII. OxA-30645 2232 ± 30, cal. 323–200 BC. Female, 35–40. A disturbed burial. Four pig's mandibles were located beyond the head.
10. Burial 24. D4 17. MP VII. OxA-30647 2202 ± 29, cal. 366–175 BC. Male, 30–35 years. *Bos* One complete mandible.

## 1.9 | Late Iron Age

11. Burial 4. D6 10/11. LP IX. 9–12 months, fragmentary skeleton. The complete mandible and maxilla of a pig.
12. Burial 5. D6 11. LP IX.? Male, 5–6 years. Bird bone within a pot. Water buffalo, one metacarpal. Pig, fragments of a cranium and mandible of a young pig.
13. Burial 6. D6 12. LP IX. Male 40–45 years. Complete *Bos* mandible. Two pots contained fragments of bagrid fish vertebrae and a fragment of pig tibia.
14. Burial 13. D4 15. LP X.? Male, 12–18 months. A dog's skeleton, somewhat disarticulated. The skull was in a bowl, the vertebrae and ribs in a pot and the rest, still in articulation, was placed over the infant's chest.
15. Burial 8, D4 11. LP X.? Female, 2–3 years. A complete pig's jaw. Several broken pots covered the skeleton, among which the following bones were identified: chicken skeleton comprising a tarsometatarsus, 2 tibias, 2 complete femurs, fragments of pelvis and the distal end of a humerus.
16. Burial 7. D4/5 12. Male 45–55 years. Found complete. Four pots covered the skeleton, containing chicken: shaft of ulna, distal end of femur, fragments of pelvis, two tibias, one tarsometatarsus. Twenty-five chicken bones were also found near the skeleton.

## 1.10 | The faunal spectrum

The four squares opened in 1975, each divided by a balk, were separately recorded, and at present, as far as is known, the correlation between the layers within each unit has not been integrated. Therefore, by default, the faunal spectrum is presented in two different ways. The first shows the number of individual animals of each species from square D5, separated into Bronze and Iron Age groups (Tables 1 and 2). The second portrays changes employing the sequence of cultural phases set out by the excavators (Gorman & Charoenwongsa, 1976). The first three phases belong to the Bronze Age occupation and the Iron Age began with phase 4 (Figure 7). The values for cattle and pigs in Figure 7 may include an unknown fraction

**TABLE 1** The Bronze Age faunal spectrum for square D5, Ban Chiang, giving the minimum number of individual animals identified per species in each layer

| Class | Order | Family | Taxon | English vernacular | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | Total MNI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mammalia | Artiodactyla | Bovidae | *Bos taurus* | Cattle | 4 | 5 | 3 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 0 | 27 |
| | | Suidae | *Sus scrofa* | Pig | 2 | 4 | 3 | 0 | 2 | 3 | 4 | 2 | 4 | 4 | 6 | 0 | 34 |
| | | Bovidae | *Bubalus bubalis* | Water buffalo | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
| | Carnivora | Canidae | *Canis familiaris* | Dog | 4 | 7 | 2 | 1 | 0 | 3 | 1 | 1 | 1 | 2 | 1 | 0 | 23 |
| | Artiodactyla | Cervidae | *Cervus unicolor* | Sambar deer | 2 | 2 | 2 | 0 | 1 | 2 | 2 | 1 | 0 | 2 | 0 | 0 | 14 |
| | | Cervidae | *Rucervus eldii* | Eld's deer | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 0 | 1 | 0 | 14 |
| | | Cervidae | *Muntiacus muntjak* | Muntjac | 1 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 11 |
| | Lagomorpha | Leporidae | *Lepus peguensis* | Burmese hare | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 |
| | Carnivora | Viverridae | *Viverricula ind.* | Civet | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Carnivora | Herpestidae | *Urva u.* | Mongoose | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 5 |
| | Rodentia | Muridae | *Rattus* | Rat | 1 | 3 | 0 | 1 | 2 | 3 | 4 | 1 | 2 | 1 | 3 | 0 | 21 |
| | Carnivora | Viverridae | Civet | Civet | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Actinopterygii | Perciformes | Channidae | *Channa* | Snakehead | 0 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 2 | 15 |
| Actinopterygii | Cypriniformes | Cyprinidae | *Barbus* | Barbel | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Actinopterygii | Perciformes | | *Channa/bagrid* | | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 2 | 1 | 2 | 0 | 11 |
| | | | Bagrid fish | | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 3 | 0 | 7 |
| Amphibia | Anura | Ranidae | *Rana tigrina* | Frog | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 1 | 0 | 8 |
| | | Bufonidae | | Toad | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Reptilia | Testudines | Trionychidae | *Trionyx* | Turtle | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Aves | Galliformes | Phasianidae | *Gallus gallus* | Chicken | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| Reptilia | Squamata | Varanidae | *Varanus n.* | Monitor lizard | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

**TABLE 2** The Iron Age faunal spectrum for square D5, Ban Chiang, giving the number of individual animals identified per species

| Class | Order | Family | Taxon | English vernacular | S | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mammalia | Artiodactyla | Bovidae | *Bos taurus* | Cattle | 1 | 1 | 0 | 2 | 3 | 3 | 4 | 3 | 1 | 1 | 2 | 2 | 1 | 3 | 4 | 4 | 2 | 37 |
| | | Suidae | *Sus scrofa* | Pig | 1 | 2 | 1 | 2 | 4 | 4 | 2 | 2 | 2 | 3 | 3 | 1 | 1 | 3 | 4 | 3 | 2 | 40 |
| | | Bovidae | *Bubalus bubalis* | Water buffalo | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 1 | 1 | 1 | 15 |
| | Carnivora | Canidae | *Canis familiaris* | Dog | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 3 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| | Artiodactyla | Cervidae | *Cervus unicolor* | Sambar deer | 1 | 2 | 0 | 2 | 2 | 3 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 28 |
| | | Cervidae | *Rucervus eldii* | Eld's deer | 0 | 1 | 0 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 2 | 24 |
| | | Cervidae | *Muntiacus muntjak* | Muntjac | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 2 | 17 |
| | Lagomorpha | Leporidae | *Lepus peguensis* | Burmese hare | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Carnivora | Viverridae | *Viverricula ind.* | Civet | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Perissodactyla | Rhinocerotidae | *Rhinoceros sondaicus* | Rhinoceros | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Carnivora | Mustelidae | *Melogale p.* | Badger | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | Pholidota | Manidae | *Manis p.* | Pangolin | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | | Bagrid fish | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| | | | | *Channa*/bagrid fish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| Actinopterygii | Perciformes | Channidae | *Channa* | Snakehead | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 |
| Aves | Galliformes | Phasianidae | *Gallus gallus* | Chicken | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 5 |
| Reptilia | Testudines | Pholidota | *Chitra indica* | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | Trionychidae | *Trionyx* | Turtle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | | Testudinidae | *Testudo* | Tortoise | 0 | 0 | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 11 |
| | | Geoemydidae | *Malayemys* | Turtle | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Amphibia | Anura | Ranidae | *Rana tigrina* | Frog | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

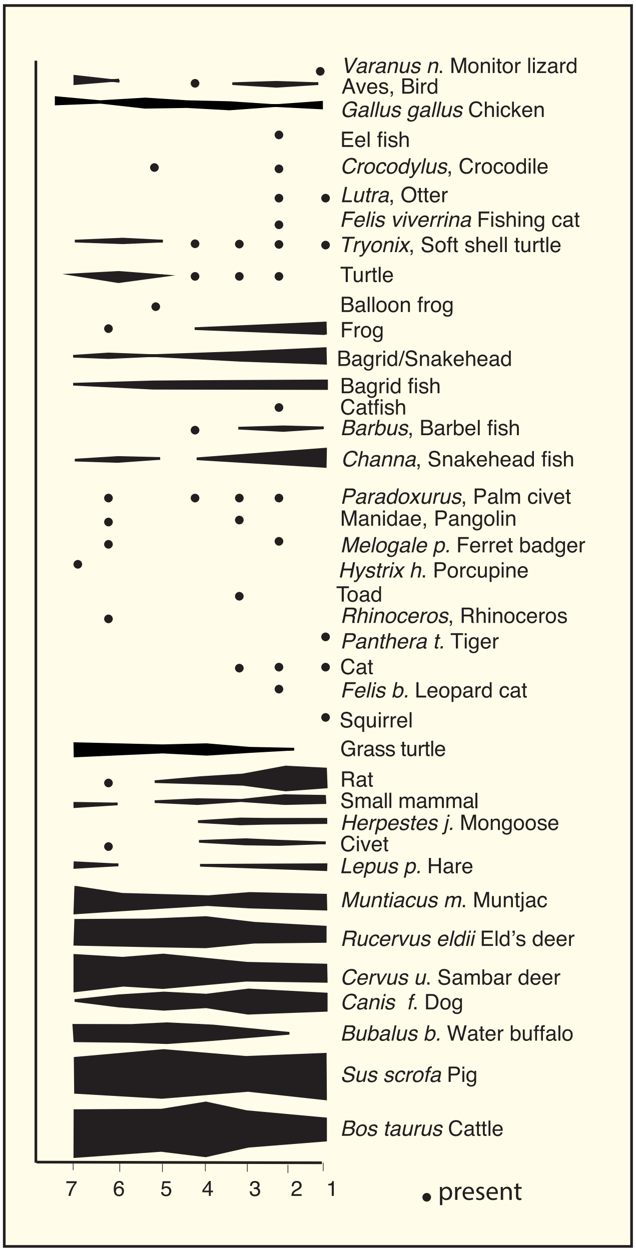


**FIGURE 7** The relative numerical presence of species in the faunal spectrum from Ban Chiang based on the number of individual animals represented by the bones. Levels 1–3 are Bronze Age; levels 4–7 are Iron Age. [Colour figure can be viewed at wileyonlinelibrary.com]

of wild animals, but the size of the bones suggests a dominance of domestic stock. Cattle were present from initial settlement at approximately 10% of all individuals, rose to 25% with the start of the Iron Age, and continued at about a fifth of the sample thereafter. Pigs according to this approach comprised approximately 20% throughout the sequence. Deer were hunted on a continuing basis, the sambar and Eld's deer being the most numerous followed by the muntjac. All three rose in frequency with the Iron Age. The water buffalo first appeared in phase 2, represented by a single bone, and thereafter was always present but never exceeding 9% of the sample.

There is a group of species that were relatively common early in the occupation, but which declined with time. This includes the three principal species of fish, though it is emphasized that these were very probably seriously under reported due to the absence of water flotation. The hare, civet, mongoose, otter, frog, and rat were more abundant during the Bronze Age occupation. The turtles and tortoises, however, increased over time. Several species were always rare: crocodile, tiger, rhinoceros, porcupine, toad, and spiny eel. Bird remains, dominated by the domestic chicken, were present throughout.

This distribution is matched and confirmed when turning to the individual animals represented in square D5 (Tables 1 and 2). During the Bronze Age, domestic cattle, dogs, and pigs dominated, followed by deer. Water buffaloes were very rare, just three being counted. This pattern continued into the Iron Age, during which the water buffalo numbers markedly increased.

The analysis of shellfish has never been completed, but fieldwork in the vicinity of Ban Chiang in 1978 sought the habitat preferences of the shellfish that were particularly abundant in the basal shell middens. These include *Pila polita*, that prefers permanent water, and *Pila ampullacea* a species that aestivates during the dry season, but occupies streams and ponds, as does *Filupaludina javanica*.

The Siamese hare prefers an open habitat and avoids forests. The small Indian civet and mongoose are often found in proximity to human settlement in long grass and scrub. Otters are aquatic, and their presence early in the sequence is compatible with the number of shellfish found in the middens. *Channa*, the serpent-headed fish, lives in lakes, ponds, and swamps. Bagrid catfish prefer warm, well-oxygenated water. The frog *Glyphoglossus molossus* lives in deciduous woodland and rice fields, and *Rana tigrina* is adapted to river flood plains and wet rice fields. Soft-shelled water turtles live in streams and rice fields, and the grass turtle is commonly reported in regenerating woodland. It is also noted that species adapted to evergreen canopied forest, such as the langur, macaque, mouse deer, and hog badger are absent. Squirrels are also absent after period 1.

## 1.11 | Comparative faunal spectra

No Neolithic residential contexts were identified during the 1975 season at Ban Chiang. The best evidence for the impact of the initial rice farmer settlement of the Khorat Plateau is found at Ban Non Wat, where intact shell middens have been dated to ca. 1600–1450 BC (Higham & Higham, 2009). The first settlers introduced domestic cattle, pigs, and dogs and according to Peters et al. (2022) locally domesticated the red jungle fowl *G. gallus* (although see Peng et al., 2022). The first two are present in equal numbers. There are very few water buffalo bones, and those measurable fall within the size range for the wild species (Kijngam, 2010). Eld's deer is the dominant species numerically, while the sambar and muntjac were also hunted. Samples of the middens and occupation contexts were wet sieved, resulting in the retention of a very large sample of small bones. Had wet sieving not been undertaken, fish would have hardly been represented in the faunal spectrum. The in situ and undisturbed Neolithic middens are the most reliable source of information on the relative importance of each species of fish. The bagrid catfish *Hemibagrus* and *Mystus* are the most abundant, with 142 individual fish being represented. The snakehead, *Channa striata*, is also well-represented. There are 55 individuals of *Clarias* sp. while *Ompok* and *Wallago* account for 72. The fish identified in the Neolithic middens of Ban Non Wat confirm the presence of an aquatic environment that could contribute significantly to sustaining a relatively large sedentary community (Thosarat, 2010).

The dominant shellfish found in the Neolithic shell middens are *Filopaludina* and *Pila*. Both inhabit freshwater ponds and lakes, and in the case of the former, streams. Bivalve shellfish were a significant part of the Neolithic diet at Ban Non Wat. *Ensidens ingalsianus* was the most abundant, followed by *Scabies* sp. These come from river and lake beds (Thosarat, 2010).

## 1.12 | Ban Na Di

Ban Na Di is located 23 km southwest of Ban Chiang. Excavations in 1981–1982 identified a cultural sequence that began in ca. 800 BC, during the Bronze Age, and continued into the Iron Age (Higham & Kijngam, 1984a). This sequence mirrors that of Ban Chiang in 1975, although the initial settlement was about two centuries later. In all respects, the timing and natural environment of both sites are similar. However, the material culture seen principally in the form of the pottery vessels were quite distinct save for one or two vessels that permit the two sequences to be harmonized.

A subset of the excavated material was passed through screens with a mesh size of 1 mm, and further samples were wet sieved. There are eight major cultural levels. Levels 8–5 are Bronze Age, and from level 4, they belong to the Iron Age. The 1 mm mesh screen and wet sieving was applied to levels 8–4. The two faunal spectra from Ban Chiang and Ban Na Di present a virtually identical pattern (Figure 8). Domestic cattle and pig are prominent numerically throughout the sequence, with the pig being particularly abundant at the end of the Bronze Age (Higham & Kijngam, 1984b). Indeed, there appears to have been a ritual interest in bulls, given the number of exquisite clay models placed in human graves (Figure 9). The domestic water buffalo was absent until the third layer. Eld's deer, the sambar, and muntjac were hunted in numbers throughout the sequence. A similar range of small terrestrial mammals was identified, and the tortoises and turtles were consumed. Domestic chickens were raised, one of which was placed in a human burial. One significant difference between the two samples reflects use of a 1 mm screen, for the fish dominated the faunal spectrum in terms of the number of bones identified (Higham & Kijngam, 1984b). Shellfish too, were abundant, dominated numerically by the gastropod *Filopaludina*, followed by *Pila*.

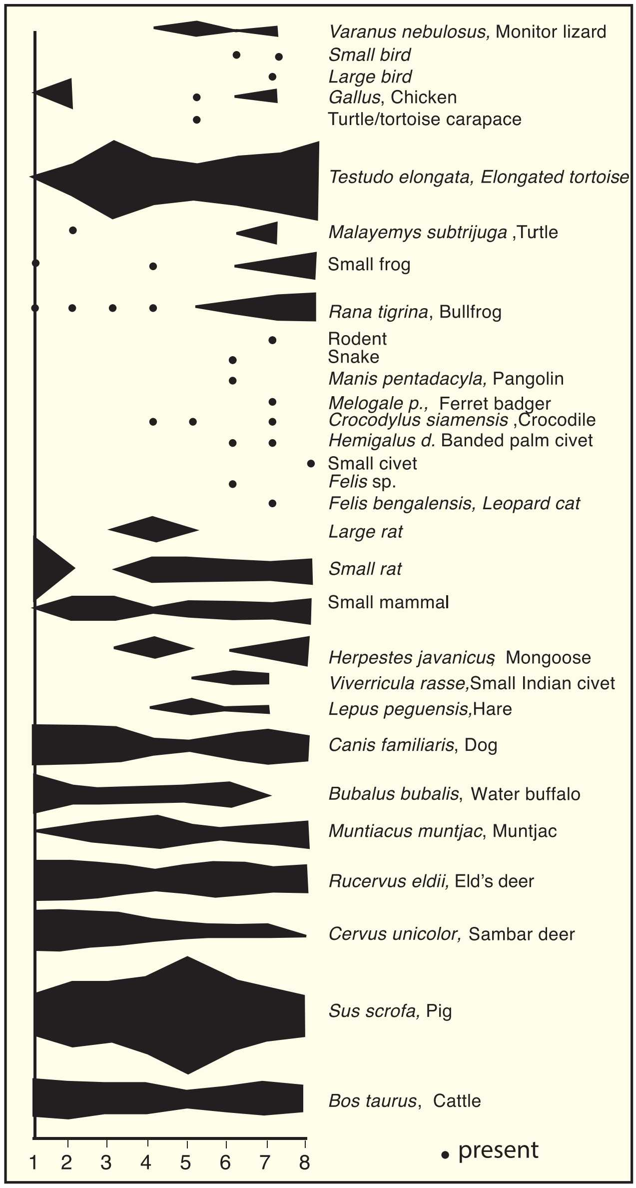


**FIGURE 8** The faunal spectrum from Ban Na Di, based on the number of individual animals represented by the bones. Levels 8–5 are Bronze Age; levels 4–1 are Iron Age. [Colour figure can be viewed at wileyonlinelibrary.com]

## 1.13 | Noen U-Loke

Noen U-Loke was occupied throughout the Iron Age. It is a large mound, surrounded by five moats linked to a canal. Domestic cattle and pigs dominate the faunal spectrum, the latter also being the preferred animal for inclusion in human graves (McCaw, 2007). An egg matching in size those of the domestic chicken was found as a mortuary offering. Water buffalo bones were rare in the earliest layer 6 but increased in layer 4 with a total of 19 individuals and 16 in layer 3. While not matching in abundance the bones of cattle or pigs, layers 4 and 3 are significant for they correspond to the construction of the moats and banks that encircle the site (Table. 3).


**FIGURE 9** Bovid clay figurines from Bronze Age graves at Ban Na Di

**TABLE 3** The basic faunal spectrum for Noen U-Loke expressed as the minimum number of individuals identified per species

| Class | Order | Family | Species | English vernacular | Layer 6 | Layer 5 | Layer 4 | Layer 3 | Layer 2 |
|---|---|---|---|---|---|---|---|---|---|
| Mammalia | Artiodactyla | Bovidae | *Bos taurus* | Cattle | 13 | 8 | 58 | 93 | 38 |
| | | Suidae | *Sus scrofa* | Pig | 9 | 4 | 52 | 89 | 32 |
| | | Bovidae | *Bubalus bubalis* | Water buffalo | 2 | 3 | 19 | 16 | 4 |
| | Carnivora | Canidae | *Canis familiaris* | Dog | 0 | 1 | 12 | 7 | 5 |
| | Artiodactyla | Cervidae | *Rucervus eldii* | Eld's deer | 4 | 2 | 18 | 13 | 6 |
| | | Cervidae | *Cervus unicolor* | Sambar | 1 | 1 | 8 | 8 | 1 |
| | | Cervidae | *Muntiacus muntjak* | Muntjac | 0 | 0 | 9 | 7 | 2 |
| | Carnivora | Felidae | *Felis* sp. | Cat | 0 | 0 | 0 | 3 | 3 |
| Reptilia | Testudines | Trionychidae | *Trionyx/Chitra* | Turtle | 2 | 2 | 13 | 11 | 7 |
| Aves | Galliformes | Phasianidae | *Gallus gallus* | Chicken | 0 | 1 | 7 | 3 | 1 |
| | | | Small mammal | | 0 | 0 | 6 | 3 | 0 |
| Mammalia | Rodentia | Muridae | *Rattus* | Rat | 0 | 0 | 5 | 3 | 0 |
| | | | Bird | | 0 | 0 | 1 | 0 | 0 |
| | | | Frog | | 0 | 0 | 4 | 0 | 0 |

## 1.14 | Non Ban Jak

This moated site was occupied during the last phase of the Iron Age. The plant remains leave no doubt that the inhabitants grew their rice in permanent wet fields (Castillo et al., 2018), while the animal remains and artifacts both support the use of animal traction to pull an iron-shod plowshare, and harvest rice with iron sickles. Permanent waterlogged fields would have encouraged the proliferation of certain species of shellfish at the expense of others. The two most abundant gastropods are *Pila* and *Filopaludina*, both of which migrate and occupy modern rice fields around Non Ban Jak. They can easily be collected by wading into the fields or reservoirs. The small gastropod *Bythinia* is also instructive. Another invader of rice fields, it is too small to be collected for food, and probably arrived in the site as a passenger on harvested rice stalks or in fish guts. At Neolithic Ban Non Wat, nine of these shells were found in a sample of 27,000 shellfish. But at Non Ban Jak, 1339 were recovered from just one midden (Higham & Thosarat, 2020).

The mammalian fauna is dominated by domestic animals, pig being the most numerous with 40.5% of all individuals. Cattle and bovids, the latter possibly including water buffaloes, account for a quarter of all individuals and definitely identified water buffalo represent nearly 5%. Deer, which range from the sambar to the muntjac, also account for a quarter. By comparison, 58.4% of all bones identified at Neolithic Ban Non Wat come from deer, 28% from domestic pigs, 15% from bovids, and 2% from water buffalo, though it is not possible to determine the ratio of domestic to wild water buffalo or pigs in all cases. The sharp decline in the fraction of hunted animals over time is again likely to reflect habitat changes caused by forest clearance.

As might be expected, the construction of moat reservoirs and wet rice fields round the site would have created a favorable environment for fish. Catfish of the genus *Clarias* account for almost half the sample, followed by *Channa* sp. Both have the habit of migrating into flooded fields during the rainy season.

### 1.15 | The coastal sites of Vietnam and Thailand

The four coastal sites in question present a marked contrast to the adaptive responses in inland settlement on the Khorat Plateau. Man Bac is located on the southern margin of the Red River delta in a habitat that gave access to a mangrove shore, forested uplands, and grassland. Occupied between ca. 2000–1500 BC, there was a mixed population of incoming Neolithic farmers and indigenous hunter gatherers. The mammalian fauna is dominated by pigs, constituting over half the entire sample. The mortality pattern reveals that the majority did not attain adulthood, suggesting that it was a managed population (Jones et al., 2019; Sawada et al., 2012). Just six bovid bones were identified, and these could have come from wild animals. No chicken remains were recovered. Other than dogs, all other mammals were hunted: deer, muntjac, civets, and otters. Many fish bones were recovered, with the black seabream accounting for over half the sample (Toizumi et al., 2012).

An Son is located on a terrace overlooking the Vam Co Dong river floodplain in the Dong Nai region of southern Vietnam (Bellwood et al., 2011). Occupied between ca. 2100 and 1051 BC, it illuminates the adaptation of Neolithic farmer settlement inland but not far removed from the coast. A striking feature of the faunal remains is the numerical dominance of the dog that to judge from post mortem treatment of the bones, was raised for consumption. Pig remains were also abundant, but cattle were absent. The inhabitants consumed many fish, turtles, and swamp eels (Piper et al., 2014).

While An Son was located well back from the coast, Rach Nui was set where streams ran through mangroves and nypa palm to the sea. Occupied between ca. 1555 and 1250 BC, this 5-m deep occupation mound presents a remarkable combination of Neolithic material culture and the exploitation of marine and mangrove resources (Oxenham et al., 2015). The domestic rice and millet remains reflect the consumption of exotic grains but not necessarily their local cultivation, since a brackish water habitat is not conducive to either plant. The only certifiable domestic animal was the dog. While pigs were four times as common as dogs, there is no compelling evidence that they were domestic. No cattle nor chicken bones were found in the faunal assemblage dominated by fish, estuarine turtles, mangrove crabs, and monkeys. In conjunction with essentially a hunter–gatherer–fisher subsistence base, the inhabitants lived in well-constructed timber framed houses, with shell lime mortar floors. Considerable quantities of coarse and poorly constructed pottery vessels were found.

Khok Phanom Di was located, for the greater part of its settlement from ca. 2200–1600 BC, on the mangrove-dominated Bang Pakong river estuary in Thailand. There was a brief interval during the occupation when the sea level fell and the sequence ended with a second and permanent retreat of the coast away from the settlement. As with Rach Nui, the inhabitants constructed timber framed houses with clay floors and made quantities of pottery vessels. The faunal spectrum is dominated, numerically, by marine fish, shellfish, crabs and shellfish (Figure 10; Kijngam, 1991). For example, 8946 crab chelae were recovered. The most common shellfish species, *Anadara granosa*, lives on mangrove shores, and 645,263 individuals were recovered (Mason, 1991). During the period of high sea level and a mangal habitat, mammalian remains were always rare, most coming from the macaque, leaf monkey, and pig all of which are adaptive to mangroves. Just one bovid bone was identified, and dogs were very rare. When the sea level finally fell away, the number of macaques, deer, and pigs increased, but bovids remained rare (Higham & Grant, 1991).

Part of the faunal sample was identified by Barbara West at the British Museum, Natural History, where the exceptional comparative collection enabled her to recognize a remarkable list of species (West, 1991). During the estuarine occupation, there were crocodile and rhinoceros remains, civets and otters, and many birds including the Sarus crane, stork, pelican, godwit, and spoonbill but not the domestic chicken. Attractive plumage might account for some of these. The reduction in sea level saw the appearance of the tiger, porcupine, heron, and crow. At all periods, the site was overrun by rats.

## 2 | DISCUSSION

The settlement of the Khorat Plateau by migratory rice farmers in the early to midsecond millennium BC opened a new chapter in the prehistory of the region. For at least 50 millennia, Southeast Asia had been occupied by Anatomically Modern hunter–gatherers. The Neolithic farmers introduced not only domestic rice but also cattle, pigs, and dogs that recent analyses of DNA suggest were domesticated, together with rice, in southern China. It has been plausibly suggested that they locally domesticated the jungle fowl. The first farmers on the Khorat Plateau encountered a monsoon climate that brought rainfall from April until November, followed by months with lack of precipitation. This favored a dry dipterocarp forest cover away from the major floodplains. However, it is critical to appreciate that the rainfall was affected by the rain shadow cast across the plain by the Truong Son cordillera to the east and the Petchabun upland to the west (Figure 11). Today, the rainfall on the northeastern part of the plateau doubles that on the southwestern (Scott & O'Reilly, 2015). This has a profound impact on the viability of rice farming.

We can trace the faunal spectrum of Ban Chiang from the start of the Bronze Age in ca. 1000 BC. The inhabitants, as did their Neolithic predecessors at Ban Non Wat, raised domestic pigs, dogs, cattle, and

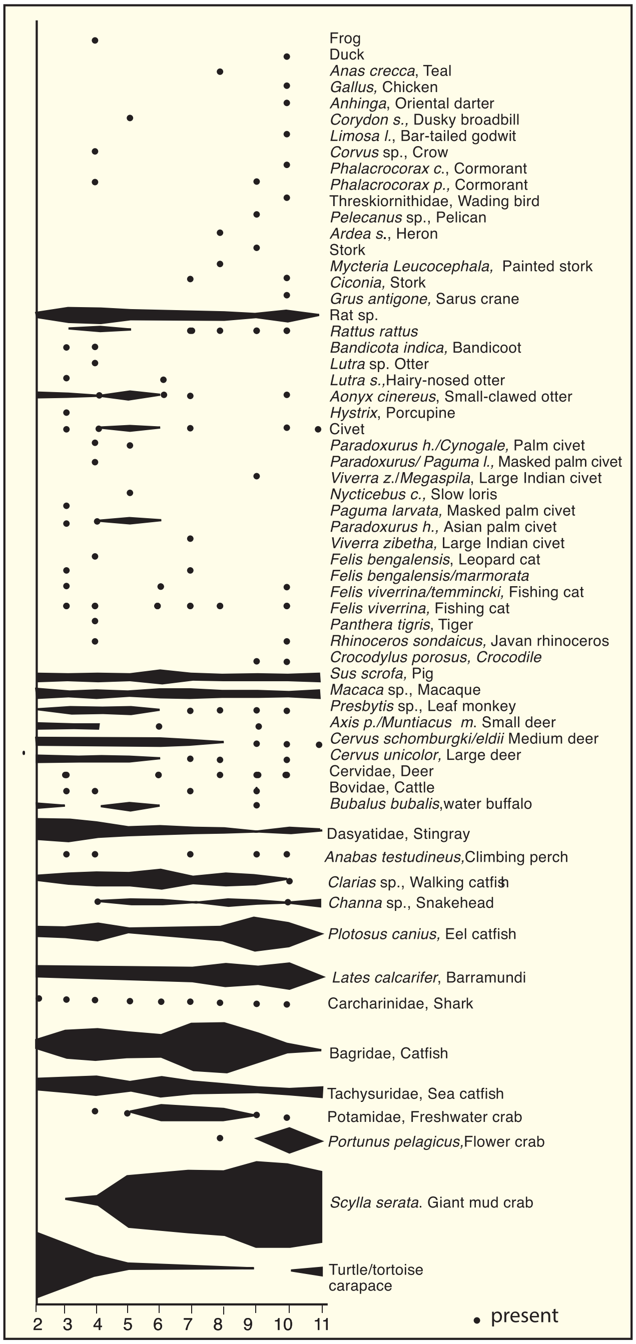


**FIGURE 10** The faunal spectrum for Khok Phanom Di based on the minimum number of individual animals. Layer 11 is the earliest. The chronological span for this Neolithic site is ca. 2200–1600 BC. [Colour figure can be viewed at wileyonlinelibrary.com]

chickens. Part way through the sequence, domestic water buffalo were added to this list. They were also regular hunters of at least three species of deer, and occasionally, they encountered tigers, crocodiles, and rhinoceros. Small mammals were adapted to lacustrine, grassland, and forest fringe habitats. There is no evidence for a canopied evergreen forest habitat. The absence of fine screening or flotation at this site has almost certainly led to an under-representation of fish and shellfish, both of which are numerically dominant at nearby and contemporary Ban Na Di. This is also the issue of the contents of mortuary vessels. At Ban Non Wat, these often contained multiple fish skeletons. To our knowledge, the contents of the Ban Chiang pots placed with the dead have not been investigated. We do, however, know that animal bones, on occasion articulated, were placed in graves. This was an enduring pattern that revealed little significant change from the initial Bronze Age to the late Iron Age ca. 1500 years later. During the earlier periods, occasional pig bones were placed with the dead. The range of species increased with the late Iron Age, when cattle, water buffalo, pig, a complete dog, and chicken bones were found. Throughout the sequence, the number of burials containing animal bone offerings, and their quantity, was always far less than at nearby Ban Na Di or Non Nok Tha.

The initial interpretation of this fauna was undertaken before the site's chronology was properly established. It concluded that from the mid second millennium BC, the advent of iron technology and the presence of the water buffalo provided evidence for plowing in permanent bunded fields that retained rainwater. This, we then suggested, was the innovation that permitted the subsequent spread of farming communities in the markedly drier southern part of the plateau. We concluded that if our first attempt at synthesis stimulated further research, we would have achieved our objective (Higham & Kijngam, 1979:232).

Further research has indeed, replaced the above model. Settlement of the southern, drier part of the plateau in fact preceded that at Ban Chiang by a couple of centuries. Wohlfarth et al. (2016) have taken cores from Lake Kumphawapi, just 10 km west of Ban Na Di and found that from ca. 200 AD, there was a sustained fall in the strength of the monsoon that led to centuries of relative aridity. Until this event, the subsistence economies of Ban Chiang, Ban Na Di, and Non Nok Tha were markedly similar to those documented at the sites on the southern, drier region. However, the climatic change would have had its most severe impact in the southwestern part of the plateau where rainfall is naturally low. It was exactly there that a swarm of Iron Age settlements, at that critical juncture, were surrounded by extensive earthworks. Banks ringed the settlements to retain water fed into moats from the local streams (Figure 11). Air photos and remote sensing have traced canals issuing from these sites into rice fields demarcated by bunds (Hawken, 2011). It was at precisely this period that burial rituals within the moated sites became markedly more complex. The dead were first laid out in discrete groups and then within the rooms of domestic houses seen most clearly at Non Ban Jak. Mortuary offerings proliferated, seen in particular in the quantity of bronze ornaments, carnelian, agate, silver, glass, gold, and iron. Just one man at Noen U-Loke during Iron Age 3 wore a greater weight of bronze ornaments than the entire mortuary assemblage from Ban Chiang. The iron smiths forged heavy socketed plowshares, spears and sickles. At Ban Non Wat, an area revealed a palimpsest of imprints from water buffalo hooves, probably representing a corral for these vital draft animals. According to the surviving weed seeds, rice was grown in permanent wet fields (Castillo et al., 2018). The impact of this agricultural revolution was felt socially in several ways. Those owning the best land fed from the reservoirs and cultivated by

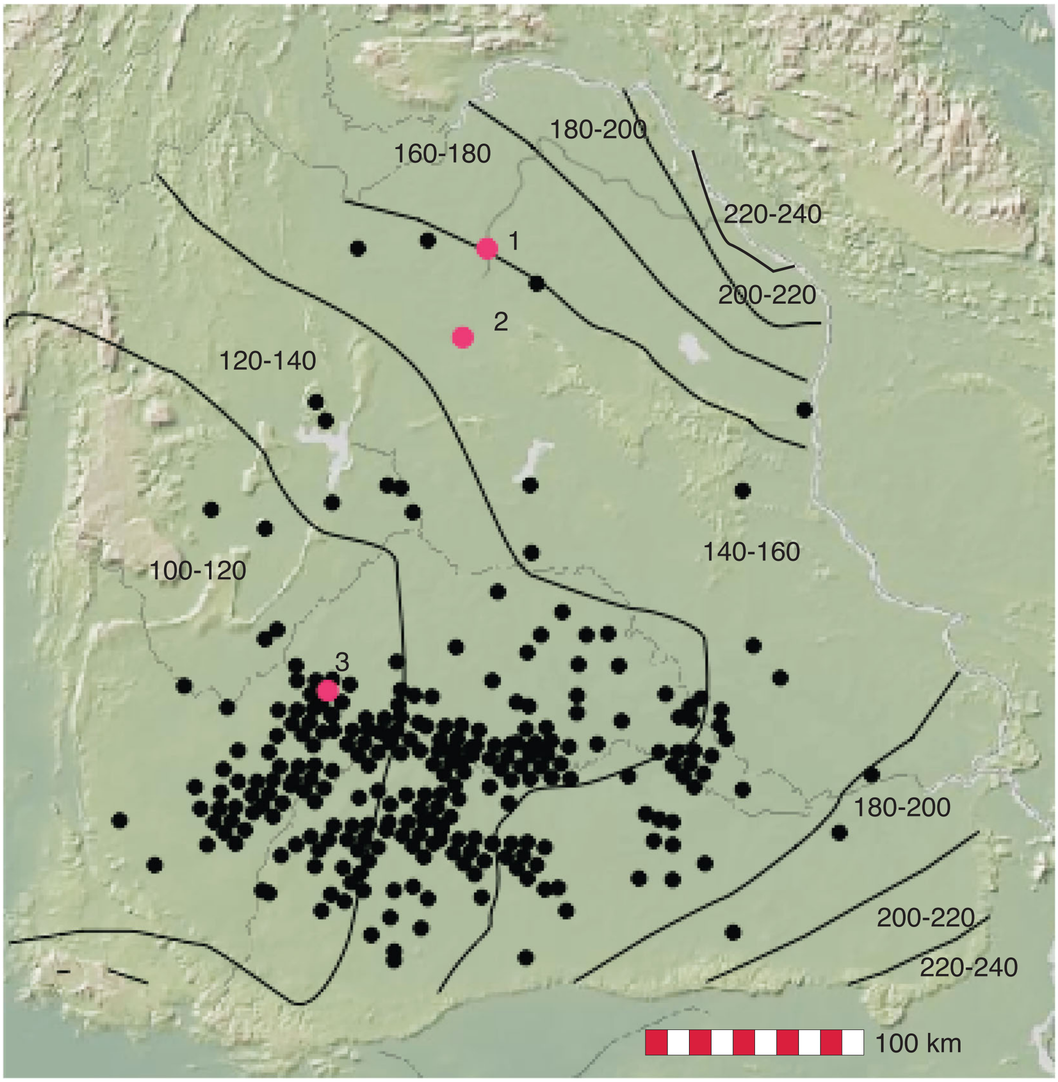


**FIGURE 11** The Khorat Plateau, showing the location of sites mentioned in the text, the distribution of moated Iron Age sites, and the rainfall isohyets in cm per annum. 1. Ban Chiang, 2. Ban Na Di, 3. Noen U-Loke and Non Ban Jak [Colour figure can be viewed at wileyonlinelibrary.com]

plowing could generate disposable wealth. However, the expansion of the essentially aquatic habitat round the sites, evidenced by the quantities of shellfish, was deleterious to human health. We therefore find a surge in infant mortality.

Within a century or two of these seminal changes, the strategically placed site of Muang Sema doubled and then trebled in size, and inscriptions describe a royal dynasty in the upper Mun River region. However, in the well-watered northeastern reaches of the Khorat Plateau, there is barely a single moated site, and neither Ban Na Di nor Ban Chiang has provided any evidence for the wealthy elites seen in the graves of Noen U-Loke. There remains, however, a continuing caveat to this conclusion. The excavations at Ban Chiang and Ban Na Di uncovered no more than 60 $m^2$ compared with over 800 $m^2$ at Ban Non Wat. It is thus possible that elsewhere at either site, an enclave of wealthy, elite Iron Age burials remains to be discovered.

## 3 | CONCLUSIONS

Archaeozoology in Southeast Asia is undergoing a transformation, seen in the impact of DNA on identifying the timing and location of episodes of domestication. Furthermore, Dr. Rosalind Gillis is undertaking analyses of the bovine dentition to evaluate seasonal dietary change from the isotopes in incremental growth contexts. This contrasts with the situation in 1975. Our initial interpretation of the faunal remains from Ban Chiang was a pioneer endeavor undertaken with hardly any comparative data (Higham & Kijngam, 1979). Subsequent research has necessitated a radical reassessment. The chronology of the initial settlement has been truncated by 2000 years, and the transition into plow-based wet rice farming from 1500 BC at Ban Chiang has been set aside. The new model incorporates the results of DNA that place the domestication of cattle, pigs, and dogs, as with rice, in southern China, and that for chickens locally. Originating from the north, the first farmers who settled the Khorat Plateau brought with them their domestic animals to establish small Neolithic communities. Adaptation to the subtropical deciduous forest involved the maintenance of domestic stock and also consistent hunting, fishing, and gathering. This involved in the main, the local deer, and abundant sources of fish and shellfish. There is, at the Ban Chiang excavation of 1975 and at Ban Na Di, a related Bronze and Iron site nearby, a consistency to the subsistence base over at least 15 centuries from initial settlement at the former in ca. 1100–1000 BC and the latter two centuries later.

This pattern, that combined rice farming with raising domestic cattle and pigs, contrasts sharply with that summarized for coastal sites. There, one finds a virtual absence of domestic cattle and chickens. Pigs and dogs dominated at An Son, but both were rare at estuarine sites with a habitat dominated by mangroves and nypa palms. The impression gained is one of rapid adaptation by migratory rice farmers to the resources at hand, and these were largely marine or found in the mangal habitat. There is a growing body of evidence that reveals mixed populations of incoming farmers and indigenous hunter–gatherers at these sites, and this might well be reflected in the diet. There is, however, an important element to the distinction between the inland and coastal sites, seen in particular in the presence of domestic cattle and chickens in the former but not the latter. It is suggested that there were two separate routes of expansion into Southeast Asia by the first farmers, one along the coast from Southern China and the other riverine along the Mekong River. When one adds to this, the distinctiveness of the material culture found at Ban Kao and Nong Ratchabat in the western part of the Central Thailand, further routes followed by early farmers are highly likely.

From the 3rd century AD, the inland region entered a period of sharply reduced rainfall. This would have had its most serious impact in the relatively dry southwestern part of the Khorat Plateau, where rainfall is naturally close to half that in the vicinity of Ban Chiang. The onset of aridity stimulated the inhabitants of the Mun River region to conserve water in reservoirs round their settlements and supplement the rainfall by feeding it into permanent rice fields. This coincided with the first iron plowshares and sickles. Rice, ritually significant, was used to fill human graves now opulently furnished with exotic ornaments. The significance of climate change is to be seen in the absence of these social and technological innovations in the well-watered northeast, whereas at Ban Chiang, there is no evidence for the same seminal changes that underwrote the transition to early states.

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## CONFLICT OF INTEREST

The authors declare no competing interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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