The ecology of chickens: An examination of the introduction of the domestic chicken across Europe after the Bronze Age

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Abstract

The domestic fowl, *Gallus gallus domesticus*, or chicken, features as an important part of human society, culture and subsistence, both now and in the past. Despite studies into the origins and spread of many of the other domestic animals, the origins and nature of spread of the chicken west and into Europe has been largely neglected due to a lack of sufficient compiled evidence.

It is widely accepted that chickens are descended from junglefowl in Asia and South East Asia, but more precise origins of the chicken are debated. As a bird with limited flight capability, the chicken has been transported worldwide by humans. Once the chicken arrived in Europe, very little attention has been given to the human-chicken interactions which governed its success, and enabled it to become permanently established in a region very different to where its ancestor originates- geographically, environmentally and culturally.

This study compiles zooarchaeological evidence for the chicken across Europe, combines it with evidence from archaeology and anthropology, and takes the novel approach of applying ecological and biogeographical techniques. Such techniques complement traditional methods of archaeological assessment, and provide new and unique insights into the origins, spread and impact of this significant species. I establish the regions which are most suitable for initial domestication, and demonstrate that Europe would not be suitable for indigenous populations of the ancestor bird. This informs us about the human investment required to maintain early populations of chicken. I identify India as the most likely origin of early European chickens, based on environmental suitability, presence of the ancestor species, and practical routes from Asia to Europe; but propose multiple centres of domestication in Asia. Once the chicken reaches Europe, multiple diffusion events associated with specific cultures are identified, primarily via trade routes. The niche of the ancestor is compared to the niche of the early domestic chicken and found to have shifted, indicating adaptation under domestication. The introduction of the chicken into Europe as a non-native species is shown to have directly and indirectly affected certain species, but the chicken itself is most affected by human agency. The date, location and context for the faunal remains, combined with literary evidence and material culture, establishes change and continuity in both use and perception of chickens by human societies.

The conclusions and methods presented in this thesis are relevant to several subjects, including archaeology, zooarchaeology, ecology and conservation, and demonstrate the benefits of a multi-disciplinary approach.

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Author's declaration

I confirm that this thesis is the result of my own work and includes nothing that is the outcome of collaboration or the work of others except where explicitly stated and appropriately referenced within the text.

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1 Introduction

1.1 The chicken

With a near global distribution, the domestic fowl, *Gallus gallus domesticus*, or chicken, is the most widely established domestic animal. Although there are currently more than 20 billion chickens on the planet (Chemnitz and Becheva 2014), the history of the species is remarkably poorly understood. Modern perceptions of human-chicken interactions tend to focus on their role as a consumable product. This is reinforced from a young age in the way in which animals are featured in children's films and literature, and in modern material culture, which emphasise the separation of food from animal (Stewart and Cole 2009). The dominant association of chicken as meat is reflected in the scientific literature, with the majority of studies focusing on chicken as a food source rather than as a bird (Marino 2017).

The few papers which have investigated the chicken as a species have mostly centered on genetics (Liu et al. 2006; Kanginakudru et al. 2008; Miao et al. 2013; Girdland Flink et al. 2014). The chicken's diffusion eastwards to the Americas via Polynesia was the subject of a small series of papers using genetics and archaeological data (Storey et al. 2007; Fitzpatrick and Callaghan 2009; Storey et al. 2010; Thomson et al. 2014). A recent paper has identified the diffusion of the chicken to New Zealand (Wood et al. 2016). Study of the dispersal and spread of the chicken to and within Europe has been hindered by a lack of available evidence (Serjeantson 2009; Storey et al. 2012). Almost all other areas of research involving the history of chickens have been largely ignored, including ecological responses to climate and environment, so crucial to the survival of any living species and instrumental to their origins, dispersal, and endurance. A single paper to date, centered on East Asia, has considered the chicken in ecological context (Peters et al. 2016).

Yet there is much to be gained from studying the chicken. A better understanding of exactly where the chicken came from, how it adapted to where it was taken, and how it was used in the past, has implications for anthropology, archaeology, conservation and ecology. Descended from tropical rainforest residing junglefowl in Asia and South East Asia, the chicken has limited flight capability so its global spread is attributable to humans. People have engaged in trade since the Palaeolithic. This has at times, and increasingly, involved movement of animals, both purposefully and inadvertently, across continents. The transfer of products, especially non-native animals, is recognised to be a valuable source of cultural, economic and ecological information (Sykes 2012). Studies of the origins and dispersal of other domestic species have provided additional insights into human dispersal and behaviour (Diamond 2002; Larson et al. 2007; Conolly et al. 2011; Manning et al. 2013). As a small, light, easily tamed, and easily transported bird, the chicken is an ideal species to inform us about human dispersal in the Late Prehistoric period and Early Antiquity. Utilisation extends beyond direct exploitation of produce (i.e. meat, eggs and feathers) into the realms of religion and culture, informing us about behaviours, beliefs, and human-animal perceptions of past societies.

The chicken was not only traded but also domesticated. It was introduced as a non-native species into new environments, where it had to adapt under domestication, a favourite topic of Charles Darwin (Darwin 1868). The introduction of non-native species is known to cause dramatic changes in ecosystems (Mooney and Cleland 2001), but the effect of the introduction of the chicken on its environment has not been researched. As one of the most recently domesticated species, more evidence is available for understanding how introducing new domesticates may have altered past ecosystems. The suitability of the environment into which the chicken was introduced determines the level of human investment required to maintain a recently domesticated exotic species. Analysing suitability and acclimation to different environments, especially in comparison to its extant ancestors, informs us about the response of the species to climate change. It provides useful information which may aid not only the future sustainability of the chicken, but also conservation of the ancestor.

1.2 Origins

Charles Darwin was the first to suggest that chickens were descended from junglefowl. In 'The Variation of Plants and Animals under Domestication', written in 1868, he offers that domestic fowl "seem all to have diverged by independent and different roads from a single type" (Darwin 1868, p. 225), suggesting a monophyletic origin for the species. For Darwin, the single type is *Gallus bankiva*, used here as a synonym for the Red Junglefowl, *Gallus gallus*. He acknowledged that "Most fanciers believe that they are descended from several primitive stocks" (Darwin, 1868, p. 230), i.e. a polyphyletic origin, a debate which has ensued into recent decades.

There are four junglefowl species currently found across India and South East Asia, namely Red Junglefowl, *Gallus gallus*; Grey Junglefowl, *Gallus sonneratii*; Sri Lanka Junglefowl, *Gallus lafayetii*; and Green Junglefowl, *Gallus varius* (Figure 1). Red Junglefowl includes the five subspecies, *Gallus gallus murghi*, *Gallus gallus spadiceus*, *Gallus gallus jabouillei*, *Gallus gallus gallus* and *Gallus gallus bankiva*. There are no known subspecies of the other junglefowl species.

The species and subspecies are largely defined by morphology and geographic dispersal (Table 1). Morphological differences between the species are best represented by the upright comb and gular wattles in the males, and pigment distribution in females (Morejohn 1968a). Based on morphology alone, Green Junglefowl are most distinct from the other species, with two extra tail feathers, an unserrated rather than serrated comb, and single median wattle as compared to the two wattles exhibited by the other three species (Stevens 1991). This may represent divergence between island and mainland species, with Sri Lanka Junglefowl included in the latter because Sri Lanka was formerly attached to mainland India (Voris 2000).

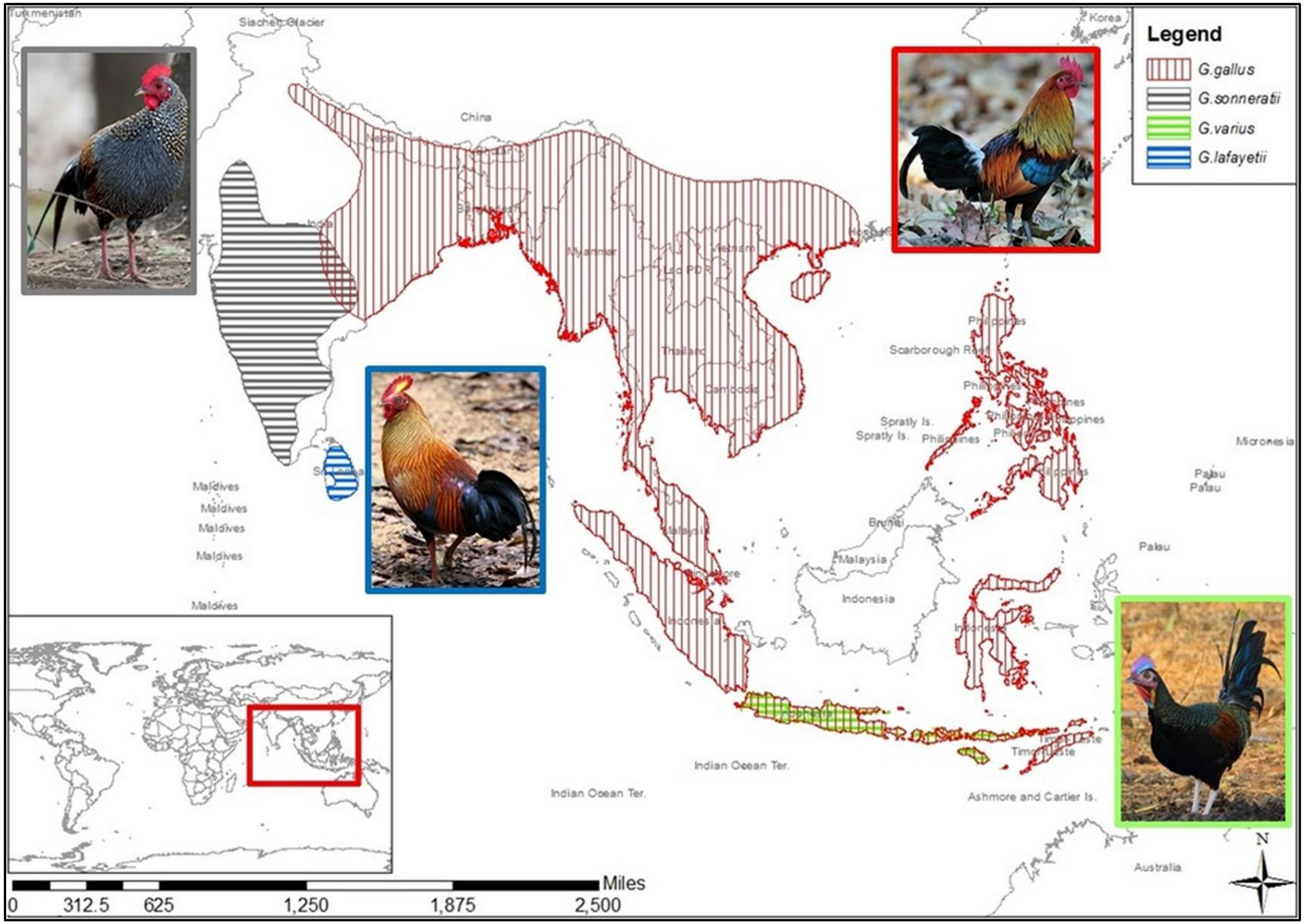


Figure 1. Junglefowl species and range (range based on IUCN, www.iucnredlist.org; images from orientalbirdimages.org).

Level	Scientific name	Common name	Current distribution	Description
species	*Gallus gallus*	Red Junglefowl	(see subspecies)	Golden yellow to mahogany red plumage with a pale patch at the base of the tail coverts; blue shanks
subspecies	*Gallus gallus murghi*	Red Junglefowl	North India, and adjacent Nepal, Bangladesh	As Red Junglefowl, but with white earlobes
subspecies	*Gallus gallus spadiceus*	Red Junglefowl	Myanmar to south-west Yunnan, Malay Peninsula and north Sumatra	As Red Junglefowl, but with red earlobes
subspecies	*Gallus gallus jabouillei*	Red Junglefowl	North Vietnam to south China	As Red Junglefowl, but with red earlobes
subspecies	*Gallus gallus gallus*	Red Junglefowl	North Indochina to east Thailand	As Red Junglefowl, but with white earlobes
subspecies	*Gallus gallus bankiva*	Red Junglefowl	South Sumatra, Java, Bali	As Red Junglefowl, but with red earlobes
species	*Gallus sonneratii*	Grey Junglefowl	Peninsula India	Black body feathers with a white shaft and grey border; black wing and tail feathers; spots on the feathers
species	*Gallus lafayetii*	Sri Lanka Junglefowl	Sri Lanka	Orange-brown breast; purple spot on the top of the neck; yellow spot on the comb
species	*Gallus varius*	Green Junglefowl	Java, Bali, Lombok, Sumbawa, Flores, Alor islands	Green plumage; two additional tail feathers; single three-coloured wattle (red, yellow, blue); lack of comb indentations

Table 1. Species and subspecies of junglefowl, (location after Clements checklist (Clements et al. 2016); description after Crawford (1990) and Tixier-Boichard et al. (2011)).

Some modern studies agreed with Darwin on the single-origin theory (Fumihito et al. 1994; Hillel et al. 2003). However, the sequencing of the chicken genome in 2004 (International Chicken Genome Sequencing Consortium), has enabled advances in knowledge using DNA analyses. Based on this, current research argues strongly for contributions from the other junglefowl species. Nishibori et al (2005) concluded that Grey Junglefowl and Sri Lanka Junglefowl had both contributed to the establishment of the domestic chicken, with additional inter-species hybridisations between these two junglefowl. This was followed by compelling evidence provided by Eriksson et al (2008) and Girdland Flink et al (2014) regarding the yellow skin allele, BCD02, which causes the yellow legs found in many domestic breeds. Given that this allele is not found in Red Junglefowl, which have grey/blue legs, this is thought to suggest contribution of Grey Junglefowl to the domestic mix (Eriksson et al. 2008; Girdland Flink et al. 2014).

Anecdotal evidence suggests that interbreeding of Red- and Grey Junglefowl occurs in their overlapping geographic range (Eriksson et al. 2008, and see Figure 1), but it is only confirmed in captivity (Morejohn 1968b). In tests, due to different courtship rituals, only mating of red hen and grey cockerels was possible, but they did produce fertile offspring (Morejohn 1968b). Interbreeding between domestic chickens and junglefowl species has been shown to be most successful with Red Junglefowl (Crawford 1990; Tixier-Boichard et al. 2011), with whom it is also morphologically most similar. Red Junglefowl appears to be the dominant ancestor for early European domestic fowl, based on the DNA of ancient chickens (Eriksson et al. 2008; Girdland Flink et al. 2014); however, it has been recently questioned whether some early examples in the Indus Valley in India could be Grey Junglefowl rather than Red Junglefowl (Peters, J., in prep), with Red Junglefowl dominance developing post-initial domestication in this region.

1.3 Initial Domestication

The location of initial domestication is generally unclear. The literature agrees that the chicken was first domesticated somewhere in Asia or South East Asia (Figure 2). In a few cases, there does appear to be some link between the country of origin of the research and a suggested origin of chicken domestication, for example Thailand (Fumihito et al. 1994), China (Liu et al. 2006; Xiang et al. 2014), and India (Kanginakudru et al. 2008).

Apart from the paper by Fumihito et al. (1994), which proposes a single domestication event in Thailand, these studies add genetic support to the argument for multiple origins of domestication. A study of mitochondrial DNA (Miao et al. 2013) identified several lineages, suggesting localised domestication events in South Asia, Northeast India, Southwest China, and a further event in Southwest China and South East Asia. Indeed, the earliest reported archaeological examples of domestic chicken are from these regions.

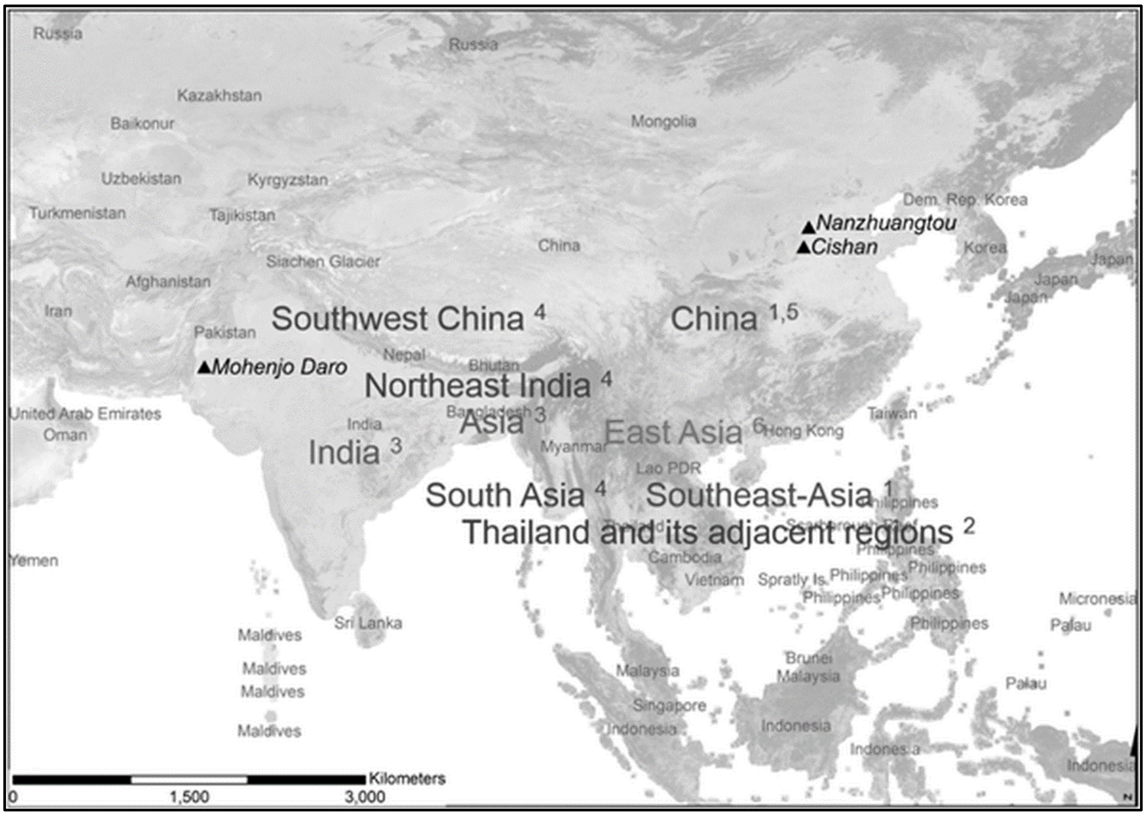


Figure 2. Suggested locations of first domestication of chicken by 1. West and Zhou, 1988; 2. Fumihito et al., 1994; 3. Kanginakudru et al., 2008; 4. Miao et al., 2013; 5. Xiang et al., 2014, 2015; 6. Peters et al., 2016.

The lack of clear chronology for the early domestication of the chicken stems largely from potential misidentification of the remains (Harrison 1980; Bochenski 2008; Serjeantson 2009), lack of secure context (Stewart 2007; Kyselý 2010) or poor dating evidence (Stewart 2005; Best et al. in prep). The earliest proposed domestication event is Nanzhuangtou, China ca. 8050 BCE (Xiang et al. 2014); but this has been contested (Peters et al. 2015; Xiang et al. 2015; Eda et al. 2016). Eda et al. (2016) recently reappraised evidence at other early Chinese sites (West and Zhou 1988) concluding that the earliest specimens are not chicken, but one or more of the other fifty-three Phasianidae species found in China. This leaves the Harappan Culture sites in the Indus valley, India, ca. 2500 BCE (Zeuner 1963; Fuller 2006) as the earliest candidates; although even here the size of the birds for the suggested date, and context security, due to possible bioturbation, have both been called into question (Peters et al. in prep).

One of the main problems in this debate is that while the chicken exhibits several traits which differ from the wild species (Table 2), many relate to plumage and soft tissue which cannot be identified in the archaeological record. This has resulted in a tendency to define chickens as ‘domestic’ based on larger skeletal size than their ancestors. There is evidence to support a change in livestock size between the Late Iron Age and Roman periods in Britain (Albarella et al. 2008); however, even though many animals, such as sheep, goats, cattle, pigs and dogs initially decrease in size under domestication, smaller domesticates, such as guinea pigs and chickens, often increase in size due to increased food provision and protection from predators (Reitz and Wing 2008). Due to inherent variability within fowl species, classification by size alone is problematic. Bones exhibiting substantial variability in size have variously been used to determine the presence of different breeds (De Cupere et al. 2005), or sexual dimorphism (Gál, E. 2013). Comparison of chicken tarsometatarsi from archaeological sites (Peters 1997) suggests that Iron Age examples are similar in size to Red Junglefowl. Late Iron Age to Roman contexts at Suddern Farm (Hamilton 2000a) all include chickens the size of modern bantams, which are smaller than junglefowl.

Red Junglefowl	***Chicken***
Moult into an eclipse plumage (Jun - Oct)	Complete lack of eclipse plumage
Slender, dusky blackish legs	Thick, warty-skinned, often yellowish legs
Lack of comb in hens	Frequently have prominent combs and wattles
Tail held horizontally	Tail held vertically
Distinctive crow	Added terminal syllable
Small mixed flocks (non-breeding)	Often a single cockerel, due to fighting
Spring breeding season	Breed year-round

Table 2. Differences between Red Junglefowl retaining traditional morphology and domestic chickens, after Peterson and Brisbin (1998).

Secure contextual evidence for domestic settlement usually implies domestic chicken. This is complicated in the native junglefowl range, where *Gallus* bones could be wild junglefowl or chicken in areas where wild *Gallus* are known (Fuller 2006). The use of wild birds by early societies is reported, but usually from higher latitudes (Serjeantson 1997; Best and Mulville 2014). Thus, establishing a definitive centre, or centres, of domestication is challenging.

1.4 Evolution under domestication

1.4.1 Dispersal

Various dispersal routes from these suggested centres of domestication have been proposed, both as single and multiple diffusion events. Based on archaeological evidence, movement north has been described as a single dispersal of the chicken from South East Asia to China, from whence they spread to Japan via Korea and Europe via Russia (West and Zhou 1988, but see Section 1.3 regarding the Chinese evidence).

An eastward expansion of the domestic chicken into Oceania has been demonstrated using archaeological evidence (Storey et al. 2008) and DNA analysis (Gongora et al. 2008; Storey et al. 2012; Thomson et al. 2014), possibly spreading via this route to South America (Storey et al. 2007; Fitzpatrick and Callaghan 2009). It has been shown, using DNA evidence, that New Zealand chickens are not related to this dispersal, but instead were transported there by Europeans in the eighteenth century (Wood et al. 2016).

Moving west, possibly due to a lack of recording, skeletal evidence for the Middle East and Africa is scarce. A single fragment of domestic chicken was recovered from deposits dated to ca. 3900 BCE, at Tepe Yahya in Iran, from whence chickens spread across Turkey and Syria, ca. 2900–2000 BCE, and into Jordan by ca. 1200 BCE (Redding 2015). Knowledge of chickens, ca. 1500 BCE, in North Africa is demonstrated by depictions of roosters with domestic traits within the Pharaohs' tombs of Rekhmara and Tutankhamun (Crawford 1990). Following a hiatus, further Egyptian depictions suggest a later dispersal in ca. 650 BCE (MacDonald and Blench 2000). Given the hiatus, it is possible that the early depictions represent knowledge rather than residency. The earliest secure dates for domestic chicken remains elsewhere in Africa are from the mid-first century CE (Dueppen 2011). DNA analysis, based on haplogroups, suggests separate maritime introductions from South East- and/or East Asia, the Indian subcontinent and possibly from Yunnan Province in China (Mwacharo et al. 2013).

The early spread of domestic chicken northwest through Europe is thought to have been associated with trade routes. Dispersal through the Mediterranean may correspond with the Phoenician traders (Becker 2013) and Greek colonists (Peters et al. in prep), the former taking a southern, and the latter a northern route through the Mediterranean. Storey et al.'s (2012) study using genetics briefly discusses European dispersal, but concludes that insufficient archaeological evidence has been compiled for further analysis.

1.4.2 Development

Regardless of the route taken or whether there were single or multiple domestication events, humans have been responsible for transporting chickens around the globe. This bird then needed to acclimate and/or adapt to its new environment. It is generally accepted that there are three main drivers of evolution- natural, sexual and artificial selection pressures. Natural selection can be seen as the genetic inheritance of advantageous traits and is an environmentally driven mechanistic process. Sexual selection is also a natural process, considered by Darwin to be a part of natural selection, related to mating and reproductive success. Artificial selection is usually a conscious, human-driven process, and applies more readily to a species evolving under domestication. This is often associated with selective breeding practices, but can also be an unintentional consequence, and generally renders sexual selection obsolete (Driscoll et al. 2009).

Darwin paid particular attention to the idea of evolution under domestication, the "variability which follows from the crossing of distinct species, and that which may be observed with plants and animals when reared under new or unnatural conditions" (Darwin 1859, p.7). He addressed the subject in both 'On the Origin of Species' (Darwin 1859) and 'The Variation of Plants and Animals under Domestication' (Darwin 1868). In the case of the domestic chicken, Darwin proposed evolution by artificial selection, initially unintentional, but replaced in more recent periods by methodical intent, with abnormalities often driving selection in the latter case (Darwin 1868). This is certainly true for some breeds of chicken, such as the crested varieties (Figure 3). A cerebral hernia caused by a recessive gene (Yoshimura et al. 2012) could be a disadvantage in the wild. Limited visibility and the potential for a fatal well-placed peck is unlikely to be selected for naturally. Darwin suggests that these abnormalities, defined as differences from wild gallinaceous birds, may have been caused by changes in climate and food, growth in size, the crossing of breeds, or unconscious selection (Darwin, 1868, p. 233).

Figure 3. Polish crested chickens (Thomas, R. 2014, 'Being Human Festival', pers. comm.).

Recent genetic studies have identified domestic traits favoured by humans, specifically those associated with growth, appetite and metabolic regulation (Rubin et al. 2010). Mutation of the thyroid stimulating hormone receptor (TSHR), which governs seasonal reproduction in wild species is noted to be of particular importance, but perhaps developed more recently than at first domestication (Girdland Flink et al. 2014). DNA evidence has been used to identify change as a consequence of selection pressures (Elferink et al. 2012). 'Domestication genes' are distinguished from 'improvement genes' in order to spatially map origins of domestication (Larson et al. 2014). The former are defined as controlling the traits desired in early selection for domestication, and the latter for enhancement of the domesticated species. Colour enhancement is an example of this. In females, it negates natural selection for the dull brown and grey colouring of the wild bird, which allows for camouflage while nesting. Hybridisation of specific breeds is required to achieve the colour variations seen in domestic chickens today (Sheppy 2011).

Not all chicken selection has been artificial. The dominant pea comb mutation, associated with gene SOX5, is an interesting natural adaptation. Present in European and Asian chickens it is thought to have occurred early in domestication. This feature is noted to have been illustrated in the tomb of Rekhmara at Thebes, Egypt, dated to ca. 1500 BCE (Crawford 1990). The mutation massively reduces the size of the comb. It has been suggested that this is a selective advantage for cockfighting by reducing target size, and for cold climates because, in the absence of sweat glands, the comb governs heat loss. It was suggested that a smaller comb would be a disadvantage in tropical environments for this reason. (Wright et al. 2009). However, the lack of a comb in female Red Junglefowl exhibiting traditional morphology, would seemingly contradict this.

1.5 The Environment

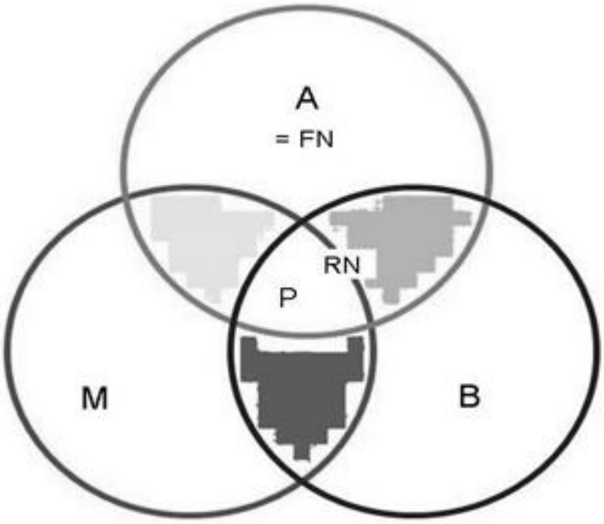
1.5.1 Ecology

Environmental conditions are a common driver of natural selection. Climate, terrain and ecological community determine the survival of individuals of a species. All ecological research is affected in some form by scale. At the broadest scale, ecology can be considered within the wider landscape, a patchwork of areas defined by vegetation cover, soils, geology, and human land use (Wiens 2002). Governed by climate, these patches determine the habitats within which communities, populations and organisms are distributed. Survival is dependent on low levels of competition, in suitable environmental conditions, with adequate resources. Within these patches, a series of microenvironments exist, each with their own unique ecosystem. They comprise local variations in vegetation, topography and species communities, which are very difficult to detect in research covering large spatial scales, but are important as they may affect how species respond to climate change or to new species introductions (Suggitt et al. 2011).

While topographic elements tend to be static, communities and populations are mobile. Species responding to changes in their ecosystem often need to expand or shift their range to compensate, a cycle whereby species find newly suitable conditions in regions vacated by others (Thomas et al. 2012). For wild animals, this movement is unassisted by humans. Domestic animals, however, including chickens, are transported by humans. Their mobility is limited to that of their human owners. The benefits conferred by this association, such as the additional provision of resources and shelter, may curtail adverse effects of environmental change. Instead, the introduction of a new domestic animal may itself be the cause of environmental change. It means that environmental conditions suitable for the survival, dispersal and breeding of the chicken need also to be conditions suitable for the survival, dispersal and breeding of humans.

1.5.2 Ecological niche

Species requirements determine their ecological niche. Definitions of ‘niche’ vary in the literature, but the concept essentially specifies a set of ecological conditions that allow a species to maintain population size, while taking into account impact on resources, interacting species, and the environment (Townsend Peterson et al. 2011). Differences in definition mainly concern whether dynamic or static variables are the key requirements (Soberón and Nakamura 2009). It is important to recognise differences between ‘fundamental niche’ (FN) and ‘realised niche’ (RN) (Figure 4). The fundamental niche represents where abiotic factors should enable the species to survive in the absence of other, negative, influences. However, within an ecosystem, biotic interactions, such as competition for resources or predators, will make parts of the fundamental niche unsuitable. The realised niche is where both abiotic and biotic factors are suitable. This does not necessarily represent where the species is found because the realised niche may include geographical areas the species simply cannot reach. Its actual distribution will be determined by the suitability of all three factors.



A represents the geographic region with the appropriate set of abiotic factors for the species **=** the Fundamental Niche (FN).

B is the region where the right combination of interacting species occurs.

A ∩ B = the Realized Niche (RN)

M is those parts of the world "accessible" to the species in some ecological sense

A ∩ B ∩ M = P = the geographic distribution of the species.

Figure 4. Fundamental and realised niche (Soberon and Peterson 2005).

For example, native Red Junglefowl are found in tropical-rainforest environments of Asia and South East Asia. Similar conditions are found elsewhere globally, such as in the Amazon basin, and would feasibly be suitable. However, without human assistance, junglefowl are limited to Asia by virtue of being unable to fly at sufficient height or distance to traverse the mountains, desert and sea that confines them. In terms of biotic interactions, the ecology of the range occupied by the Grey Junglefowl in India is not dissimilar to the neighbouring range occupied by Red Junglefowl, and, in fact, they overlap (Figure 1). However, there are very few occurrences of Red Junglefowl found within the range dominated by Grey Junglefowl, presumably due to competition for resources.

Determining the ecological niche of the chickens' ancestors, Red and/or Grey Junglefowl, is relatively straight-forward. Determining an ecological niche for the chicken is more challenging. Over the past two millennia it has evolved under domestication. Dispersal via humans has caused the chicken to acclimate and/or adapt to new habitats. As a domestic animal, negative abiotic and biotic interactions are lessened by humans, resulting in an almost global realised niche and an almost global distribution.

1.5.3 Species interactions (animal / animal)

Biotic interactions define the ecological community. They are generally divided into two types. Intra-specific relationships describe the interaction of individuals of the same species, while inter-specific describes the interaction of two or more different species (Lang and Benbow 2013). The natural world is essentially a complex network of these interactions, which usually take the form of competition, predation, herbivory or symbiosis. Lang and Benbow (2013) define competition as species vying over the same resources, usually resulting in a negative outcome for the weaker competitor. Predation is a predator/prey relationship, whereby the predator kills the prey. The intra-specific version of this is cannibalism. Herbivory is similar to predation, where the prey is plant or algae, and may subsequently survive. Symbiosis is a relationship which may be beneficial to both species, typically commensalism or mutualism, or to only one species, i.e. parasitism.

In terms of intra-specific relations, it is precisely how the chicken functions within a flock that makes them suitable for domestication. While not as tame as some domestic animals, for example the dog, chickens are not flighty compared to most birds. They organise themselves into a hierarchical social structure which protects its own, and breed easily with no complex courtship rituals (Reitz and Wing 2008). From personal experience as a keeper of chickens, a flock adopts a mutual relationship, although competition within flocks for limited or desirable resources is not unknown, and can be fatal for weaker members. There is also an element of cannibalism in that they will eat their own eggs.

The introduction of any new species into a community will inevitably alter inter-specific interactions in some way. The chicken offers an interesting opportunity to examine the effects of this on an ecosystem over an extended period. Comparison of species abundance at site level has been used to interpret the relationships between species (Maltby 1997; O'Connor 2013), and links have been suggested between the dispersal of the chicken and several other species, predominantly commensals. Usual methods of feeding chickens can involve more waste than when feeding other livestock and so create more opportunities for commensals than other farming practices. Specifically, it has been suggested that the provision of cereal grain and other plant materials to feed chickens assisted the global spread of commensals such as rats (*Rattus*) and mice (*Mus*) (Kovács 2012). The spread of the chicken is also reported to coincide with the arrival of the house sparrow (*Passer domesticus*) (Ericson et al. 1997). As towns grew in the Roman period, the synanthropisation and synurbanisation of species increased. Environments associated with the keeping and breeding of chickens may have attracted other species to human settlements, including predator species, such as foxes and rats. The consequent success of species adapting to this new environment is determined by their feeding and hunting behaviour (O'Connor 1993). Species which are known to be successful in these environments, such as feral pigeon or rock dove (*Columba livia*); corvids, particularly raven (*Corvus corax*); and some raptors, including the common buzzard (*Buteo buteo*), sparrowhawk (*Accipiter gentilis*), and red and black kites (*Milvus sp.*) (Boev 1993; O'Connor 1993), are all present on archaeological sites containing chicken.

1.5.4 Species interactions (human / animal)

The inter-specific relationship which has been most important in the history of chicken is interaction with humans. To take Britain as an example, local and regional studies into human-animal interactions (Albarella et al. 2008; Sykes 2012) have indicated a change in the social and economic importance of the chicken between the Iron Age and Roman periods in Britain. It has been observed that domestic fowl have been more frequently recovered from Roman urban and military sites than rural sites (Maltby 1997), perhaps reflecting differential availability or cultural preference. Such studies have not been applied commonly on a wider geographic scale. As an exotic species, the chicken has fascinated humans for millennia, and different cultures appear to have included the chicken in their culture and daily lives in very different ways.

One of the earliest documentation of chickens can be found in Sanskrit literature, the *Atharvaveda* and the *Yajurveda*, both dated to ca. 1500 BCE, which praise the chicken for his courage, his pride and his ability to tell time (Zeuner 1963). Evidence suggests that initially the chicken may not have been domesticated for food. Zeuner (1963) notes that in India the eating of chicken meat was forbidden for religious reasons, ca. 1000 BCE, while within the Indus culture chickens were bred for cockfighting and not as food. In Japan, there is little evidence for consumption of chickens until the nineteenth century (MacDonald and Blench 2000). Similar taboos are noted of British Iron Age people. Caesar's writings describe how they "do not regard it lawful to eat the hare, and the cock, and the goose; they, however, breed them for amusement and pleasure" (Gallic War, V, 12). Interestingly, hare and goose appear infrequently though in British Iron Age assemblages, and the hare is thought to be wild, not domestic (Hambleton 2009). Iron Age chickens in southern England are commonly recovered as partial or complete skeletons, which do not appear to have been consumed (Hambleton 2009; Morris 2011) although cut marks have been observed on a few chicken bones of Iron Age date (Maltby pers. comm.). This may represent cultural or regional differences though. Benecke, in contrast, argues that his results for the Iron Age in Central Europe indicate that "domestic fowl was mainly used in meat production" (1993, p.29). The consumption of eggs by pre-Roman societies is unclear, mainly because eggshell is infrequently recovered or reported in the archaeological record.

Even if the meat was not eaten, it appears to have been frequently cooked and used at religious sites. Ritual offerings are a primary use for chicken in Late Prehistoric societies. This is clear from the archaeological record. Interesting ritual chicken burials occur, such as Iron Age burials at Rochefort a Gerzat (Alfonso 2007), where two complete dog skeletons were found overlying two complete chicken skeletons, positioned two metres apart, and in association with a perinatal infant. Inclusion of animals as grave goods was thought to "stop the soul from pining away and troubling the living in their search for food" (Lauwerier 2002, p. 65). As an exotic bird, the chicken makes a suitable offering to the gods, a practice which continued through the Roman period. Chickens are depicted alongside the Roman god Mercury and ritual feasts and/or votive offerings devoted to this god are often associated with large quantities of chicken bones (Woodward and Leach 1993). Additionally, ‘sacred chickens’ were kept for divination. Romans texts by Varro (De Re Rustica, III:3, 36 BCE) and Cicero (De Divinatione, II:35, 44 BCE) confirm this use. Usually, it took the form of a ‘tripudium’ (the falling of food to the ground from the beak taken as a favourable sign). The practice was criticized in its day by Cicero, who questions the validity of using caged chickens for this purpose.

The written record also contains other useful pieces of information regarding breeding and use. Detailed advice on the keeping of chickens is provided by Cato (*De Agri Cultura*, 2nd century BCE, 89):

> “Force-feed chickens and geese as follows. One shuts in young chickens that have just begun to lay. One makes cakes of moistened fine wheat flour or barley flour, dips them in water, and puts them in the mouth, increasing gradually day by day, judging from the gullet what is a sufficient amount. One force-feeds twice a day and gives water at midday. Water should not be allowed for more than an hour”.

Columella discusses the benefits of importing ‘foreign’ breeds for cockfighting (*Tanagrian*, *Rhodic*, *Chalkidic* and *Median*) (Jennison, 1937). This activity is first known from the ancient writings of Manu in India (Hams 1983). It is thought to have been inherited by the Romans from the Ancient Greeks (Sykes 2015). The Ancient Greeks may have inherited it from Iron Age populations in Israel and Palestine, where the chicken is depicted on seals and pottery in this manner in the seventh century BCE (MacDonald and Blench 2000). Cockfighting is mainly known from the written record and material culture as cock-fighting arenas are generally too ephemeral to be preserved in situ. Large numbers of spurred tarsometatarsi within the faunal remains on some sites may, however, suggest this activity (Serjeantson 2009; Doherty 2013).

The available contemporary literary evidence suggests that chickens are mainly used for ritual and cock-fighting in the Iron Age, and these are practices that continued into the Roman period despite becoming more commonly utilised as a food source. It was an expensive food source though, reflecting its exotic status as observed in its ritual use. This is known from the Vindolanda writing tablets, which include a shopping list, with instructions to buy “chickens, twenty… a hundred or two hundred eggs, if they are for sale there at a fair price" (Tab. Vindol. II 302). Chicken features in several recipes in the cookbook of Apicius (*De re coquinaria*, ca. 385 CE). It has been suggested that the frequency with which a meat features in an exclusive cookbook, is a measure of its regard, thus making chicken and pig very highly regarded (Lauwerier 1986), at least in the Roman homeland. The chicken can be considered part of the ‘flavourscape’ of the Roman Empire- a network of movement of exotic produce (Livarda and Orengo 2015), its increasing popularity evident in increasing numbers of chicken remains found across Europe as the Romans advanced and settled.

1.6 Thesis aims and structure

This thesis draws on archaeology, zooarchaeology, ecology, biogeography, and literature, to explore environmental constraints and impacts associated with the introduction and spread of the domestic chicken in Europe between the Later Bronze Age to Roman period. The chicken's dispersal to Europe has been identified as an area of research which has been particularly neglected (Storey et al. 2012). The time span ranges from the earliest evidence of chicken until it is permanently established in Europe.

An absence of data made the study of the dispersal of the chicken to Europe previously unfeasible. The information has been collated as part of this project, and is used alongside novel approaches and techniques to explore how, when, and why the chicken diffused to Europe, in ecological context. It also explores the consequences of chicken domestication, and its widespread dispersal, on the other species with which is it associated. The focal bird, the chicken, provides an excellent means by which to better understand species response to climate change in the past; human population movements; human beliefs and behaviours; human perceptions of animals; and the consequences of introducing non-native species into past ecosystems.

The research uses a variety of techniques more frequently used in ecological or biogeographical studies, such as ecological niche modelling (Chapters 3 and 6), community models (Chapter 7), and least-cost models (Chapter 4). The methods for those specific techniques are more thoroughly discussed in the relevant chapters.

Chapter 2 explains the data collection strategy and general methods that formed the basis for this thesis. It focusses primarily on the construction of a pan-European database of fauna at sites where birds have been recorded, which provides the archaeological information used throughout this thesis. Chapter 2 also investigates potential biases in the European archaeological record, and discusses challenges, caveats and potential solutions when collating and using large datasets from multiple sources of information. In Chapter 3, modern occurrences of Red Junglefowl are used to ascertain the ecological niche of current Red Junglefowl. Establishing this niche enables better understanding of the ecological constraints on an early domestic version of this species, establishes likely centres of initial domestication, and determines the level of human investment required to maintain early chickens. Chapter 4 draws on the results of Chapter 3, combined with additional biogeographical data, to consider suitable dispersal routes out of Asia and into Europe, addressing whether the evidence supports a single or multiple dispersals. The likely points of entry into Europe are identified, to better understand the potential for inherited perceptions of chickens from the cultures with which they travelled. This is explored further in Chapter 5, which analyses dispersal within Europe using archaeological data and ancient literature. Chapter 5 uses the location and date of faunal remains of chicken to identify dispersal events and to ascertain changes over time in the frequency, use and perception of the chicken in cultural context. Over this period, the chicken has been evolving under domestication. By applying methods similar to those used in Chapter 3, but adapted for archaeological chickens, Chapter 6 explores how association with humans has affected the ecological niche of the chicken, as compared to its ancestor. It identifies the geographic extent at which chicken-keeping may become socially or economically unviable in different periods. Chapter 7 investigates the impact of introducing a non-native species into Europe. The zooarchaeological record is considered alongside environmental variables to establish how the introduction of the chicken may have altered the ecological community into which it was placed, and how the ecological community and the local environment may have enhanced the success of the chicken. The final chapter summarises the findings from the other chapters and demonstrates the benefits of an interdisciplinary approach, and why zooarchaeology and palaeoecology should be regarded as key components of research into complex prehistoric and historic societies.

2 General Methods and Data Collection

2.1 Summary

Understanding why an animal is selected for domestication and the implications this has for the society, culture and ecosystem into which it is introduced, requires a sufficiently broad dataset. Information spanning large spatial and temporal scales is required to identify patterns and relationships between species and their environments. This chapter outlines the reasoning and methodologies behind the construction of the database assembled as part of this project, and describes an audit strategy devised to maintain consistency in the data used for analysis. It discusses the challenges associated with amalgamating the necessary archaeological records, and demonstrates how multi-disciplinary approaches can be employed to fill in gaps and enhance understanding of the archaeological record.

2.2 Introduction

The zooarchaeological record, provides an excellent resource, describing abundance, species diversity and species distributions, within archaeological contexts. Individual bones and bone assemblage information can be used to evaluate frequency and/or presence. This enables ecological analyses to be performed on the data to understand the complex relationship of species, both animals and humans, within specific environments. Unlike ecological studies, however, whereby careful sampling strategies can record presence and absence of species, the nature of archaeology presents a far more opportunistic sample. Variability in terms of excavation methods, purpose, recording and reporting need to be considered in order to compile consistent and comparable information. Ultimately, the performance and usefulness of any database is limited by the quantity and quality of its entries.

2.2.1 Quantity of data

While modern political boundaries have little bearing on the actions of our ancestors, they do affect the quality and quantity of available archaeological evidence. On a broad spatial scale, such as ‘Europe’, this varies greatly. The United Kingdom (UK) and France have stricter policies regarding preservation of the historic environment and this is apparent in the quantity and availability of data which was available for inclusion in the database (Figure 5). Contacts have been made over the duration of the project in countries for which little faunal information was available, and have confirmed that in most cases it simply has not been recorded, or at least not reported (Best, J., pers. comm.).

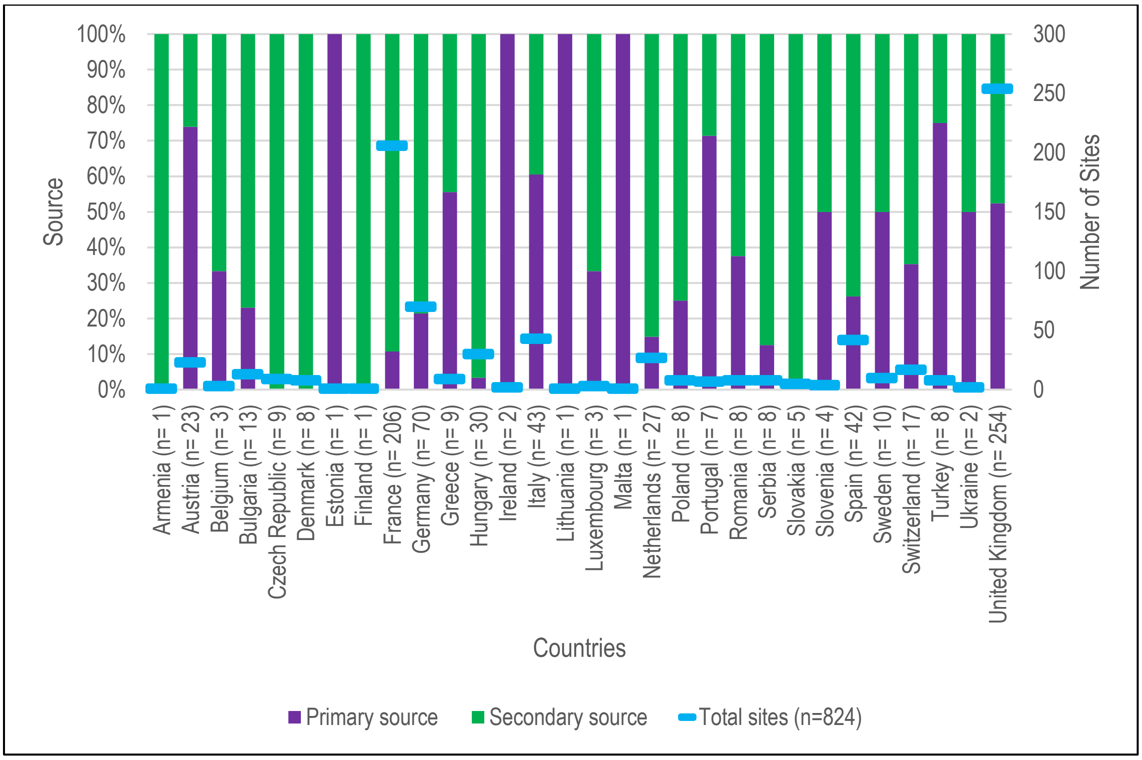


Figure 5. Frequency of sites in the database by country (line markers) and source used (bars in percent).

2.2.2 Quality of data

Combining diverse information into a single usable database presents a challenge. Archaeological reporting varies greatly in its scope and detail. This is especially the case with zooarchaeological reporting. Not all reports contain the same information, but some factors may still be worth recording if reported, such as geology (which affects vegetation). This can be supplemented using readily available GIS shapefiles. These files tend to be at coarse resolution, so accuracy can be tested using the evidence at local site level.

The three primary factors affecting the quality of data in any archaeological database are likely to be secure dating, confident interpretation and accurate recording/reporting. Where, what and how a site is excavated affects this outcome. The study aims influence the reporting, and databases are limited by the report content. In an ideal world, each site would have been visited and each assemblage reviewed. In practice this is unfeasible. Due to the nature of archaeology, most sites no longer exist and the resulting assemblages are not always accessible. The written report is, therefore, the only practical source of data for compiling databases of evidence on broad spatial and temporal scales.

‘Where’ is important, for several reasons. Many sites are dated by associated finds. This can result in dates given as cultures, rather than numerals. This would not be a problem if there was an agreed upon chronology for Europe, but this is not the case. Even divisions, such as ‘Bronze

Age', 'Iron Age' or 'Roman' are difficult, as these cultures are associated with populations at different times in different parts of Europe. Soil conditions on a site affect the preservation of animal bones. Poor preservation hinders identification to species and means that smaller bones would be less likely to survive or be recovered. This is particularly challenging for research focused on presence of birds and/or small mammals (Payne 1972). 'Where' also determines the extent of later disturbance on a site. Many of the earliest recorded examples of Red Junglefowl and/or chicken in Europe, such as Bora Gran d'en Carreres (ca. 14000 BCE) and Reclau Viver (ca. 5000 BCE), Spain (Petit 2005); Borduşani-Popină (ca. 4250 BCE), Romania (Gal and Kessler 2003); and Loona (ca. 3000 BCE), Estonia (Mannermaa and Lougas 2005) all note dating or stratigraphic issues. Bird bones are small, so individual bones can be transported through different layers by bioturbation. Unless specifically noted, this is difficult to recognise. Chicken bones are found in very small frequencies (sometimes single bones) on pre-Roman sites. This is unsurprising for a newly-introduced exotic species. For this reason, excavation technique, which can vary by country, is important. Legislation in some countries may request particular approaches. An open-area approach excavates large areas by context, and is favoured by many western European countries, while the USA and several countries in Asia prefer a box-grid approach, excavated vertically in spits (Drewett 1999). Both methods have advantages and disadvantages; however, limited frequency and potential for assisted stratigraphic mobility of small animal bones highlights the importance of understanding context security if possible, and the method of dating. Open area excavation lends itself better to this. In an ideal situation, the bone will have been radiocarbon dated and found in a sealed context, although this is rarely the case.

'What' has been excavated may not actually be chicken. Recent literature has highlighted issues with identification of early evidence of chicken (Kyselý 2010; Peters et al. 2015; Eda et al. 2016; Best et al. in prep). The primary cause is similarity in the appearance of chicken bones to those of other Galliformes. Identification of bones to species is limited by the knowledge of the bone specialist. Most countries only have a few avian bone specialists. Knowledge and identification techniques have improved in recent decades, and a wealth of easily accessible resources, including books, electronic articles, electronic reference collections and special-interest forums have now extended the discipline beyond the domain of a few individuals. Advances have also been made in genetics and morphometrics, both excellent methods for identifying to species, which have gradually reduced in cost of both time and money. Even so, these methods are only generally used to verify important dubious examples.

With modern excavations 'how' a site is dug corresponds to the reason for excavation. Research excavations in the United Kingdom are generally funded by universities, often as training digs, which means they are usually excavated in fine detail, but by inexperienced archaeologists. British commercial excavations are funded by developers, are excavated by professional archaeologists, and are under tight time pressures to complete. This can result in different study aims. In the

United Kingdom, as recently as a decade ago, animal bone was often not considered important enough in commercial archaeology to always retain or to fully analyse (personal experience). This situation has been somewhat rectified by new guidelines from Historic England (Baker and Worley 2014).

Where faunal remains are considered, often only mammals are reported, and occasionally only primary domesticates, presumably because primary domesticates tend to be larger and less easy to overlook during excavation. Recovery method is another factor. Sieving, in addition to hand collection, is likely to result in the recovery of greater quantities of smaller bones and artefacts (Wilkinson 2007; Davis 2012), but costs additional time and money.

2.2.3 Consequences of quantity and quality issues

These factors result in huge variation in the presence and scope of faunal information reported. It is often unclear whether absence of faunal remains reflects true absence, recovery bias, or project scope. Despite this, due to reliance on secondary sources, the identification of the report author needs to be used and trusted. Additional detail in the report including associated bone groups, bone size, bone preservation, bone elements, comparison to similar species, and even large quantities of the same species provides some reassurance that the identification is correct and that the bone has not been found where it lies due to taphonomic factors.

In terms of this project, recognition of the caveats above determined the methodology for assembling a sufficiently broad database required to analyse the dispersal of the chicken westwards into Europe. Additional information was recorded to mitigate anticipated issues, and an audit strategy devised and implemented to ensure consistency of information for the analyses which rely on this data. This chapter has been submitted for publication as part of conference proceedings to British Archaeological Reports (Pitt and Stewart in press). The paper can be found in appendix I.

2.3 Materials and methods

2.3.1 Geographic extent

Modern political boundaries are somewhat arbitrary when considering past civilisations; however, they do provide a useful limit for determining a geographic range for academic research. The study area (Figure 6) defines Europe after the United Nations (UN, www.un.org) 2014 continental boundary. An additional ‘border’ group of countries have been included, comprising Turkey (a small part of which lies within Europe); Armenia; Georgia and Azerbaijan. These countries form an interesting corridor at the edges of Europe and Asia, the westernmost of these falling within the Roman Empire (Figure 7). The Roman Empire also extended into modern-day Israel, Syria and North Africa, which is beyond the geographic scope of this study, but would be interesting for future research.

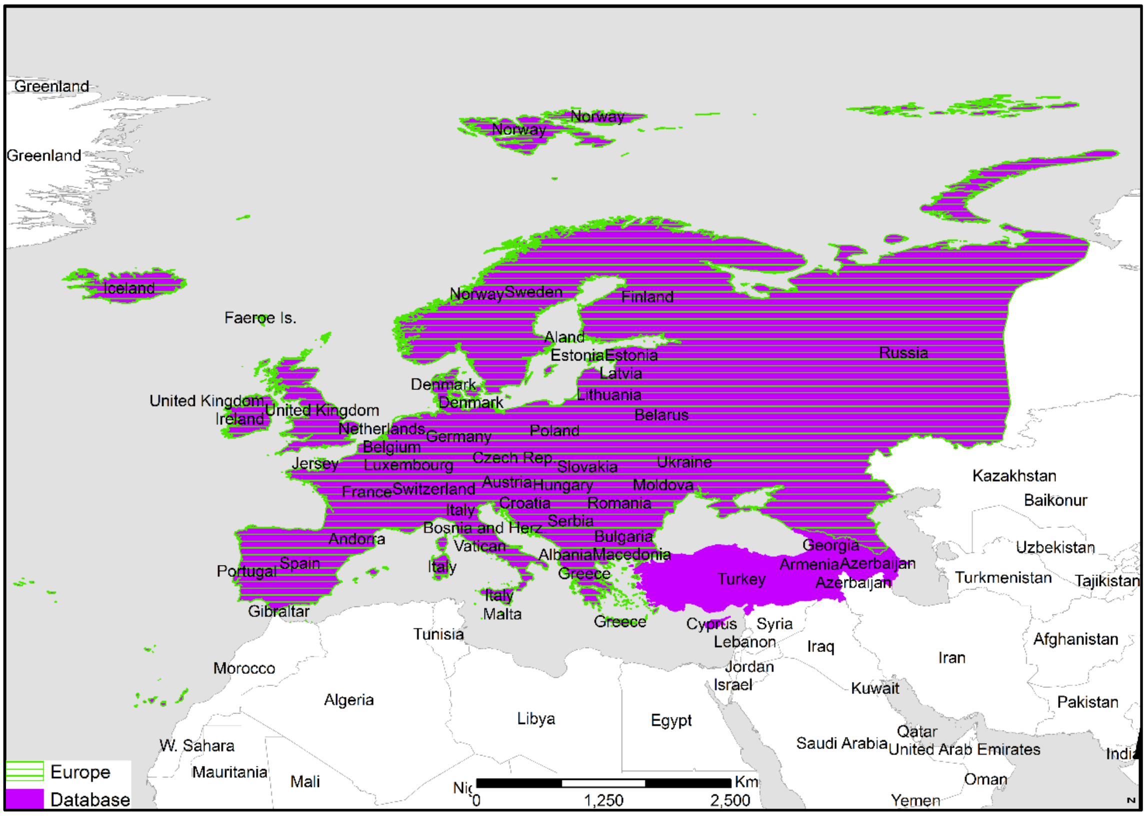


Figure 6. Extent of database study area.

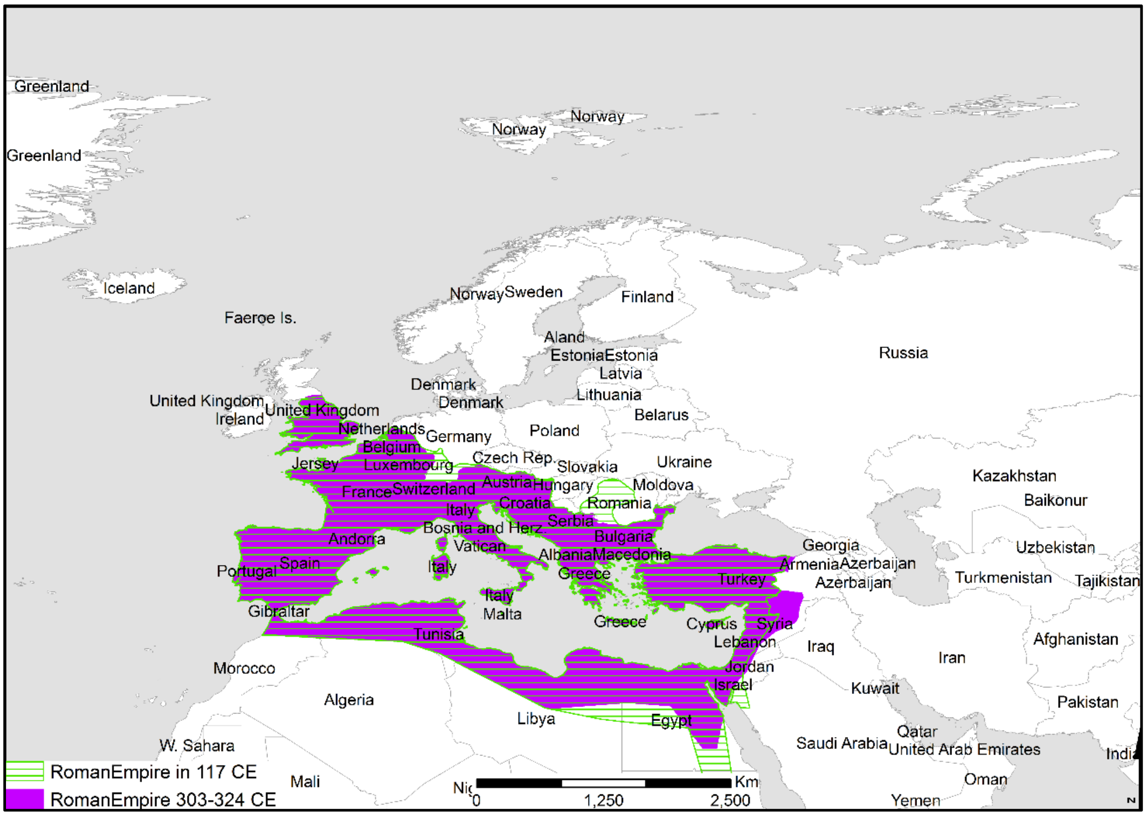


Figure 7. Extent of the Roman Empire, ca.117AD (based on data from DARMC (www.darmc.harvard.edu)).

The research area was further subdivided into North, South, East and West, again according to the UN classification, with an additional ‘border’ group, for use in specific analyses (see Chapter 6).

2.3.2 Temporal range

This study considers the chicken from its earliest reported presence, up to 500 CE. The chicken is reported to be present in Europe from at least the Iron Age, particularly after ca. 500 BCE to the turn of the millennium (Benecke 1993; Kyselý 2010; Poole 2010). It is during the Roman period that it is found in greater frequency, particularly in towns (Maltby 1997; Serjeantson 2009). It can be argued that it was during this period the chicken became permanently established in Europe. The Western Roman Empire fell in 476 CE, following the deposition of Romulus Augustus, and represents a distinct cultural change in Europe. As many archaeological sites can only be dated to the nearest century, the end of the fifth century marks the end of the period of study for this research.

2.3.3 Database sources

The archaeological data was gathered from various sources (see appendix II), up until June 2016, to allow time for analyses within the timeframe of the project. Most of the data for all countries came from bibliographic cross-referencing or online searches using Google Scholar™. Search terms combined scientific names and synonyms for species, with relevant epochs in both English and European languages. The British Library proved to be an excellent resource for books and journals unavailable elsewhere. Many reports and articles were readily accessible online. Within the UK, many of the unpublished reports from commercial excavations are available online from the Archaeological Data Service (ADS) [www.http://archaeologydataservice.ac.uk]. These include some useful regional summaries of information (Albarella and Pirnie 2008; Hambleton 2009). The original reference was consulted where easily available. The French Natural History Museum has collated much of the French zooarchaeological record and broad detail is available on its Inventaire National du Patrimoine Naturel [https://inpn.mnhn.fr]. The sources are referenced and can sometimes be found on regional archaeological websites. Many researchers upload their articles to Academia.edu or Researchgate.net. Requests for materials were also sent direct to the author, with mixed results. Email enquiries to local historical or archaeological societies for literature also yielded some positive results.

Written evidence includes several varieties, ranging from primary sources, such as monographs, unpublished site reports or isolated bone reports, to secondary evidence, such as datasets, books and journal articles on related themes or species-specific gazetteers. Primary sources were used where available (Figure 5). In the absence of being able to verify the details of every site and assemblage the report was assumed to be accurate, although issues such as potential contamination or disturbance were noted.

2.3.4 Database structure and content

Information was compiled using Microsoft™ Access (2010-2016 versions). Relational databases facilitate easy extraction of data, which can be exported to other applications. The structure of the database comprises four main tables, with a series of sub-tables containing ancillary information, all linked using unique ID's. A diagram showing the database structure can be found in appendix III. The main tables are:

Site. Contains details which are applicable to all phases of the site, including site name, geographic details, geology, date of excavation, and a link to the bibliographic reference sub-table.

Phase. Contains detail of the phases present at the site, including date from/to, chronological period, site type, site function, whether chickens are present, and vegetation. The number of phases was determined by the available evidence, and its logical division into chronological periods.

Context. Contains detail of the contexts found within each phase, including context type, dating method, faunal totals, whether totals are NISP (Number of Identified Specimens) and/or MNI (Minimum Number of Individuals), and presence of chicken. The number of contexts was determined by the available evidence and its logical division into context type. Due to the scope of the project, recording of all individual contexts found on a site is unfeasible. The methods used for reporting faunal remains means that it is also usually unavailable. It is, however, useful to distinguish specific context types for further analysis, especially cremations and burials. An audit strategy was applied to assess the accuracy and reliability of the data (see Section 2.2.5).

Evidence. Contains detail of the species found within each context, including totals, skeletal element where noted, bone condition and recovery method. A series of cascading dropdown boxes were linked to a species sub-table to reduce input error.

Limited reporting of avian remains greatly reduced the quantity of eligible reports. The total number of sites included was 824, including a 13 per cent sample of sites with birds, but no chickens. The sites comprised 1156 phases, 1409 contexts and 17318 bone records from 589 species.

The database is dominated by sites from the United Kingdom and France, but does not include all sites from those countries. Rather, a decision was taken to achieve as broad a geographical and deep time coverage as possible. It would be an almost impossible task to find details of every site in Europe containing birds, particularly within the time-scale available for this project, so once good coverage in the UK and France was achieved, focus was diverted to locating sites in areas of Europe where data was scarce.

The minimum criteria for inclusion of a source included recording of geographic location to at least place name, the presence to at least family taxonomic level of bird species (see Morales (1993) for discussion of issues with "general categories"), and a 'date to' of 500 CE or earlier. Sites lacking chicken, but with evidence of other birds, were included as they infer genuine absence of chicken. All sites were assigned co-ordinates in latitude and longitude. This enables use of the data in geographical information systems (GIS) software for spatial mapping, data visualisation and extraction of relevant missing variables, including elevation, vegetation, and geology, if required. It also enables use of the data in cross-disciplinary techniques, such as biogeographical modelling (see Chapter 4) or ecological niche models (see Chapters 3 and 6).

Chronological groups were assigned in the phase table, with specific cultures noted in the context table. Dates were assigned at site, phase and context. Chronological periods vary by date range in different parts of Europe. A chronology for Europe was created from multiple sources to ensure the correct dates were applied to the database. Appendix IV details the date range applied to the different periods, with associated cultures and references.

Mammals, fish and reptiles were also recorded where reported. Taxonomy is after the IUCN Redlist (www.iucnredlist.org). Where available, pollen records were reviewed to determine the dominant vegetation present at the site, and categorised according to the European Environment Agency Corine Land Cover classifications (European Environment Agency 1995). The same classification was used for preferred species habitat. The primary habitat for mammals, birds and reptiles was taken from the IUCN Redlist. Habitat for fish was taken from www.fishbase.org.

2.3.5 Strategy for mitigation of issues associated with zooarchaeological recording

Information was included in the database to enable assessment of anticipated issues, such as dating method, context type, and additional comments regarding the bones. A simple, replicable audit strategy (Table 3) was designed and implemented. The benefits are three-fold. It ensures consistency of data for the analyses used elsewhere in this thesis; it enables future updates to the database; and can be applied to other datasets to ensure comparable quality of data can be used in conjunction with the information in this database in the future. Objective components of the written report were identified to ascertain how well the key inter-related factors of dating, interpretation and accuracy are reported at each site. The strategy divides the information into four 'quality' groups- 'Poor', 'Adequate', 'Reasonable' and 'Good'. Each key factor has three levels, with '1' being the most detailed and/or accurate and '3' the least. Two or more of each category level are required to achieve the respective score. Otherwise, a well dated bone may still not be a correctly-identified chicken; or may be intrusive to that site or feature. Requiring all three criteria in a level would be so constrictive as to render the upper scores almost unattainable. The upper score is still only achieved by very few sites, which can be considered to be secure evidence. The majority fall into the 'reasonable' and 'adequate' categories (Table 4).

Priority	dating	context	recording accuracy
1	Scientifically-dated animal bone Reason: Dating accuracy	Sealed context Reason: No intrusion; dating accuracy	Associated-bone-group or well-described elements Reason: Accurate species identification
2	Bone(s) recovered from a closely-dated cut feature Reason: Dating by cultural association is more likely to be accurate; reduced chance of intrusion	5+ chicken/bird bones. Reason: Larger quantities of bones belonging to a single species make it less likely to be intrusive	Species smaller than a chicken recorded Reason: Small bones have been retrieved and analysed, rather than false absence
3	Well-dated or well-stratified site Reason: Context information is not always available, despite the site being well-dated by e.g. C14, coins, distinctive artefacts	Total fauna = 100+ bones Reason: Implies deliberate deposition	Above average bone preservation Reason: Better preserved bones are easier to correctly identify to species
Good	2 or more priority 1 criteria		
Reasonable	2 or more priority 2 or better		
Adequate	2 or more priority 3 or better		
Poor	1 or less or over-riding issue (provide detail in comments)		

Table 3. Audit strategy, including reasons and method for applying scores.

Audit score	Poor	Adequate	Reasonable	Good	Total
No. of sites	129	332	352	11	824

Table 4. Frequency of sites for each audit score category.

Sites were also assigned a georeference score, whereby 2 denotes an accurate position; 1 indicates reasonable accuracy, for example, street is known, but the exact position on that street is not given; or 0 for those located to the nearest settlement. This enables exclusion of poorly georeferenced sites for analyses or exportation of data which require an accurate location.

2.4 Discussion

Applying the strategy does not invalidate any sites, but can be used to weight potential reliability or error. This enables tailored use of appropriate information for analyses of different types and scales. For example, simply mapping locations where a species has been reported is not at all limited by quality or accuracy of data. Spatial mapping of such information enables easily visualisation of where and when chickens are reported to have been present (Figure 8).

Given the highly mobile nature of chicken bones, most analyses exclude sites with over-riding issues, which are generally those with noted disturbance and intrusion. Otherwise the quality of sites depends on the type and scale of the analysis, and is advised in the methodology for the analysis.

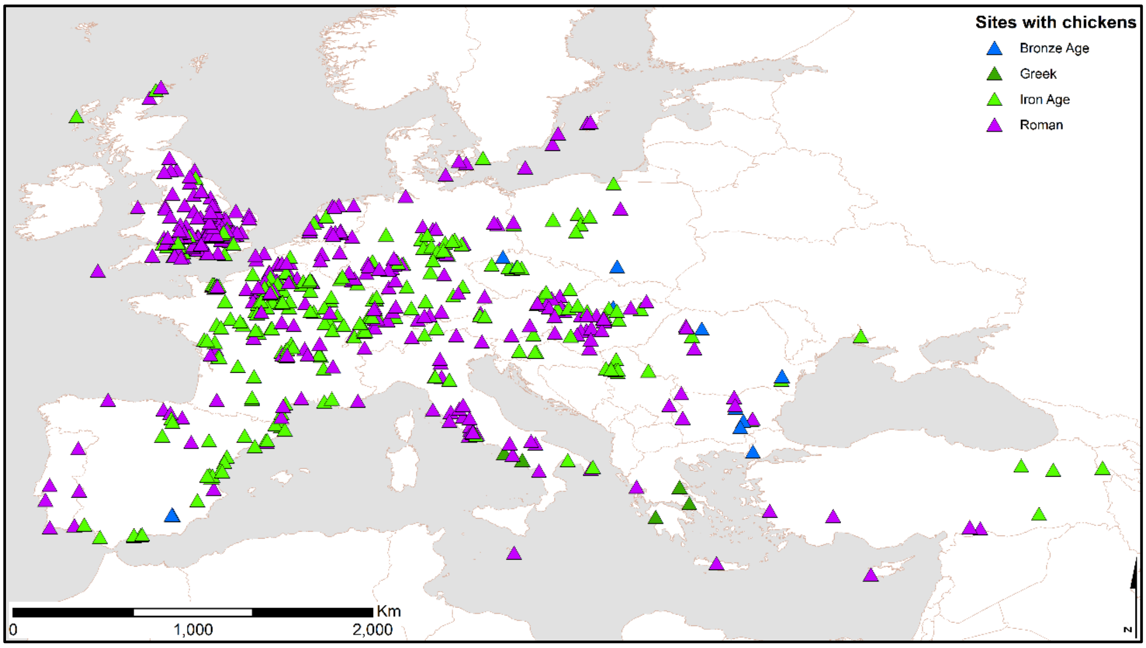


Figure 8. Distribution of database sites by period.

For simplification and clarity of interpretation, in most analyses the data is divided by date into three periods to avoid the complicated chronology of Europe. ‘Date to’ is used for most analyses as this represents a *terminus ante quem*, or latest date for the phase. An exception is the least cost models in Chapter 4, which use ‘date from’ as a *terminus post quem*, or the earliest possible date the chicken could be present. The divisions are ‘to 801 BCE’, ‘800 BCE – 0/42 CE’ and ‘1/ 43 - 500 CE’, referred to as ‘period 1’, ‘period 2’ and ‘period 3’ respectively. The periods broadly correspond with the Bronze Age, Iron Age or Roman periods as these cultures dominate those time frames, but it is recognised that the Bronze Age ended at different dates in different parts of Europe, that the Greek civilisation and Roman Republic fall within the time frame of ‘period 2’, and not all phases in Europe in ‘period 3’ were occupied by the Romans. Due to the large numbers of sites from the United Kingdom in the database, and the fact that it is an island at the edge of Europe, the later date of Roman influence is taken into account. Sites from 0-42 CE are included in period 2 as sites of these dates correspond better with the cultures of period 2 in the rest of Europe.

2.5 Conclusions

A database of faunal remains found at sites containing birds across Europe from the Bronze Age to the end of the Roman period was created. Caveats related to quality of data, including secure dating, secure contexts, and secure species identification, are applicable to most zooarchaeological databases of any species, and were considered as part of the methodology. A simple audit strategy was devised, which offers an objective means by which to evaluate quality of data taken from diverse sources, based on key factors. This allows for the selection of consistent quality of data for the analyses presented in this thesis which rely on information from the database. The strategy should be easy to apply to other databases containing faunal archaeological data, to allow for use of future use of other datasets with this database.

3 What is the fundamental niche of the wild ancestor?

3.1 Summary

Ecological niche modelling of extant Red Junglefowl, *Gallus gallus*, and Grey Junglefowl, *Gallus sonneratii*, presents a unique opportunity to examine historical ecological implications associated with their descendant, the chicken, in early stages of domestication. This chapter presents the results of modelling the environmental conditions associated with junglefowl populations both in South East Asia, where the bird originates, and populations transported further afield due to human interaction.

3.2 Introduction

Of the four extant junglefowl species, it has been demonstrated that Red and Grey Junglefowl both contribute DNA to domestic chicken, with Red Junglefowl most likely the dominant ancestor for early chickens in Europe (Eriksson et al. 2008; Girdland Flink et al. 2014). Predominantly occupying tropical rainforest environments (Figure 9), junglefowl have historically been confined to Southern and South East Asia, India and Indonesia by geographical barriers. Junglefowl (and chickens), are non-migratory with limited flight capability, rendering mountains and large bodies of water impassable. Although Red Junglefowl have been transported by humans to most continents in more recent times, the other three species of junglefowl have remained in Asia and South East Asia. Inhospitable environments such as desert or semi-desert, lacking corridors of environmental suitability, restrict natural dispersal to areas which would otherwise be suitable.

Very few archaeological specimens of *Gallus* found outside of the native range have been identified as junglefowl, rather than chicken (and only evidence of Red Junglefowl is reported); although bones bearing *Gallus* traits may automatically have been identified as chicken in areas outside the native junglefowl range (Stewart 2005). Early chickens are often noted to be of similar size to Red Junglefowl (Peters 1997). For this reason, chickens within the native range of the Red Junglefowl are more likely to be interpreted as wild Red Junglefowl, further complicating disputes regarding the location of first domestication (see Section 1.3).

Determining locations of better environmental suitability identifies regions where the species is more likely to be able to survive and breed. First domestication of a species in an area of poor environmental suitability is unlikely to be successful, and so better suitability increases the likelihood for the site being a location of first domestication, and vice versa. The earliest examples of domestic fowl would have had little time to evolve distinct physiological and morphological traits from their ancestor. Therefore, lower suitability outside of the junglefowl's native habitat would necessitate increased assistance by other means, i.e. direct (feeding and housing) or indirect (selection during breeding) human intervention. This informs us about the extent of human effort required to ensure survival of this newly domesticated, exotic species.

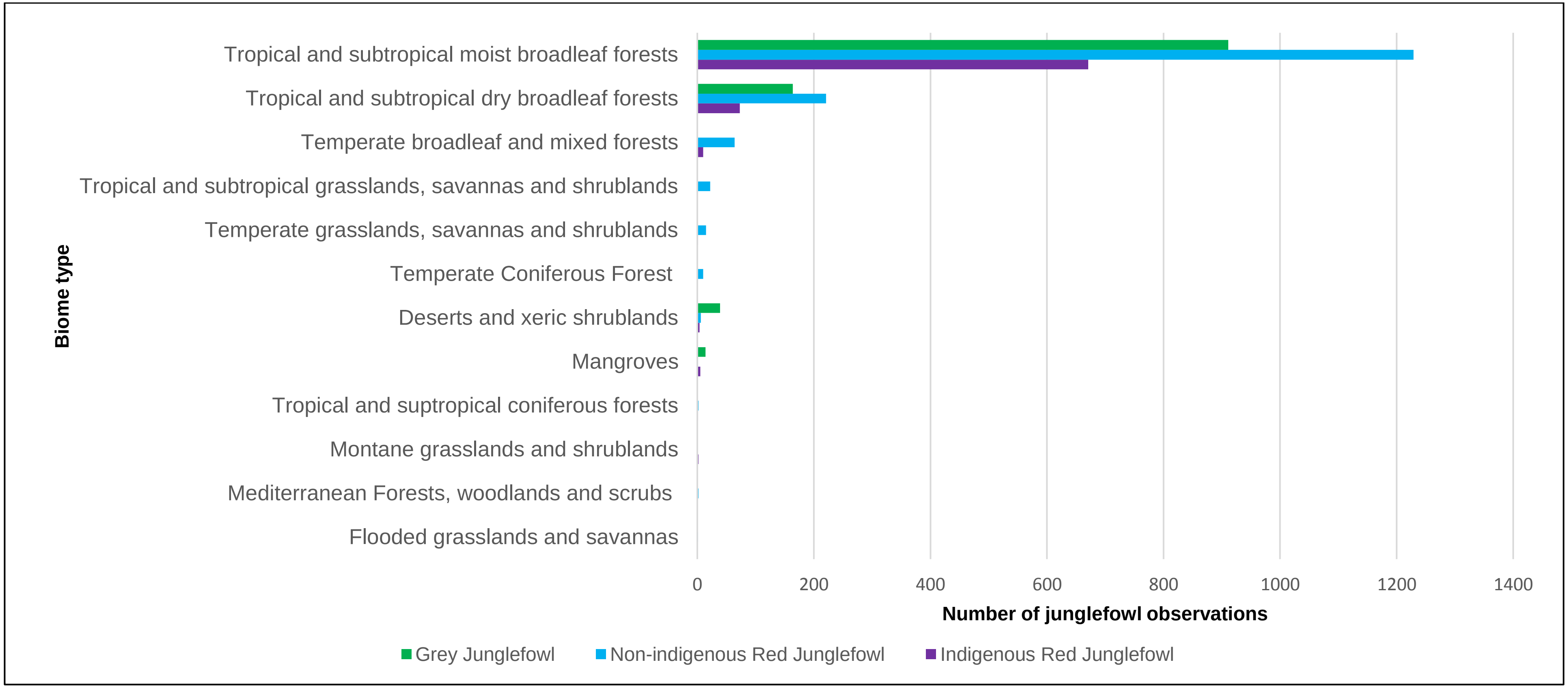


Figure 9. Biome type at observations of Grey Junglefowl (n=1128) and indigenous (n=767) and non-indigenous (n=1573) Red Junglefowl.

‘Ecological niche models’ (ENM) and ‘species distribution modelling’ (SDM) have become popular in ecological studies, and are used to better understand the environmental conditions that enable a species to persist (Araújo et al. 2011; Fordham et al. 2013; Pearson et al. 2013). The terms appear to be used interchangeably, although it can be argued that they address different targets and aims. ENMs predicts the presence of suitable conditions, but not where the species will necessarily be found; while SDMs predict spatial distribution of species (Townsend Peterson et al. 2011). This study is concerned with establishing what constituted suitable ecological conditions in the past and where they were found, rather than predicting where species are likely to persist now and in the future, so ENM is preferred here.

Most ecological studies are limited to current distributions of extant taxa, although the fossil record is increasingly used for testing models. Hindcasting has become a popular means for checking ENM predictions, but very few studies use this technique to inform us about the past. Banks et al. (2008a; 2008b) successfully applied ENM to Palaeolithic data to understand the ecological niches and ranges of Pleistocene deer and human populations, and to determine the niche of the first prehistoric farmers (Banks et al. 2013). Nogues-Bravo et al (2008) confirmed the range contraction of the woolly mammoth to Siberia around the date of its extinction, and suggested that although over-hunting is likely the primary factor for the extinction of the mammoth, the environmental niche determined the location of its final demise. Until now, there has been no application of ENM to domestic chickens or junglefowl species. The use of other bird taxa for predicting dispersal under future climate change (Lu et al. 2012; Khaliq et al. 2014) shows that such models are not limited to mammals.

This chapter takes a unique approach to applying this method to archaeological interpretation. While other studies have modelled archaeological data, this study uses modern data to inform us about the past. The chicken is fortunate in that its ancestor is an extant species. Modelling the ecological niche of the indigenous Grey- and Red Junglefowl populations enables evaluation of how far the chicken has conserved or shifted its fundamental niche. However, wild populations within the region of origin may not represent the full fundamental niche of the species. Geographical barriers limiting movement mean that any niche based on these observations more closely reflects a realised niche, and ENM enables us to predict the consequences of removing these barriers to movement. Comparing the niches of native wild Red Junglefowl populations, to Red Junglefowl populations which are known to have already been transported by humans to locations that would otherwise be geographically inaccessible, identifies how well they acclimate to different environments and latitudes. The combination of both niches establishes the full suite of environmental tolerance for this species, including those that have been subject to human interaction and, inevitably, some level of artificial selection.

Regions lacking suitable environmental conditions would require additional human intervention, especially during early domestication before the species had time to evolve. Locations containing the most suitable conditions within the species' native range offer the best potential for successfully first domesticating the chicken. It establishes where in Asia the two species of junglefowl, which are known to have contributed DNA to the chicken, are most likely to have been domesticated. More suitable conditions outside of the native range offer the best ecological potential to aid survival for a recently domesticated version of this species on the long journey from Asia to Europe.

The Red Junglefowl modelling component of this chapter was published in the Journal of Archaeological Science (Pitt et al. 2016) in October 2016. New debates arose regarding Grey Junglefowl after publication and have been added here. The article can be found in appendix V.

3.3 Materials and Methods:

Various methods exist for performing ENM. However, maximum entropy modelling (Maxent, Phillips et al. 2004) has been demonstrated to work well with presence-only data (as opposed to data with known presences and confirmed absences), such as the data available for this study (Phillips et al. 2004; Elith et al. 2006; Banks et al. 2013). It is a machine-learning method which takes the average value for a set of random sample points within a calibrated region (study area where the species is found and able to survive within geographical boundaries and environmental tolerance). It calculates how this differs from known sets of environmental values at locations the species is known to occur, to estimate the probability of occurrence given particular environmental conditions. This can then be projected to other regions of the world or other time-periods (Phillips et al. 2006).

ENM input requires a dataset of occurrence points (Section 3.3.1) and environmental variable layers (Section 3.3.3) for relevant geographic extents (Section 3.3.2).

3.3.1 Occurrence points

Observation data for both Red (RJF)- and Grey (GJF) Junglefowl species post-1950 was downloaded from the Global Biodiversity Information Facility (GBIF.org 2016a; GBIF.org 2016b). Observations which were described as domestic, or were unclearly georeferenced, exact duplicates, or located outside of the boundary of the global terrestrial environmental layers were removed. This resulted in a presence-only dataset of 2356 Red Junglefowl and 997 Grey Junglefowl occurrence points for the ENMs. There is a danger with this type of large open access dataset that sampling bias towards more easily accessible regions could bias the random background data for the ENM. However, Maxent contains inbuilt functionality to account for this (Phillips et al. 2009).

These occurrences vary from wild junglefowl in National Parks or protected forests, to managed reserves, and to birds inhabiting urban settings (including zoos, botanical gardens and residential properties). Wild Grey Junglefowl populations are known to be in decline (Birdlife International 2012), while 'wild' Red Junglefowl are most likely to be a hybridised version of wild birds. Hybridisation between 'true' wild Red Junglefowl and domestic fowl has resulted in very limited populations retaining their original morphology, making the Red Junglefowl, in its original wild form, now highly endangered (Peterson and Brisbin 1998; Gering et al. 2015). As the aim was to understand the broadest ecological tolerance of the species, the observations were not subdivided by habitat type. Principal component analysis (PCA, Figure 10) did identify differences in response to environmental conditions depending on whether the bird is within its natural range or has been subject to human transportation. The latter is only relevant to Red Junglefowl as observations of Grey Junglefowl are not recorded outside of its indigenous range. Therefore, Red Junglefowl observations were divided into two groups accordingly. Hereafter, observations located in suitable environments which are geographically accessible without human help are defined as 'indigenous', while all other observations are defined as 'non-indigenous'. Once transported, 'non-indigenous' occurrences are subject to the same dispersal limitations as those within the natural range, due to lack of migration or capacity for flight.

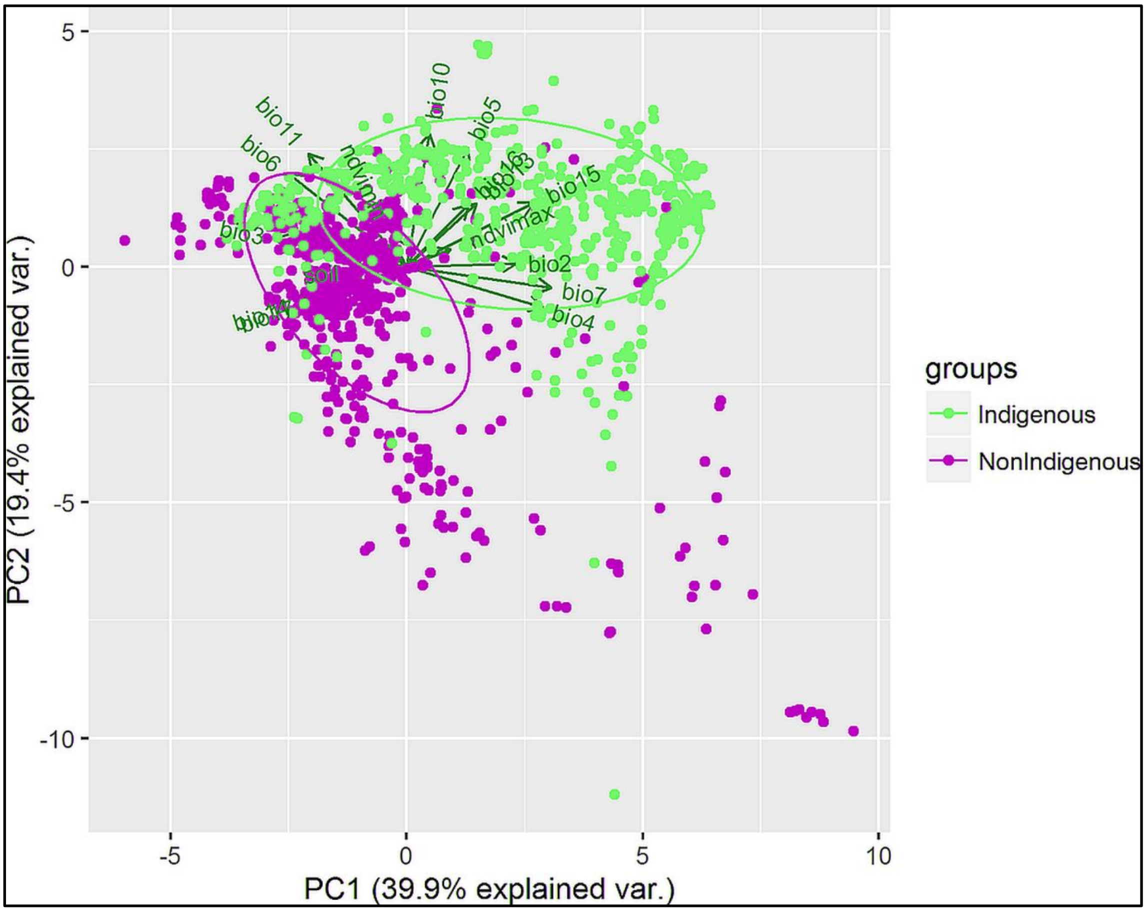


Figure 10. Principal component analysis of all variables (present climate) and Red Junglefowl occurrences by geographic location. Green points represent occurrences within Asia (the continent of origin for Red Junglefowl), while purple points represent all other occurrences. Spatial clustering indicates difference in response to environmental conditions based on geographic location.

Recent changes affecting the habitat of junglefowl due to human activity in the native region could affect interpretation when projecting to the past. With some exceptions, such as Mexico City, urbanisation occurs more frequently at low elevations. To assess the potential impact of this, altitude (CGIAR Consortium for Spatial Information 2008) at the location of known observations within its native range was analysed to gauge the impact of the spread of urbanisation over the past 25 years. No significant changes in elevation are observed over this time period, indicating that the species has not been forced to alter their habitat by moving to higher elevations to survive.

3.3.2 Geographic extent

The study area comprises calibrated and projected global ranges for indigenous Grey Junglefowl (Figure 11) and both indigenous- and non-indigenous Red Junglefowl (Figure 12). Calibrated ranges for the final models are defined by potential species movement (determined by convex hull based on known occurrences), and which are at least minimally environmentally suitable (ENM suitability value>0, calculated using preliminary ENM within geographically accessible areas).

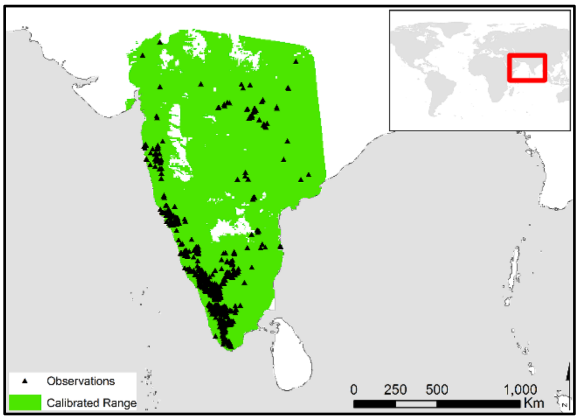


Figure 11. Grey Junglefowl observation locations (points) and extent of indigenous (solid green) calibrated range.

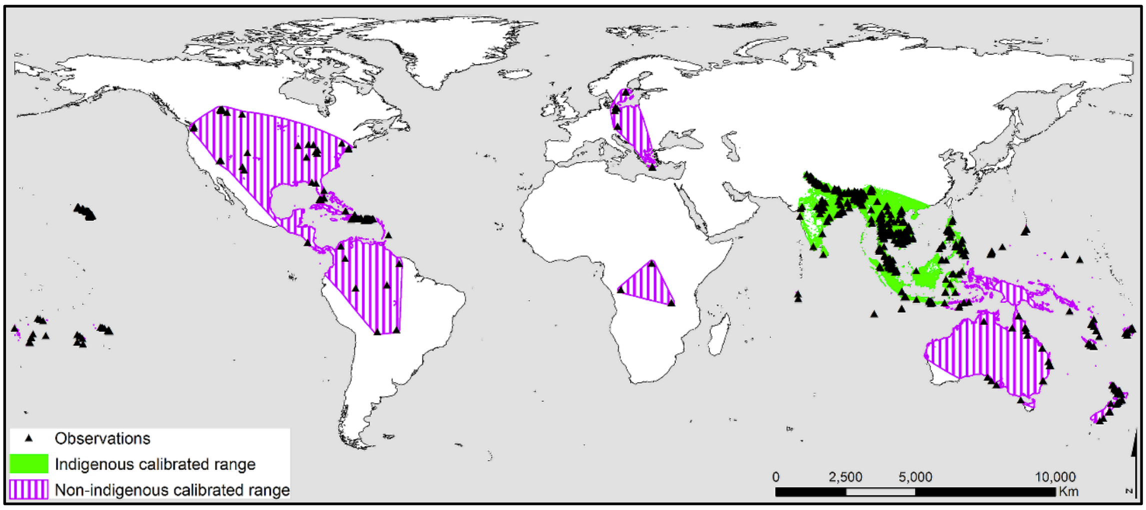


Figure 12. Red Junglefowl observation locations (points) and extent of indigenous (solid green) and non-indigenous (striped purple) calibrated ranges.

As mentioned in Section 3.2, dispersal outside of the native range requires transportation by humans. For this reason, the global projection range is not limited geographically, as humans have transported the chicken a long way beyond its native range. However, the range is limited environmentally. Maxent uses an exponential model for probabilities, which can result in large predicted suitability values for environmental conditions outside the range present in the study area (Phillips et al. 2006). To avoid spurious predictions, global projection was limited to areas of the world where the values of the environmental variables fall within the range of those in the calibrated area (Ficetola et al. 2007).

3.3.3 Environmental variables

Environmental variables were selected based on relevance to the biological requirements of Red Junglefowl. Minimum and maximum temperatures determine thermal tolerance, which has been demonstrated to limit species distributions (Araujo et al. 2013; Khaliq et al. 2014), with minimum winter temperature shown to be the best predictor of variation in avian metabolic scope, outperforming all other thermal variables (Stager et al. 2015). Seasonal variation identifies tolerance for change by predominantly equatorial species. Precipitation variables explain the availability of drinking water. Soil type determines ease of foraging for food, and explains the availability of grit, used to macerate ground-foraged food in the crop due to a lack of stomach acid. Vegetation cover is critical for food, shelter and protection from predation. The latter was excluded for past climate simulations, due to changes in vegetation cover between the time periods under consideration.

Bioclimatic (bioclim) variables were downloaded for both current climate and the mid-Holocene (ca. 4000 BCE) from the WorldClim database at 2.5 arc-minute resolution, or approximately 5km at the equator (Hijmans et al. 2005). Current climate is likely to be similar to that experienced by early chickens in Europe, ca. 500 BCE, a period which corresponds with improving climate, and is therefore used as a proxy. Projecting to the mid-Holocene enables comparison of suitability for some of the earliest proposed evidence for chicken. Annual average vegetation cover was compiled from the individual 0.1-degree (approximately 10km at the equator) resolution 1-month Terra/Modis Normalized Difference Vegetation Index (NDVI) (Nasa Earth Observations 2015) for 2008, the mean year for the observation points. Soil type was derived from the ‘Harmonized world soil dataset - Major soil groups’ (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009); and degree of slope was calculated using the standard function in ArcGIS (v.10.2.2), based on a 250m resolution digital elevation model (CGIAR Consortium for Spatial Information 2008). Final variable selection (Table 5) was chosen according to least correlation between variables and greatest importance to the species. Importance was assessed using the Maxent jackknife test of variable importance from a preliminary model using all variables and occurrences. These showed that Red- and Grey Junglefowl respond slightly differently to precipitation variables and seasonality.

Variable	Description	Purpose	Red Junglefowl	Grey Junglefowl
Bio4	Temperature seasonality (standard deviation *100)	Seasonality	✓	✓
Bio5	Maximum temperature of warmest month	Thermal tolerance	✓	✓
Bio6	Minimum temperature of coldest month	Thermal tolerance	✓	✓
Bio12	Annual precipitation	Water availability		✓
Bio13	Precipitation of the wettest month	Water availability	✓	
Bio14	Precipitation of the driest month	Water availability	✓	
Bio15	Precipitation seasonality (coefficient of variation)	Seasonality	✓	
Bio18	Precipitation of the warmest quarter	Water availability		✓
Bio19	Precipitation of the coldest quarter	Water availability		✓
Ndvimin	Terra/Modis NDVI, annual minimum (0-255)	Vegetation cover	✓	
Ndvimax	Terra/Modis NDVI, annual maximum (0-255)	Vegetation cover	✓	
Ndvimean	Terra/Modis NDVI, annual mean (0-255)	Vegetation cover		✓
Soil	Soil type (categorical variable)	Grit availability/food	✓	
Slope	Degree of gradient	Terrain		✓

Table 5. Environmental variables selected for final models.

3.3.4 Model parameters

Ecological niche models for this study were run using Maxent for 100 replicates with a subsample of 30 per cent test data, random seed, and a regularization parameter of 2.5 to prevent overfitting. Each replicate uses different random sets of training and test data, and the results presented here represent averages. Model performance was evaluated using the area under the receiver operating curve (AUC), which produces a value between 0-1 based on how well the model predicts presence at the training locations (see Phillips et al. 2006 for a full discussion of the validity of AUC in Maxent). A value of 0.5 would indicate no better than expected by chance, 0.7-0.9 indicates reasonable performance, and above 0.9 indicates very good performance (Swets 1988). Thresholds for environmental suitability were calculated from the output summary using a sensitivity-specificity equality approach (see Liu et al. 2005 for evaluation of determining thresholds in niche modelling).

3.4 Results

3.4.1 Red Junglefowl

The performance of the ENMs for the Red Junglefowl can be considered reasonable to good, with AUC values ranging from 0.76 to 0.95. Areas predicted to be suitable for the Red Junglefowl, both currently and in the past, based on indigenous occurrences, largely lie between the latitudes of the Tropics of Cancer and Capricorn (Figure 13). The most suitable sets of conditions are found within its native range, central Africa, and the Amazon basin. For indigenous populations, precipitation and minimum vegetation cover are most important. Probability of suitable conditions increases with high rainfall in the wettest month, corroborating the exclusion of much of Europe from the global projection due to low rainfall relative to the tropics. An optimal vegetation cover is indicated by a positive relationship for increased levels of minimum vegetation, but a negative relationship when the maximum vegetation is too dense. Apart from very small pockets in Portugal, Greece, Montenegro and Albania, Europe is unlikely to contain suitable environmental conditions for indigenous Red Junglefowl, either today or when projected back to 4000 BCE.

Models based on ‘non-indigenous’ occurrences (Figure 14) reveal potential suitability at broader latitudes, with fewer large areas of high potential. The most suitable sets of conditions are found in the South Pacific islands and New Zealand; Kenya, Tanzania and the southern coast of South Africa; eastern Madagascar; the Caribbean islands; and eastern Brazil. Above threshold potential for suitable conditions is present in Europe, with fairly good potential in north-west France, north-west Iberia, and the south coast of Ireland. Projection to past climate predicts better potential at more northerly latitudes than current climate simulations. For non-indigenous populations, temperature seasonality and temperature range are most important. Seasonality increases with distance from the equator, requiring much greater tolerance within an annual cycle. Probability of suitable conditions decreases with warmer temperatures in the warmest month, and increases with warmer temperatures in the coldest month, reflecting the thermal tolerance range.

Geographically, only limited overlap of suitable niche is observed between the indigenous and non-indigenous ENMs (Figure 15). Environmentally, niche similarity between the two was compared using ENMTools (Warren et al. 2010). ‘Schoener’s D’ (Schoener 1968) and ‘Hellinger’s I’ (Warren et al. 2008) are similarity measures which compare suitability estimates from two or more ENM, then normalise the resulting score to a value of 0-1, where 0 indicates complete dissimilarity and 1 would indicate the niches were identical. Analysis returned overlap values of 0.76 and 0.86 respectively, suggesting that the niches are environmentally more similar than suggested by geographical overlap.

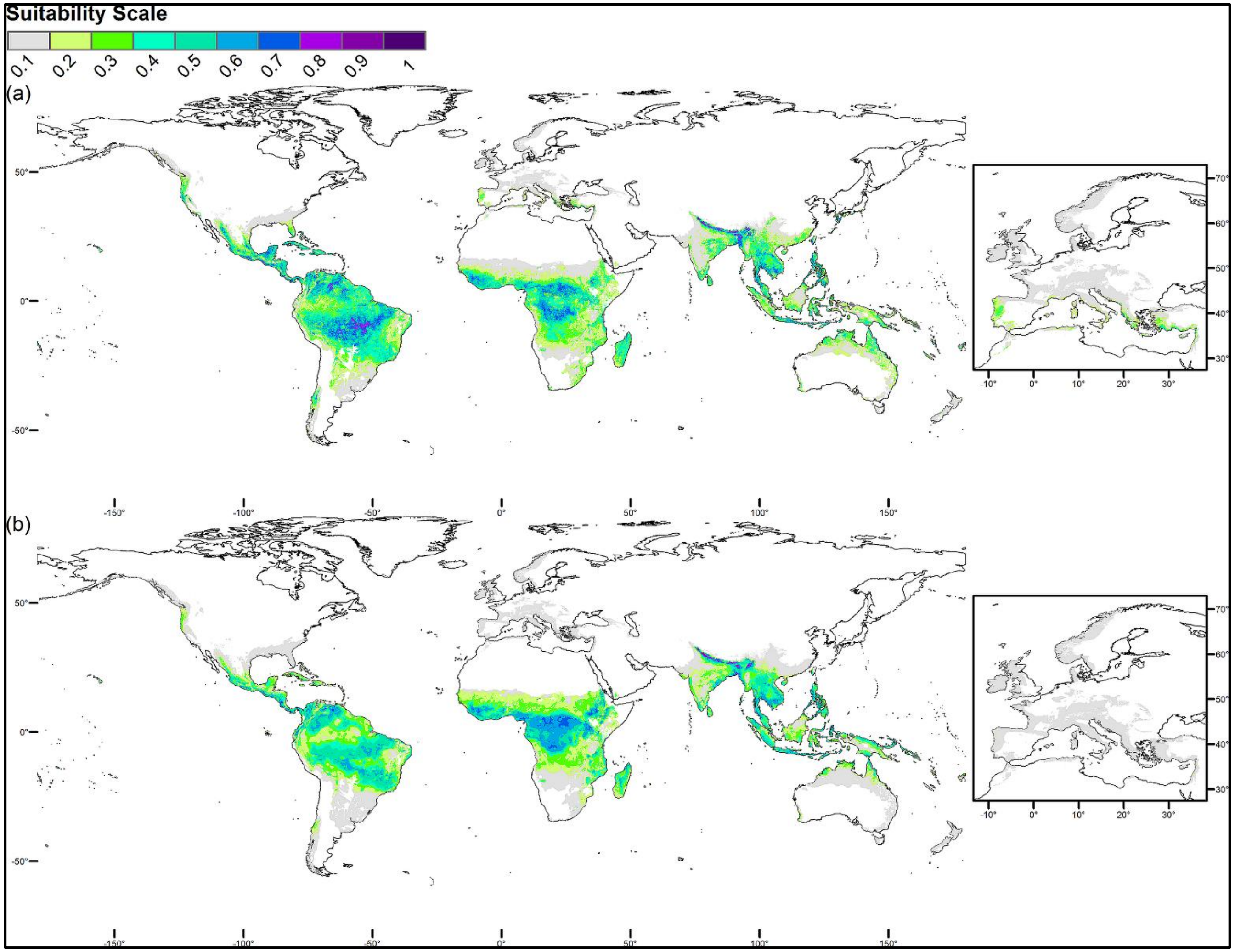


Figure 13. Global projections of predicted environmental suitability for Red Junglefowl (n=796) based on indigenous observations for current climate (a), past climate (b). Suitability threshold= 0.4; areas in white fall outside the range of calibration area.

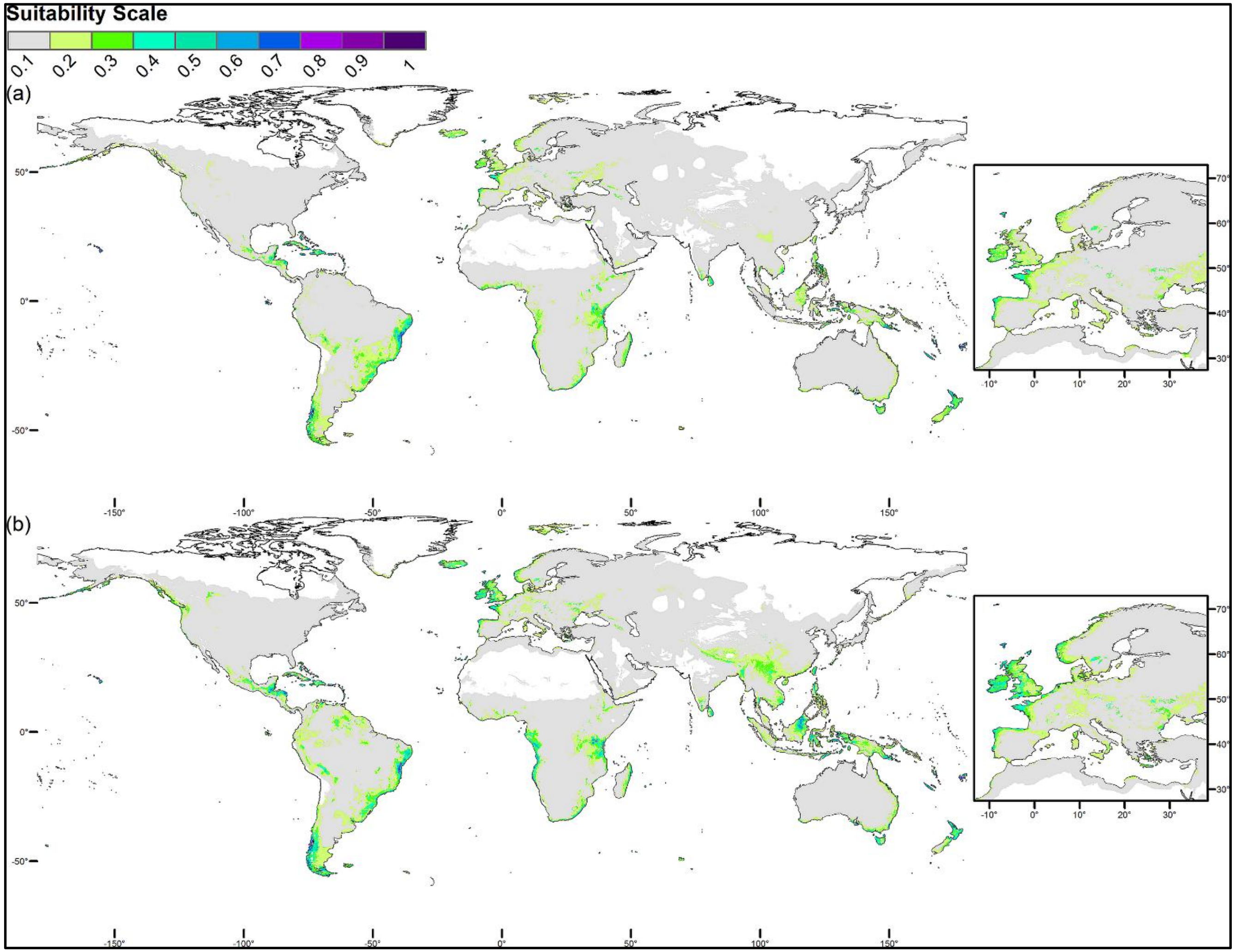


Figure 14. Global projections of predicted environmental suitability for Red Junglefowl (n=1559) based on non-indigenous observations for current climate (a), past climate (b). Suitability threshold= 0.2; areas in white fall outside the range of calibration area.

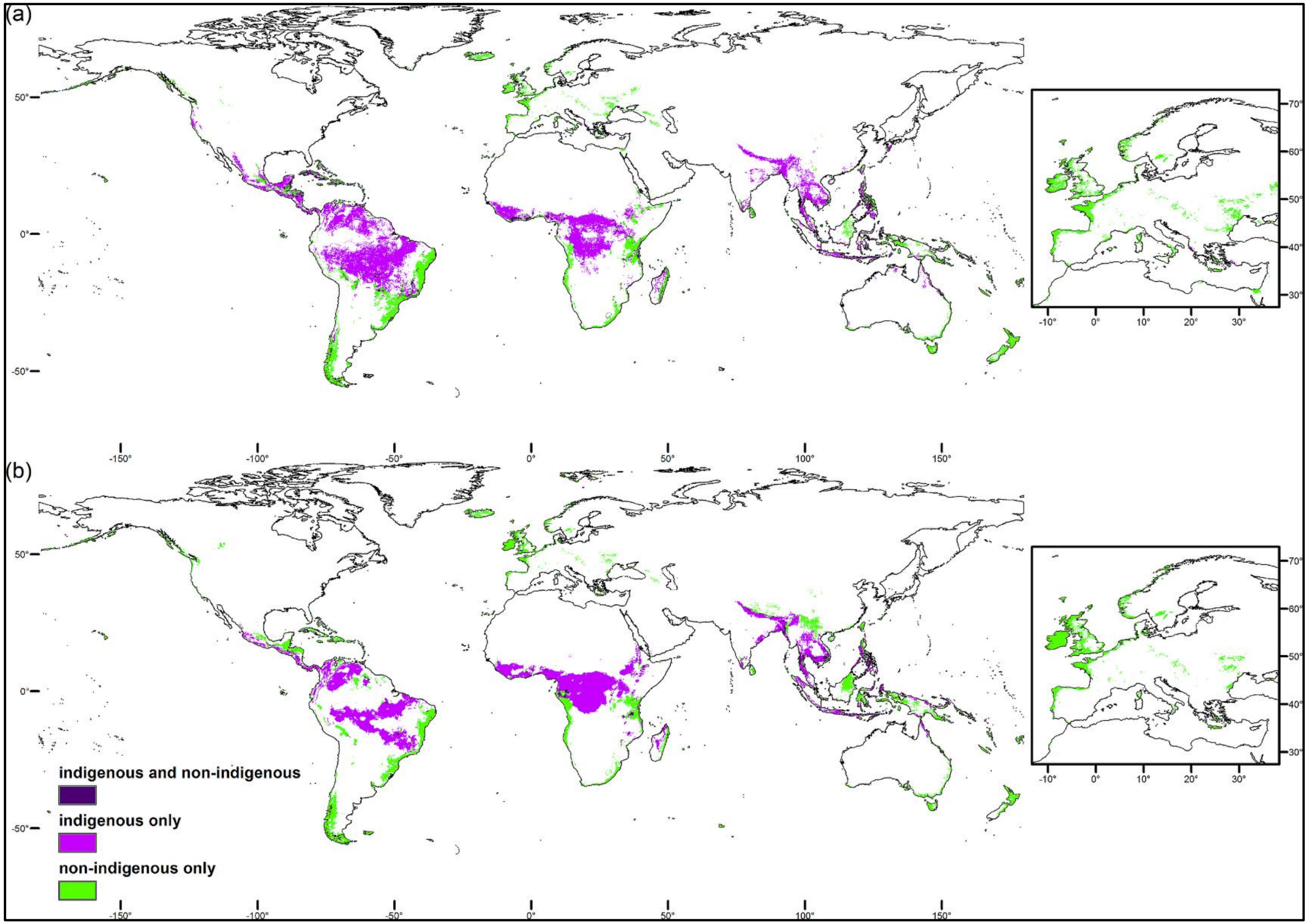


Figure 15. Areas of environmental suitability predicted to be above threshold for Red Junglefowl for (a) present climate and (b) climate in 4000 BCE.

3.4.2 Grey Junglefowl

The performance of the ENMs for the Grey Junglefowl can be considered good, with AUC values ranging from 0.914 to 0.916. Like the indigenous Red Junglefowl, areas predicted to be suitable for the Grey Junglefowl, both currently and in the past, largely lie between the latitudes of the Tropics of Cancer and Capricorn (Figure 16). The environmental conditions found within the calibrated range greatly inhibit global projection (see section 3.3.2), and excludes many areas most suitable for Red Junglefowl in Africa and South America. Otherwise, regions of predicted suitability are similar. For Grey Junglefowl, maximum temperature and seasonality are most important, preferring warmer temperatures and less change in seasonality. An increase in mean vegetation cover also improves potential. Apart from a narrow strip along the northwest edge of Iberia, and very small pockets in Italy and Albania, Europe is unlikely to contain suitable environmental conditions for indigenous Grey Junglefowl, either now or when projected back to 4000 BCE.

Geographically, the suitable niche for indigenous Grey Junglefowl and combined indigenous and non-indigenous Red Junglefowl, overlaps in South America, central Africa and small pockets within the indigenous range of Grey Junglefowl (Figure 17). The environmental niche similarity test, using ENMTools (Warren et al. 2010), produced a 'Schoener's D' (Schoener 1968) value of 0.87 and 'Hellinger's I' (Warren et al. 2008) value of 0.94. This suggests the niches of Grey and Red Junglefowl are, environmentally, almost identical.

3.4.3 Archaeological relevance

Suitability values were extracted for each model at selected archaeological sites (Table 6). Sites chosen include those purported to have early examples of domestic fowl and/or which are found at the extremes of Europe (see Figure 18 for locations):

1. Nanzhuangtou, China (ca. 8050 BCE), Neolithic site with evidence for grain milling. One of the earliest sites proposed for chicken domestication worldwide (Xiang et al. 2014), but this has been contested (Peters et al. 2015; Eda et al. 2016).

2. Cishan, China (ca. 5000 BCE), type-site of the Cishan culture, which is associated with farming. A Neolithic settlement with dwellings, it is often cited as one of the earliest sites of chicken (West and Zhou 1988). The evidence has been recently contested and reappraised (Yuan 2010; Eda et al. 2016).

3. Hotnitsa, Bulgaria (ca. 5000 BCE), Chalcolithic settlement and the earliest in Europe reported to have chicken (Boev 2009). It is included here as the site was used in the published article. Radiocarbon-dating since publication indicates a modern date for the chicken remains (Best et al. in prep).

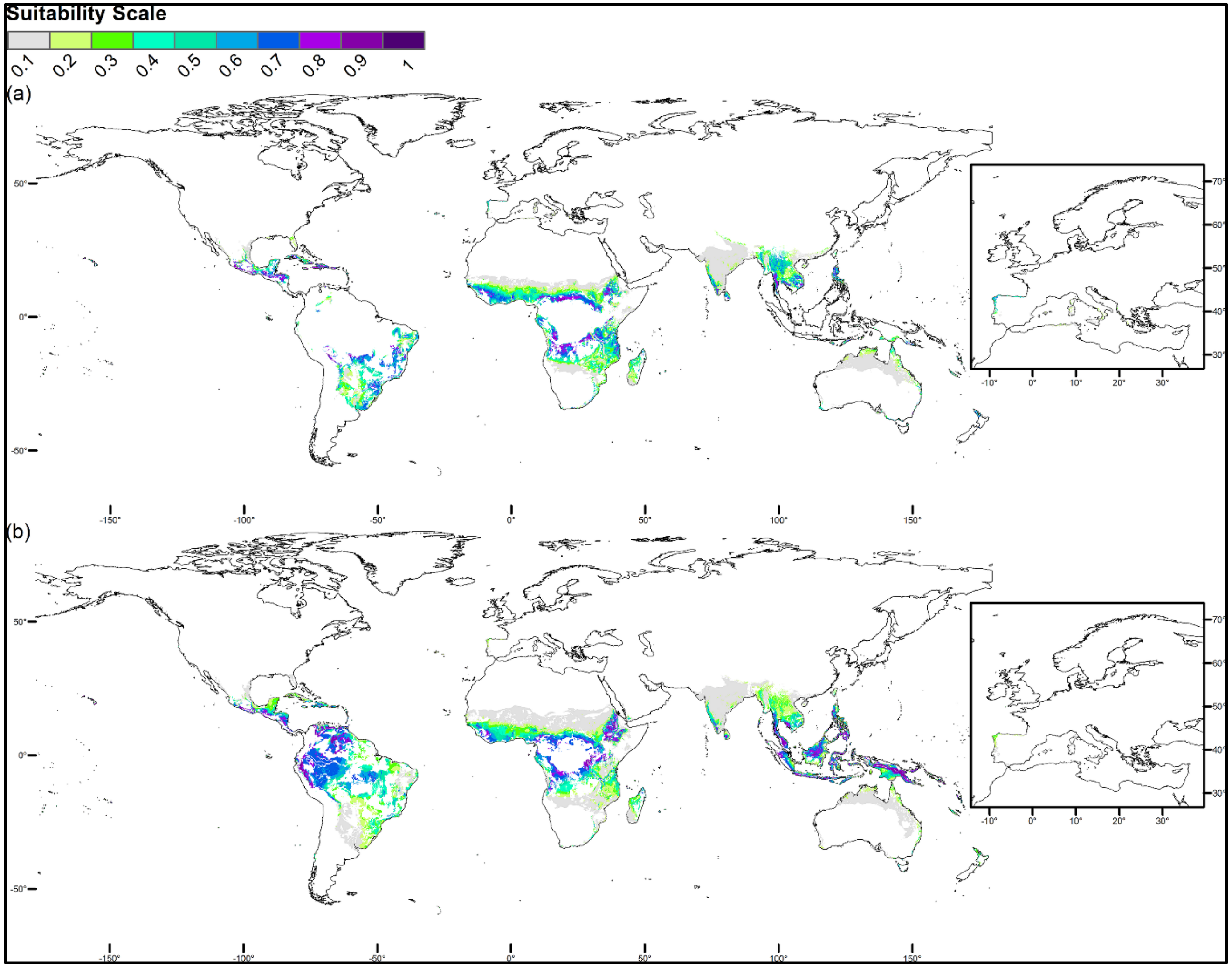


Figure 16. Global projections of predicted environmental suitability for Grey Junglefowl (n=997) based on indigenous observations for current climate (a), past climate (b). Suitability threshold= 0.2; areas in white fall outside the range of calibration area.

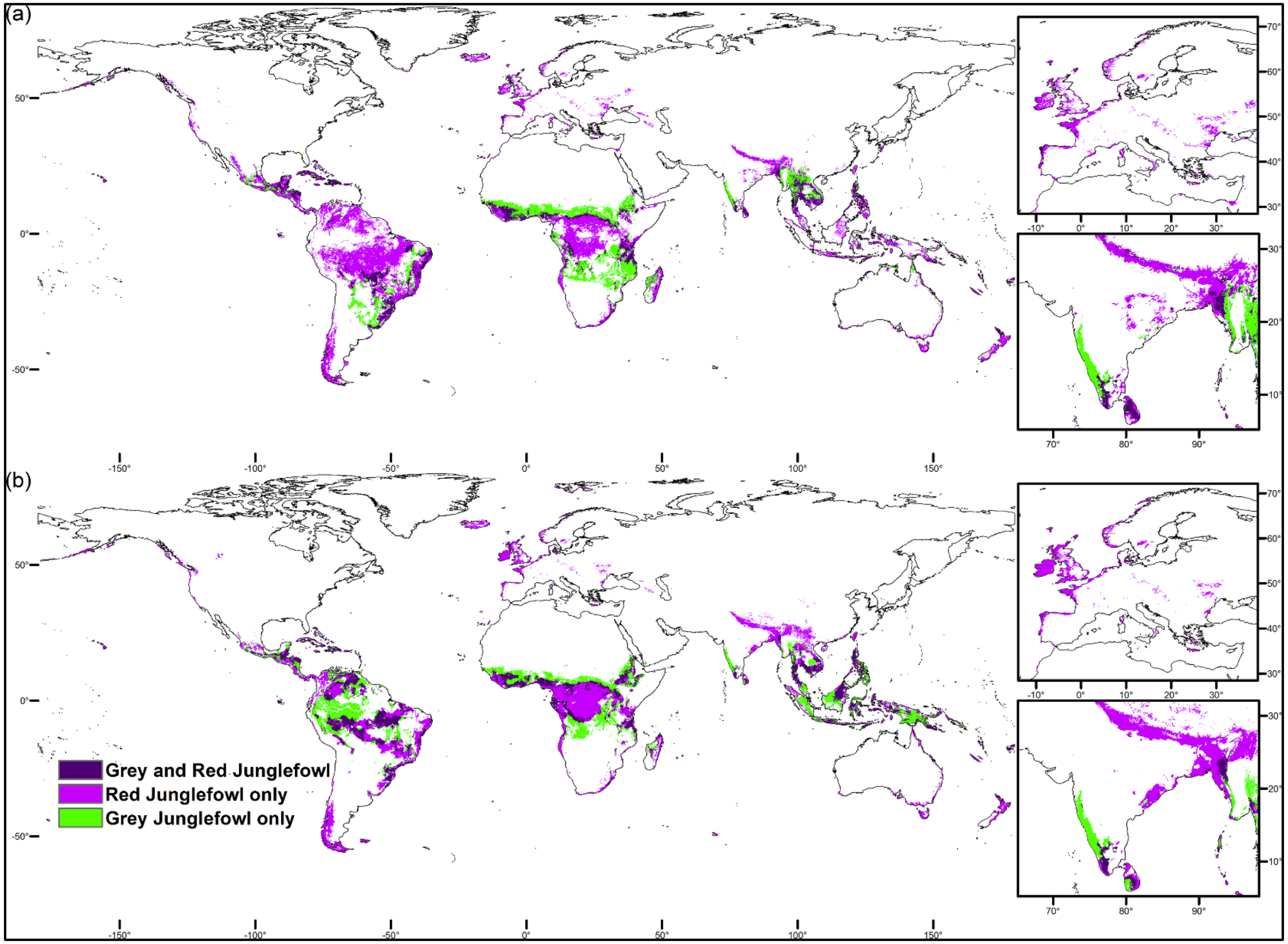


Figure 17. Areas of environmental suitability predicted to be above threshold for Grey and/or Red Junglefowl for (a) present climate and (b) climate in 4000 BCE.

4. Mohenjo Daro, India (ca. 2500 BCE), large settlement of the Harrapan civilisation. Among the earliest sites generally accepted to contain evidence of chicken from secure archaeological contexts (Zeuner 1963; Fuller 2006), although the early dates are now being questioned, based on the large size of the chicken remains so early in domestication (Peters et al. in prep).

5. Cerro de la Virgen (ca. 2500 BCE), Argar Culture (Bronze Age) dwelling mound. Earliest claimed evidence of chicken in the Iberian Peninsula (von den Driesch 1973) and of interest here due to its early date and location at the far west of Europe.

6. Eleftherna, Rethymnon, Crete (ca. 850 BCE), settlement including an Early Geometric cemetery. Earliest evidence in Greece (Nobis 1998) and situated on Phoenician trade routes into Europe (Becker 2013)

7. Biskupin, Poland (ca. 650 BCE), Hallstatt (Iron Age) period fortified settlement (Bochenski et al. 2012). Date and location may favour a northern dispersal route from Asia via Russia into Europe.

8. Alcáçova de Santarém, Portugal (ca. 800-300 BCE), fortified enclosure. Earliest reliable site in the Iberian Peninsula with chicken from a secure context (Davis 2006).

9. Houghton Down, Hampshire, UK (ca. 390-206 BCE), two nearly complete articulated skeletons from an Early Iron Age pit within a settlement. Early evidence of chicken in the United Kingdom, at the north-west extent of Europe (Hamilton 2000b). The date has been confirmed by radiocarbon-dating (Best et al. in prep).

10. Skedemosse, Öland, Sweden (ca. 15 CE), pre-Roman Iron Age fishing lake (Hagberg 1967). Among the earliest evidence in Scandinavia for chicken, and located at the northernmost extent of Europe.

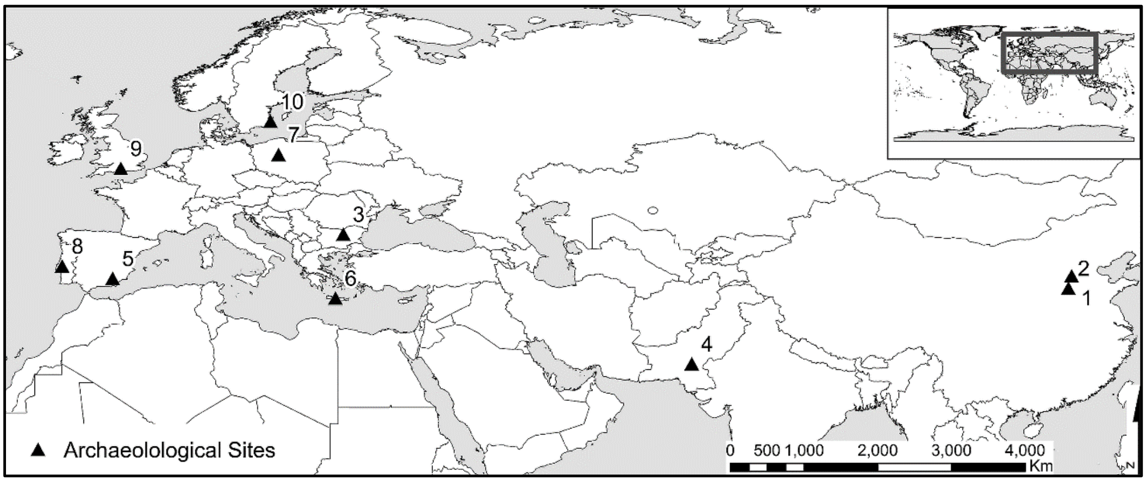


Figure 18. Location of archaeological sites mentioned in Table 6.

Model				Archaeological Site									
Climate	**Species**	**Occurrence type**	**Suitability threshold value**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Present	Red Junglefowl	Indigenous	0.39	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.19	0.00	0.00
Present	Red Junglefowl	Non-indigenous	0.16	0.01	0.01	0.06	0.00	0.04	0.13	0.05	**0.28**	0.16	0.06
Present	Grey Junglefowl	Indigenous	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Past	Red Junglefowl	Indigenous	0.41	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.06	0.00	0.00
Past	Red Junglefowl	Non-indigenous	0.21	0.01	0.01	0.04	0.00	0.01	**0.24**	0.07	**0.32**	**0.26**	0.12
Past	Grey Junglefowl	Indigenous	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Environmental suitability (scale:0-1) for early archaeological sites containing faunal remains of domestic fowl. Above threshold values are highlighted in bold.

The models based on indigenous occurrences indicate a complete lack of potential for suitable sets of environments at many of these locations. The poorest potential is found at the Chinese Neolithic sites and in India. Limited potential for suitable conditions may have been present in 4000 BCE at Eleftherna in Crete, Alcáçova de Santarém in Portugal, and Houghton Down in the UK for Red Junglefowl; but for Eleftherna and Houghton Down, it is unlikely to be suitable today and thus at the time the material was deposited. These locations are entirely unsuitable for Grey Junglefowl.

The highest suitability value at a known Red Junglefowl location for both present and past climate simulations is located only approximately 1000km from Mohenjo Daro. Mohenjo Daro is not the only Harappan Culture site thought to have chickens. Fuller et al. (2006) identify *Gallus* from other Indian Bronze Age sites. Those further from the native range of the junglefowl are more likely to be described as chicken (Figure 19). Some of these sites are located closer to a range which would be more suitable for Grey Junglefowl.

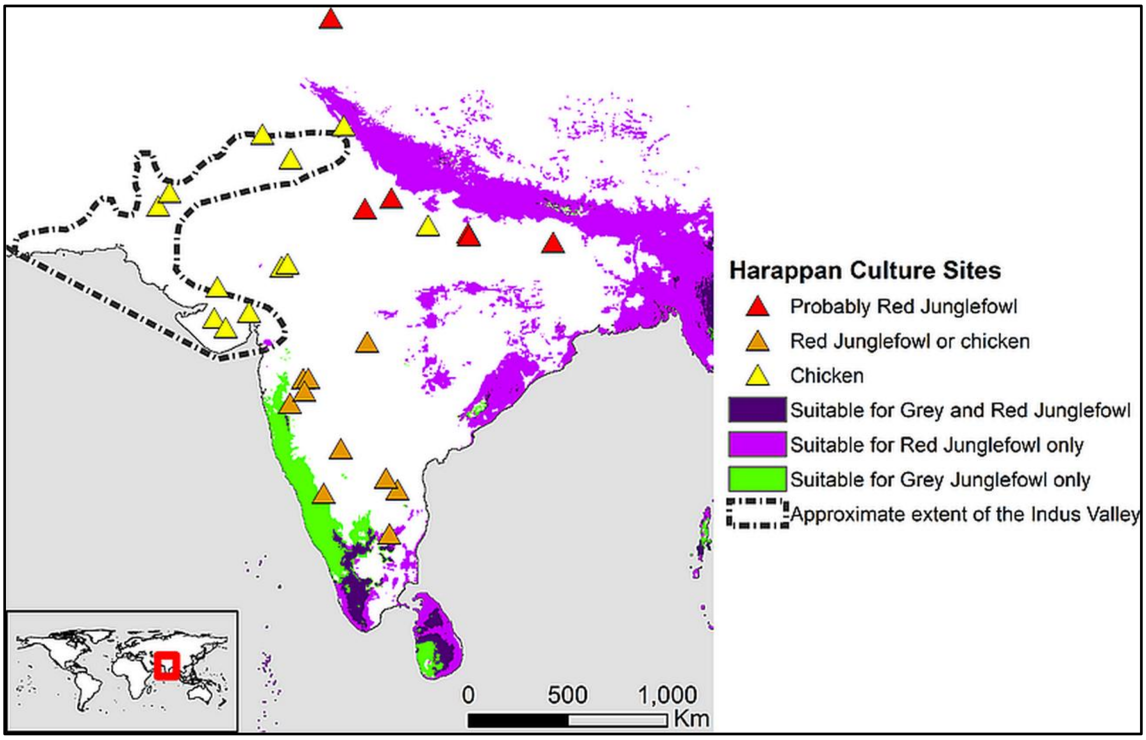


Figure 19. Environmental suitability for Red and Grey Junglefowl in relation to Gallus bones from archaeological sites in India (after Fuller et al. 2006).

3.5 Discussion

The models indicate that environmental conditions suitable for indigenous junglefowl are largely limited to a geographical band close to the equator. This suggests that if a wild Red- or Grey Junglefowl was to be taken from this region and left to survive in Europe, it would be unlikely to survive without help.

Therefore, non-indigenous populations of Red Junglefowl are of great interest. Like the domestic chicken, these populations are likely to have been subject to some level of selection. Tamer Red Junglefowl are likely to have been easier to catch and preferable for transporting; or if capturing them for fighting, then natural aggression might be preferred. The removal of natural barriers by human transportation has enabled these populations of Red Junglefowl to successfully inhabit environments geographically distinct from the natural habitat of the indigenous wild bird. The models indicate that they can survive and breed at very different latitudes and in colder climates to where the species originate. This suggests that Red Junglefowl have a broader fundamental niche than the suite of environmental conditions present in their native range suggests.

Niche similarity tests indicate that the environmental niche of indigenous and non-indigenous Red Junglefowl is more similar than the geographic overlap might suggest. Interestingly, niche similarity between Grey- and Red Junglefowl is even more similar than that between indigenous and non-indigenous Red Junglefowl. Yet despite preferences for similar environments, observations of the two species rarely overlap geographically. It seems likely, therefore, that inter-species competition is responsible for their generally exclusive ranges. This being the case, inter-breeding between the two species is more likely to be a rare occurrence in the wild, and may have occurred as part of the domestication process in regions which are environmentally suitable for both species.

In terms of survival, environmental suitability values below the threshold for the species maximum tolerance are expected to require additional human intervention to ensure survival. The same would be true for a recently domesticated version of this species. The junglefowl is a bird that is easily tamed, self-organises into hierarchical groups, and provides a good source of protein and feathers, and as such is an ideal species for domestication. However, despite millennia of domestication and selective breeding the chicken has retained traits that would make it difficult to maintain flocks in unsuitable environments, particularly without the aid of modern technology. Transporting and/or keeping a bird from escaping is more challenging than for a species that does not fly, such as ungulate livestock. Keeping chickens in small confined spaces is not ideal in any case, as inability to exhibit natural behaviour, such as foraging, is displaced with abnormal behaviour, which can be aggressive (Baxter et al. 1983).

Therefore, first domestication in an area of poor environmental suitability would be unlikely to succeed. Geographical barriers limiting junglefowl dispersal prior to domestication means the most likely location(s) for first domestication should be in environmentally suitable areas of the indigenous calibrated ranges. This would be challenging archaeologically. *Gallus* bones in this region are more likely to be interpreted as wild Red Junglefowl, because of the difficulties of identifying between domestic and wild *Gallus* (Peters et al. in prep). Even if bones are found associated with domestic features, this would not necessarily indicate a domestic bird. Use of wild birds in early societies is documented (Serjeantson 1997; Grimm 2010; Best and Mulville 2014). The models show that the tolerance of Red Junglefowl exceeds that of conditions within the native range. Therefore, archaeological bones found outside of this area (but within the ecological niche of non-indigenous Red Junglefowl) may not belong to domestic fowl, but to wild birds selected for transportation that have subsequently escaped.

Poor environmental suitability values at locations of early archaeological evidence suggest that early chickens were either present in areas which were environmentally unsuitable for their ancestor, even at its broadest tolerance, that these early sites are incorrectly dated, or that these are not chickens. Based on reappraisal of some of the evidence, the reason may be that the remains represent a different Galliform (after Eda et al. 2016). If they are domestic fowl, then increased human provision would be needed to meet essential requirements, including food, water and/or shelter. The chicken was an expensive commodity, as attested by depictions in material culture and evidence of use in ritual proceedings (Sykes 2012). Decreasing suitability values by moving into higher latitudes implies greater investment of effort and resources. Colder winters require storage of feed and additional shelter, and egg-laying is affected by daylight hours, causing an issue for reproduction as well as provisioning. This is exacerbated by the fact that wild junglefowl lay eggs only in spring and although the loss of seasonal reproduction is thought to have occurred fairly early in domestication, the date of this adaptation remains unclear (Girdland Flink et al. 2014).

Based on proximity to suitable environmental conditions for Grey Junglefowl as opposed to Red Junglefowl, it is possible that some of the early *Gallus* bones identified from Bronze Age archaeological sites in India, particularly those in Southern India in the Northern Deccan region, may be more likely to be remains of Grey rather than Red Junglefowl. Although there is less evidence for introgression with Grey Junglefowl in early European specimens (Girdland Flink et al. 2014), it is not unthinkable that Grey Junglefowl were also domesticated at this time.

In terms of transporting tamed Red Junglefowl or recently domesticated chicken, the models indicate that a northern route via China and Russia into Eastern Europe would be environmentally challenging. Movement west via the Indus Valley appears more likely, based on proximity to regions offering ideal environmental conditions. Areas predicted as suitable by models based on non-indigenous observations correspond well with Greek and Phoenician trade routes through the Mediterranean and up into southern Britain and Ireland (Becker 2013). The start of these routes also link up with known Bronze Age commercial roads through the Near and Middle East (Covington 2013). Suitable environmental conditions would likely improve potential for survival of an early domestic descendent of the Red Junglefowl into Europe via this route. Although the same cannot be stated for the Grey Junglefowl based on these models and the available evidence, it seems probable, based on the evidence for Red Junglefowl, that the tolerance of Grey Junglefowl may also exceed that of conditions within its native range. It is possible that this species, transported by humans, may acclimate equally as well as its Red neighbour.

Small pockets of environmental suitability are present in Europe for Red Junglefowl. However, a lack of potential for suitable sets of environments for most of Europe suggests that the chicken needed to adapt further by the time it reached parts of central and northern Europe, and/or would have required substantial human investment to survive in such climates outside of the environmental tolerance of its ancestor.

3.6 Conclusions

The analyses confirm that the climate of Europe is not suitable for indigenous Red- or Grey Junglefowl, or by extension, its descendant in early stages of domestication. A junglefowl taken from Asia to Europe today is unlikely to find conditions suitable for unaided survival. This suggests that early domestic fowl could not just be transported and left to disperse, survive and breed. Rather, it provides an interesting example of the human investment required to sustain a new domestic species, especially since sites containing early examples of chicken are likely to have lacked suitable environmental conditions.

Based on environmental considerations, first domestication is likely to have occurred in the native range of the species and not in areas such as northern China, where environmental conditions are likely to have been entirely unsuitable. For Red Junglefowl, the most suitable conditions are found in India, particularly northern and north-eastern regions, offering good potential for these areas as initial centres of domestication. Very good environmental suitability in Thailand, Cambodia and the Lao People's Democratic Republic also indicates potential for being first or additional centres of domestication. For the Grey Junglefowl, the Kerala district of south-east India offers best potential within its indigenous range; although, again Thailand and Cambodia offer very suitable conditions. Hybridisation would be easiest in the southern tip of India, Sri Lanka, the border area of east India, Bangladesh and Myanmar, Thailand, Cambodia, and the Lao People's Democratic Republic.

Occurrences of Red Junglefowl outside of its natural range suggests that Red Junglefowl can, and have, acclimated to alternative environments. This suggests that the environmental niche of the species may be broader than might be suspected based on conditions within its native range. This has implications for other ecological niche modelling studies of species confined by geographic limitations. It also suggests that a dispersal route through the Mediterranean into Europe has the best potential for presence of environmental conditions to aid survival of a new domestic species.

4 How, when and by what means did the chicken arrive in Europe?

4.1 Summary

The route the chicken took from Asia to Europe has been little considered. It is thought that they travelled with traders or settlers (Becker 2013; Peters et al. in prep). Trade or settler routes are likely to have followed paths of least difficulty for the humans transporting their belongings or wares, including livestock. This chapter uses the least cost path functionality of Geographic Information Systems (GIS) to identify the pathways with the best potential for transporting the chicken from its origins in Asia to Europe.

4.2 Introduction

The dispersal of the chicken, following first domestication, is unclear. Based on the native range of the ancestor bird, early domestic chicken must have initially dispersed from Asia or South East Asia. Several Bronze Age sites in this region are known to contain *Gallus* bones, some of which are thought to be chicken (Fuller 2006). Despite questions regarding the validity of the information contained within it (Yuan 2010; Eda et al. 2016), most literature about chickens continue to refer to the work of West and Zhou (1988). Therefore, any discussion of dispersal routes usually repeat their suggestion that chickens were transported via the silk roads or into Europe via Mongolia and Russia (West and Zhou 1988). A few studies have proposed an alternative route, using the Mediterranean as a dispersal corridor. It is suggested that the chicken may have been traded by Phoenicians as one of their commodities and therefore followed their trade routes (Serjeantson 2009; Becker 2013), or that they accompanied Greek settlers (Peters et al., in prep).

Least cost path (LCP) analysis can identify suitable routes, based on environmental and terrestrial limitations to movement. Factors which may hinder movement are simultaneously analysed to produce a route, which would require least effort to travel, based on the input variables. The technique is most frequently used in modern planning decisions. It has, however, been successfully applied to archaeological studies. Herzog (2013) offers an interesting summary of the history of archaeological use of such methods, application and limitations. In many cases, LCP is used to predict absent sections of historical roads. Pelfer (2005) used LCP to identify a communication network in the territory of Tarquinia in South Etruria, Italy during the late Bronze to Iron Age, and found it corresponded well with archaeologically identified paths. The technique was also tested against the road network of ancient Cyprus, which had been mapped by extensive fieldwork (Ejstrud 2005) and found to show general, if not absolute, agreement. Other authors have used LCP to inform broader archaeological questions. Orengo and Livarda (2016) successfully combined cultural with terrestrial and environmental factors to fill in the gaps of the Roman road network in Britain, enabling them to identify trade networks of exotic plant species; while Güimil-Fariña and Parcero-Oubiña (2015) used LCP to better understand the decisions behind the choice of location for known stretches of the Roman roads of the NW Iberian Peninsula. Such research emphasises the usefulness of applying these techniques to inform archaeological interpretation. Naturally, it is difficult to include factors which account for human decision making in the past, so the results of such analyses must be considered in combination with evidence derived from archaeological and historical investigation.

People have been moving livestock and exotic commodities around the landscape for millennia. The period under consideration is no exception. Several known long-distance trade or settlement routes were in operation. A series of trade networks developed in Mesopotamia and the Persian Gulf region from the fourth millennium BCE, with a lapis lazuli trade route linking the Himalayas to Egypt via Mesopotamia (Sherratt 2004; Covington 2013). Continued trade between India and Mesopotamia is evidenced by the presence of many Harrapan seals at the Mesopotamian city of Ur between 2300 and 2000 BCE (Lockard 2015). Mesopotamian trade networks expanded into Eastern Mediterranean and Baltic regions by ca. 2000 BCE, with relay routes from these regions spreading throughout Europe (Sherratt 2004). Networks between west and east were negatively affected by the collapse of the Persian Gulf network, ca. 1700 BCE, which coincided with the collapse of the Indus Valley Civilisation in India (Lockard 2015). In India, a drought is thought to have occurred ca. 2000 BCE which may have been the cause of this collapse (Carr 2014), forcing populations westward. In the west, maritime trade continued to expand in the eastern Mediterranean (Sherratt 2004); while in Asia, following the fall of the Harrapan Culture, Aryan people moved into north-west India from Iran, ca. 1600-1400 BCE (Lockard 2015). The formation of a new amber trade route (ca. 1800 BCE-1350 BCE) revived trade between east and west, linking Northern Europe to the Mediterranean and Asia (Sherratt 2004; Lockard 2015). Within the Mediterranean, Mesopotamian trade linked North Africa and Mycenaean Greece (Walton et al. 2009). The end of the 2nd millennium saw the development and spread of ironworking and expansion of networks in the Mediterranean, Middle-east and the Ganges (Sherratt 2004), influenced by increased use of camels aiding movement in the Arabian Peninsula (Covington 2013); and Phoenician traders operating through the Mediterranean, around Africa, and up to the United Kingdom via Iberia. The Phoenicians are reported to have been mining copper in Spain by 1240 BCE, and importing tin from Armenia, Cornwall and Saxony during the Bronze Age (Northrup 2005).

Using knowledge of trade and settler movement and the earliest known evidence for potential chicken bones found at archaeological sites across Asia and Europe, it is possible to spatially analyse the dispersal of the chicken within given date ranges. Applying least cost paths, using GIS, enables identification of the pathways, both overland and by sea, based on environmental and terrestrial variables, which best facilitate human movement across the landscape. Comparing these to locations where chicken is known to be present from the archaeological literature enables us to identify the most likely dispersal routes for the chicken. The costs associated with movement can be calculated for each site where chicken is found, to determine how far the chicken could reasonably be moved before the costs become more than rationally viable. If the cost distances cannot overlap with another known site of a similar date, then there is insufficient evidence to support dispersal via that route.

Combining these analyses with knowledge of trade and population contraction and expansion in relevant geographic locales, enables us to identify likely centres of distribution. Paths of least cost between sites of similar dates can be modelled and used to predict the course and speed of the chicken's dispersal to Europe. Where the paths follow known trade or settler routes, it adds credence to the assumption that the chicken was being transported in this fashion and by these groups of people.

4.3 Materials and Methods:

Period 1 sites (up to 800 BCE) were extracted from the database (see Chapter 2). 'Date from' was used in this instance as it provides a *terminus post quem*, or the earliest possible date that sites known to contain chicken might be part of a trade or settlement network with sites outside of Europe. By period 2 (800 BCE – 0 BCE/42 CE), the chicken is present in Europe, and so it is period 1 sites which explain how it got there. Period 1 database sites were combined with sites dated to 800 BCE not included in the database which are reported to contain chicken (Fuller 2006, Peters et al., in prep; Becker 2013; Redding 2015; Eda et al. 2016). These sites were identified during the research for Chapters 1 and 3. The resulting dataset was divided into four broad chronological groups based on events occurring in the region at the time. Group 1 contains the earliest known sites, dating from 5500 BCE to 2800 BCE, the period prior to the height of the Indus Valley Civilisation. Group 2 includes sites at the peak of the Indus Valley Civilisation (from ca. 2600-1700 BCE) (Fuller 2006). The contraction in trade networks until the late 2nd millennium BCE (Sherratt 2004) forms the date range (1800 BCE-1000 BCE) for group 3. Finally, sites dated to the period of rapid expansion in trade networks at the beginning of the Iron Age (1000 BCE to 800 BCE) (Sherratt 2004), which sees the chicken become established in Europe, are included in the fourth group. Sites which fall into more than one group are included in both groups.

A spanning tree model (Patterson 2013) was applied to the points by group to spatially analyse the network based on Euclidean distance. It is generally considered that the nearer things are to one another, the more closely related they are likely to be. Applying this method enables a visual assessment of clusters and to identify the extent of the dispersal within that timeframe. An attempt can then be made to effectively 'join the dots' and seek to better the understand the routes which may offer the best potential for moving chickens around the landscape in different periods.

The least cost path models were run using the standard 'cost path' function in ArcGIS. Routes were modelled for sites at the ends of the spanning tree analysis, and from east to west, due to the focus of this study.

The cost factors combined environmental and terrestrial variables, based on the assumed effort to cross a land- (or sea-) scape where each factor is present (Table 7). Geographical factors included sea depth, gradient of slope and altitude. Given that larger vessels are required for deeper waters, cost values increase with depth of water. Sea depth was determined using bathymetry layers (www.naturalearth.org.uk; accessed 10 June 2016). Slopes greater than 12 degrees up or down require increased effort (Langmuir 1984), while those greater than 35 degrees are impassable without specialist equipment (Blackburn 2011). Slope (in degrees) was calculated using the standard slope function in ArcGIS from a digital elevation model (DEM) (CGIAR Consortium for Spatial Information 2008). This DEM was also used for altitude. Altitudes above 2500m require days of acclimatisation, and above 8000m humans cannot survive.

Landcover factors centre on vegetation, as different types of vegetation require different levels of effort to traverse. Landcover for the pre-Roman period is unavailable, so pre-industrial landcover information was used as a proxy (National Climatic Data Center, 2013). Landcover types include forest (tropical, boreal and temperate), semi natural areas (savanna, grassland, shrubland), and open spaces with little or no vegetation (steppe, tundra, desert, polar). Cost increases based on the difficulty of traversing, e.g. low density temperate forests and grasslands offer easiest navigation and contain resources, while dense tropical forests or arctic conditions present a far greater challenge.

Finally, biological requirements for survival were considered. Any animal, including humans, requires access to fresh water. Cost increases with distance from a fresh water source (rivers and streams). Rivers and streams were calculated using the standard flow accumulation function in ArcGIS using a digital elevation model (CGIAR Consortium for Spatial Information 2008). These factors can all be considered important for facilitating human movement. It is assumed that traders would take the most expeditious route, while settlers moving domestic livestock around the landscape would additionally need to consider the wellbeing of their animals. For this reason, the additional factor of environmental suitability for Red Junglefowl was included in some models as it may affect the potential for survival and persistence of early chicken as it disperses across the continents. This was predicted using ecological niche models (Pitt et al. 2016), whereby poor suitability incurred a cost (Table 7).

Cost	Cost description	Geography			Landcover										Biological	
		sea	terrain		vegetation											
					forest			Natural-grass/shrub				barren				
Cost	**Cost description**	Sea depth (m)	Gradient (degrees)	Altitude (m above sea level)	Tropical (% of area)	Boreal (% of area)	Temperate (% of area)	Savanna (% of area)	grassland/steppe (% of area)	shrubland (open) (% of area)	shrubland (dense) (% of area)	Tundra (% of area)	Desert (% of area)	Polar (% of area)	Suitability for Red Junglefowl (see Pitt et al. 2016)	Distance to fresh water (m)
0	no cost/not present	200m	0	<2500	0	0	0, 1-25	0	0, 100-50	0	0	0-25	0-25	0	suitable	0-5
1	easy	1000m	1-3				25-50		50-1	100-50						5-10
2			3-12			1-25	50-75	1-25		50-1	1-25				not suitable	10-15
3		2000m				25-50	75-100	25-50			25-50					15-20
4	not so easy											25-50	25-50			>20
5	difficult	3000m	12-30		1-25	50-75		50-75			50-75					
6			30-35	2500-3500	25-50	75-100		75-100			75-100	50-75	50-75	1-50		
7		4000m		3500-5500	50-75											
8	very difficult	5000m		>5500	75-100							75-100	75-100	50-100		
100	impassable		>35	>8000												
Inclusion in model	Solid LCP	y	y	y	y	y	y	y	y	y	y	y	y	y	y	y
	Dashed line LCP	y	y	y	y	y	y	y	y	y	y	y	y	y	n	y

Table 7 Costs assigned to least cost path model variables. Costs are based on assumed difficulty of traversing terrain.

4.4 Results

Applying a spanning tree model to the known site locations creates a network based on Euclidean distance (Figure 20). It enables visual identification of the spatial extent of the grouped sites and how this changes over time.

Initially, dispersal is limited to Asia, with early sites in India and China. The chicken then becomes more frequently found in north-west India, on sites associated with the Harrapan culture, along with an early recording of chicken at the edge of Europe at the site of Korucutepe in Turkey. It is worth noting that a single bone was recovered in the site phase dated 1800-1600 BCE, with better evidence (14 bones) from the subsequent 1500-1200 BCE phase (Boessneck and von den Driesch 1974). By 1500 BCE chicken presence in India is found further east and south, and has spread into South East Asia, with occurrences appearing again in China. By 1000 BCE the chicken is found at several sites in the Middle East and has reached as far as Hungary and Spain, deep within Europe. By the final group, dating approximately to the start of the Iron Age, the chicken starts to become established in Europe and the Middle East.

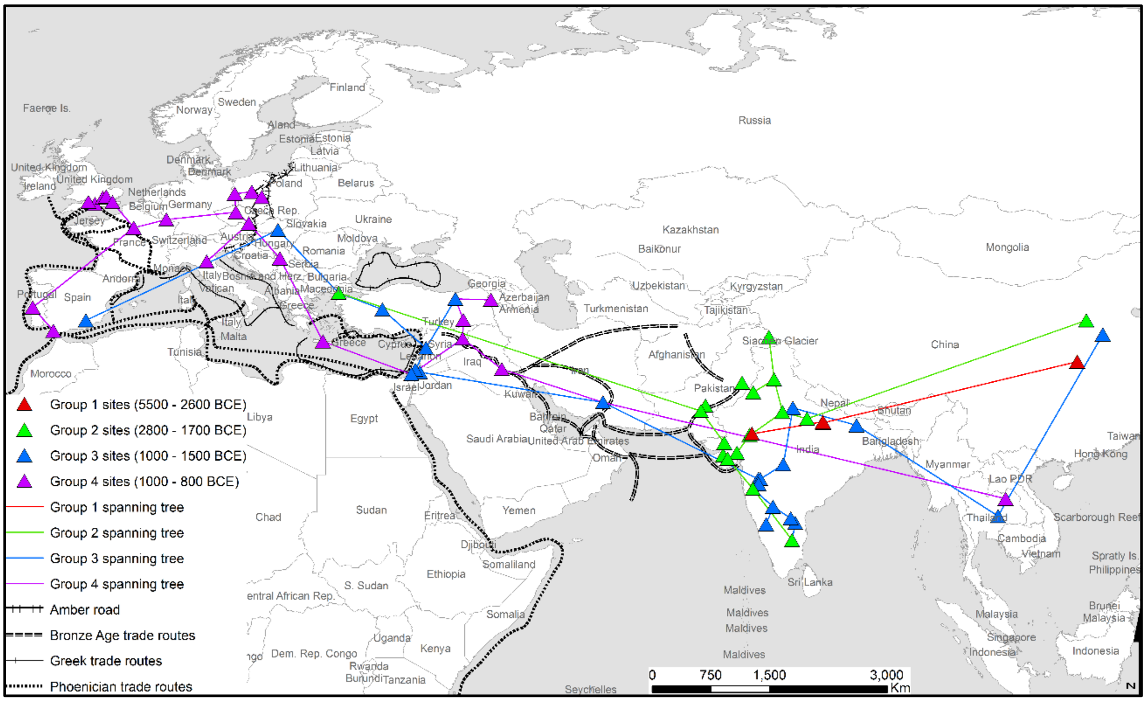


Figure 20. Spanning Tree model for early sites containing chicken or junglefowl remains. Connecting lines are based on Euclidean distance between sites.

Least cost paths were modelled by group. For each group, separate models were run including or excluding environmental suitability for Red Junglefowl.

4.4.1 Least Cost Path, group 1 (5500-2600 BCE)

The earliest site is Mahadaha (5500-2500 BCE) in the Ganges, an area known to contain wild Gallus. The later site of Balathal (2600-1500 BCE) to the west is included in this group as it predates the height of the Indus Valley Civilisation. The Chinese evidence at Xiawanggang (5000-3000 BCE) is one of two reappraised phasianid bones with potential for being *Gallus* (Eda et al. 2016). Paths which are more suitable for Red Junglefowl are least costly (Table 8). Least cost paths to China, which take the same route whether considering environmental suitability for junglefowl or not, go around the coast of SE Asia (Figure 21), due to difficult terrain. This implies there is no easier direct route from India to China.

Path from	Path to	Accumulated cost value	Number of cells	Includes the RJF variable
Mahadaha, India	Xiawanggang, China	78	1344	y
Mahadaha, India	Balathal, India	16	249	y
Mahadaha, India	Xiawanggang, China	81	1344	n
Mahadaha, India	Balathal, India	18	248	n

Table 8. Start and end locations of group 1 least cost paths, with accumulated costs, number of cells included in the route, and whether the model includes or excludes the Red Junglefowl suitability variable.

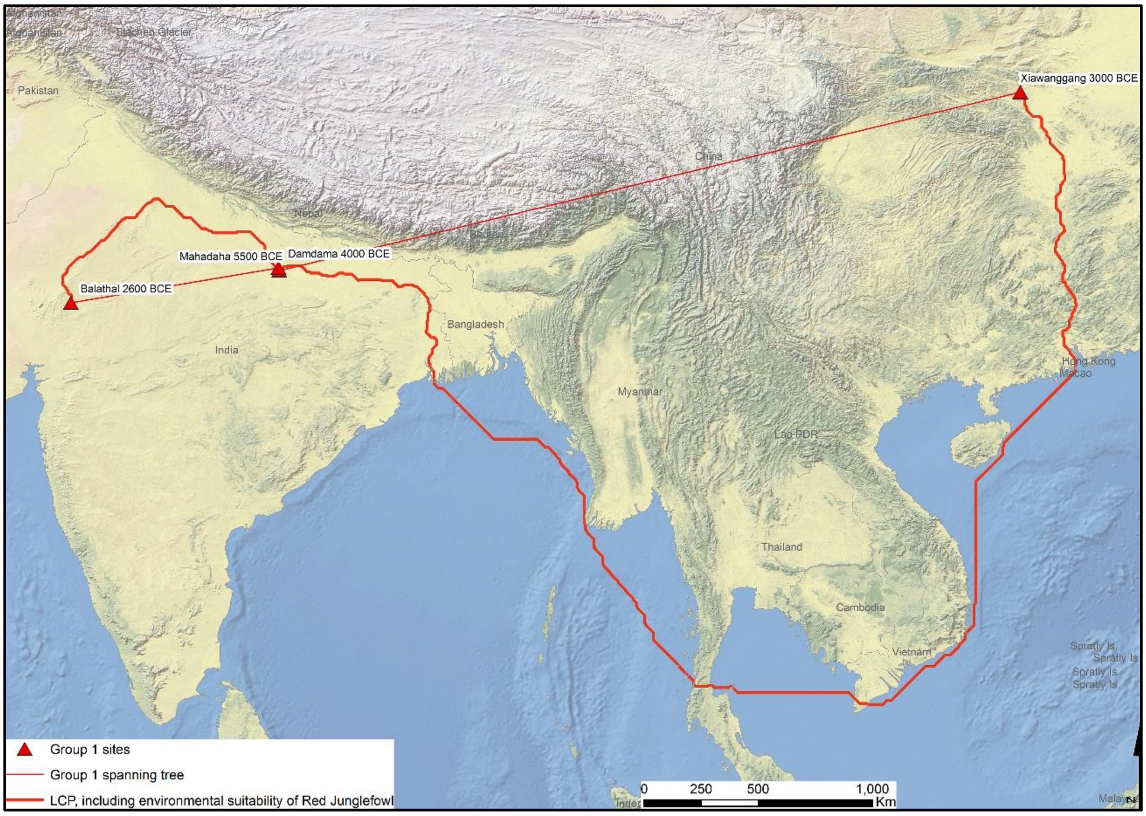


Figure 21. Least cost paths for group 1 sites, dating from ca. 5500 - 2600 BCE.

4.4.2 Least Cost Path, group 2 (2800-1700 BCE)

The earliest site is Balathal (2600-1500 BCE) in Rajasthan. Nearly all the sites in this group are associated with the Indus Valley Civilisation in India, except for an early chicken bone in Turkey. Routes from India have equal cost values but differ if environmental suitability for Red Junglefowl is included (Figure 22). If included, a northern route runs through Pakistan, Afghanistan and Iran, crosses the Caspian Sea and enters Turkey by the Black Sea via the southwest tip of Russia. If not, a southern route into and across the Near East, via the Gulf of Oman and Persian Gulf, offers the best route. The southern route closely follows known Bronze Age trade routes in and out of the Middle East (Covington 2013).

Zhoujiazhuang was used to assess early dispersal into Europe from China as the only other bone from a Chinese site with potential for being *Gallus* (Eda et al. 2016). Paths from China offer similar cost whether Red Junglefowl suitability is included or not, but is far costlier than paths out of India (Table 9).

Figure 22. Least cost paths for group 2 sites, dating from ca. 2800-1700 BCE. Solid or dashed lines indicate models where environmental suitability for Red Junglefowl is included whilst dashed lines indicate where this was excluded.

Path from	Path to	Accumulated cost value	Number of cells	Includes the RJF variable
Zhoujiazhuang, China	Korucutepe, Turkey	125	2168	y
Zhoujiazhuang, China	Korucutepe, Turkey	127	2218	n
Balathal, India	Korucutepe, Turkey	71	1298	y
Balathal, India	Korucutepe, Turkey	71	1281	n

Table 9. Start and end locations of group 2 least cost paths, with accumulated costs, number of cells included in the route, and whether the model includes or excludes the Red Junglefowl suitability variable.

4.4.3 Least Cost Path, group 3 (1800-1000 BCE)

Sites in southern India are among the earliest in this group, along with the previously discussed site at Korucutepe in Turkey. There are two clusters of sites, one in the eastern Mediterranean/Levant and one in southern India, joined in the Middle East. In fact, Tepe Yahya (ca. 1000 BCE) in Iran lies at the Euclidean centre of this group. These clusters of sites may have been independently breeding chickens, but there is evidence for trade between these regions and so routes from the Far East (China and India) to Europe were modelled (Figure 23).

Routes including suitability for Red Junglefowl are less costly in all cases (Table 10). It is marginal for the route from Paiyampalli in India to Spain. Either way, the path proceeds through the Middle East and enters Europe via the Eastern Mediterranean. Here it divides. If Red Junglefowl suitability is included, then the path goes north around Greece and Italy. Conversely, if Red Junglefowl suitability is excluded, then it follows the North African coastline. Routes to Hungary from Asia are less costly from India than from China. A route to Hungary from India would go via the Caspian and Black Seas, Russia and Bulgaria.

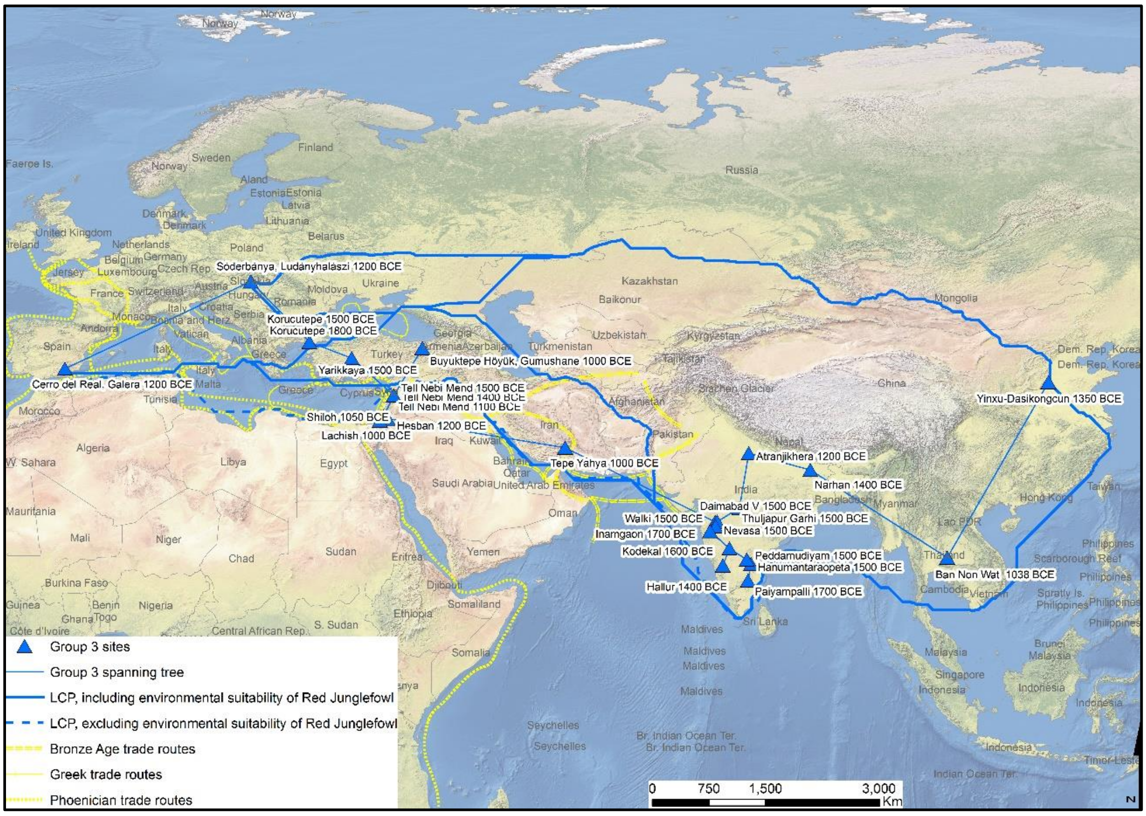


Figure 23. Least cost paths for group 3 sites, dating from ca. 1800-1000 BCE. Solid or dashed lines indicate models where environmental suitability for Red Junglefowl is included or excluded respectively.

Path from	Path to	Accumulated cost value	Number of cells	Includes the RJF variable
Paiyampalli, India	Cerro del Real, Spain	125	2195	y
Paiyampalli, India	Cerro del Real, Spain	127	2258	n
Paiyampalli, India	Sóderbánya, Ludányhalászi	103	1684	y
Paiyampalli, India	Sóderbánya, Ludányhalászi	111	1818	n
Paiyampalli, India	Yinxu-Dasikongcun, China	79	1377	y
Paiyampalli, India	Yinxu-Dasikongcun, China	89	1442	n
Yinxu-Dasikongcun, China	Sóderbánya, Ludányhalászi	137	2401	y
Yinxu-Dasikongcun, China	Sóderbánya, Ludányhalászi	143	2477	n
Yinxu-Dasikongcun, China	Cerro del Real, Spain	163	2932	y
Yinxu-Dasikongcun, China	Cerro del Real, Spain	171	3014	n

Table 10. Start and end locations of group 3 least cost paths, with accumulated costs, number of cells included in the route, and whether the model includes or excludes the Red Junglefowl suitability variable.

4.4.4 Least Cost Path, group 4 (1000-800 BCE)

In this final group, a large increase is seen in the frequency of sites within Europe. The earliest sites in group 4 are in the Middle- or Near East (Iran, Israel and Turkey). Of the sites dated to ca. 1000 BCE, the furthest east is Tepe Yahya, in Iran. A further site in Thailand, Ban Na Di, ca. 800 BCE, also falls within this group but is excluded from the models due to being less likely to be connected to the cluster of chicken sites in Europe, especially since it post-dates Tepe Yahya.

Paths from Iran to the United Kingdom (UK) or to Portugal are again less costly if Red Junglefowl suitability is included (Table 11). They take very different routes if not (Figure 24). The path to Iberia follows the same pattern as for group 3. For the UK, the route including junglefowl suitability goes north between the Black Sea and the Caspian Sea and into Europe from the east. When Red Junglefowl suitability is excluded, the path follows the northern part of the Mediterranean before heading north through France.

Path from	Path to	Accumulated cost value	Number of cells	Includes the RJF variable
Tepe Yahya, Iran	Blackhorse Road, UK	85	1591	y
Tepe Yahya, Iran	Blackhorse Road, UK	91	1542	n
Tepe Yahya, Iran	Alcáçova de Santarém	91	1690	y
Tepe Yahya, Iran	Alcáçova de Santarém	92	1675	n

Table 11. Start and end locations of group 4 least cost paths, with accumulated costs, number of cells included in the route, and whether the model includes or excludes the Red Junglefowl suitability variable.

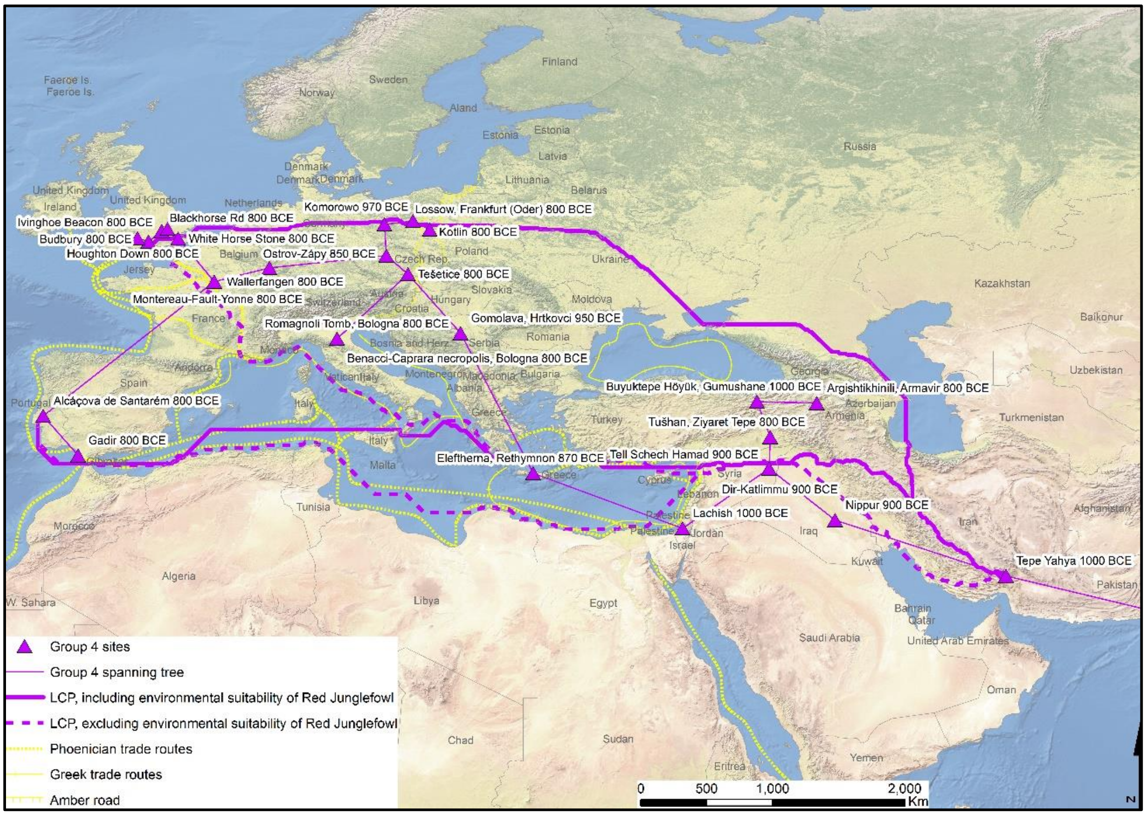


Figure 24. Least cost paths for group 4 sites, dating from ca. 1000-800 BCE. Solid or dashed lines indicate models where environmental suitability for Red Junglefowl is included or excluded respectively.

4.5 Discussion

The spanning tree analysis identifies a progressive movement west for the chicken. Unsurprisingly, dispersal begins in Asia, near the native range of the ancestor species; however, there is a noticeable absence of sites in the northern part of the continent. If China was the location for initial domestication, then there is little evidence for movement out of China northwards. India also contains early sites at which chickens are reported. Most of the early sites in India are at locations containing, at best, minimally environmentally suitable conditions (Pitt et al. 2016), so it is likely that humans are directly or indirectly aiding survival, given their presence at human settlements. It is unclear whether the remains found on these sites are chicken or junglefowl, so in some instances, it may not be domestic breeding, but rather exploitation of wild birds. Dispersing out of Asia, the chicken is possibly present at the eastern edge of Europe by group 2 (from 1800 BCE), has dispersed deeper into Europe by group 3 (from 1200 BCE), and become relatively widespread by the Early- or Middle Iron Age (group 4, from 1000 BCE). A single chicken bone in Korucutepe in Turkey in 1800 BCE provides dubious early evidence, but better evidence for the chicken on the outskirts of Europe is present here by ca. 1500 BCE (Boessneck and von den Driesch 1974). The presence of chicken in Spain a few centuries later is certainly plausible, given Phoenician copper mining in the area by 1200 BCE (Northrup 2005).

The least cost path analysis produced paths offering most suitable traversal between chronologically similar sites. Group 1 includes the earliest available evidence, with sites in both India and China as potential origin locations. Interestingly, there does not appear to be an easy direct route from India to China. This means that if domesticated birds were only dispersing from either China or India, archaeological evidence of *Gallus* should be found in South East Asia. As evidence is only present there in later periods, the lack of reported sites prior to 2600 BCE is consistent with separate centres of breeding both in China and India in the Early Bronze Age. Geographically, Vietnam offers the closest location with junglefowl available for capture and subsequent transportation to China. Based on their native range, these would have been Red Junglefowl. If the chicken was unable to diffuse from India to China, then early chickens in Europe with the BCD02 yellow skin allele (Girdland Flink et al. 2014), are more likely to have come from India, because of the limited native range of Grey Junglefowl, which is only found in southern India.

Given the potential for breeding origins in India and China, group 2 sites were modelled out of both countries. West and Zhou (1988) suggested a route north from China into Europe via Mongolia and Russia, and the LCP does predict this route as far as Eastern Europe. This path is costlier than that out of India, and the distance far greater, with no convincing evidence for chickens found along the route. It would be impossible to transport chickens such distances in a single journey. The period represents the peak of the Indus Valley Civilisation, who kept chickens (based on faunal evidence), and traded with Mesopotamia in the Middle East. Routes out of India, particularly those for which environmental suitability of Red Junglefowl is not included, closely follow Bronze Age trade routes (after Covington 2013). It is not impossible, therefore, that the chicken could have reached Turkey via these trade routes; although, again, positive evidence of chicken at sites along the route is unknown to date. Given the problematic dating of Korucutepe (a single bone), it is more likely that chickens did not leave Asia during this period.

Scarcity of remains outside of Asia suggests that the chicken was still dispersing from the east to the west from Asia at the start of the period represented by group 3 sites. Based on dates and increased networks, dispersal could be moving in any direction after about 1500 BCE. The fall of the Indus Valley Civilisation, possibly due to drought, resulted in population movement westward, (Carr 2014). A westward movement is supported by the LCPs, which predicts that movement from the Indus Valley (Balathal) to Mesopotamia (Iraq) is further but less costly (732 cells; 40.1 cost value) than to southern India (Paiyampalli; 641 cells; 45.0 cost value). People of the Harrapan Culture associated with this civilisation could have taken experience of chicken-keeping, and possibly the birds themselves, with them. The contemporary collapse of the Persian Gulf network affected transport networks, resulting in an east-west divide (Sherratt 2004). Therefore, it can be assumed that the chicken is likely to have been present in the Middle East during or before this time.

Expansion in trade networks in the Arabian Peninsula, the Levant and the Mediterranean during the second millennium BCE (Sherratt 2004; Cline 2007; Covington 2013) will have facilitated the dispersal of exotic species. These trade networks extended to Egypt, but chicken remains have not been found at any sites in North Africa early enough to be included in this analysis (Fothergill, T., pers. comm.), and routes overland in North Africa are not predicted by the LCPs. The easiest path from Asia to Spain starts from India and follows Bronze Age trade routes into the Middle- and Near East, before connecting with the Phoenician routes in the Mediterranean. Once in the Mediterranean, the path including environmental suitability for Red Junglefowl runs to the north, more commonly associated with Greek settlers (as argued by Peters et al. in prep), while the route with this factor excluded runs to the south, as per Phoenician trade routes (as proposed by Becker 2013). Linguistic evidence provides additional support for a route into the Mediterranean via the Middle-east, since the Ancient Greeks refer to the chicken as Persian Fowl (Aristophanes, *The Birds*, ca. 414 BCE). From Asia to Hungary the least costly route is again from India rather than from China. The India to Hungary route is mostly overland passing through the Middle East, Russia and Bulgaria along the route. It is easier to get to Eastern Europe than to Spain, implying trade as the primary purpose for the latter location.

While the chicken may genuinely be present in small quantities in Europe before 1000 BCE, the evidence is very scarce. This would suggest that, even if the dates are correct, then they are non-breeding populations and are perhaps trade or gift exchange. The Near East offers best potential source for the subsequent diffusion of the chicken throughout Europe. A good concentration of sites and links to trade networks in this region corresponds with least cost paths following known trade routes through the Mediterranean and up into Northern Europe. The LCPs also identify easy paths into Eastern Europe via Georgia and the Ukraine from the Middle East. The models excluding suitability for Red Junglefowl most closely follow the trade routes. Models including environmental suitability for Red Junglefowl are generally less costly than those for which it is excluded. This improves potential for the chicken surviving the journey to its destination. Such routes would offer good potential for settlers breeding domestic chickens. It is possible that the site located in Thailand in this group could be a result of trade from the Middle East, but dispersal from other sites in Thailand, present in the previous group, seems more likely.

4.6 Conclusions

The application of least cost path analysis enables the consideration of environmental aids and barriers to movement, facilitating or hindering the dispersal of the chicken into Europe. When combined with knowledge of past communication networks, determined through movement of other exotic products, it is possible to predict paths with best potential for transporting the chicken from Asia to Europe. Early diffusion from China into Europe had been proposed (West and Zhou 1988). The evidence from these results suggest otherwise. Paths from India are far less costly than those from China. Further evidence along the path from China to Eastern Europe would need to be found to suggest that this this route would be a viable option, prior to the establishment of the ‘Silk Road’ ca. 200 BCE.

Routes between India and China are also challenging. This means that early chickens in Europe with the BCD02 allele are unlikely to have come out of China. This is consistent with the lack of evidence for environmental suitability for Red and Grey Junglefowl in China that was identified in Chapter 3.

The direction of travel appears to follow an east to west orientation until the middle of the second millennium BCE, at which point chickens seem to be diffusing in multiple directions. The easiest path often appears to be along routes with better suitability for Red Junglefowl (and by extension early chickens), compared to alternative routes. The Middle- and Near East served as a trading network hub and is the logical centre of diffusion via multiple routes into Europe during the Early Iron Age. There is limited evidence for chickens in Europe before this time, and certainly insufficient to propagate the future European chicken population. From the Middle East and the Levant, the results of the LCPs, which are in accordance with known trading and settling movement of populations, suggest that the Mediterranean offered the best route into southern, western and northern Europe. The lack of evidence or routes through North Africa, despite known trading networks, may imply that environmental conditions were unsuitable to maintain the chicken, even with human assistance, that people chose not to keep them, or that the evidence has simply not been found.

The results are consistent with multiple dispersal events from different origin points across Eurasia at different times, with India as the starting point. The journey from Asia to Europe took approximately two millennia, based on current dating. It is unlikely to have been unidirectional but rather the dates of the sites suggest two-way exchange. Once the chicken made it to Europe, it quickly became established and spread.

Chapter 5: Where, when, how and why did the chicken become established in Europe?

5.1 Summary

Isolated occurrences of chicken in Iberia and Eastern Europe by possibly as early as ca. 1200 BCE (von den Driesch 1973; Gal 2011) supports the view that these were not breeding birds, but rather exotic trade items (von Schmitzberger 2012). In contrast, by the fall of the Roman Empire in 476 CE, the chicken is known from at least eight-hundred and twenty-four sites, from thirty different countries (Chapter 2). Literary and archaeological evidence confirms that the chicken had an important role in the culture and behaviours of the human societies with which it was associated, including ritual, entertainment, and diet. This chapter investigates how, when, where and why this change came about.

5.2 Introduction

The period from 1200 BCE to 500 CE saw huge changes in technology, culture and society. In broad terms, the date range includes the Bronze Age, Iron Age, Ancient Greek and Hellenistic civilisations, Roman Republic and Roman Empire (or Roman Iron Age in regions the Romans did not conquer). Each ‘age’ or ‘civilisation’ is comprised of numerous local and regional communities, connected by trade and communication networks, identified as similar based on date, technology or evidence of cultural behaviour. It is logical that people living during similar periods would have certain behaviours in common, based on available technology, but regional and cultural diversity can be found in the archaeological evidence, both in the faunal evidence and in material culture.

The chicken is an interesting animal to use to examine changes or continuity in the behaviours of past societies. Presence or absence may in part be a consequence of the climate and environment, but is not the sole factor in the decision to keep or not keep chickens. Other factors, such as economics, religion, culture and social behaviour also govern where, when and why the chicken is present. The faunal archaeological record can be used to determine presence, habitat, husbandry, and change of use. While the chicken may occur in low frequency on some sites, especially compared to the bigger domestic animals, it has been argued that large presence in the archaeological record suggests an animal may have been consumed on a regular basis, and therefore may have had less social significance. Animals which are held in high social esteem may occur in lower frequency in the faunal record due to cultural use, but their importance is reflected in art and literature (Sykes 2015, 9). This does appear to be true for the chicken, particularly in the early periods. Chicken is infrequently portrayed in mundane settings, and is not usually depicted with other species with which it would be assumed to be associated, such as other domestic animals, foxes or rodents. Instead, it is associated with exotic species, or depicted on its own (Pitt and Feider 2016). Artefact depiction primarily focuses on the chicken as an exotic or fighting bird or with a connection to the gods (Feider 2017).

Depictions of chickens or mention of them in ancient texts can be used to chart knowledge of this species. One of the earliest documentation of chickens can be found in Sanskrit literature, the *Atharvaveda* and the *Yajurveda*, both dated to ca. 1500 BCE, and associated with Hinduism. They praise the chicken for his courage, his pride and his ability to tell time (Zeuner 1963). If, as suspected, the chicken entered Europe via the Middle East then the Persian Zoroastrian belief that the chicken banished the sloth demon and called men to prayer with its crowing (Lawler 2014, 46) may have influenced how it was perceived further west. The Vedas and association with the Zoroaster religion illustrate knowledge of chickens in India and Iran respectively. The chicken was also known in Ancient Egypt from at least ca. 1500 BCE, as it features on the walls of the tombs of Rekhmara and Tutankhamun at Thebes (Crawford 1990). It appears that the Greeks were unfamiliar with the species until the seventh century BCE, given that chickens are not mentioned in either Homer or Hesiod (Hehn and Mallory 1976, 243; Serjeantson 2009, 270). Infrequent presence in Europe at the beginning of the first millennium BCE is accompanied by infrequent early depiction or written reference in this region. After this date the chicken becomes more prevalent on artefacts, and is discussed, sometimes at length, in ancient texts.

While the Roman texts offer practical advice and anecdotal evidence (Cato (*De agri cultura*, 2nd century BCE); Varro (*De Re Rustica, III:3*, 36 BCE); Cicero (*De Divinatione, II:35*, 44 BCE)), many of the written sources from the Classical period and Antiquity are still related to religion. The cock is linked to Asklepios, the god of Healing, to whom the chicken was sacrificed for a painless death (Hehn and Mallory 1976, 245, referencing Plato's Phaedo written in 360 BCE). According to Plutarch (45 - 120 CE), animals were sacrificed to Spartan gods at the end of a battle. The type of animal depended on how the battle was won- a bullock for a win by craft and persuasion, or a cock for those who attained an end by fighting (Lawler 2014).

Association with gods and ritual can be traced throughout the early history of the chicken. In addition to those mentioned above, chickens are also linked to the Greek solar god, Apollo, and goddesses, Leto and Asteria (Lawler 2014). The Zoroaster religion has been linked to the Roman cult of Mithras, with which the chicken is also associated (Serjeantson 2009, 351). The most common association with a Roman god is with Mercury (Crummy 2007). There are many artefacts which depict this god with a chicken, often with Mercury's other favourite animals, the turtle or tortoise and sheep or goat (Feider 2017). Among other things, Mercury is the god of trade and wealth. This may explain the frequency with which chickens are found on coins and signet rings (Feider 2017). As a signet ring is used to produce a symbol to represent the owner, this indicates a very personal, positive, relationship. In the Roman period, chickens were also used for divination, usually prior to battle to foretell the outcome. This took the form of a 'tripudium' (the falling of food to the ground from the beak taken as a favourable sign). Cicero (De Divinatione, II:35, 44 BCE) notes that "Any bird may make a tripudium", but discusses this practice only with examples of chicken, and questions the validity of using caged birds for this purpose. This is interesting as it provides evidence of chickens being kept in this manner.

Ritual association is not just found in depiction and texts. The faunal evidence also reflects this use of chicken. Chicken remains found in Italian tombs have been radiocarbon-dated to the sixth century BCE (Best et al. in prep). Several interesting ritual burials are also known from the late part of the first millennium BCE (Alfonso 2007; Blaizot et al. 2014), along with ritual deposits found at shrines or sanctuaries (Woodward and Leach 1993; Brun et al. 2015). This persists into the Roman period, when chicken are the second-most frequently occurring species found in human graves (Lauwerier 1993) and continue to be found in ritual deposits at religious sites (Lauwerier 1988; Grimm 2010).

Portrayal and sacrifice of chicken tends to be primarily focused on male rather than female birds. There has been some suggestion that ritual burial may be gender specific, with men buried with cocks and women with hens (Sykes 2015, 84), but this may not be universal (Lauwerier 1993). This raises questions of gender association and symbolism, the cockerel associated with fighting, dominance and sexual prowess. One of the earliest and recurring themes of depiction is cockfighting (Feider 2017). This emphasises its importance as a use for chicken (Sykes 2012). The Romans are assumed to have inherited the practice of cock-fighting from the Ancient Greeks (Sykes 2015, 85), although the chicken is depicted on seals and pottery in this manner in seventh century BCE Israel and Palestine (MacDonald and Blench 2000). Caesar’s suggestion that the Iron Age people “breed them for amusement and pleasure” (*Gallic War, V, 12*) could also refer to this activity. Jennison (1937) writes that Columella discusses the benefits of importing ‘foreign’ breeds for cockfighting (Tanagrian, Rhodic, Chalkidic and Median), recognising differences in the size and stature of the birds, compared to ‘native’ Italian ones. Columella dismisses the use of bantams for anything other than pleasure (Jennison 1937), suggesting that bantams may also have been used for fighting.

Thus, the chicken does not appear to be used or perceived in the same way as most other domestic livestock (i.e. primarily a food source). In some belief systems, such as the Zoroaster religion, which incidentally coincides well with the early spread of chicken and with which there is known association, eating of chicken was forbidden (Lawler 2014). Caesar suggests that the Iron Age people of Britain regarded it as unlawful to consume chickens, hare or goose (*Gallic War, V, 12*), and this has been interpreted to reflect the consumption of exotic or wild foods only as part of ritual feasting and sacrifice, given the types of deposits in which they are usually found (Allen and Sykes 2011, 14). The ancient Greeks may have not eaten much chicken either. While present in the faunal record there, a compilation of Ancient Greek recipes (Salza Prina Ricotti 2007) features chicken in only a single recipe (of fifty-six, and even then, only ‘chicken brains’). It seems unlikely that they would waste the rest of the bird, so either this is an exotic delicacy or perhaps the other parts cannot be eaten for religious or lawful reasons?

As an imported species, it is not as prevalent as most livestock. As an exotic species, it makes an excellent offering to the gods. As a recently introduced domesticate, those keeping and breeding them would need to spend time observing and understanding this bird, to learn how to aid survival and how to keep them contained. As a chicken keeper, I can confirm that this is as true today as it would have been in the past. For the most part, this knowledge is and would have been passed via word of mouth; although by the Roman period, there is detailed guidance in the literature for those who could read (approximately 10% of the population in Rome (Watson 2006), although presumably far lower elsewhere). Most of the advice goes well beyond what is required today. Cato and Varro both provide recommendations for breeding young chicks, while Varro also discusses the environment in which these birds are being raised. Predominantly bred on farmsteads, an anecdote also discusses the raising of chickens within a villa, although in this instance their purpose was for divination (*De Re Rustica, III:3*, 36 BCE).

For a bird whose past is so entwined with human society, how the chicken is perceived, and what it is used for will affect where, when and why it is found in the archaeological record. Most literature about chickens discuss dispersal in terms of earliest evidence, but there is less focus on its subsequent diffusion. Analysing the faunal remains in social context can inform us about this diffusion, by identifying association with the specific cultures with which it spread. Understanding changes and continuity in terms of how the chicken is used within these societies, provides a better understanding of human-chicken interactions in the past, and how these contributed to the success of chicken. Where chickens are found in particularly unsuitable climates, the social environment, rather than natural environment, may better explain that decision.

This chapter uses spatial analysis of sites containing chicken bones to determine where and when chicken was present in Europe. The data is analysed in relation to the movement of people, and connections with known cultures. The extent of dispersal is considered in light of known ecological conditions and human use of chicken. Site evidence is used to investigate change or continuity of use and perception over time, as reflected by the contexts in which chicken is found in different periods, to better understand the behaviour that established the chicken as an integral part of European society.

5.3 Materials and Methods:

The chronology of Europe in this period is challenging. Different ‘ages’ or ‘civilisations’ begin and end at different times in different parts of Europe. Where the analysis is not by century, for clarity, discussion of analyses follows the divisions outlined in Chapter 2, whereby ‘period 1’ corresponds with dates to ca. 800 BCE, ‘period 2’ with a date range of ca. 800 BCE to 0 BCE and ‘period 3’ to a date range of ca. 0 to 500 CE. To put the period groups into context, for most of Europe, 800 - 500 BCE usually represents the earlier Iron Age, and 500 - 100 BCE, the later Iron Age. The period from 100 BCE to 100 CE can be considered a transitional phase from Late Iron Age to

Roman. The Roman conquest began earlier in the Mediterranean region than in northern Europe and did not extend as far as most of north or north-eastern Europe; however, from the start of the first millennium, Roman influence cannot have failed but to play an important part in European culture and trade. Most archaeological contexts are dated by associated finds, often pottery or artefacts which can only be dated to relatively broad date ranges. The latest date of the phase (date to) provides a *terminus ante quem* for the presence of chicken at a site during that phase, and is used here.

Information, including geographic location, date, site type, site function, associated culture, species type, species quantity, species habitat, audit detail and georeferencing accuracy was extracted from the database by site phase. Sites with ‘over-riding issues’, such as noted intrusion, were excluded. Precise information variables and quality of data selected for use for specific analyses are detailed alongside the results for each (see Chapter 2 for criteria and description of all of these components).

An additional set of basic information was gathered from contacts (Best, J., Fothergill, T., Maltby, M., Perry-Gal, L., Peters, J.; pers. comm.) for countries with no chicken present prior to 500 CE (the cut-off date for the database) to understand when chicken reached these areas. This was only used to determine the maximum spatial extent. All other analyses use only information from the database developed as part of this project.

Local environment was established using database evidence of species habitat by number of identified specimens (NISP). NISP information was preferred as quantity of bone is a better indicator of dominant habitat than presence only. Chicken NISP was excluded to avoid the inherent bias towards this species in the database. The habitat categories ‘urban’, ‘agricultural’, ‘forests and semi-natural areas’, ‘sparsely vegetated areas’, ‘wetlands’ and ‘water bodies’, correspond with those used by the EAA Corine land cover report (European Environment Agency 1995). K-means cluster analysis was performed using “R Commander” (Fox and Bouchet-Valat 2005) in R (R Studio, Version 0.98.1091) to group site phases which contain similar combinations of habitat as represented by the individual species present in the faunal assemblages. A within groups sum of squares analysis identified an optimal number of four to six groups. Six groups offered the clearest definition of data for analyses.

Spatial analyses were performed by importing the data into ArcGIS (v.10.2.2). Distance to major rivers (naturalearth.org.uk) and known communication routes (Hallstatt, Greek: Cunliffe 2008; Roman Roads: McCormick et al. 2013; Phoenician: Khalaf 2016) were calculated using the standard ‘distance’ tool. Height above sea level was extracted from a 250m resolution digital elevation model (DEM) (CGIAR Consortium for Spatial Information 2008). Accuracy was checked against sites where this information was given in the site report. Over 60% (62.33%) are within 10m, over 75% (75.81%) within 20m and over 93% (93.02%) within 50m accuracy. Given a range of 3-1800m above sea level for reported sites, and extracted values of -3 to 1762m above sea level derived from the DEM, this was deemed acceptable as a means of supplementing missing information. Correlation between distance to rivers, Iron Age trade routes, Roman Roads and height above sea level were calculated using Pearson's product moment correlation coefficient, Kendall's *tau* and Spearman's *rho* in R (core package stats version 3.1.2).

5.4 Results

Frequency of chicken by date was analysed to establish whether chicken presence in Europe resulted from single or multiple dispersals. For this purpose, sites with very broad date ranges, for example a site dated as broadly as 'Bronze Age to Roman' or '800 BCE – 500 CE'), were excluded as they would skew the data to the end of the period. The result based on all of the sites suggests two distinct dispersals (Figure 25), based on peaks in frequency at 500 – 400 BCE and 100 BCE to 0 CE. When this is analysed further (Figure 26) it becomes clear that the first increase is dominated by the Hallstatt culture and the second increase is dominated by the La Tène culture.

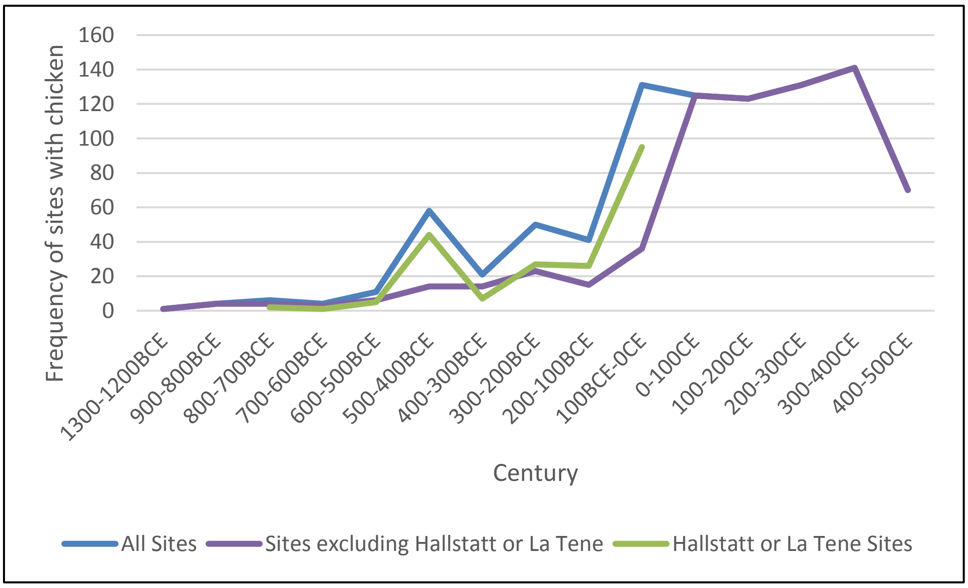


Figure 25. Frequency of sites with chicken by century.

These are both Iron Age cultures found consecutively in central Europe. A dip in popularity is observed after the transition from Hallstatt to La Tène in this region of Europe, with a renewed interest in the species in the final La Tène period, from ca. 100 BCE. Outside of these specific cultures a different pattern is observed (Figure 25). There is a steady increase in frequency of chicken sites from approximately 600 - 200 BCE. A slight reduction in frequency occurs between 200-100 BCE and begins to increase from 100 BCE - 0 CE, with the largest gain in frequency, suggesting a third dispersal, occurring between 0 - 100 CE.

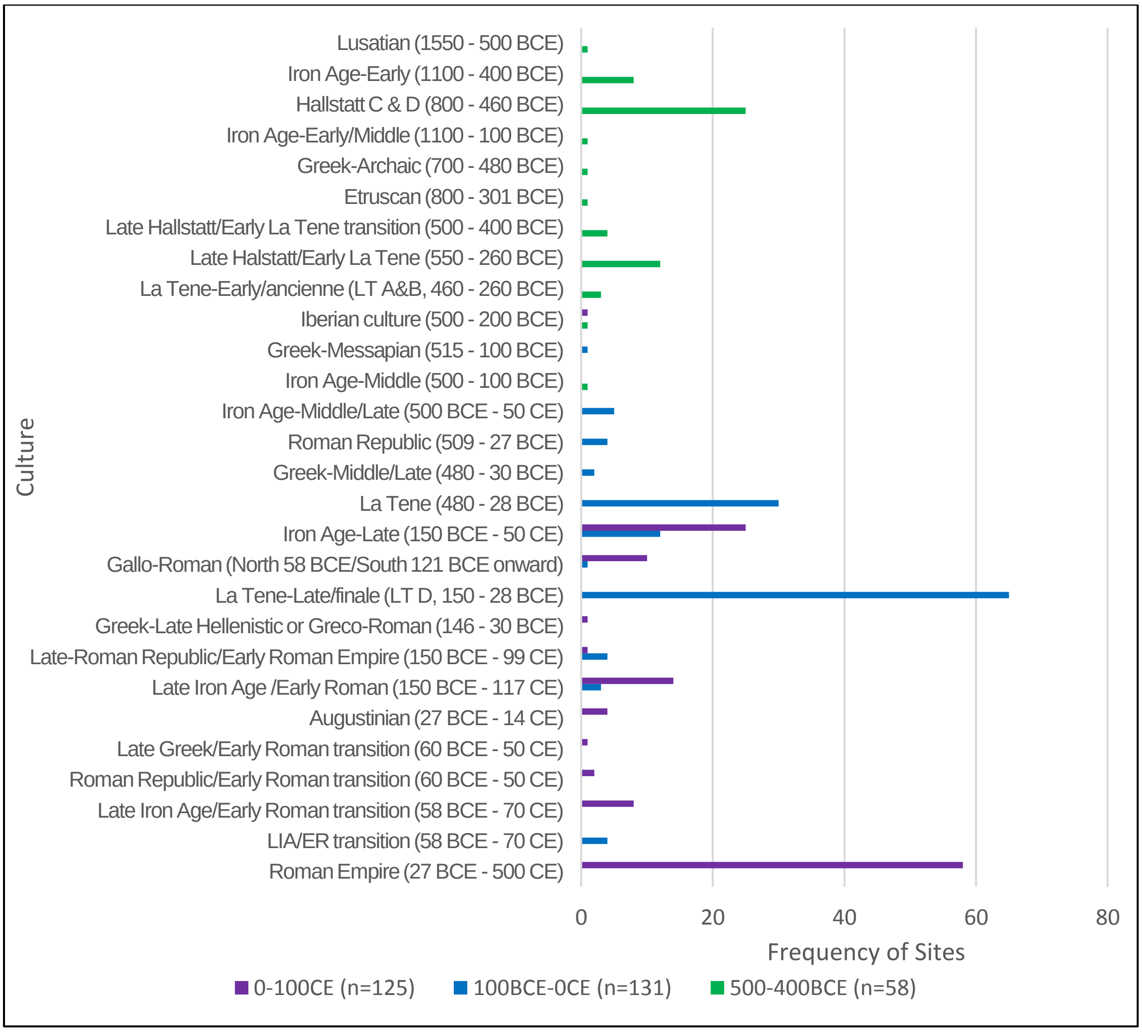


Figure 26. Frequency of sites with chicken by culture.

Analysis of the cultural composition of the database (Figure 27), using the same dataset, confirms the predominance of Hallstatt and La Tène culture sites in period 2. The Roman Empire dominates period 3. This analysis also shows the variety of distinct cultures present in period 2, compared to period 3.

Spatial analyses were performed to investigate the geographic extent of chicken distribution over time (Figure 28). For clarity of display, the earliest sites within a 1 degree grid square were used. For this purpose, the dataset comprising the database entries and additional sites outside of the geographic or temporal range of the database was used to provide the complete extent of the chicken’s range. Only sites with audit scores of reasonable or above were used, to increase confidence that these sites represent the appropriate date, and have been correctly identified as chicken.

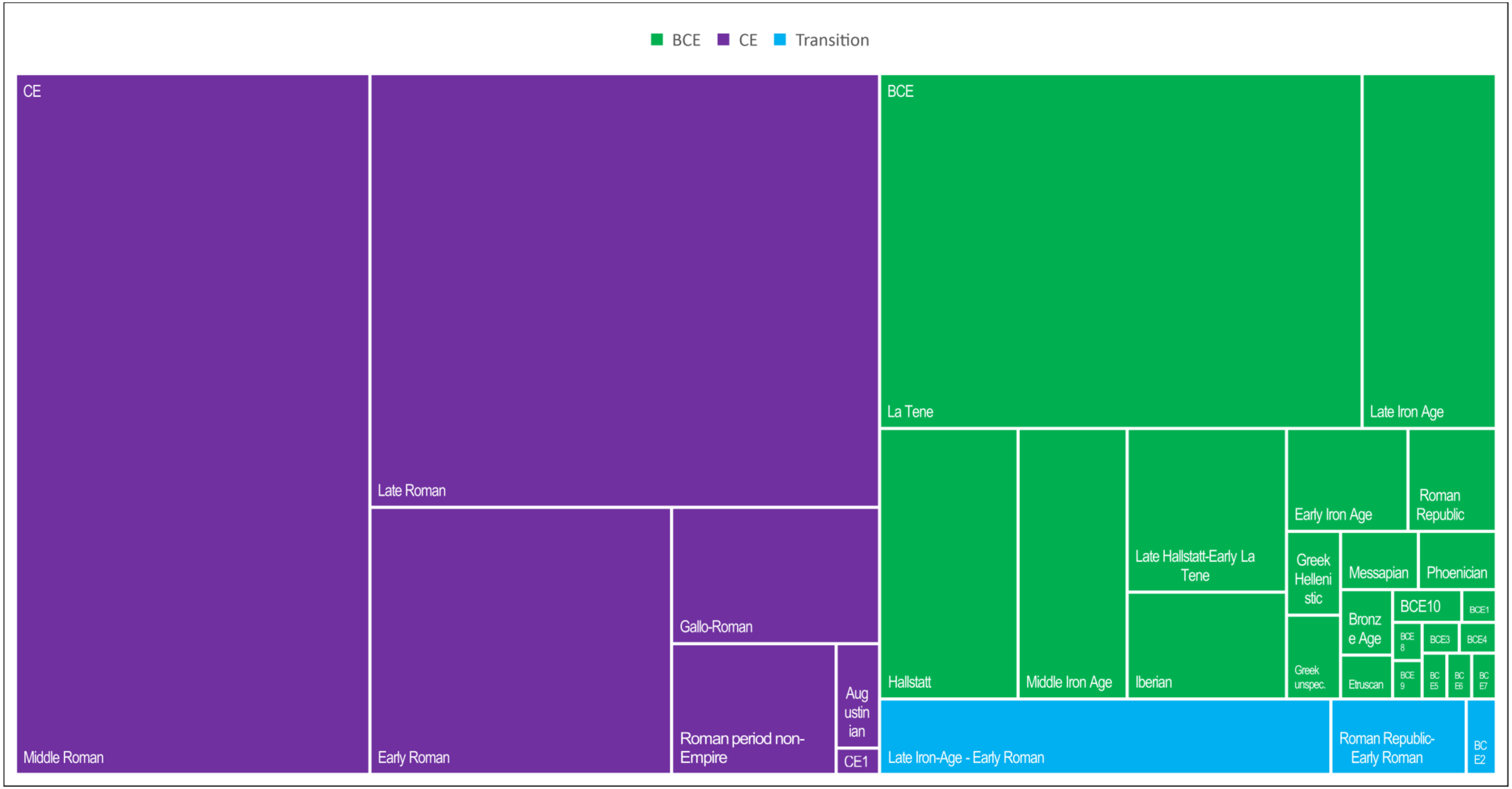


Figure 27. Composition of database sites by culture. Box size represents frequency of sites within that culture. Purple boxes are period 3 sites and green boxes are sites in period 2. Blue boxes represent transitional sites between periods 2 and 3. (CE1: Przeworsk; BCE1: Kyjatice; BCE2: Late Bronze-Early Iron Age unspec.; BCE3: Latial; BCE4: Urartian; BCE5: Neo-Assyrian; BCE6: Lusatian; BCE7: Scythian; BCE8: Greek Geometric; BCE9: Greek Classical; BCE10: Late Hellenistic or Greco-Roman).

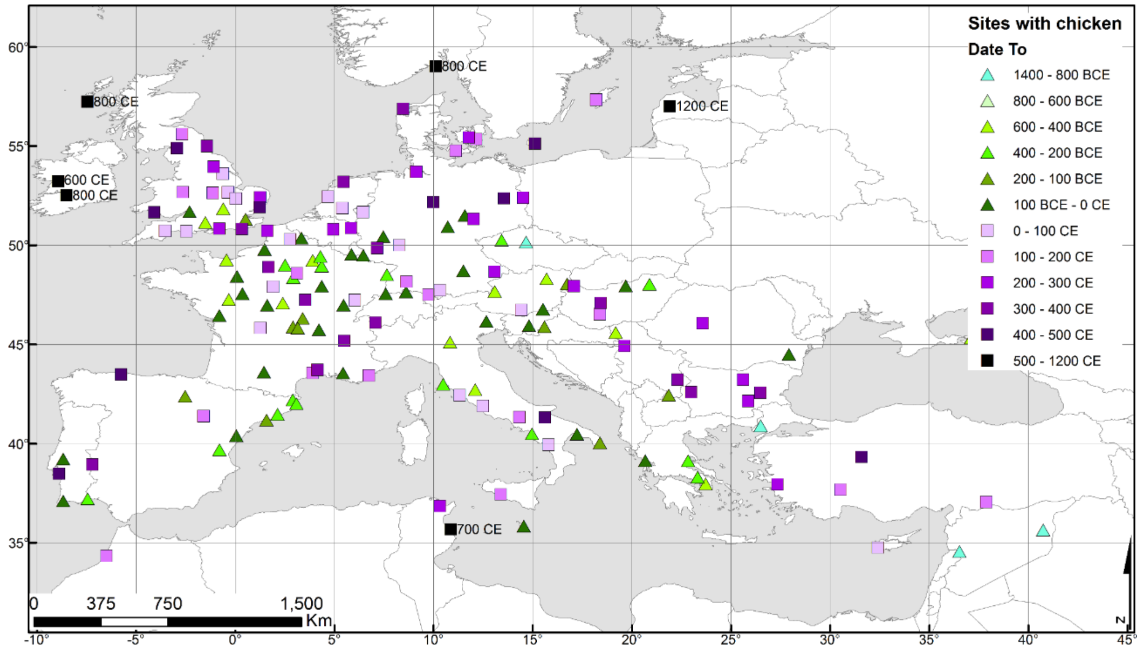


Figure 28. Spatial distribution of sites with chicken by century.

The earliest sites represent those assumed to be a consequence of trade, rather than breeding stock, based on previous analyses (see Chapter 4). The chicken reached its maximum period 2 latitude of approximately 52 degrees north by 400 BCE, about the time of the Hallstatt association; with the later period 2 dispersal reaching a similar extent. This dispersal in ca. 100 BCE does, however, extend the range further west into Portugal than the initial dispersal. The period 3 extent reaches increasingly higher latitudes, to a maximum of approximately 57 degrees north by the late second century. Based on available evidence, chicken does not appear to be present at sites at the extremes of Europe; for example, Ireland, the Scottish islands and highlands and Norway until the Medieval period. A distinct south-east to north-west pattern of dispersal over time is not noted, supporting the theory that multiple dispersals occurred at different times.

Analyses exploring how the chicken may have spread throughout Europe, identified correlations between chicken presence and distance to Iron Age trade routes, distance to Roman Roads, and distance to rivers. This was tested using correlation coefficients (Table 12). The dataset included frequencies of sites with and without chickens, for relevant temporal and spatial extents (all for rivers; sites dated to period 2 for the Iron Age trade routes; sites within the extent of the Roman Empire for the Roman roads), with georeferenced and audit scores of adequate or above. The tests identify a negative correlation between distance and frequency of sites with chickens in all cases, suggesting that greater distance from these known pathways reduces the potential for presence of chicken. Elevation was also considered, and while chicken presence has a positive correlation with height above sea level for sites in period 2, the null hypothesis of no relationship cannot be rejected for Roman Empire sites. For period 2 this is likely to reflect the presence of chicken on hillforts.

Test	**Pearson**		**Spearman**		**Kendall**	
	correlation coefficient	p-value	rho value	p-value	tau value	p-value
Distance to rivers	-0.144	<0.001	-0.130	<0.001	-0.106	<0.001
Distance to Iron Age trade routes	-0.283	<0.001	-0.205	<0.001	-0.167	<0.001
Distance to Roman roads	-0.154	<0.001	-0.167	<0.001	-0.137	<0.001
Height above sea level (all)	0.078	0.031	0.107	0.003	0.087	0.003
Height above sea level (period 2)	0.193	0.001	0.261	<0.001	0.214	<0.001
Height above sea level (Roman Empire)	0.064	0.091	0.081	0.032	0.067	0.032

Table 12. Correlation values for proximity to known features and elevation.

The geographic location of a site determines the local ecology. This was analysed to determine whether the local environment where chicken is found, or where it is not found, changes over time (Figure 29). Species habitat preference was used as a proxy for local environmental conditions. This is based on species NISP and so sites lacking NISP information were excluded. Due to low frequency of sites dated to period 1, these were combined with period 2 to represent the habitat of the period before the chicken becomes permanently established. The analyses identify the spread of urban settlement at the expense of rural habitats. At the same time, an increase in chicken is found on urban sites, suggesting a strong association. Except for urban areas, period 3 sees the chicken present in most environments in almost equal quantity. This contrasts with the earlier period when a clearer distinction is observed between environments where chicken is present or absent. Period 1/2 chickens are rarely found in wetlands or near water bodies, and are far more likely to be present in agricultural settings, compared to those dominated by semi-natural environments.

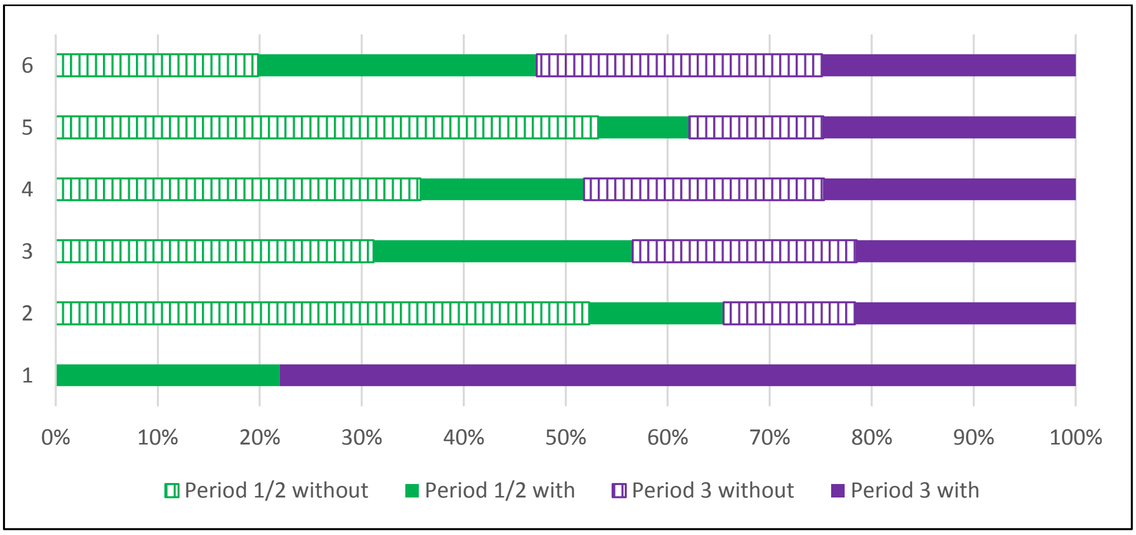


Figure 29. Comparison of local environment based on species habitat by date and presence or absence of chicken. Key: 1= urban; 2= wetlands and water bodies; 3= agricultural with some semi-natural areas; 4= forest and semi natural areas; 5= mixed environment (of which 49% is agricultural); 6= agricultural.

Chicken does not only appear on a greater number of sites as time progresses, the number of chickens found on these sites also increases and chicken becomes a greater percentage of the total faunal assemblage. Analysis of the faunal evidence used sites with five or more chicken bones, as this reduces risk of presence by intrusion, divided into period 2 and period 3 sites. Only sites with an audit score of reasonable or above were used as this has been shown to produce the clearest results for interpretation (Pitt and Stewart in press). The results show a large increase in the numbers of identified bones present on sites in period 3 compared to period 2 sites (Figure 30). In period 2, chicken accounts for just over two percent of the faunal total. By period 3, this has risen to nearly seven per cent (Figure 31).

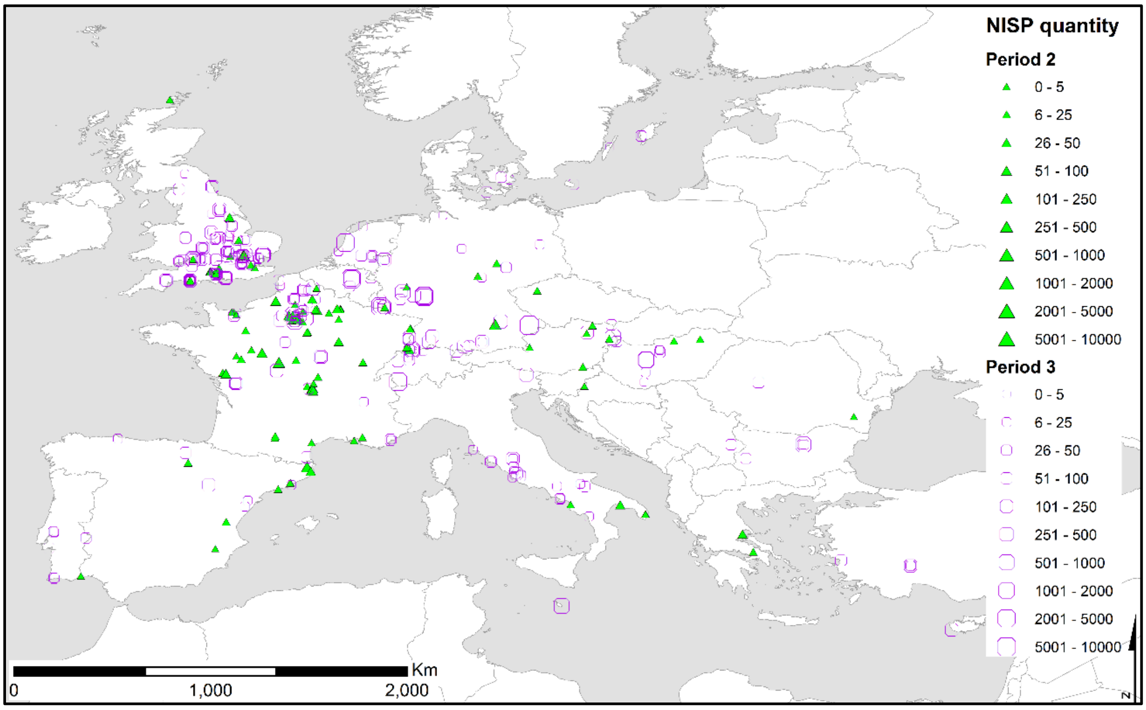


Figure 30. Bone frequency on sites with chicken.

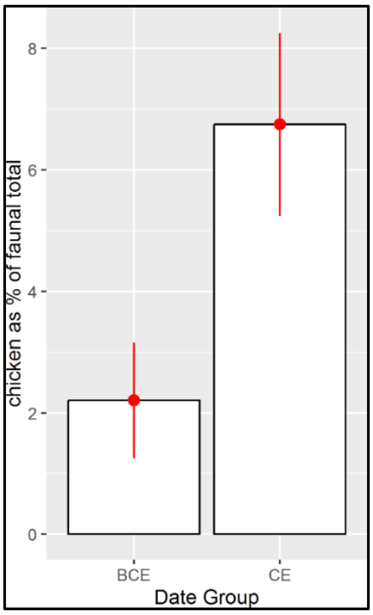


Figure 31. Frequency of chicken as a percentage of the faunal total by date group. Point range is in red.

Site type was explored to understand the context for this increase (Figure 32 and Table 13). As might be assumed from the analysis of the local environment, urban settlements are the single most common site type to contain chicken. In addition to the urban settlement category, many enclosed settlements can also be considered urban, but with a defensive purpose. Enclosed settlements are mostly Iron Age hillforts, with those found in later centuries, Roman forts. These settlements have large populations, but not usually on the same scale as a town. Combining the figures for these site types still results in a greater presence of chicken, compared to absence.

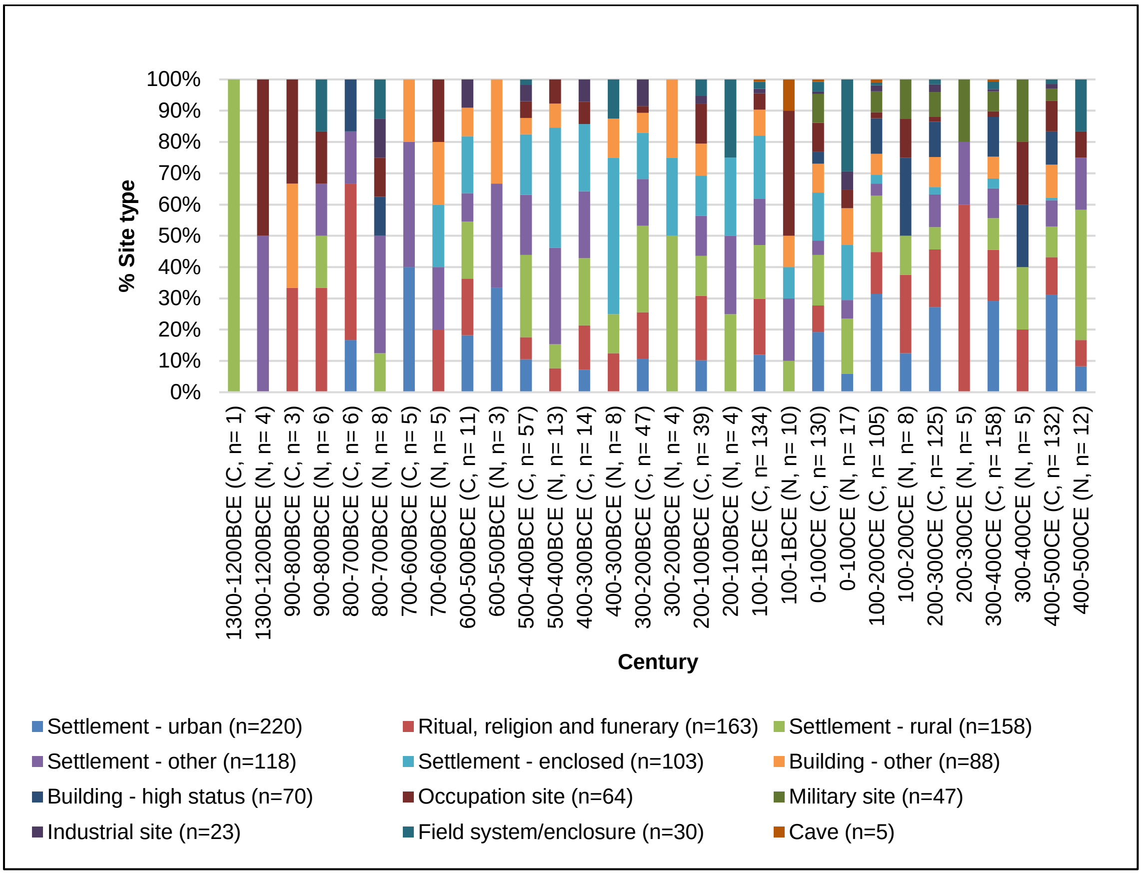


Figure 32. Comparison of site types with chicken ('C') or without chicken ('N') by century.

Chicken present	Building - high status	Building - other	Cave	Enclosure	Field system	Industrial site	Military site	Occupation site	Other - see comments	Ritual, religion and funerary	Settlement - enclosed	Settlement - other	Settlement - rural	Settlement - urban
Chickens	7	2	-10	-35	-20	-13	6	-24	-6	3	-6	-8	-1	10
No Chickens	-55	-15	88	292	168	109	-52	198	48	-28	50	66	7	-84

Table 13. Percentage difference by site type compared to expected for sample size of sites with and without chickens / frequency of site type.

Sites without chickens tend to be more frequently found in rural areas, but the main difference is observed in frequency within field systems or enclosures. Occupation sites are more likely to be rural, given a lack of feature density to interpret the site as a permanent settlement, and also feature a higher proportion of non-chicken sites. Rural settlements and 'other' buildings (often farmsteads or isolated dwellings) exhibit comparable percentages for sites with and without chickens. In contrast, high-status buildings feature chickens more frequently. In fact, this is true for all site types which include high status features (Table 14). Ritual, religious or funerary sites represent the second-most important site type for chickens, and are the third-most common site type where chickens are not found. No ritual, religion and funerary sites are found without chicken between 300 BCE and 100 CE.

	High Status (%)
Chickens	6
No chickens	-50

Table 14. Percentage difference of high status sites compared to expected for sample size/frequency of high status sites.

Comparison of the functions of the site on which chicken is found, or not found, highlights further contrasts. This differs from site type in that it includes all activities present at a site, rather than just the function that defines it. For example, a villa is a high-status building that has a primary function of domestic, but it may contain evidence for corn drying and agricultural out-buildings, and so industry and agriculture can be considered secondary functions of the site. The primary function for the majority of sites throughout the study period is domestic (Figure 33 and Table 15).

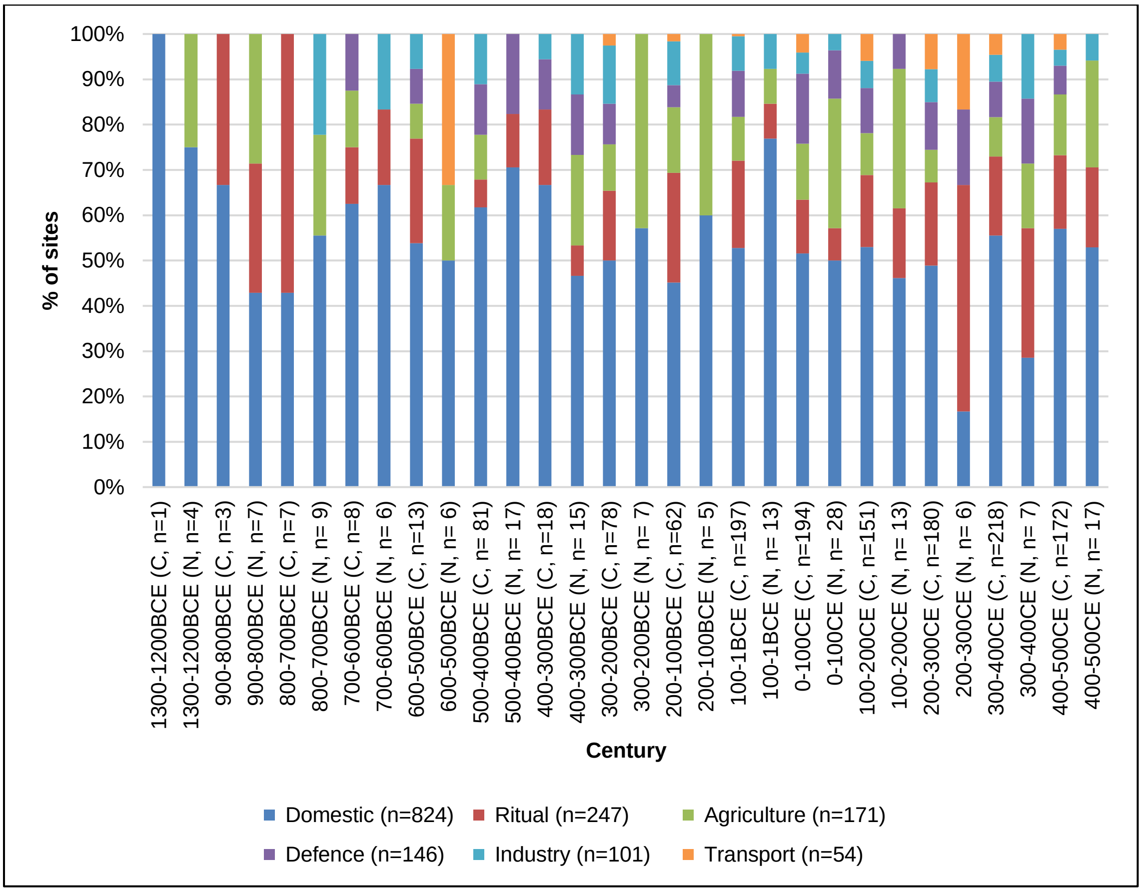


Figure 33. Comparison of site function with chicken ('C') or without chicken ('N') by century.

	Domestic	Ritual	Agriculture	Defense	Industry	Transport
Chickens	0	3	-9	3	2	5
No chickens	1	-26	80	-27	-14	-46

Table 15. Percentage difference by site function compared to expected for sample size of sites with and without chickens /frequency of site with particular function.

This is the same whether chickens are present or not. For sites containing chicken, ritual is the second-most numerous function. Ritual sites are found in all but the earliest phase of sites with chicken, but feature more prevalently in 900 - 700 BCE sites as a percentage of the sites in those centuries. Ritual is also an important function for sites without chickens, particularly in 900 - 800 BCE and 200 - 400 CE. However, even allowing for secondary functions, for example individual burials, there remains the hiatus between 300 - 100 BCE of ritual sites without chickens, which was also observed in the site type analysis.

Ritual sites without chickens are far fewer than agricultural sites. Agriculture represents the greatest difference between the two groups, accounting for 20% of the total sites without chicken, compared to 10% of sites with chickens. Association of chicken with defensive and industrial sites is constant, if only in low frequency; and is more sporadic for sites without. The highest frequency of chicken sites with a defensive function occurs in the first century CE. The average distance of a Roman Empire site containing chicken to a Roman road is only 5.83km. However, while it can be seen to increase in 200 - 300 CE, transport is rarely a notable function of a site.

5.5 Discussion

Rapid increases in the frequency of sites containing chicken in different centuries suggests peaks of popularity for the species. These peaks correspond with particular cultures, with whom they will have dispersed throughout the continent. The first major dispersal appears to have occurred in the Early Iron Age, primarily driven by populations connected with the Hallstatt C and D cultures. These cultures had an extensive network of trade routes throughout central and eastern Europe, which meet up with the trade networks of the Phoenicians in western Europe (from whom they may well have first encountered the chicken) and with Greek settler and trade routes in the south east (Figure 34). By this date, the chicken was possibly carried as far north as 54 degrees latitude (Tolkmicko (Fst. 1), Poland, audit score: adequate). The chicken continued to spread after this time, and is certainly present at 51 degrees north at Houghton Down in the United Kingdom by 390-206 cal. BCE (a specimen with a calibrated radiocarbon date on a chicken bone (Best et al. in prep).

Following a slight reduction in the frequency of sites with chickens between 400 and 100 BCE, a new wave of chickens appears to have spread in association with the La Tène D culture in the first century BCE. A third spike in frequency, unrelated to these central European cultures, occurs in the first century CE. It is unlikely to be a coincidence that this corresponds with the early spread of the Roman Empire. The third wave of chicken dispersal extends to greater latitudes, well beyond the extent of the Roman Empire, possibly reaching the Scottish Highlands at nearly 56 degrees north (Trimontium, Newstead, audit score: adequate) by 150 CE, and Sweden (Syrmannsberg, Fröjel, audit score: reasonable) at over 57 degrees north by 199 CE.

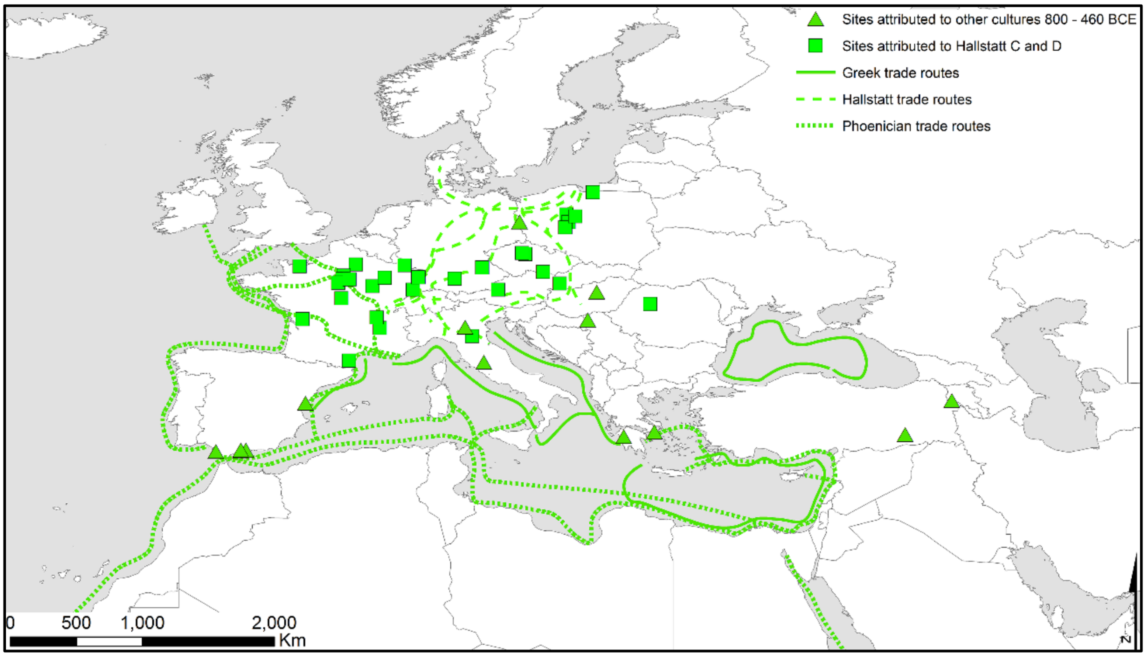


Figure 34. Initial dispersal with relevant Iron Age trade routes (after Bolmarcich 2007; Cunliffe 2008; Becker 2013).

Why chickens are now able to survive further north than was previously the case, despite evidence of occupation at more northerly latitudes prior to this date, is unclear and would make for interesting further study. A combination of the following factors may be accountable:

1. A slight change in climate enabled agricultural activity further north
2. Technology improved farming methods, enabling agricultural activity further north
3. Technology improved provision of chicken shelter, feed and protection
4. Knowledge of chicken-keeping improved compared to the Iron Age, enhancing survival
5. Market demand made it economically viable to keep chickens at latitudes where daylight hours inhibited breeding and egg-laying
6. Society and culture influenced a desire to breed this species despite difficult conditions
7. A hardier breed developed by natural selection that was better able to cope with such climates
8. A hardier breed was created by artificial selection that was better able to cope with such climates

There is support for all these suggestions:

1. Past climate simulations based on tree-ring chronologies have identified an episode of warming in the Roman period in northern Europe (Esper et al. 2014). A link has been made between wet and warm summers and periods of prosperity in history (Büntgen 2011).

2-3. The Romans took new technologies with them as they advanced across Europe. One of the major advances featured new means of water transportation and drainage, factors critical for agriculture (Greene 1990).

4. Books appear (in Rome) in the Roman period offering guidance on chicken-keeping.

5. The Vindolanda tablets demonstrate that there is consumer demand as far north as Hadrian's wall in the United Kingdom by ca. 100 CE.

6. Use in divination and association with the Roman Gods Mercury and Mithras makes the chicken part of the culture. Offerings of preferred animals was thought to increase the chance of favour, and so there would have been an impetus to breed them.

7. Pure breed chickens live on average approximately ten years (Verhoeff and Rijs 2009), which allows for many generations between first domestication and the early first millennium CE to evolve traits to aid survival in environments different to where the species originates. Ecological niche modelling showed the bird to be quite adaptable to conditions outside of the native range (Chapter 3).

8. There have also been many generations to artificially select for birds which exhibit preferable traits. That different breeds were available and should be carefully selected was noted by Varro (*De Re Rustica*, 36 BCE) and Columella (*De Re Rustica*, 1st century CE). By the fourth century, people in Pannonia had developed their own form of animal husbandry suitable for the local environment by crossing with southern or Italian breeds (Bökönyi 1984, 18-19).

How chickens got further north is easier to establish. Correlation between presence of chicken, Iron Age trade routes, rivers and Roman roads, all adds support to transport by humans via these means. Given the timing of the dispersals, spread due to trade appears most plausible for the dispersals associated with the Hallstatt and La Tène cultures. The final dispersal coincides with a substantial movement of people as the Roman military spread through much of Europe. An increase during this period is also noted in the frequency of military sites containing chicken.

That this represents a separate dispersal, associated with a separate culture, to the previous distribution is also suggested by the change in environments in which the chicken occurs between periods 1/2 and 3. There is a clear move from more rural environments to more urban, and the chicken appears to now be found in greater frequency in environments which were previously lacking chicken, particularly wetlands and water bodies and a mixed environment. The sudden increase in wetlands and water bodies may reflect a more varied Roman diet, compared to period 2 populations, rather than habitat shift. Wetland species may have been brought into other habitats as food. Apicius' recipe book features many different species, including ostrich, crane, duck, partridge, turtle dove, wood pigeon, squab, woodcock, turtle dove, and flamingo (*De Re Coquinaria*, (385 CE)). Alternatively, Roman advances in technology and water drainage could have enabled settlement in previously uninhabitable environments, such as closer proximity to water bodies. Although the chicken was found more frequently in urban habitats compared to rural habitats in the CE era, compared to BCE, this does not necessarily mean that this is where they are being bred. Based on literature, it seems more likely that chicken is mainly found in towns because of trade, having been imported from more rural areas. This fits with the observation that wild birds were brought into urban centres (Parker 1988).

There is certainly an increase over time in the number of sites on which chicken occur and in the numbers of chicken bones found on these sites. Far from being merely a tamed example of an exotic bird, the chicken was being bred for purpose already by period 2 and more intensively so in period 3. Even so, it is still not present in very large numbers compared to other domestic mammal species, with the exception of certain temple sites, such as Uley (UK, Woodward and Leach 1993), Tienen (Belgium, Lentacker et al. 2004) and Mogontiacum (Germany, Hochmuth et al. 2005) where chicken is found in huge numbers, especially compared to other species. At Mogontiacum in Mainz, for instance, a minimum of seven hundred and six individual chickens were identified from three phases dating from 0 - 299 CE (Hochmuth et al. 2005). There were also thirty-four finches, nine rock doves, five yellowhammer sparrows, two unspecified sparrows, one starling, one skylark, four greylag geese, and a common quail. Domestic mammals were limited to three sheep/goat, two pigs and two cattle.

As an exotic species, the chicken appears to have enjoyed a different status to most other livestock. This is evident in the way it is depicted in material culture and discussed in the literature. Although a form of domestic livestock, its role within the domestic sphere is much more closely associated with humans than most domestic mammals. Its purpose seems most likely to have initially been primarily for ritual use and cock-fighting. The type and function of sites where chicken bones are found and the frequency of bones found prior to period 3 supports this theory. Its considerable presence on ritual, religious and funerary sites, second only to sites with a domestic function, emphasises the important role of this species in society, and the importance of the chicken as an offering to the gods. That there are no ritual, religious or funerary sites without chicken recorded in the database between 300 BCE and 100 CE may imply the dominance of the chicken for this purpose in these centuries. It is difficult to establish where in Europe taboos on eating the birds may have been in place, due to a lack of written record, although it is certainly plausible. If the primary function is breeding birds for sacrifice or entertainment, then the species does not need to be bred in such large quantities compared to if it were to be regularly eaten. In more northerly latitudes, reproduction is likely to be more of an issue and so chicken is unlikely to be bred in larger numbers than necessary.

From the beginning of the Roman era, increased use of the chicken as a food source is clear from both the literature and the faunal record. Despite this, the chicken retained its unique status. Birds, as a class, are somewhat under-represented in Roman faunal assemblages, compared to mammals (Albarella 2005). We know from recipes that a wide variety of species, including wild birds, were consumed, but chicken dominates the poultry assemblage (Lauwerier 1993). A taste for chicken is supported by written evidence, for example the shopping lists of Vindolanda (Tab. Vindol. II 302), but the evidence suggests that the chicken is an expensive commodity, and, therefore, may not have been readily available to the average person. This may explain the higher percentage of high status sites containing chicken, compared to sites without. It means that the investment of time and resources required to maintain the chicken in any environmental conditions is likely to be more economically viable.

Although more commonly eaten in period 3, chicken continued to be used in ritual feasting and sacrifice as a primary use. A relatively constant percentage of ritual site type or function persists throughout the study period. The tradition of cock-fighting also continued into the Roman period. This activity was reportedly associated with the import of different breeds, at least in Rome. The recognition of different breeds for different purpose in the ancient Roman texts demonstrates that artificial selection was happening, and may have been a factor in ensuring the persistence of the species.

5.6 Conclusions

Combining faunal evidence and knowledge of cultural association has identified three distinct dispersal events across Europe, spreading via known routes, and reaching increasingly northerly latitudes. The first two occur with the Hallstatt and La Tène Iron Age populations, and the third with the expansion of the Roman Empire. Sites containing chickens are positively correlated with proximity to rivers, known Iron Age trade routes and Roman roads, indicating good potential for dispersal via these means. At the extremes of Europe, absence of chicken in areas where humans are present identifies the geographic limit at which chicken-keeping becomes environmentally or economically unviable in different periods. The greatest extent occurs in the final dispersal, reaching latitudes of 57 degrees north by 199 CE. Several alternative and complementary factors may have aided survival at such latitudes by this date. Based on literary evidence, the most likely factors include selective breeding resulting in hardier, more environmentally tolerant, breeds; or that greater knowledge of the species or market demand has made the breeding of chickens easier and/or more economically viable at these latitudes.

A change is observed in the local environment where chickens are found in period 1/2 compared to period 3. The chicken, or at least their remains, are found in predominantly urban environments rather than predominantly rural ones. The distinction between environments where chicken is more, or less, likely to be found is clear in period 1/2 but becomes less-differentiated in period 3. Consumption of a wide range of species and human adaptation of environment are likely to be the cause.

Ultimately, the fate of an exotic domestic species is determined by its human keepers. That the chicken became embedded in the culture and continued to be held in high esteem throughout the study period almost certainly contributed to its success. This esteem is evident not only from the literature and material culture, but also from the archaeological evidence. High frequency at ritual and high-status sites confirms the information provided in the ancient texts. Chickens increase steadily in site frequency and population density over this period, responding to the demand for ritual purpose, meat or eggs. Change of use towards greater consumption of the bird did not reduce its status, and offers interesting insights into the perception and behaviour of past societies towards the animals that shared their domestic sphere. It attests to the social significance of the chicken within past societies.

Chapter 6: What is the realised domestic niche of the chicken?

6.1 Summary

As has been demonstrated in previous chapters, the chicken was transferred from its location of first domestication to new environments by people. The locations where it is found in the archaeological record ought to represent the environmental conditions suitable for the chicken's survival under domestication, or what could be termed a realised domestic niche. This chapter adopts a similar approach to Chapter 3, with an adjustment of the method to separate the chicken niche from the human niche.

6.2 Introduction

The earliest evidence for domestic chicken is disputed (Yuan 2010; Xiang et al. 2014; Peters et al. 2015; Xiang et al. 2015; Eda et al. 2016). The chicken is most likely to have been domesticated within areas of India where indigenous junglefowl are known (Chapter 3), but accurately identifying chicken in the archaeological record has proven to be problematic (Kyselý 2010; Best et al. in prep; Peters et al. in prep). A conservative interpretation of the available evidence suggests that chicken have been domesticated by at least the Bronze Age, ca. 1500 BCE, in Asia, and have reached the Middle and Near East by ca. 1000 BCE. From here, they become relatively widespread, if in low frequency, in Europe by approximately 500 BCE.

Chickens are descended from junglefowl of Asia and South East Asia. The indigenous range of the ancestor is predominantly tropical forest and located very close to the equator. Europe, on the other hand, is at more northerly latitudes with varied vegetation, including temperate forests, shrublands and grasslands (Olson et al. 2001). Except for Khanpur (2000 - 1700 BCE, Fuller 2006) and Xiawanggang (3000 - 700 BCE, Eda et al. 2016), Asian sites reported to contain chicken are very different in climate compared to those identified in Europe (Figure 35).

'Ecological niche models' (ENM) have been frequently used in ecological studies, to better understand the environmental conditions that enable a species to persist, and how a species might be affected by changing climates (Araújo et al. 2011; Fordham et al. 2013; Pearson et al. 2013). The fundamental niche of the ancestor has been established using such models (Pitt et al. 2016). Similar methods are used to predict the domestic niche of the chicken, and to explore the geographical extent at which chicken might be expected to be found in different time periods, based on where suitable environmental conditions should be found. Comparison of the domestic and wild niches at sites where chickens are known to be present establishes how far the ecological tolerance of the chicken has changed compared to its ancestor.

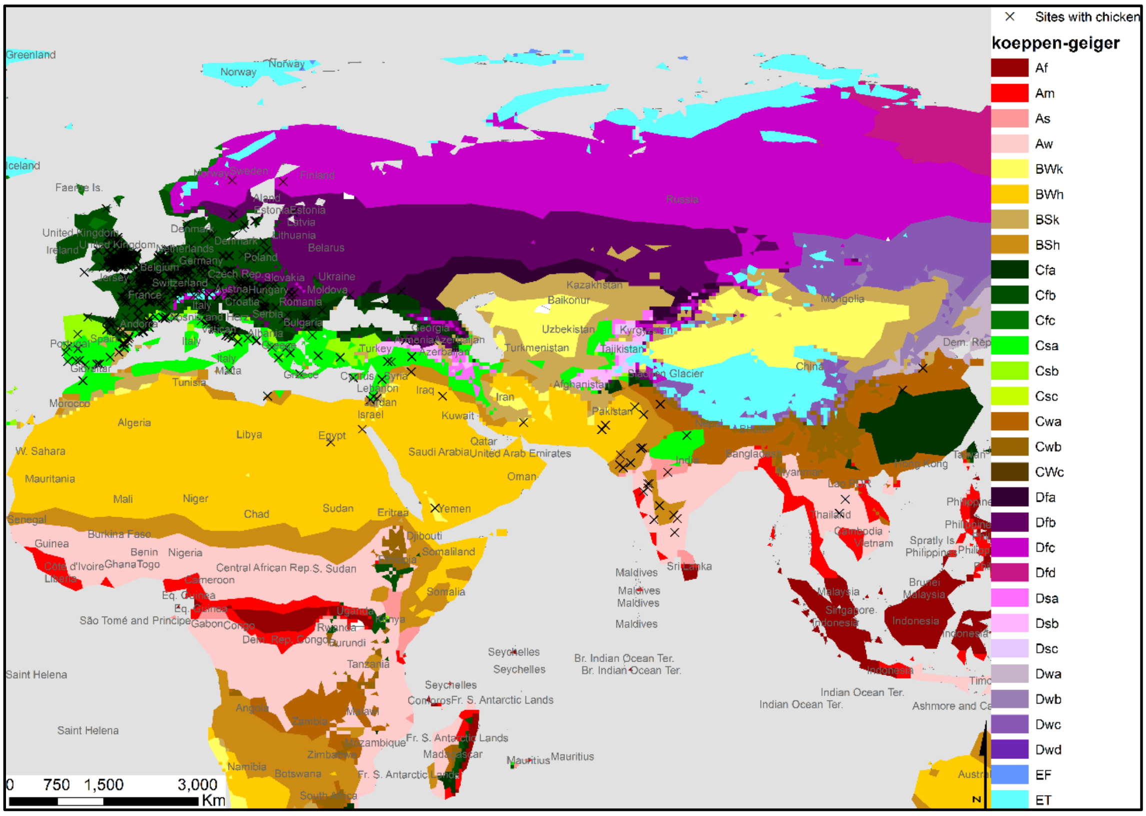


Figure 35. Climate at sites reported to contain chicken, based on the Koeppen-geiger climate classification (Kottek et al. 2006).

6.3 Materials and Methods:

For clarity of interpretation and to avoid issues associated with the complicated chronology of Europe, discussion of analyses follows the divisions outlined in Chapter 2, whereby ‘period 1’ corresponds with dates to ca. 800 BCE, ‘period 2’ with a date range of ca. 800 BCE to 0 BCE and ‘period 3’ to a date range of ca. 0 to 500 CE.

As evidence of faunal remains represent only where archaeological investigation has been performed, the data most closely matches presence-only ecological information and so maximum entropy modelling (Maxent, see Chapter 3 for discussion of this modelling program) (Phillips et al. 2004) was applied to locations where the chicken is known to have been present in Eurasia. Additionally, as the United Kingdom has good coverage of both presence and absence data, conventional statistical techniques, such as generalised linear models (GLM) and regression trees can be used as a case study. These methods should produce the best result (Townsend Peterson et al. 2011, 41), and were run using the ‘sdm’ package in R (Naimi and Araujo 2016).

6.3.1 Ecological niche modelling using presence-only data

Identifying occurrences of chicken in Europe and using these to establish where else might be suitable for domestic chicken would bias the data to Europe only. It would also more closely represent the fundamental niche for European human populations during those periods, rather than that of the chicken, as it would exclude many environments where the chicken is known to be present elsewhere. Therefore, the methodology was adjusted from that used for the ecological niche modelling of junglefowl (Chapter 3). As it is necessary to encompass all potential environments in which the chicken might be able to survive, a broader calibrated range (area where chicken is known to survive and breed, and is geographically accessible), was used for the model and then projected into Europe (after Pearson et al. 2002). This projection predicts where suitable sets of environments are present in Europe for chicken. As the chicken is transported by humans, then areas that are geographically accessible to the chicken include anywhere that humans can inhabit. As human population estimates are not known accurately for Iron Age/Ancient Greek or Roman Europe, this was based on modern (2015) estimates (Center for International Earth Science Information Network - CIESIN - Columbia University 2016), on the assumption that if regions are uninhabitable now, then they would probably have been so in the past.

Occurrences of chicken for Europe include all sites identified as containing chicken from the database (see Chapter 2), excluding those with noted stratigraphic issues. Presence outside of the geographic scope of the database (Europe and bordering countries in the Near East), includes sites identified from the literature and used in the research for previous chapters (Fuller 2006; Becker 2013; Redding 2015; Eda et al. 2016; Peters et al. in prep). These were required to include known presence of chicken outside of Europe, which represent different environments where chickens are also known to survive and breed. The dataset was divided into two groups. The first group (‘BCE’) includes sites with dates to ca. 0 BCE (sites dating to 42 CE in the United Kingdom are included in this group, due to comparability of culture, see Chapter 2) which corresponds with periods 1 and 2. The second group (‘CE’) includes all sites up to ca. 500 CE (periods 1, 2 and 3), to determine how far the niche extends by this date.

In some regions of Europe, chickens are not present until after the final date for inclusion in the database (500 CE). Basic information about such sites was obtained from contacts (Best, J., Forthergill, T., Maltby, M., Perry-Gal, L., Peters, J.; pers. comm.), to examine why chickens might have arrived so late at these locations. Sites outside of the temporal scope of the study were not included in the models, but are considered in the discussion of results.

Eurasia was divided into five regions and a sample of sites was taken from each to avoid biases caused by high frequency of sites with chicken in some regions compared to others. The regions are based on the United Nations division of Europe into North, South, East and West, with the final region representing anywhere outside of Europe. Sample size was calculated based on the average numbers of sites with chickens in each region (excluding sites from the United Kingdom and France in the calculation due to their unrepresentative high frequency). This resulted in a more even sample across the regions of thirty-six sites (or the maximum available in regions with scarcer evidence) from each region for the 'BCE' group, and sixty-five sites (or the maximum available in regions with scarcer evidence) from each region for the 'CE' group. Sites from the United Kingdom and France were included in the sample selection. The selection process involved refining the data based on spatial proximity of sites (by 10km, 25km, 50km and 100km grid squares, excluding sites with poorer audit scores first (Pitt and Stewart in press)), to ensure that the broadest range of environments were included, and then by random sample as required using the add-in 'Sampling Design Tool' (Buja 2016) in ArcGIS (v. 10.2.2). Table 16 provides details of the final numbers of sites for each region by period used for the models.

	Sample size (see main text)	south	west	north	east	Outside Europe
'CE'	65	65 (90)	65 (271)	65 (173)	58 (58)	47 (47)
'BCE'	36	36 (62)	36 (153)	33 (33)	31 (31)	36 (39)

Table 16. Sample size out of the total number of sites (in parentheses) by region and period for presence-only models.

Environmental variables were selected based on relevance to the biological requirements of chicken and availability of information for past climate simulations. Minimum and maximum temperatures determine thermal tolerance, which has been demonstrated to limit species distributions (Araujo et al. 2013; Khaliq et al. 2014). Precipitation variables explain the availability of drinking water. Soil type determines how easy it is to forage for food and explains the availability of grit, used to macerate ground-foraged food in the crop due to a lack of stomach acid.

Bioclimatic (bioclim) variables corresponding to annual mean temperature, mean temperature of the warmest quarter, mean temperature of the coldest quarter, annual precipitation, precipitation of the warmest quarter and precipitation of the coldest quarter were downloaded for current and past (ca. 4000 BCE) climate from the WorldClim database at 2.5 arc-minute resolution, or approx. 5km at the equator (Hijmans et al. 2005). These climate variables correspond with coarse past climate simulations (ca. 1 degree) for Europe (Mauri et al. 2015). The Mauri et al. simulations include a simulation for ca. 4150 BCE, comparable to the bioclim 4000 BCE (Hijmans et al. 2005). By calculating the mean differences between the Mauri et al. past climate simulations for 4150 BCE and their 2150 BCE, 150 BCE, and 850 CE simulations, it was possible to adjust the current bioclim layers to produce 2.5 arc-minute resolution layers for those dates. It is a very broad approach which cannot differentiate between regional differences in climate change, but no better datasets are available. Soil type was derived from the 'Harmonized World Soil Dataset - Major Soil Groups' (FAO/IIASA/ISRIC/ISS-CAS/JRC 2009). Degree of slope was also included as this affects inhabitable terrain. This was calculated using the standard function in ArcGIS (v.10.2.2), with a 250m digital elevation model (CGIAR Consortium for Spatial Information 2008).

Ecological niche models were run using Maxent (Phillips et al. 2004) for 100 replicates with a subsample of 30 per cent test data, random seed, and a regularization parameter of 2.5 to prevent overfitting. Each replicate uses different random sets of training and test data, and the results presented here represent averages. Model performance was evaluated using the area under the receiver operating curve (AUC), which produces a value between 0-1 based on how well the model predicts presence at the training locations (see Phillips et al. 2006 for a full discussion of the validity of AUC in Maxent). A value of 0.5 would indicate no better than expected by chance, 0.7-0.9 indicates reasonable performance, and above 0.9 indicates very good performance (Swets 1988). Thresholds for environmental suitability were calculated from the output summary using a sensitivity-specificity equality approach (see Liu et al. 2005 for evaluation of determining thresholds in niche modelling). Models were run for each group of occurrences in the calibrated range using the 150 BCE climate simulation and then projected to the 2150 BCE, 150 BCE and 850CE climate simulations for inhabited regions of Europe.

6.3.2 United Kingdom case study using presence-absence data

Accessible data are available for the United Kingdom in the form of Derek Yalden and Umberto Albarella’s (2009) work on British archaeological birds which provides detail of absence (inferred from a lack of chicken despite recovery of other birds). Added to known presence and absence from the project database (Chapter 2), these occurrences formed a presence-absence dataset for use in presence/absence species distribution models using the ‘sdm’ (Naimi and Araujo 2016) package in RStudio (version 0.98.1091). The data were divided two groups. The first group represents Iron Age sites (42 CE and earlier in the UK (periods 1 and 2)) and the second group contains Romano-British sites (43 - 410 CE (period 3)). These were refined to a single occurrence per environmental grid cell (2.5 arc-minute), based on presence and audit score (after Pitt and Stewart in press) (Table 17). The models used the same bioclimatic variables as the presence-only models, adjusted for 150 BCE. The 150 BCE climate simulation is closest in date to the average site date of both groups. The model was run for inhabited areas of Europe and projected to inhabited regions of the UK (after Pearson et al. 2002). This enables examination of whether the niche changed between period 2 and period 3, based on where chickens are present or absent in those periods. As with the Maxent method, models were run for 100 replicates with a subsample of 30 per cent test data. Each replicate uses different random sets of training and test data, and the results presented here represent averages. Model performance was evaluated using AUC (see Section 6.3.1 above).

	Presence	**Absence**	**Total**
Iron Age	154	56	210
Roman	119	48	167

Table 17. Occurrences by type and period for ‘sdm’ models.

6.4 Results

6.4.1 Presence-only models

Models were run for each of the BCE and CE observation datasets for 150 BCE climate simulations and then projected to 2150 BCE, 150 BCE and 850 CE climate simulations (Figure 36). For both the BCE and CE occurrence datasets, the 150 BCE simulation is closest to the average date of the archaeological site evidence. 2150 BCE represents the climate in period 1, 150 BCE represents the climate towards the end of period 2, and 850 CE represents the climate just after period 3, which is the approximate climate at the time of the first occurrence of chicken in some locations at the extremes of Europe. The aim was to identify changes over time in the extent of the domestic niche. The performance of the ENMs can be considered good, with AUC values ranging from 0.91 to 0.92.

The models suggest that shifts in the domestic niche are very subtle. The niche shifts slightly south and east in period 2, compared to period 1, and then shifts back north in period 3 and later (850 CE). In period 1, the regions predicted to be most suitable are the United Kingdom, Ireland, northern Iberia and southern France. In period 2, southern Iberia, Italy, eastern Europe, the eastern Mediterranean and the area around the Black Sea become more suitable and Ireland and Portugal slightly less so. In period 3 Italy becomes even more suitable, as does Scandinavia, the northern part of the UK and Ireland. There are also very small pockets of suitability in Russia. Southern Iberia becomes slightly less suitable than in period 2. By the Early Medieval period (850 CE), the best potential for suitable conditions is found in the north and north-west of the continent, with the eastern Mediterranean, Black Sea region, and southern Iberia slightly less suitable than in period 2.

For all models mean temperature of the coldest quarter is by far the most important variable, with annual precipitation also contributing heavily. Below -4˚C there is little predicted suitability (and below -22˚C, none at all). Warm temperatures in the coldest quarter of above 20˚C also reduce potential for suitable conditions. Annual rainfall of 0 or more than 1200mm adversely affects suitability.

Environmental niche similarity between the four models was compared using ENMTools (Warren et al. 2010). 'Schoener's D' (Schoener 1968) and 'Hellinger's I' (Warren et al. 2008) (Table 18, see Chapter 3 for details) returned overlap values of almost 1 for all models, suggesting that the niches are almost identical.

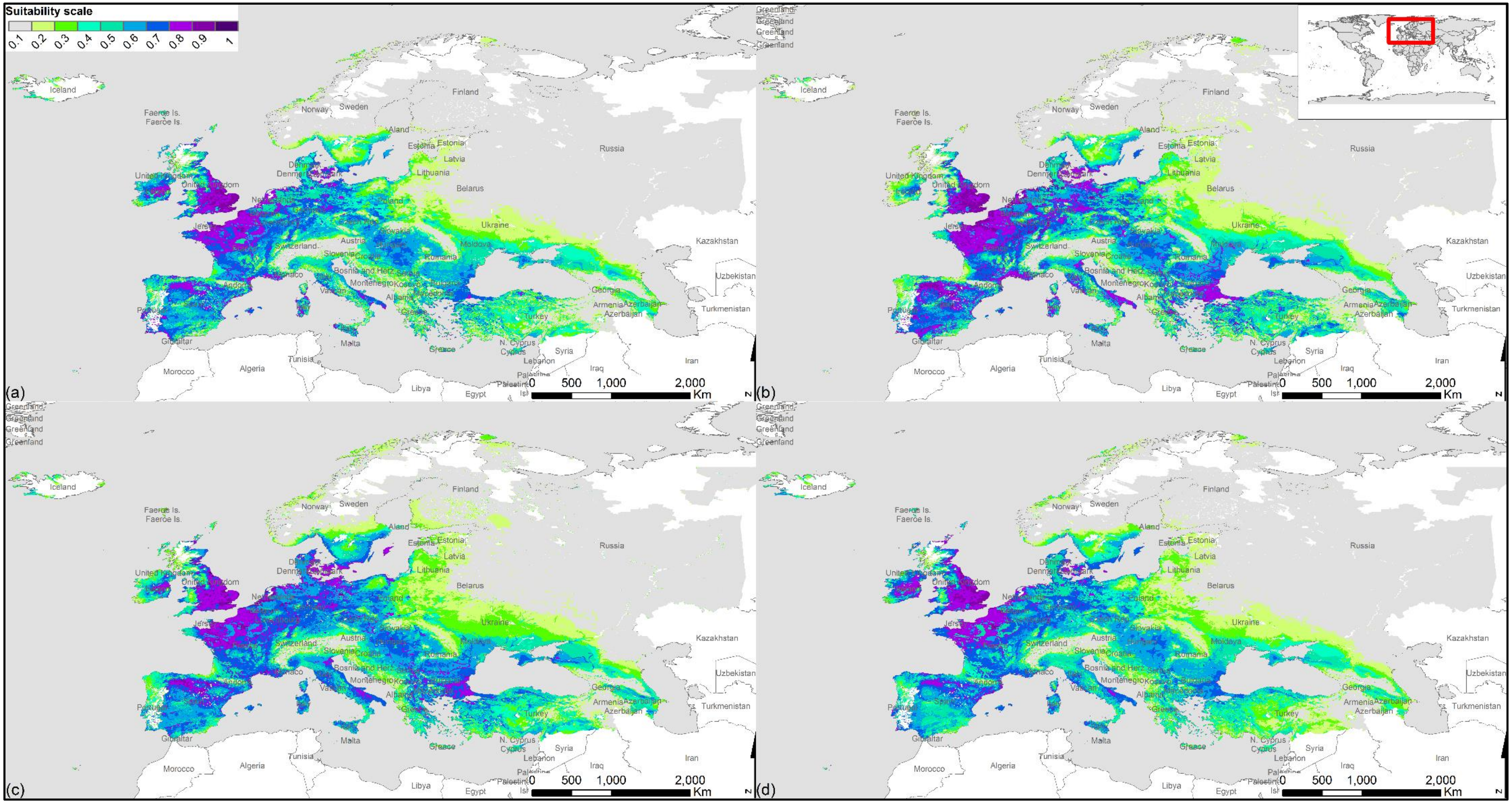


Figure 36. Predicted areas of environmental suitability for (a) BCE occurrences, 2150 BCE climate; (b) BCE occurrences, 150 BCE climate; (c) CE occurrences, 150 BCE climate; (d) CE occurrences, 850 CE climate.

	BCE occurrence, 150 BCE climate	CE occurrence, 150 BCE climate	CE occurrence, 850 CE climate	BCE occurrence, 2150 BCE climate
BCE occurrence, 150 BCE climate		0.91 (0.99)	0.90 (0.99)	0.91 (0.99)
CE occurrence, 150 BCE climate			0.92 (0.99)	0.88 (0.99)
CE occurrence, 850 CE climate				0.92 (0.99)
BCE occurrence, 2150 BCE climate				

Table 18. Comparison of niche similarity using Schoener's 'D' and Hellinger's 'I' (in parentheses) scores for the ENM models. 0= completely different; 1= identical.

Archaeological relevance

Suitability values were extracted for each model at selected archaeological sites (Table 19). Sites chosen include those which have early or very late examples of chicken and/or are found at the extremes of Europe (see Figure 37 for locations):

1. Argishtikhinili, Armenia (date to: 800 BCE). Early Iron Age urban settlement (Liarsou 2013). The site found furthest southeast in Europe with chickens.
2. Cerro del Real, Spain (date to: 800 BCE). Late Bronze Age mound (von den Driesch 1973). One of two unusually early sites based on 'date from' discussed in Chapter 4.
3. Soderbanya, Hungary (date to: 700 BCE). Settlement associated with the Late Bronze Age Kyjatice culture (Beáta 2010). Unusually early site in eastern Europe.
4. Eleftherna, Rethymnon, Crete (date to: 600 BCE). Settlement including an Early Geometric cemetery (Nobis 1998). One of the earliest sites. It is also one of the sites found furthest south in Europe.
5. Biskupin, Poland (date to: 597 BCE). Hallstatt (Iron Age) period fortified settlement (Bochenski et al. 2012). One of the earliest sites in eastern Europe.
6. Houghton Down, United Kingdom (date to: 243 BCE). Two nearly complete articulated skeletons from an Early Iron Age pit within a settlement (Hamilton 2000b). Recently reassessed and radiocarbon-dated (Best et al. in prep), this site was included in Chapter 3 as one of the earliest sites in the UK.
7. Alcáçova de Santarém, Portugal (date to: 200 BCE). Fortified enclosure (Davis 2006). One of the earliest sites at the western extent of Europe.
8. Skedemosse, Öland, Sweden (date to: 15 CE). Pre-Roman Iron Age fishing lake (Hagberg 1967). One of the earliest sites in Scandinavia.
9. Jämtland, Sweden (date to: 550 CE). Roman Iron Age settlement. The site found at the most northerly latitude with chickens (Best, J. pers. comm.).

10. Rathgurreen, Ireland (date to: 600 CE). Iron Age ringfort. One of the furthest west, and one of the earliest sites in Ireland with chicken (Fothergill, T. pers. comm.).

11. Scherbetskoe settlement (date to: 700 CE). Imenkov culture settlement. The furthest east of a small cluster of sites belonging to the same culture, representing the earliest evidence for chicken in the Russian Federation (Best, J. pers. comm.).

12. Dun Vulan, Scotland (date to: 800 CE). Roman Iron Age-Norse broch. The earliest reliable evidence for chicken on the Scottish islands, and the earliest site found furthest northwest in the first millennium CE (Best, J. pers. comm.).

Figure 37. Location of archaeological sites in Table 19.

Site	CE occurrences, 850 CE climate	CE occurrences, 150 BCE climate	BCE occurrences, 150 BCE climate	BCE occurrences, 2150 BCE climate	Non-indigenous Red Junglefowl, present climate	Non-indigenous Red Junglefowl, past (4000 BCE) climate
Threshold	**0.30**	**0.26**	**0.29**	**0.31**	**0.16**	**0.21**
1	0.11	0.19	0.27	0.16	0.01	0.00
2	**0.57**	**0.72**	**0.80**	**0.64**	0.04	0.01
3	**0.56**	**0.64**	**0.66**	**0.57**	0.03	0.03
4	0.16	0.14	0.07	0.06	0.13	**0.24**
5	**0.50**	**0.61**	**0.63**	**0.54**	0.05	0.07
6	**0.73**	**0.73**	**0.77**	**0.77**	**0.16**	**0.26**
7	**0.68**	**0.71**	**0.75**	**0.75**	**0.28**	**0.32**
8	**0.62**	**0.64**	**0.56**	**0.52**	0.06	0.12
9	0.05	0.07	0.04	0.02	0.01	0.02
10	**0.71**	**0.50**	**0.32**	**0.64**	**0.30**	**0.44**
11	0.02	0.02	0.02	0.02	0.03	0.02
12	**0.55**	**0.28**	0.18	**0.44**	**0.33**	**0.46**

Table 19. Environmental suitability values for the different ENM's by site (see text for site detail). Values above the threshold for suitability are highlighted in bold.

6.4.2 Presence-absence UK case study

The performance of the models can be considered only a little better than chance, with AUC values ranging from 0.57 to 0.68 (Table 20).

Model	AUC Iron Age	AUC Roman era
Generalised linear model (GLM)	0.57	0.68
Boosted regression tree (BRT)	0.60	0.64
Classification and regression tree (CART)	0.61	0.63

Table 20. Model performance by period and model technique.

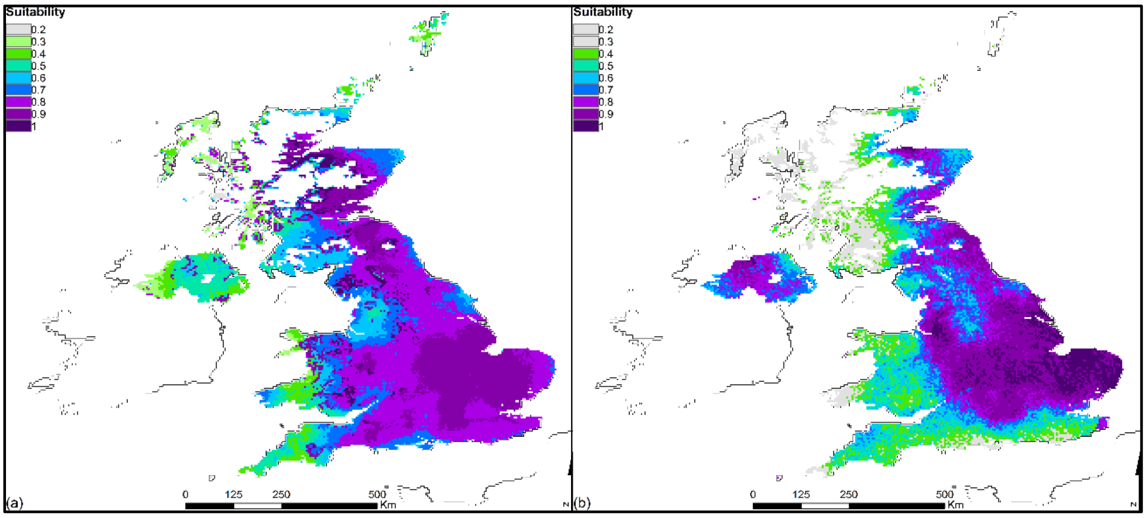


Figure 38. Composite map of glm, brt and cart models predicting the domestic niche of (a) Iron Age and (b) Roman chickens in the United Kingdom.

Given the performance of the models, it is difficult to draw many conclusions from the results (Figure 38). With the exception of predicting better suitability for Northern Ireland in period 3, compared to period 2, the results contrast with those predicted by the better-performing presence-only models (Section 6.4.1).

6.5 Discussion

In terms of model performance, evaluated using AUC values, the presence-only models work far better than the presence-absence models. The presence-absence models imply that chickens could have survived further north in the earlier period had there been opportunity or incentive to do so; however, evaluation of the models showed them to be little better than chance, and so any conclusions must be purely speculative.

The habitats where chicken is found compared to where it is not found was shown in Chapter 5 to be very similar. This is perhaps the main reason that the presence-absence models perform so poorly, and is almost certainly a consequence of being a domestic animal. Its place within the domestic sphere blurs the distinction between where the species could easily survive with little assistance and where humans are countering the negative effects of poor environments. A model which was able to incorporate relative frequency, rather than absence, might produce more conclusive results.

The presence-only models also show that over time the niches are geographically very similar and, environmentally, they are almost identical. This allows very few confident conclusions to be drawn. Despite this, there are some interesting observations. Potential for suitable conditions is found in the regions where most excavation and publication has taken place. These regions offer generally fairly mild climates, and may explain why chickens are found on archaeological sites in greatest frequency in northern France and southern Britain, compared to the rest of Europe. Based on these models, environmental factors would not explain the lack of chickens in Ireland in period 1, supporting the theory that chickens did not disperse this far in this period. The models for period 2 climates differ slightly in geographic extent depending on whether BCE or CE occurrences are modelled. That the latter covers a broader geographic extent, albeit in small pockets, may suggest that people in period 3 Europe successfully developed hardier breeds.

Examination of the suitability values extracted at selected archaeological sites suggests that of the early examples, Armenia is not especially suitable, perhaps due to low winter temperatures (www.weather-and-climate.com), and the Greek climate appears to be more suitable for junglefowl than for chicken. The two unusually early sites from Spain and Hungary do have good suitability for the domestic niche, but not for the junglefowl niche, with which chickens of this date (prior to 800 BCE and 700 BCE respectively) might be expected to show better affinity. The location of the sites in the UK and Portugal would offer minimally suitable conditions for junglefowl, and have good suitability for chicken. The site in Ireland also has suitability for both domestic and wild Gallus in all periods, but the best suitability is after period 3, which corresponds with the date of the known earliest evidence of chicken from an archaeological site at 600 CE (Fothergill, T. pers. comm.). The earliest evidence in Scotland is from the Scottish islands (Best, J. pers. comm.), and it is also not until after period 3 that there is good suitability in this part of the UK. There is suitability in eastern and north-eastern Scotland, particularly around Fife and Caithness, from period 2, and yet chickens are not recorded here. This may be due to the Romans not expanding their empire this far north, and so chickens on the Scottish islands may have arrived via a different route, perhaps from Ireland or with the Vikings. Situated less than 400km from the Arctic Circle, it is unsurprising that Jämtland in Sweden does not offer suitable conditions, as the mean temperature of the coldest quarter is likely to fall well below -4˚C. More surprising is that although the Russian site has low potential for being environmentally suitable, it is located only 20km from the small suitable areas predicted by the models using CE occurrences, projected to 150 BCE. Sites dated to after 500 CE were not included in the models and so predicted suitability at the location of those sites is particularly interesting.

For most sites with good predicted suitability within the domestic niche, including Spain, Hungary, Poland, UK, Portugal, and the Swedish islands, predicted suitability for the wild niche is far lower. This reflects how far the domestic niche has shifted from the niche of its ancestor.

6.6 Conclusions

The analyses suggest that presence-only models work best for the study of domestic animals using archaeological data. Even with a relatively comprehensive dataset, presence-absence models perform poorly. This is probably because the chicken is a domestic animal, and human intervention allows the chicken to be present in many of the same environments as those where chickens are absent. High versus low frequency, as opposed to presence versus absence, may better reflect the other factors determining whether people choose to keep chickens or not.

Although distinct changes over time in the domestic niche of the chicken are not observed, subtle changes can be seen. This suggests that the domestic niche does change slightly over time. A slight shift in niche eastwards is observed in period 2, with a slight shift northwards from period 3. Interestingly, predicted suitability for regions without chicken until after 500 CE is often not found until after period 3, suggesting that this is genuine absence in the earlier periods. Where suitability remains poor, such as near the Arctic Circle in Sweden or in Russia, this again demonstrates that there must be good social or economic value that makes breeding this species in adverse conditions viable.

Evidence of very early sites with good suitability for the domestic niche, but low suitability for the wild niche, suggests that the evidence at these sites may need reappraising. Considerably better suitability within the domestic niche than the wild niche, especially for early well-dated sites, such as Houghton Down (390 – 206 cal BCE (Best et al. in prep)) in the UK, reflects how far the environmental tolerance of the chicken has changed from that of its ancestor in a relatively short period of time.

Chapter 7: What was the impact of the introduction of the chicken on the ecological community and the ecological community on the chicken?

7.1 Summary

This chapter examines how the introduction of the chicken affected the ecosystem into which it was introduced, and how relationships within spheres of association contributed to the success of the chicken. These are analysed through traditional methods of exploring interspecies variability in archaeology, alongside a novel new method, using a Bayesian Belief Network, for understanding multiple interspecies interactions.

7.2 Introduction

Relationships between different species, otherwise termed inter-specific interactions, can be both positive and negative. Interactions usually take the form of competition, predation, herbivory, and symbiosis (a useful description of the nature of each of these interactions can be found in Lang and Benbow (2013)). Symbiosis, literally meaning ‘living-together’, encompasses commensalism, amensalism, parasitism and mutualism, whereby only the latter is a mutually beneficial relationship and is not necessarily equally so (Parmentier and Michel 2013). Within ecological communities these relationships become established over time but can be upset by environmental change or by the introduction of non-native species. It has been recognised that introducing a non-native species into a new environment can cause dramatic changes, including evolutionary change, in both the invader and the native populations within a very short period (as little as fifty years) (Mooney and Cleland 2001). Niche displacement, hybridisation and reorganisation of mutual relationships can all be consequences of such an introduction. As a bird that has descended from junglefowl of Asia and South East Asia, and then been transported to Europe by people, the chicken is a prime example of introducing a non-native species into a new environment. Therefore, it makes an excellent case study for investigating the consequences of such introductions to past ecological communities.

There are several other aspects of interspecies relationships which can inform archaeological interpretation. Understanding the interactions between species found together in the faunal record provides additional context. Investigation of past ecological communities has identified unusual compositions of species assemblages compared to what might be expected today (Stewart 2009) and these can cause can evolutionary change in the constituent species. Changes in species interactions happen for a reason, and a better understanding of the nature of these interactions can help determine whether such changes are occurring because of human influence or natural change.

The role of the chicken lies within the domestic sphere. Changes within the domestic sphere reflects change in human behaviour towards, and perception of, domestic species. As one species is preferred, it is likely that another may fall out of favour. Examination of interactions within the domestic sphere is not new to archaeology. The faunal reports used to construct the database for this project (Appendix II) often discuss domestic interactions in the form of assemblage composition, and the frequency of domestic animals is often compared to wild species if they are present. Such analyses are very relevant and can produce interesting results in terms of human cultural behaviour, choice of habitat and animal use. However, these usually focus primarily on human use of animals as a product, rather than how individual species presence may affect one another. A tri-plot method of examining species interactions has been successfully used in archaeological reporting as a comparative tool which enables good visual analysis of interspecies relationships (Hambleton 1999; King 1999; Morris 2011). By its nature, it is limited to three species, and has primarily been applied to major domesticates within the domestic sphere, usually comparing sheep/goat, pig and cattle, as with the examples cited above.

Yet the presence of humans and the animals they keep has an effect beyond the domestic sphere, directly and indirectly. Boev (1993) and O'Connor (1993) both report on the implications of the spread of urbanisation on adaptable scavenger birds. Comparison of current Bulgarian avifauna found that almost half (41.9%) of a study of 155 extant bird species can be considered 'synanthropic' or 'synurban' (Boev 1993, 152). Synanthropic species benefit from association with humans but usually have habitats outside of human settlements. Synurbanisation is defined as the 'highest level of synanthropisation' (Boev 1993, 145) and includes species which nest in human settlements. Of these, it is observed that species such as coot, mute swan, woodpigeon, pheasant and grey partridge would not have been part of this group in the past (Boev 1993, 153).

Such an observation demonstrates how species niche can alter over time because of changing environments or behavioural evolution. O'Connor (1993) discusses the displacement of certain groups of birds, particularly those which rely on other live species for food or have specific dietary needs, by facultative carnivores and carrion-feeders. The consequence of this is that certain species should be expected to be encountered in the faunal remains, and where this pattern is not found, then other factors (in the case of urban environments, then most likely human influence) must be responsible. The fox is an interesting example, especially for any study of the chicken. A predator of the chicken and a scavenger carnivore, it might be assumed that increase in frequency of chicken would provide additional prey, which could increase the fox population. A study of Anglo-Saxon fauna found this not to be the case, identifying no direct correlation between the two species (Poole 2015, 415). It was suggested that, in these instances, humans may have been reducing the fox population as a threat to human infant burials. Human perception of synanthropic, and particularly commensal species, varies greatly and will determine how people respond to them. Commensal species are drawn to human habitations for food and shelter, and might be enjoyed, reviled, tolerated or hunted (O'Connor 2013a). The pigeon is a prime example of a species which receives a very mixed response. It is also a species which would benefit from the way in which chickens are often fed, by scattering feed on the ground.

Understanding complex networks of species interactions, related to other species or to changing environments is challenging using traditional methods of comparing faunal assemblages. It is not just archaeologists that face such problems, but also ecologists. As mentioned in previous chapters, species distribution models have been extensively used in ecological studies. One of the oft-noted challenges is the incorporation of biotic relationships as opposed to models based purely on abiotic variables (Pearson and Dawson 2003; Soberón 2007; Baselga and Araújo 2009; Soberón and Nakamura 2009; Wisz et al. 2013). The ‘next generation’ of species distribution models are being developed to redress this. Using pairwise species interaction matrices, ‘community models’ attempt to incorporate multiple biotic species interactions to address fine scale variability (McInerny and Purves 2011; Kissling et al. 2012; Araújo and Rozenfeld 2014; Pollock et al. 2014). Such models enable greater understanding of the relationships between species which influence presence or absence in specific regions. Although the previous chapter demonstrated that traditional statistical species distribution models (those requiring presence and absence information) failed to produce meaningful results for the available archaeological data, ecological community models have good potential to benefit archaeological interpretation. Rather than using them to predict where species might occur in the form of a niche model, it is the interaction itself which is of most interest to archaeology.

A Bayesian Belief Network (BBN) model (Stafford et al. 2015; Spiers et al. 2016) offers an effective means of understanding complex networks of species interactions. The model predicts how changes in certain variables, for example an increase in the number of sites containing chicken, would affect other species, for example, other edible birds, other fighting birds, predators and commensal species. These are not limited to environmental factors, such as climate or site type, but can be used to investigate more practical aspects of archaeology, such as how archaeological recovery methods affect the retrieval of small animal bones. It is generally assumed that sieving will result in greater recovery of small animal bones (Wilkinson 2007, 87; Davis 2012, 29); however, there are instances where sieving has produced limited or no additional results (Zeiler and de Vries 2008; Elevelt 2012). Given the additional costs (time and financial) associated with this process it is important to understand how useful it might be. A methodology for adapting archaeological data for use in a BBN is presented in Section 7.3.2. Used alongside traditional methods of exploring archaeological data, it is possible to assess the impact of introducing the chicken into a new ecosystem and the effect of other species on the chicken. Applying new techniques to the archaeological record offers a novel means of better understanding the relationships between species in the past; and to investigate the consequences of recovery or sampling bias, a unique application of this method, not previously applied to any study.

7.3 Materials and methods

Species, date, site-type, number of identified specimens (NISP), recovery and condition information was extracted from the database developed as part of this project (Chapter 2) by phase. Only data with an audit score of adequate or above was used (see Chapter 2) to exclude less reliable evidence. Each phase is represented by a faunal assemblage of the animal bones found together during a specific period or use of the site. As many animal bones cannot be reliably or consistently identified to species, genus level data was used. Assemblages containing only one of the selected species (see Section 7.3.2) were excluded for most analyses because they offer no insights into the species relationships which form the primary focus of this study. This resulted in a dataset containing 825 archaeological assemblages. Analysis of recovery method drew data from the complete dataset (n=1152), as dating and species relationships are irrelevant for such analyses, and the bone has been identified to genus. More important for this analysis are assemblages for which relevant information is reported, such as whether sieving was employed and bone condition. Specific numbers of assemblages containing this information are given in the results.

As has been applied in other chapters, for clarity and to avoid issues surrounding the complicated chronology of Europe, analyses investigating changes over time are based on a tri-part division of the dataset. Assemblages from site phases dating from ca. 3000 - 800 BCE are referred to as ‘period 1’; ‘800 BCE – 0/42 CE’ as ‘period 2’; and ‘1 - 500 CE’ as ‘period 3’. The periods broadly correspond with the Bronze Age, Iron Age and Roman periods in Europe as these cultures dominate those time frames, but it is recognised that the Bronze Age ended at different dates in different parts of Europe, that the Greek civilisation and Roman Republic fall within the time frame of ‘period 2’, and not all phases in Europe in ‘period 3’ were occupied by the Romans. Period 2 includes sites from the United Kingdom up until 42 CE, due to the later arrival of the Romans in this region (see Chapter 2 for discussion).

Climate and environmental information was extracted from the modern bioclim (Hijmans et al. 2005), 2150 BCE layers created for Chapter 6 (Mauri et al. 2015), and a 250m resolution digital elevation model (CGIAR Consortium for Spatial Information 2008) using ArcGIS (v.10.2.2). Modern climate was adjusted to pre-industrial values, using the methodology described in Chapter 6, to enable comparison with detailed information for Iron Age to Roman mean precipitation and June, July, August (JJA) temperatures (Büntgen 2011). High resolution climate information for this period is scarce, so although this limits climate analysis to these two variables, both precipitation and temperature are represented.

7.3.1 Traditional faunal analyses

Changes in the faunal record over time were assessed using bar graphs, charting increases and decreases in the frequency of selected species within each period. Tri-plot analyses (otherwise termed ternary diagrams) were conducted in Microsoft® Excel using a spreadsheet created by Graham and Midgley (Graham and Midgley 2000). This method allows for comparison of three species, subdivided by an abiotic variable, such as site type or cultural regions (King 1999). The data is converted into percentage form and plotted onto triangular graphs. The plots visually represent the distribution of the archaeological assemblage (number of bones found in each phase of the site, in this instance). The location of the point on the graph explains the composition of the assemblage, and enables comparison of large numbers of assemblages.

Two separate analyses investigate the relationship between chicken and the primary domestic mammals, pig and ovicaprines; and between chicken and the other primary domestic birds, duck and goose. Cattle were not selected for this analysis, nor for the other analyses in this study, as it has been noted that comparison of cattle with other primary mammals and with birds is problematic, due to recovery and preservation issues (Maltby 1997). Site type is used as an additional abiotic variable for comparison. The assemblages used for the analyses include chicken and either sheep/goat or pig and duck or goose. They were refined by NISP quantity to enhance reliability of data and to avoid confusing visual interpretation by including too many assemblages (see Chapter 2 for discussion on NISP and quality of data). Due to low frequency of recovered bones, the criteria for inclusion for the analyses of domestic birds included >5 NISP of chicken and over 10 total chicken, duck and goose within an assemblage. Due to high frequency of recovered bones, the criteria for inclusion for the analyses of the domestic mammals included >50 NISP of chicken and over 500 total chicken, sheep/goat and pig within an assemblage. These were divided by period and by site type. Site type categories include religious sites (e.g. cemeteries, temples), rural sites (e.g. low-density settlements, farmsteads, field systems, enclosures), urban sites (high density settlements, e.g. towns, hillforts), and other sites combined (e.g. industrial sites, caves, and sites lacking detail to define more closely).

7.3.2 Analyses using a Bayesian Belief Network (BBN)

The community modelling method uses a Bayesian Belief Network (BBN) in the form of a Microsoft® Excel spreadsheet, developed by Stafford et al. (2015). Unlike the tri-plot method which requires, and is limited to, three biotic variables (but can be subdivided by abiotic variables), this method is much more flexible, allowing comparison of any relevant number of biotic and abiotic variables. While this method has never before been applied to archaeological data, traditional Bayesian statistics have been successfully used to examine occupational sequences in Medieval Iberia (Quirós Castillo et al. 2015) and are frequently used to interpret radiocarbon dates (see Bayliss 2015 for a review of papers using this method). Bayesian statistics use ‘prior beliefs’, which, in a BBN, represent the probabilities of a species increasing or decreasing. When used in ecological studies, the prior beliefs predict increase or decrease in populations of species caused by future changes to the ecosystem. In archaeology, the outcome is already known. The BBN provides a means by which to understand that outcome.

It uses information present in the dataset to predict how a combination of multiple variables should affect species occurrence. Data containing number of identified specimens (NISP) is most useful as it better reflects the composition of the assemblage. If only presence data is available then the potential for species occurring together more, or less, than might be expected can be used. The variables can range from individual or groups of species, - to climate, - to environmental setting, such as site type or elevation, - or even recovery method. This application is best suited to the evaluation of changes in the faunal record over time or for understanding how a single variable, such as recovery method, might have affected the outcome of the known archaeological record. Comparison with the known record, specifically increases or decreases in species occurrence or frequency, explains whether the factors modelled are resulting in observed changes over time. If the models fail to predict the known outcome, then other factors must explain the differences. In the case of animals in the domestic sphere this might well be human influence, which is unfortunately difficult to model due to the unpredictability of human behaviour, but does at least exclude the variables modelled, thereby aiding interpretation of the assemblage.

There are three stages in a BBN. The first stage requires a value between 0-1 representing the strength of the relationship between two variables. This reflects the probability of increase or decrease of pairs of variables, whereby a value of 0.5 represents no relationship, a value of 1 indicates that variable A would increase with variable B, and a value of 0 would indicate that variable A would decrease with variable B. This was established for each pair of variables by calculating how the relationships compare to what would be expected by chance:

$$x\ (expected) = \frac{\sum variable\ A\ (e.g.\ chicken\ bones\ occuring\ with\ any\ species) \times \sum variable\ B\ (e.g.\ duck\ bones\ occuring\ with\ any\ species)}{\sum total\ of\ all\ variables\ (e.g.\ total\ number\ of\ all\ bones\ of\ all\ species\ under\ consideration\ in\ the\ study)}$$

for variables based on frequency (e.g. species or site type); or

$x\ (expected) = \frac{\sum variable\ A\ (e.g.\ sum\ of\ elevation\ in\ metres\ of\ all\ assemblages)}{n\ (variable\ A)(\ number\ of\ assemblages)}$ for variables based on averages (e.g. climate or elevation)

and then establishing how far this interaction differs from a value of 0.5, representing no relationship:

$$y\ (standard\ deviation) = \sigma\ (\sum variable\ A)$$

$$z\ (difference) = (variable\ A\ (observed) - x) \div y$$

$$BBN\ value = \left(\frac{z}{sd}\right) + 0.5\ (value\ of\ no\ relationship),$$

where *sd* represents the number of standard deviations required to scale the data to a value between 0 and 1, with a minimum value of *sd* = 3. If an interaction (positive or negative) is present, this is input into the second stage of the BBN. Based on the formula for the BBN value, relationships of 0.55 or above and 0.45 or below were interpreted as interactions. As 0.5 represents no change, the range between 0.45 and 0.55 is unlikely to represent a meaningful relationship. The third stage of the BBN is used to adjust the prior beliefs, or known archaeological record. The model uses Bayesian inference to assess how changes in stage three (e.g. an increase in chicken) would affect the other variables in the study, based on their interactions with one another. Where a known increase occurred, albeit limited by caveats associated with archaeological excavation (Pitt and Stewart in press), the prior belief was adjusted to 1.

Species were selected based on association with chicken within specific spheres of interest (Table 21). The chicken is found in the domestic sphere, along with the other primary domestic animals, dog, horse, pig, sheep/goat, and the domestic birds, duck, goose and pigeon. Although it should be noted that not all duck, goose or pigeon species found on archaeological sites are necessarily domestic but may have been merely tamed (Albarella 2005), or imported (Parker 1988). Many of the selected domestic species are also edible, as are partridge and quail, although partridge and quail are additionally of interest for their use as alternative fighting birds (Gal 2008). Dog and horse are the two domestic animals which do not feature as ingredients in Apicius' recipe book (*De re coquinaria*, ca.385 CE), but also fall into the entertainment sphere for their contribution to hunting (Bennett and Timm 2016) and chariot racing (Bennett 1997).

	Genera	**Domestic**	**Edible**	**Entertainment**	**Religious**	**Synanthropic**
Chicken	*Gallus*	✓	✓	✓	✓	
Dog	*Canis*	✓		✓	✓	
Duck	*Anas, Aythya*	✓	✓			
Fox	*Vulpes*					✓
Goose	*Anser, Branta*	✓	✓		✓	
Horse	*Equus*	✓		✓	✓	
Marten	*Martes*					✓
Mouse	*Apodemus, Mus, Micromys*					✓
Partridge	*Alectoris, Perdix*		✓	✓		
Pig	*Sus*	✓	✓		✓	
Pigeon	*Columba*	✓	✓			✓
Quail	*Coturnix*		✓	✓		
Rat	*Rattus*					✓
Sheep/goat	*Capra, Ovis*	✓	✓		✓	
Sparrow	*Passer*					✓
Weasel	*Mustela*					✓

Table 21. Species associations with chickens.

Although all of the chosen species are present on religious sites, chicken, pig and sheep/goat are most common (Table 22). The presence of the synanthropic species on ritual sites is unlikely to be deliberate, especially given low frequency. These species are most likely to benefit from the introduction of the chicken, either as a new prey for meat or eggs in the case of the fox, marten and weasel, or through scavenging feed and water left out for chickens.

Species	Frequency on religious sites
Pig	119
Chicken	114
Sheep/goat	108
Dog	74
Horse	71
Goose	39
Duck	34
Pigeon	25
Fox	18
Mouse	16
Partridge	9
Weasel	6
Rat	5
Sparrow	4
Marten	2
Quail	2
Total religious sites	131

Table 22. Frequency of species on religious sites.

7.4 Results

7.4.1 Analysis of changes in the faunal record

This study, centered on chickens, is concerned with understanding how the perceived increase in chicken affected other species with which it is associated, and whether changes in the frequency of those species may have contributed to this increase. The data was analysed to establish how species populations changed over time, as represented by the percentage of identified bones recovered from each period (Figure 39). This represents the known outcome from the archaeological data, or prior beliefs, for the Bayesian belief models and aids interpretation of the tri-plots.

Domestic animals dominate the evidence in all periods, with pig and sheep/goat found in greatest frequency. As has been established in other chapters, chicken is present in small numbers by period 2. By period 3 it is widespread with larger populations. This huge change in frequency of chicken is paralleled by other species, including duck, goose, mouse, partridge, quail, rat and weasel. Sparrow and pigeon also increase in frequency in period 3, but are present in reasonable numbers in period 2. The increase in the chicken population appears to coincide with decreases in the fox, marten, pig and sheep/goat populations. The primary edible mammals experience minor population decreases in period 3, but horse and dog continue to increase. Only marten experience population declines over both periods.

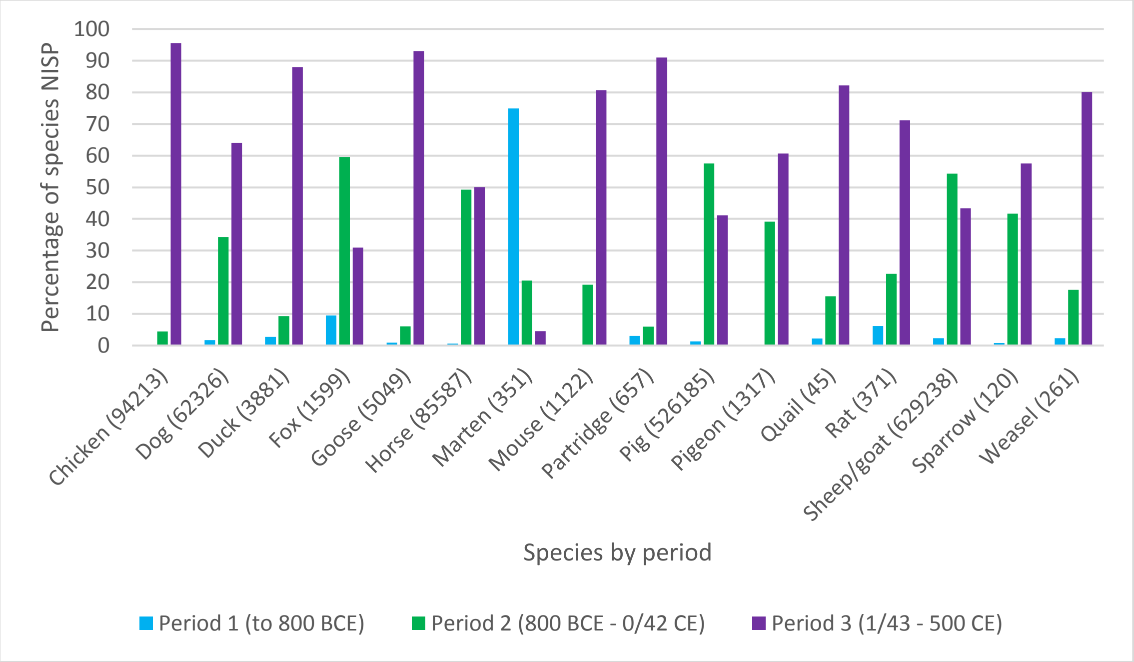


Figure 39. Species populations change over time, as represented by the percentage of identified bones of each species recovered within each period. Number in parentheses is total NISP.

7.4.2 Tri-plot analyses of primary domestic species

Tri-plot analyses (Figure 40) compared assemblage composition of chicken with the primary domestic mammals, pig and sheep/goat and with the primary domestic birds, duck and goose. Analyses were performed for time periods 2 and 3. Period 1 contained insufficient evidence for chicken found on sites with these species.

The results show that the assemblage composition does vary over time and by site type. In period 2, the domestic mammals plot largely along one axis, suggesting a dominance of pig and sheep-goat in the assemblages and low frequency of chicken. This corresponds with the NISP totals (Figure 39), in that pig and sheep/goat have far higher NISP frequency than any other species. In period 3, assemblage composition is more varied, with two and sometimes all three species occurring together in reasonable quantity on domestic sites; although where chicken appear in greater NISP, this does appear to mostly correspond with higher frequency of pig rather than sheep/goat. A different pattern is seen for religious sites. Many religious sites in period 3, (particularly noticeable for the birds), plot towards the corners, suggesting a preference for fewer species in association. The clustering of the bird assemblages in both periods towards the bottom left corner indicates that higher frequency of chicken corresponds with low frequency of both duck and goose. This corresponds with the evidence from the database (Figure 39) which suggests that these species were not occurring in great numbers in period 2. Their increase in period 3 does correspond with the more varied bird assemblage composition shown in the period 3 tri-plot, which also suggests that duck is slightly more likely to occur with chicken on rural sites and goose with chicken on urban sites.

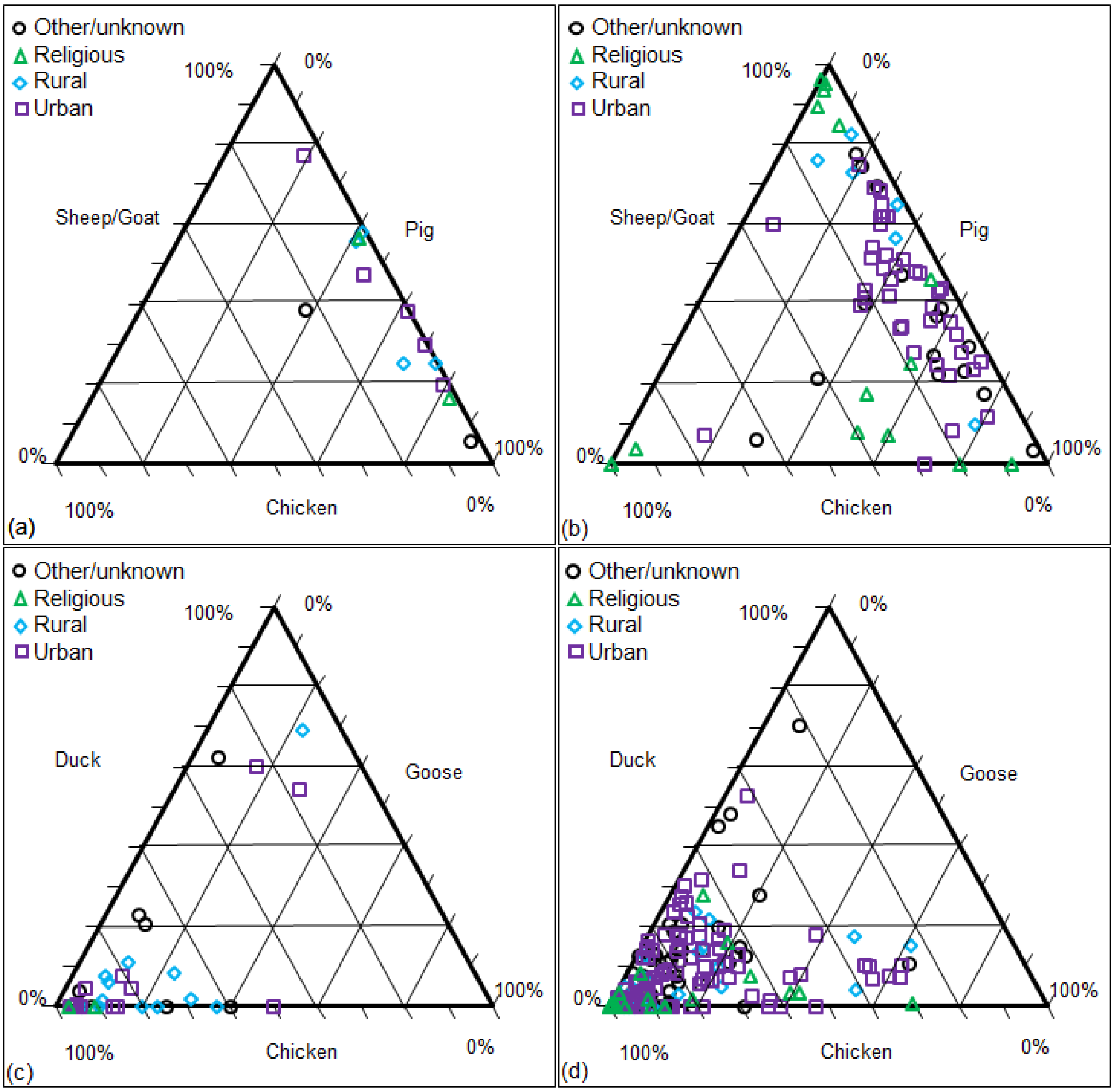


Figure 40. Tri-plot analyses of chicken with primary mammals in (a) period 2, (b) period 3; and chicken and primary domestic birds in (c) period 2, (d) period 3.

7.4.3 Bayesian belief network analyses

7.4.3.1 Part 1: Biotic interactions

The tri-plot analyses provide useful results, but it is difficult to analyse the complex network of relationships the chicken may have with the species with which it is associated in different spheres. To understand whether abiotic factors or the introduction of the chicken may have caused the changes seen in the archaeological record, the relationships between these were calculated. A Bayesian Belief Network (BBN) approach was employed to understand the consequence of the increase in chicken observed in the archaeological record on the other species with which it is associated, both directly and indirectly. It also enables analysis of whether increase in other species, e.g. horse, and/or changes in environmental conditions, may have affected the chicken.

A species relationship matrix was calculated using the formula given in Section 7.3.2. In this instance, a positive relationship suggests that an increase in population size of one species should result in greater frequency of the other, while a negative relationship suggests the opposite. For inclusion in the model, positive relationships of 0.55 or above and negative relationships of 0.45 or below were used. As 0.5 represents no change, the range between 0.45 and 0.55 is unlikely to represent a meaningful relationship, and is not factored in the model.

The complex network of relationships (Table 23) demonstrates why the BBN is useful, since it can account for all of these interactions in one model. The results show that chicken has positive relationships with dog, duck, goose, horse, partridge, pig, pigeon, and rat; and negative relationships with fox and marten. The strongest negative relationship is with marten, and the strongest positive relationship is with goose. The chicken is negatively affected by dog, duck, fox, horse, pig, and weasel, and positively affected by goose, mouse, pigeon, quail, sheep/goat and sparrow. The strongest negative relationship is with fox, and the strongest positive relationship is with sheep/goat. The domestic mammals are largely unaffected by other species, and where this is the case, then it is another domestic animal. It is not a completely insular ecosystem though as the domestic mammals frequently have stronger positive or negative relationships with wild animals than might be expected. The domestic birds, on the other hand are affected by a mix of wild and domestic species, both positively and negatively.

	Chicken	Dog	Duck	Fox	Goose	Horse	Marten	Mouse	Partridge	Pig	Pigeon	Quail	Rat	Sheep/goat	Sparrow	Weasel
Chicken	0.50	0.56	0.60	0.39	0.71	0.58	0.27	0.47	0.56	0.57	0.64	0.49	0.58	0.54	0.53	0.53
Dog	0.40	0.50	0.46	0.57	0.36	0.57	0.61	0.48	0.40	0.55	0.39	0.44	0.54	0.55	0.46	0.51
Duck	0.44	0.51	0.50	0.44	0.77	0.47	0.61	0.51	0.44	0.51	0.65	0.53	0.34	0.51	0.51	0.27
Fox	0.35	0.48	0.38	0.50	0.41	0.53	0.66	0.25	0.41	0.52	0.41	0.34	0.35	0.50	0.41	0.31
Goose	0.64	0.46	0.59	0.42	0.50	0.48	0.33	0.42	0.50	0.53	0.47	0.55	0.34	0.46	0.37	0.25
Horse	0.42	0.59	0.48	0.58	0.36	0.50	0.63	0.48	0.38	0.57	0.34	0.42	0.30	0.56	0.48	0.31
Marten	0.50	0.49	0.54	0.52	0.55	0.49	0.50	0.62	0.63	0.51	0.53	0.46	0.46	0.49	0.44	0.45
Mouse	0.58	0.53	0.50	0.46	0.51	0.49	0.48	0.50	0.43	0.47	0.49	0.44	0.69	0.52	0.64	0.76
Partridge	0.50	0.48	0.58	0.54	0.54	0.49	0.51	0.64	0.50	0.49	0.70	0.80	0.62	0.51	0.46	0.74
Pig	0.89	0.85	0.80	0.85	0.67	0.84	0.85	0.82	0.81	0.50	0.75	0.78	0.86	0.87	0.83	0.82
Pigeon	0.66	0.54	0.61	0.48	0.63	0.44	0.43	0.57	0.68	0.48	0.50	0.44	0.41	0.50	0.58	0.39
Quail	0.55	0.48	0.53	0.50	0.55	0.49	0.51	0.43	0.56	0.49	0.53	0.50	0.58	0.51	0.45	0.74
Rat	0.51	0.49	0.55	0.50	0.55	0.49	0.51	0.69	0.64	0.50	0.55	0.50	0.50	0.50	0.45	0.75
Sheep/goat	0.97	0.92	0.88	0.92	0.73	0.91	0.61	0.90	0.91	0.91	0.90	0.87	0.94	0.50	0.90	0.89
Sparrow	0.59	0.51	0.49	0.56	0.52	0.50	0.49	0.45	0.46	0.47	0.47	0.69	0.51	0.52	0.50	0.46
Weasel	0.43	0.47	0.42	0.46	0.43	0.51	0.41	0.40	0.39	0.51	0.40	0.37	0.57	0.50	0.53	0.50

Table 23. Matrix of inter-species relationships, whereby the species in the row affects the species in the column. Green represents a positive relationship, purple represents a negative relationship and grey indicates no relationship.

For the second stage of the model, these values were applied to the BBN. For the third stage, prior beliefs were adjusted in turn (either increased or decreased) to reflect known changes in variables (in this instance, individual species frequency). An ecological study would need to understand the probability of change. In archaeology, that change has already been observed and so the probability of it happening is 1. It is worth acknowledging, however, that this observed change is affected by the usual issues associated with archaeological excavation (Pitt and Stewart in press). The model then calculates how changing each prior belief affects the network of relationships, using Bayesian inference. Interpretation of the model can help to assess how far each variable (species, in this instance) might account directly or indirectly for observed changes in the other variables. If the variable contributed to the known outcome, then the model should predict a similar pattern to the archaeological record (Figure 39). If it fails to show a similar pattern, then the variable is unlikely to have been a major factor.

For the first model (Figure 41), using biotic variables only, the intention is to determine the effect of the chicken on other species, and so the parameter for chicken in the second stage is altered from 0.5 (no change) to 1 (increase), based on the known increase in chicken in both periods evident in the archaeological record (Figure 39).

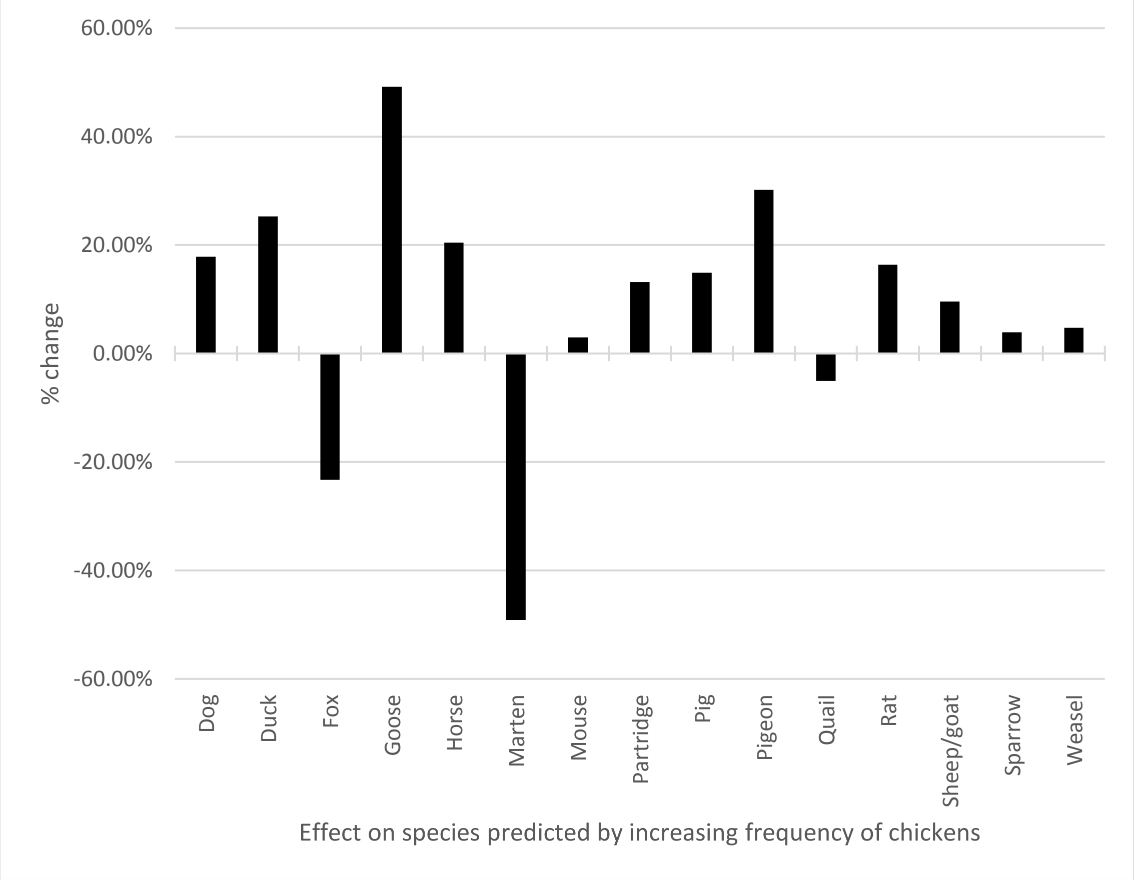


Figure 41. BBN model predictions for change in species frequency when chicken frequency increases.

The results show that when the relationships of the other species with each other are taken into account, an increase in chicken is predicted to have a negative impact on fox, marten and quail.

Its increase should coincide with increases in all other species, particularly goose. Marten had already declined before chicken began to increase substantially in number and so is probably affected by a different variable. The model suggests that the chicken may, nevertheless, have contributed to further its decline in period 3. As quail increase at the same time as chicken, the negative response predicted by the model suggests that chicken is not affecting quail directly. The same is true for the edible domestic mammals (pig and sheep/goat), which decrease in period 3, contrary to predictions, and despite an increase in chicken. Given the predicted decline of the other predators, the positive relationship between chicken and weasel, another egg-eater, is somewhat surprising. The known outcome for weasel, dog, duck, goose, partridge, pigeon and rat do correspond with the model predictions.

The prior beliefs of the species ‘affecting’ the chicken were altered in turn in the third stage of the model (Figure 42). Periods 2 and 3 were modelled separately due to some of the interacting species increasing in one period, but decreasing in another (Figure 39).

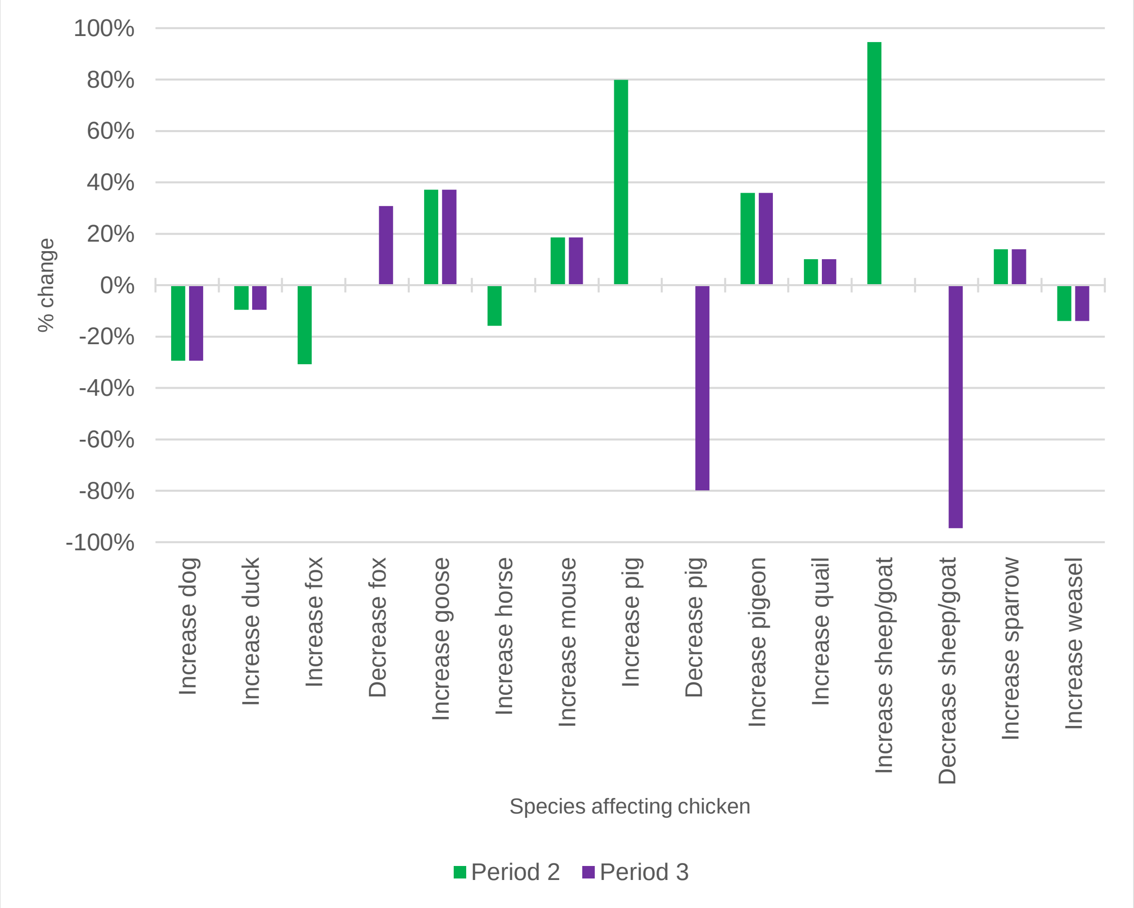


Figure 42. BBN model prediction for changes in chicken frequency as a response to changes in species with which it is calculated to have positive or negative relationships.

The results show that increasing numbers of dog, fox, horse, and weasel is predicted to hinder growth of the chicken population in period 2. This is plausible, given low frequency of chicken in period 2. If, however, dog and weasel were influential factors, then their continued increase in frequency should have prevented the chicken from increasing in period 3, but did not. The horse does not especially change in frequency between periods 2 and 3. Increases in pig and sheep/goat may have benefitted the chicken in period 2, perhaps by association with the domestic sphere. It is the fox, which best matches the pattern seen in the archaeological data, with its increase perhaps inhibiting numbers of chicken initially and then experiencing population decline as chicken grew in number. Increases in goose, mouse, pigeon, quail and sparrow possibly contribute to the increase of chicken in period 3.

7.4.3.2 Part 2: Biotic and abiotic interactions

Further analyses included consideration of abiotic environmental variables, including site type, climate and elevation. The relationships between the abiotic variables and both the chicken and the species affected by chicken (Table 24), were calculated as per the method in Section 7.3.2. Abiotic variables provide information regarding factors outside of the ecological community which could have caused the observed changes. These may better explain the observed changes either for species upon which chicken has an effect, or it may better explain factors affecting the chicken. If not, then these factors can be excluded from the interpretation. Precipitation and elevation variables influence all species. Temperature does not affect chicken, marten, pig or pigeon, but it does not change much over the different time periods (Figure 43).

	Chicken	Dog	Duck	Fox	Goose	Horse	Marten	Partridge	Pig	Pigeon	Rat
Religious	0.65	0.45	0.5	0.43	0.5	0.5	0.5	0.5	0.5	0.58	0.61
Rural	0.5	0.56	0.5	0.63	0.5	0.5	0.65	0.5	0.5	0.45	0.86
Urban	0.39	0.5	0.55	0.44	0.5	0.5	0.39	0.55	0.5	0.5	0.03
Elevation	0.46	0.40	0.27	0.47	0.29	0.41	0.83	0.91	0.43	0.58	0.61
Temperature	0.5	0.43	0.38	0.5	0.4	0.42	0.5	0.94	0.5	0.5	0.62
Precipitation	0.4	0.38	0.43	0.21	0.3	0.39	0.43	0.94	0.43	0.76	0.68

Table 24. Matrix of species relationships with climate and environment variables, whereby the variable in the row affects the species in the column. Green represents a positive relationship, purple represents a negative relationship and grey indicates no relationship.

For the models, the abiotic variable relationships were used as additional values in the second stage of the model. The inter-species relationships were retained. As with the inter-species model, the prior beliefs of each of the abiotic variables were altered in the third stage of the model to reflect known changes (Figure 43), as observed in historical records (climate) or derived from the database (elevation of sites and site status). Each was modelled in turn. Known changes in period 2, compared to period 1, include a decrease in religious sites; and increase in rural and urban sites. The average height of a site above sea level increases, as does annual rainfall. In period 3, urban sites increase at the expense of rural sites; sites are located at lower elevation, and annual rainfall decreases slightly, compared to period 2.

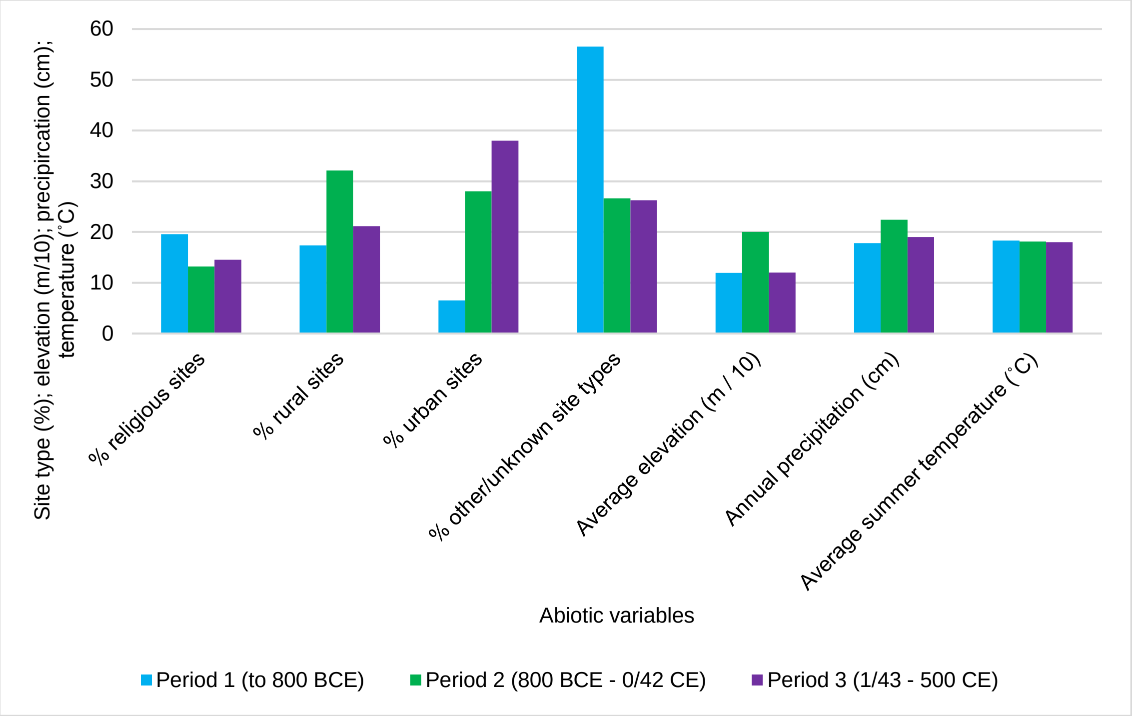


Figure 43 Changes in abiotic variables between periods 1-3. Site type represents the percentage of each type by period.

The results (Figure 44) show that the slight increase in religious sites, decrease in precipitation and a move to lower elevations may explain the rise in chicken numbers. The increase in urban spread, however, is predicted to negatively affect the chicken. This is due, in part, to high frequency of chicken bones found at religious sites (Table 22, and see Chapter 6). Increase in chicken is predicted to cause increases in most of the domestic animals, particularly goose and horse. Pigeon increases in frequency over time, despite negative responses to the climate variables. While it may have benefitted from an increase in religious sites in period 3, this increase is very small and so the increase in chicken would better explain increase in pigeon. The most negative factor on the fox is the chicken. The fox should have benefited from most of the abiotic variables, but the reverse is true for period 3, and coincides with a large increase in chicken. Chicken may have contributed to the decline of the marten, but greater human occupation provides convincing reasons for its decline in both periods 2 and 3, due to negative responses to increased rural settlements (the reverse of the chart in period 2) and increase in urban settlements in period 3, which also tend to occupy lower elevations. Climate variables cannot explain the increase of partridge, for which chicken is the most positive factor. It is likely that the increase in religious and urban sites also contributed. Confusingly, while the rat increases as rural sites decrease, it appears to have a negative relationship with urban spread. Its presence on religious sites is also not a well-known association (Table 22). It is entirely likely that the increase in chicken does indeed increase rat populations, but the nature of the prediction suggests another factor is affecting this species.

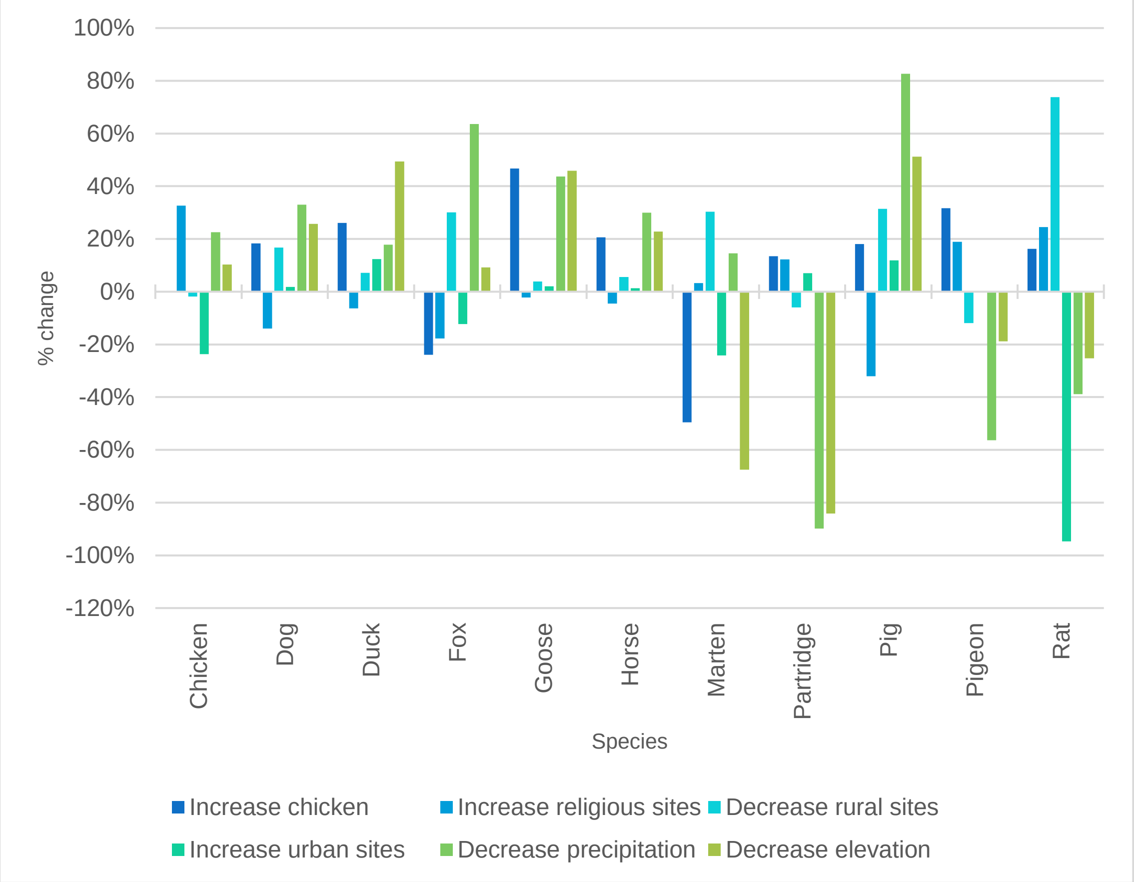


Figure 44. BBN model prediction for response of chicken and species affected by chicken to climate and environmental variables.

7.4.3.3 Part 3: Modern consequences

One of the main benefits of this kind of model is that it is not limited to purely environmental variables. This allows testing of a further theory- that the frequency of small animals is affected by excavation recovery methods. Larger bones are easier to detect during hand excavation, and smaller more likely to be missed unless contexts are sieved (Payne 1972). Other factors influence whether sieving is part of the excavation methodology, and were considered in the models. Type of site was included because religious sites, particularly burials and cremations, are more likely to be sieved. This was confirmed by the relationship calculation (Table 25). The type of excavation, whether described in the report as commercial, rescue or research was included, as this can influence the type of site excavated and whether sieving is performed. The calculations suggest that far higher NISP were identified on rural sites by commercial excavation than expected. On religious sites, higher NISP were recovered from rescue excavations with fewer than expected from research digs. Bone condition can also affect whether more bones are recovered by sieving, and sieving was calculated to procure greater numbers of bones in poor condition.

	Chicken	Dog	Duck	Fox	Goose	Horse	Marten	Mouse	Partridge	Pig	Pigeon	Quail	Rat	Sheep/goat	Sparrow	Weasel	Hand excavated	Sieved	Poor condition	Religious	Rural	Urban
Hand excavated	0.33	0.5	0.5	0.3	0.5	0.5	0.5	0.01	0.52	0.54	0	0.39	0.29	0.31	0.51	0.43	0.5	0.5	0.5	0.38	0.5	0.5
Sieved	0.67	0.5	0.5	0.7	0.5	0.5	0.5	0.99	0.48	0.46	1	0.61	0.71	0.69	0.49	0.57	0.5	0.5	0.5	0.62	0.5	0.5
Good condition	0.34	0.5	0.5	0.4	0.5	0.5	0.36	0.32	0.54	0.51	0.02	0.55	0.42	0.51	0.52	0.55	0.5	0.5	0.5	0.5	0.5	0.5
Poor condition	0.68	0.5	0.5	0.43	0.56	0.5	0.64	0.69	0.46	0.5	0.58	0.47	0.43	0.48	0.5	0.46	0.5	0.5	0.5	0.5	0.5	0.5
Commercial	0.45	0.88	1	0.58	0.69	0.51	0.44	0.48	0.45	0.47	0.44	0.42	0.71	0.52	0.48	0.46	0.5	0.5	0.5	0.5	0.5	0.5
Rescue	0.67	0.43	0	0.49	0.5	0.44	0.79	0.3	0.27	0.36	0.32	0.3	0.18	0.64	0.8	0.27	0.5	0.5	0.5	0.5	0.5	0.5
Research	0.38	0.19	0	0.43	0.31	0.55	0.27	0.72	0.78	0.67	0.74	0.78	0.61	0.34	0.23	0.77	0.76	0	0.5	0.5	0.5	0.5
Religious	0.7	0.43	0.5	0.4	0.5	0.5	0.5	0.5	0.45	0.47	0.58	0.44	0.62	0.49	0.48	0.45	0.43	0.73	0.5	0.5	0.5	0.5
Rural	0.44	0.56	0.5	0.61	0.44	0.5	0.69	0.5	0.47	0.49	0.39	0.46	0.8	0.52	0.7	0.7	0.5	0.44	0.5	0.5	0.5	0.5
Urban	0.38	0.5	0.57	0.43	0.5	0.5	0.37	0.28	0.58	0.55	0.39	0.56	0.03	0.48	0.34	0.34	0.55	0.33	0.5	0.5	0.5	0.5

Table 25. Matrix of species and method variables relationships, whereby the variable in the row affects the species in the column. Green represents a positive relationship, purple represents a negative relationship and grey indicates no relationship.

These values were input into a BBN to assess the predicted increase in NISP if more sieving is done (Figure 45). Inter-species relationships were not included as they are not relevant to this analysis. The results indicate that nine of the selected species in this study would benefit from more sieving. Logically, it is the smaller species which would benefit from increased sieving. Contrary to expectation, database entries of sheep/goat have high NISP recovered by sieving, and sparrow have high NISP by excavation, which is why sheep/goat is included in the nine species that should benefit, but sparrow is not. This is unlikely to be true and so another factor is surely affecting sparrow. It is possible that higher NISP of sparrow are recovered from sieving, but are recorded as small passerines (family level) due to issues with definitive identification (Serjeantson 2009). This might help to explain the low NISP quantity of only 120 bones recorded to genus, but even at family level only 392 NISP are recorded. In period 3, when an increase in the frequency of small mammals is observed, the percentage of sites that were sieved is less than in previous periods (Table 26). This suggests that the frequency of small mammals present was, in all likelihood, higher, but that they were not recovered. The same is probably true for small birds.

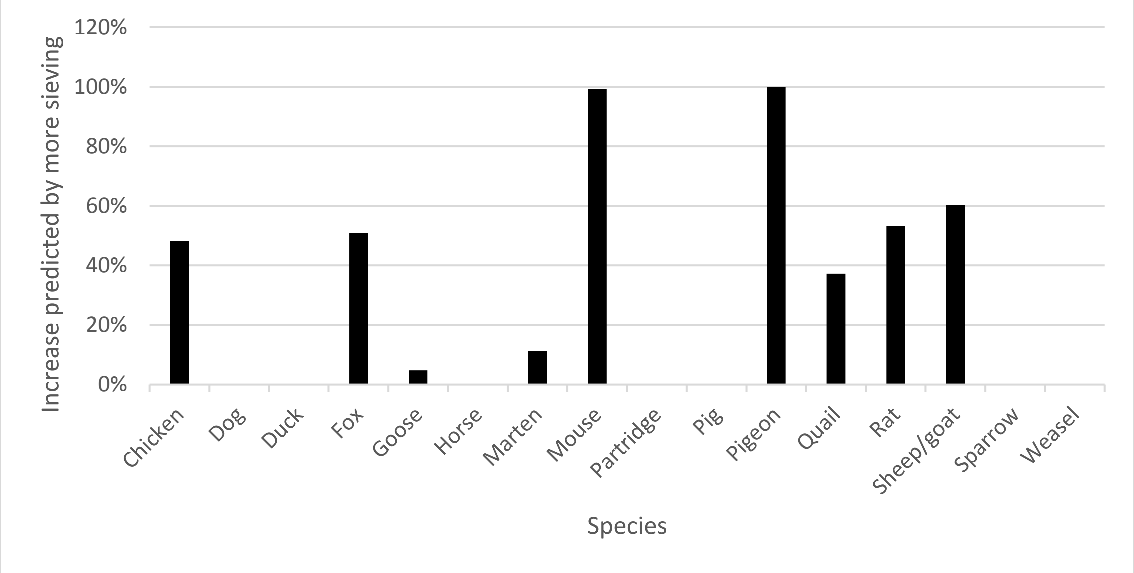


Figure 45. BBN model prediction for recovery of animal bones with more sieving.

	Recovery method	
	Excavated by hand (n=389)	Sieved (n=185)
to 800 BCE (n=23)	52.2	47.8
800 BCE - 0/42 CE (n=160)	61.3	38.8
1/43 - 500 CE (n=391)	71.4	28.6

Table 26. Recovery method by period (%).

7.5 Discussion

Analysis of presence on archaeological sites shows that increase in chicken occurs at the same time as increases and decreases of other species related to the chicken in various spheres of influence. Decreases in pig and sheep/goat and only minimal increase in horse in period 3 suggests that observed increase of other species is not merely because there are more humans and more intensive human activity. It could, however, be affected by changes in human settlement patterns. Period 3 corresponds with spreading urbanisation. In a comparison of site types on which chicken were found in the United Kingdom, Maltby (1997) concluded that chickens were found more frequently in towns. The largest percentage change observed is the chicken in period 3, closely followed by goose and partridge. Neither partridge nor goose reach the frequency of chicken remains, but the large change seen for both is interesting and suggests that they were not adversely affected by the introduction of the chicken - another edible, fighting, domestic bird. The large increase of chicken also coincides with increases in duck, mouse, quail, rat and weasel and decreases in fox and marten. As a predator species, which is known to steal eggs, the fortune of the weasel contrasts with that of the fox and marten. This raises interesting observations for further analysis. Does the chicken affect the increase of weasel and cause fox and marten to decline? Perhaps the weasel is perceived differently by humans (after O'Connor 2013a), or is harder to catch? Does the presence of other domestic species cause higher occurrence of chicken, and vice versa? Or does the increasing popularity of the chicken in period 3 cause decreases in the primary domesticates? Does the method of feeding chickens enhance populations of commensal species such as mouse, rat, feral pigeon and sparrow? Are other factors causing these changes instead?

Tri-plot analyses investigating the assemblage composition of sites containing the primary domestic animals and birds suggest that chicken has a stronger association with pig than with sheep/goat, and that increased frequency of chicken often corresponds with lower frequency of duck or goose. The low frequency of duck and goose was noted to be a general pattern in the Roman period (Albarella 2005). The association of pig and chicken, particularly in towns, was also found in the comparison by Maltby (1997). The association of these two species also fits well with the observation by King (1999) that, in many parts of the Roman empire, intense cultivation of other crops, such as olives, provided a local environment more suited to the keeping of pigs rather than sheep/goat. The chicken would also be well-suited to such environments (open areas with shady trees). Despite the omnivorous diet of the pig, chickens and pigs can be kept together as long as they have plenty of space and are separated overnight (York 2010).

The association of the species does appear to change between periods 2 and 3. In the later period they are more likely to be found together in reasonable frequencies than in the earlier period. This is probably a consequence of increased use of chicken as a food source by the Romans. All of these species feature in Apicius’ recipe book, *De re coquinaria* (385 CE), and the dominance of combinations of all species on domestic sites may imply food waste. This fits with the observation that religious sites show a different pattern and are more likely to contain only one or two of the species, rather than a combination of all three. This is consistent with the findings of King (2005), that at certain temple sites, such as Uley, goat and chicken feature prevalently; while cult shrines usually contain individual deposits of chicken or pig.

In terms of numbers, pig and sheep/goat have a far stronger association with each other than with the chicken. This supports the theory that chicken was not a major part of the human diet, but rather an exotic delicacy (Lauwerier 1986). It is the site type, particularly if religious, that seems more likely to determine the composition of assemblages containing chicken and domestic mammals. Chickens dominate the bird assemblage in both periods, and the increase in sites containing duck and goose in period 3 (Figure 39) corresponds with more varied assemblage composition. It is unclear whether duck and goose might have been more popular if chicken had not been available, or whether the presence of chicken may have encouraged the keeping of other domestic birds.

Calculating the relationships for the Bayesian belief network inter-species model identified that the ecosystem dynamics are different for domestic birds compared to domestic mammals, and, due to differences in species interactions, the chicken belongs in a domestic sphere influenced by the other domestic birds. The models predicted that chicken neither influenced, nor was influenced by, the primary domestic mammals. The models predict that goose and pigeon are most likely to increase chicken. This may be due to their position within the domestic sphere. This corresponds with the conclusions of the tri-plots, which found stronger associations between sheep/goat and pig with one another than with chicken, and may explain the increased variability in the period 3 domestic bird tri-plot. Goose husbandry is well established by the Roman period, but duck domestication appears to be in its infancy, based on ancient literature (Albarella 2005). Positive association of duck with urban settlements and lower elevations may, therefore, be better explained by importation into towns (after Parker 1988). Association with religious sites, consistent with the findings of King (2005), is predicted to be the abiotic variable most affecting chicken.

Chicken are known to be frequently found in towns (Maltby 1997). Depsite this, environmental variables, particularly the spread of urbanisation, deforestation, and construction of settlements at lower elevations explain the reduction of marten in the archaeological record better than the influence of chicken, although exacerbation by increase of chicken in period 3 is not discounted. The models show that the effect of the chicken on the other egg-thief, weasel is little more than expected by chance, and that the weasel does not, in fact, affect chicken. Of the predators, fox matches the pattern seen in the archaeological data, with its increase perhaps inhibiting numbers of chicken initially and then experiencing population decline as chicken appear more frequently in the archaeological record.

As common quail prefer open, agricultural habitats (BirdLife International 2016), it might be expected that they should not be found associated with chicken. Yet, an increase in quail is predicted to increase chicken populations. An increase in chicken, however, is predicted to reduce numbers of quail. The known evidence suggests otherwise. They are both fighting, edible birds and quail could be imported to towns for these purposes. The same is true for partridge, the other fighting bird, which is predicted to increase with increased numbers of chicken. Environmental variables cannot explain what is seen in the faunal record. This suggests that the increase of the chicken is not to the detriment of the other potential fighting birds, which are, of course, also edible.

The best explanation for the quail is the recovery variable. A total NISP of only 45, the least of any species in this study, suggests it is either very unpopular or has not been retrieved where present. That is was unpopular is refuted by Roman recipes for quail in period 3 (Apicius, 385 CE), and that the Greeks (period 2) were known to fight them, along with chicken and partridge (Gal 2008). As a small bird, it is identified in the recovery BBN as one of the species which would benefit from increased sieving.

The other small birds, sparrow and pigeon, along with mouse and rat, are predicted to increase with increased numbers of chicken, and thus the introduction of the chicken may have benefited these species. These species are all small and recovery is likely to have been a major issue. Mouse, pigeon and rat were all shown to benefit from more sieving. This suggests that the frequency of small mammals and birds present was, in all likelihood, higher, but that they were not recovered. With the exception, perhaps, of pigeon, they are all also species which have less direct human interaction and so their presence on archaeological sites is opportunistic. Their remains are more likely to be found where humans have chosen to deposit their refuse, rather than in the main centres of human activity (O'Connor 2013b) and so are likely to be underrepresented in the archaeological literature.

Underrepresentation may have caused the conflicting responses to environmental variables predicted for rat. There is another explanation, not accounted for in the models, which could apply to rat and to fox. As a chicken-keeper, personal experience confirms the relationship between chicken and these two species. Both would thrive around chickens, and eat their eggs, were it not for humans, who will take measures to protect their flock from both animals. Foxes can decimate a flock, while rats can contaminate feed and water and cause illness in chickens. This offers a good explanation for the predicted and observed results for fox, which increases in period 2 while chicken is present, but only in low frequency and has been newly introduced. It decreases in period 3 when chicken increases dramatically and humans are likely to have developed better means of protecting them.

7.6 Conclusions

The impact of the chicken on its environment and of the environment on the chicken was examined using various methods to identify and exclude potential causes and effects. Analysis of the relationships and associations between species found in similar spheres of human activity, and their responses to external environmental factors, allows us to establish which of the many possible correlations are likely to have contributed to, or been most affected by, the success of the chicken in Europe. The results show that chicken demonstrate most affinity with the other domestic birds. Where chicken is found, goose and pigeon are more likely to be found, and, indirectly, duck via a positive mutual relationship between duck and goose. The other fighting birds are not adversely affected by increases in chicken, possibly due to their use as food also. Changing dietary patterns between periods 2 and 3 (King 1999) and particularly the varied diet enjoyed by the Romans (Rowan 2017) might offer a good explanation for the increase in birds, and slight decrease in domestic mammals. Increase in chicken provides the best explanation for the decrease of fox, having established that environmental changes in period 3 should have led to increases in fox numbers. While the chicken may have contributed to the decline of marten, external environmental factors, particularly the spread of urbanisation, offer a better explanation. Previously observed association between chickens and urban settlements (Maltby 1997 and Chapter 5) are supported by these analyses. Chicken may also have aided increases in mouse, pigeon, quail and rat; although models suggest that recovery of these species, which are present in unexpectedly low numbers in the dataset, are affected by retrieval methods and may be under-represented. Recovery models find that sieving would enhance recovery of nine of the sixteen species assessed (over 50%).

Use of a Bayesian Belief Network offers a novel means of interpreting archaeological data. As a model, the results are predictions and must be interpreted as such. They do offer an efficient means of comparing various inter-related aspects of large quantities of data. Careful selection of input data can help to refine or exclude variables to help better interpret the archaeological record.

There is a second application of this technique that could be applied to archaeology with two or more independent datasets. No independent datasets were available for this study, as any accessible datasets were used in compiling the database. Therefore, in this instance, interpretation is restricted to better understanding of the information present in the data. Two independent datasets would enable the user to establish the values from one dataset (stage 1 of the model), and use this information to test hypotheses from another dataset (in stages 2 and 3). This would facilitate testing of site scale hypotheses as well as those at larger regional scales. The method described here for establishing the relationships (prior beliefs) can be easily applied to any archaeological dataset. As independent datasets will have been assembled by different methods and using different sources, the audit strategy outlined in Chapter 2 could be applied to ensure comparability of data quality.

Chapter 8: Conclusions

8.1 Aims of the thesis

The history of the chicken is inherently tied to human society. Without human intervention, the chicken would not have been domesticated and would not have left Asia. Today, it is the most widespread domestic bird, and, while human perceptions towards this species may have changed compared to the past, it remains one of the most important animals in our modern culture and society, not only as a highly-sustainable food source, but also in our material culture. Prior to the wider project of which this study is a part, very little research had been conducted into the natural and cultural history of the chicken, particularly its westward dispersal out of Asia and into Europe. Following millennia of selective breeding, the genetic variability of the chicken has fallen by over half (Muir et al. 2008). One of its ancestors, the Red Junglefowl, is now highly endangered in its original form (Peterson and Brisbin 1998). Therefore, it was an opportune time to carry out research designed to gain a better understanding of where where the chicken came from, how it got to where it is today, and how it responds to changing climates and environments.

The aim of this thesis was, therefore, to fill this gap in knowledge. Responses to climate and environment are critical to the survival of any species, and so this research focused on the early history of the chicken in ecological context. The main purpose of the research was to examine the effects of climate and environment on the chicken, and the effect of the chicken on its environment. This broad topic enabled investigation of several interesting questions, including considering the likely locations for first domestication; early dispersal events; later dispersal events; acclimation to new environments; the development of the species under domestication; and the consequences of introducing non-native species into new environments. Furthermore, the strong association with humans means that any study of the chicken is also a study of the culture, economy and ecology of past societies. The presence of chicken in the archaeological record has the potential to inform us about who was transporting them, when and why. Where they are found provides important information about how they were used by the communities with which they are associated; how much human investment was required, based on environmental suitability at these locations; and the economy of chicken keeping in the past.

This research project assembled information from the vast, but underused, and uncollated, zooarchaeological record of Europe, and employed the novel approach of applying it to both established techniques within the field of archaeology and new techniques used in ecological studies of modern species. Biogeographical techniques, more frequently used in modern planning infrastructure, were employed to understand the spatial distribution of the chicken and suitable routes for its dispersal. The data was used alongside cultural information derived from ancient texts and material culture, and knowledge of modern animal behaviour. This thesis demonstrates how a multi-disciplinary approach, combining zooarchaeology, archaeology, ecology, biogeography and anthropology can enhance our understanding of the past and the present.

8.2 Summary and discussion of the main results

Charles Darwin wrote,

> “It may be doubted, whether if the wild parent-form or multiple parent-forms of the… Fowl… were suddenly carried from their wild native state into the various climates under which the domestic races now flourish, they would be prolific & healthy… I conclude that most animals & plants are capable of spreading beyond their present confines, when no physical barrier is opposed to their progress; the main & general check being the presence of other & better adapted organic beings; a second check being their native acclimatisation but that this may be overcome by habit & natural selection; & that when overcome, the being tends to gain a general degree of flexibility of organisation, allowing it to spread very widely, as far as climate is concerned; its means of obtaining food & escaping danger being then the sole but powerful checks to extension.” ((Darwin, C. R., *Natural Selection; being the second part of his big species book written from 1856 to 1858: Laws of Variation*, 228-229, in Stauffer 1975).

Darwin may have been proven incorrect with his theory of a single origin for the domestic fowl, or chicken (Darwin 1868; Girdland Flink et al. 2014), but his observations on adaptation to climate and environment by this species were very accurate (Stauffer 1975). Niche modelling of both Red and Grey Junglefowl (Chapter 3) confirms Darwin’s assumption that the wild species would not survive well if taken from their native range to other regions where it is known in domestic form. The models demonstrate that the ecological tolerance of Red Junglefowl extends beyond that of the conditions found within Asia, if humans assist in transporting the species beyond its natural confines. The environmental niche of non-indigenous Red Junglefowl is geographically very different to that of the indigenous populations, with suitable conditions found at very different latitudes. Despite this, the niches are ecologically similar. This suggests that junglefowl can acclimate to conditions not present in the indigenous range, and so the environmental conditions present in Asia and South East Asia do not explain the full tolerance of the species. This observation could have implications for ecological niche modelling of other species confined by geography, for example island species.

The novel approach of using current ecological data for an ancestor species, to better understand potential ecological factors affecting an early domestic version, offers new insights into the origin of the chicken. Attempting first domestication of a species in areas that are entirely unsuitable for it would be unlikely to succeed. The models identified that India, Cambodia, Vietnam and the Lao People’s Democratic Republic offer the most suitable environmental conditions for first domestication. In contrast, the locations of sites in India and China which are reported to contain the earliest examples of domesticated chicken (West and Zhou 1988; Fuller 2006; Xiang et al. 2014) were not in environmentally suitable areas, and so are unlikely to have been initial centres of domestication.

Least-cost path models (Chapter 4) of potential routes out of Asia, identified India as being the area with best potential for the origin of early European chickens. Early evidence of chicken is reported from India and China at similar dates (2600 BCE and 3000 BCE respectively). China had been suggested as an initial centre of domestication, from whence chickens spread to Europe via Russia (West and Zhou 1988), but while the least cost path models did predict this route, the associated costs would be too great for a single journey. Until convincing evidence of chicken elsewhere along this route between China and Europe can be found, it must be considered very unlikely that early European chickens dispersed via this route.

A route from India to Europe is not only less costly than a route from China, but evidence of chicken is reported in the Middle and Near East from ca. 1000 BCE (Becker 2013; Redding 2015; Peters et al. in prep). Convincing evidence of trade with the Middle and Near East around that time is known (Sherratt 2004; Lockard 2015), as is trade between the Middle East and the Mediterranean region (Walton et al. 2009), providing a corridor of networks along which the chicken may have travelled.

The least cost models indicated that a terrestrial route from India to China might be challenging, preferring instead a path around the coasts of South East Asia by sea. As only limited evidence is known from South East Asia in the earliest periods, this supports the theory that separate domestication events occurred in different parts of Asia (Miao et al. 2013). As Grey Junglefowl are only currently found in India (GBIF.org 2016b), this suggests that early domestic chickens in Europe with the BCD02 allele, which is only found in Grey- and not Red Junglefowl (Eriksson et al. 2008), are more likely to have arrived from India.

Dating and identification of early specimens of chicken have both been shown to be problematic (Kyselý 2010; Eda et al. 2016; Best et al. in prep), and so it is currently very difficult to establish an accurate chronology for the dispersal of chicken from Asia into Europe. Based on current dating, the evidence suggests that chickens were domesticated in Asia between ca. 2500 - 1500 BCE (Fuller 2006). They were not found outside of Asia until ca. 1500 – 1000 BCE, when they are reported on sites in the Middle- and Near East (Becker 2013; Redding 2015; Peters et al. in prep). It is likely that they then spread from here into Europe via different routes, based on least cost paths into western and eastern Europe (Chapter 4), and are confidently known from several sites in Europe by ca. 800 – 500 BCE (Chapter 2; Best et al. in prep). Thus, it probably took the chicken approximately two thousand years to reach Europe, via a succession of dispersals from different parts of Eurasia at different times (Chapter 4), in association with population movements and trade. Further direct dating of chicken bones outside of Europe is needed to confirm or refute this timeline.

Least cost paths (Chapter 4) from India to Europe via the Middle East closely follow known Bronze Age (Cunliffe 2008), Phoenician (Becker 2013), and Greek (Bolmarcich 2007) trade routes. This association was tested and supported by correlation coefficients (Chapter 5), suggesting that trade was an important factor in the dispersal of the chicken. The least costly routes (Chapter 4) are generally those for which environmental suitability of Red Junglefowl (Chapter 3) was included as an extra variable, suggesting that the easiest path for settlers and traders was, perhaps coincidentally, also best for the chicken. That is not to say that the entire route had environmentally suitable conditions, as is clear from the ecological niche models, but just that the easiest routes are better for the chicken than some of the alternative paths.

Where conditions are environmentally unsuitable (Chapters 3 and 6), then additional human investment would be required to compensate for the variables that make the area unsuitable. How environmentally unsuitable the conditions are, determines the extent of human investment required. Much of Europe is unlikely to have contained suitable sets of environmental conditions for junglefowl (Chapter 3), and so this may have affected transporting and maintaining early chicken populations. Despite this, people chose to keep chickens, and were prepared to make the investments required to maintain a sustainable chicken population. This indicates that it had to be socially or economically viable to do so.

Evidence of chicken in the European archaeological record was compiled in a database, from the earliest reported occurrence of chicken (an unverifiable report of an unspecified number of chicken bones from a site in France, with a highly dubious date of 4701 BCE (Callou 2015)) until the fall of the Roman Empire, ca. 500 CE. The data was assembled from a variety of secondary sources, so before using the database for further analyses, it was first prudent to understand and assess the potential biases inherent in the data, and devise a means of selecting comparable and appropriate quality of data for use in specific analyses. A review of the caveats associated with archaeological excavation, interpretation and reporting was presented in Chapter 2. This chapter also outlined an objective and easily replicable audit strategy which can be applied to most zooarchaeological databases. This not only allowed for selection of suitable data for the analyses throughout this thesis, but will enable the database to be updated with new information in the future. It will also allow for selection of comparable data from other databases to use with the information held within this database. Given increasing availability of such datasets online, it may be of use to others attempting similar research. Unfortunately, while it offers a means by which to select comparable and relevant data, it cannot improve the quality of the information. Ideally, only those sites attaining the highest score would be used for analysis, but this would have limited the data to thirteen sites, none without chicken. I felt that the benefits of using more data in the analyses, outweighed the caveats associated with archaeological reporting (Pitt and Stewart in press). Appropriate quality of data was considered for each individual analysis and selected accordingly.

Cultural associations indicate social acceptance of keeping and breeding chickens, and were identified in the faunal record. Once the species arrived in Europe, sharp increases were observed in the frequency of sites on which chicken remains were found that coincide with the Hallstatt, and then La Tène cultures of central Europe (Chapter 5). These cultures had networks throughout Europe, which connect with trade routes of contemporary cultures (Cunliffe 2008), and could have enabled further diffusion of the chicken. A separate diffusion, corresponding with the spread of the Roman Empire (ca. 0 – 100 CE) was also observed.

By the time the chicken is found relatively frequently in the archaeological record, from the beginning of the first millennium CE, it had had over five hundred years to adapt to the climate of Europe; and/or, people have had over five hundred years to learn how to maintain chicken populations. Given the number of generations this represents (on average, a pure breed chicken today has a life-span of approximately ten years, and hens can begin laying from six-months old (Verhoef-Verhallen and Rijs 2009)), a combination of artificial and natural selection pressures are probably responsible. This would explain why the domestic niche is very different to that of the wild ancestor (Chapter 6). More, although by no means all, of Europe contains suitable conditions for the chicken, compared to the junglefowl. Where suitable conditions are not present, the chicken is generally not found until much later, for example in Russia, the Scottish Highlands and northern Scandinavia, possibly representing the extent at which chicken-keeping becomes economically unviable, or that it simply was not associated with cultures in those regions until later. For instance, it may be more than coincidence that the areas where it is not found until later were not part of the Roman Empire.

Only subtle shifts were identified in the domestic niche over time, moving slightly east in period 2 (broadly corresponding with the Iron Age), and slightly north in period 3 (broadly corresponding with the Roman period). Modelling the domestic niche was only successful using presence-only ecological niche models. Poor results using conventional statistical techniques with presence and absence data (Chapter 6) are suspected to be a consequence of the strong relationship between chickens and humans (Chapter 5). The chicken occupied a different role in the domestic sphere to most other livestock (Chapter 5). Further analyses, using a Bayesian Belief Network (BBN, Stafford et al. 2015), refined this observation, suggesting that the chicken belongs in a domestic bird sphere, which is different to that of the domestic mammals (Chapter 7). The domestic bird sphere has stronger correlations with wild species than the domestic mammal sphere, thereby blurring the distinction between the environments in which chickens are found and where they are not found. This observation was also made of the habitat at site locations, based on the faunal record (Chapter 5).

Where and when the chicken appears in the faunal record is determined by human use and perceptions of chicken. While use changes slightly over time, there is continuity in the perception of this bird as an exotic, high-status animal during the time period covered by this research. Analyses of the faunal and archaeological evidence were performed alongside a review of the literary evidence, to gain a better understanding of why chickens are found on certain sites, and how and why this might change. The findings of this study (Chapter 5) are consistent with the theory that chickens were initially used primarily for ritual sacrifice or feasting (Poole 2010; Sykes 2012). Of 131 ritual or funerary sites, chickens occur on 87 per cent, and are often found in large numbers (Chapter 5). This is second only to pig, which occur on 91 per cent of these sites. Comparison of species assemblages suggested that religious sites contained combinations of fewer species types than other types of site (Chapter 7), implying that those species selected had been chosen for a specific purpose. King (2005), observed similar patterns at certain temple sites, such as Uley, where goat and chicken feature prevalently; and at cult shrines where individual deposits of chicken or pig were found. It is evident from the literature that the chicken was associated with several religions and gods, within and outside of Europe, explaining the choice of chicken as offerings to these deities (Chapter 5). Association with Roman gods, and with religious rituals is known from ancient texts (Varro (*De Re Rustica*), Cicero (*De Divinatione*), Cato (*De Agri Cultura*), but the extent of the chicken's importance for this purpose is even more apparent in the faunal record, with large numbers of chicken bones found at temple sites, such as Uley (2013 NISP (Woodward and Leach 1993)) and Tienen (8922 NISP (Lentacker et al. 2004)).

Cockfighting is harder to detect in the archaeological record, but was another early use for chicken, based on the review of ancient texts (Caesar, *Gallic War*; Columella, *De Re Rustica*) and the occasional images of this activity in the material culture (Pitt and Feider 2016; Feider 2017) discussed in Chapter 5. Skeletal elements and observations regarding the sex or size of the bones were noted in the database where reported (Chapter 2), but this information was too scarce for broad scale analyses. It is unclear how far absence of observations which might indicate this activity (Serjeantson 2009), such as large numbers of spurred tarsometatarsi, particularly if the spur has been shortened, have not been reported because they are too difficult to identify, or because this activity was not widely practised outside of Italy.

Low frequency of chicken remains on sites dated prior to the first millennium, suggest that it was not particularly used as a food source (Chapter 5). From the first millennium, evidence for the eating of chicken is present in the literature, for example in the Apicius recipe book (Apicius, 385 CE), and Vindolanda tablets (Tab. Vindol. II 302). This corresponds with the faunal record, with chicken found on far greater numbers of sites and in greater frequency on those sites, compared to the previous period. The Europe-wide analyses are also consistent with Maltby's (1997) observation for the United Kingdom, that chickens are more usually associated with urban settlements in the Roman period. Compared to the other primary domesticates, however, frequency is still relatively low (Chapter 7). The evidence suggests that people in the Roman period retained their perception of the chicken as an exotic, high-status animal, despite increased use for food (Chapter 5).

Having been transported from Asia, and being relatively rare compared to the other domestic animals, it is unsurprising that the chicken was perceived as an exotic bird. While the consequences of introducing commensal (O'Connor 2013) and wild (Stewart 2009) species have been discussed in terms of how they affected their ecosystem, domestic animals have only been discussed as ‘movement packages’ of humans, animals and agriculture during the period ca. 7000 – 3000 BCE. Some argue for association of domesticates and agriculture (Larson et al. 2014), while others argue that animal domestication pre-dates agriculture in many regions of the world (Fuller 2006), or post-dates agriculture as a process of progression from hunter-gatherer practices (Craig et al. 2011). The chicken does not fit within this time frame, and was brought into an already established domestic ecosystem, enabling examination of the causal effect of the introduction of non-native species within human-adapted environments.

Chapter 7 presented a methodology for adapting any archaeological dataset for use in a Bayesian Belief Network (Stafford et al. 2015), to investigate multiple interactions in the past. The results suggest that increases in chicken coincides with increases of other edible poultry, and with commensal species, such as mouse, pigeon, and rat (Chapter 7). The association of chickens with the spread of urbanisation (Chapter 5) is consistent with an increase in synanthropic fauna benefitting from human activity (Boev 1993; O'Connor 1993). The provision of food and water for the chickens presents a readily available source for commensal species. A decrease in fox is seen in bone assemblages as the numbers of chickens rise (Chapter 7). This is assumed to be a consequence of human populations protecting their flocks, as other external environmental factors could not explain their decline; unlike for other species, particularly the marten. Analyses of assemblage composition identified strong associations between chicken and pig, suggesting that these species may have been kept together. It has been noted that the environment created by the cultivation of other popular plant species, such as olive or fig trees in the southern Mediterranean would be ideal for pigs (King 1999). Such environments would also be good for chickens. Both could also be kept in towns and take advantage of being fed on human discarded food.

A unique application of the BBN (Stafford et al. 2015), enabled not only the consideration of biotic and abiotic interactions, but also the examination of archaeological recovery methods on the retrieval of faunal remains. Sieving was predicted to enhance recovery of more than 50 per cent of the species, confirming Payne’s (1972) findings, despite some excavations noting the opposite result (Zeiler and de Vries 2008; Elevelt 2012).

To conclude, this thesis investigated the history of the chicken, from its earliest beginnings to it becoming permanently established in Europe. The novel application of ecological and biogeographical techniques offered new insights into the origins and spread of the chicken westward to Europe. It identified regions of Asia which would be suitable for first domestication, and suggested that India offers the best potential as the region of origin for European chickens. It showed that the introduction of this non-native species into Europe is likely to have affected other species in its spheres of association, but the primary relationship for the chicken is with humans. The compilation of an extensive number of zooarchaeological records in Europe, identified where and when chickens were present in Europe, filling a previously noted gap in knowledge (Storey et al. 2012). Multi-disciplinary investigation of this database, combining literary evidence, material culture, ecological techniques and spatial and statistical analyses, helped to characterise past perceptions of human-chicken interactions. The results showed that the relationship between chickens and humans in the past was very different to today, with the bird held in high regard and probably revered as an exotic animal. Due to association with particular cultures and religions, this status made the keeping and breeding of early chickens socially and economically viable, despite environmental conditions initially being largely unsuitable. Over millennia, the chicken acclimated or adapted to its new ecosystem under domestication, shifting its ecological niche substantially from that of its ancestor.

Compiling the data necessary for this study made me more aware of the many caveats associated with archaeological datasets, particularly variations in archaeological coverage and reporting between countries, and the challenges associated with identification, dating and context security. This does not make the data uninformative, but demonstrates the need for caution in interpretation. While a means by which to assess quality of data was proposed, it nevertheless highlighted the need for further direct dating of chicken bones to establish a true chronology of the chicken. It also demonstrated why sieving should be included in any excavation strategy.

Following on from this research, there are several recommendations for further study. It would be interesting to understand the dispersal of chicken to other regions of the world, which have not yet been studied, for example Africa. Ecological niche modelling of other Galliformes in the future, particularly the pheasant, which originates from a similar region to junglefowl and is now found globally, could enhance understanding of how other species in the same family respond to changes in climate. It was not possible to include every European site with birds, or even every instance of chicken, due to the time constraints of the project, so the database would benefit from additional entries, particularly sites with negative evidence for chicken (see Chapter 2). The information contained within the database has several other potential applications to answer different research goals (see appendix III for an overview of the information recorded). The interactions of other species could be examined using the Bayesian Belief Network method, and, with the benefit of an additional, independent dataset, regional, or even site level, interspecies relationships could be investigated, providing better evidence for interpretation of the faunal record. Advances in genetic studies will soon be able to identify the development of certain traits in chickens, such as non-seasonal laying and pea combs. Some of these traits may be related to climate and environment and so examination in ecological context will provide additional information to better appreciate how and why they occurred.

Finally, being part of an inter-disciplinary project team made me fully appreciate the benefits that can be gained by integrating information and techniques from other disciplines. Such an approach offers a means by which to better understand the faunal remains, and the behaviours of the people who shaped the archaeological record we uncover. In this study, a combination of zooarchaeology, archaeology, ecology, biogeography and anthropology enhanced knowledge of where the chicken came from, how it adapted to new climates and environments, and about human-chicken interactions in the past. The chicken is not just a sustainable source of meat; it is a remarkable and fascinating bird which has been an important part of European society and culture ever since it arrived. I hope that some of the information in this research might help to conserve its ancestor in the wild, and to influence future human-chicken interactions.

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Appendix I: Paper submitted to British Archaeological Reports, December 2016

Garbage in, garbage out? Issues and suggestions for small vertebrate zooarchaeological databases

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Abstract: Recent decades have seen several species-based studies but the chicken, Gallus gallus domesticus, one of the most culturally important animals, has been almost completely neglected due to a lack of compiled archaeological evidence. As a small, light, easily tamed, and easily transported domesticate, it is an ideal species to inform human dispersal in the Late Prehistoric period and Early Antiquity. Furthermore, utilisation extends beyond direct exploitation of products (e.g. meat, eggs and feathers) into the realms of religion and culture. This informs perceptions of behaviour, society and belief of these early civilisations. We discuss the challenges associated with amalgamating the necessary archaeological records, and demonstrate how multi-disciplinary approaches can be employed to fill in gaps and enhance understanding of the archaeological record. While we recognise that each dataset is necessarily limited by the scope of its study aims, we detail the issues we encountered that would be broadly applicable to other similar endeavours, and offer suggestions for mitigation.

Key words: Chicken, database, zooarchaeology, auditing strategy, small vertebrates

1. Introduction

People have engaged in trade since the earliest civilisations. This has involved movement of animals and plants, both purposefully and inadvertently, across continents. This transfer of products, especially non-native animals, is recognised to be a valuable source of cultural, economic and ecological information (Sykes 2012). There have been a number of studies investigating these factors (Diamond 2002; Larson et al. 2007; Conolly et al. 2011) but the chicken, one of the most culturally important animals, has been largely ignored.

An eastward expansion of the domestic chicken into Oceania has been demonstrated using archaeological evidence (Storey et al. 2008) and DNA analysis (Gongora et al. 2008), possibly spreading via this route to South America (Storey et al. 2007; Fitzpatrick and Callaghan 2009). However, little is understood regarding its dispersal elsewhere. Storey et al. (2012) briefly discuss European dispersal, but conclude that insufficient archaeological evidence has been compiled for further analysis.

Europe is interesting from an archaeological point of view because of its implications for human-chicken interactions and cultural associations. Charting the dispersal of the chicken through Europe over time using the archaeological record should enable greater understanding of European trade routes, human population movement, and changes in cultural behaviour. The chicken was transported from origins in Asia and South-east Asia after ca. 2500BC (Zeuner 1963). It is treated as an exotic species, as evidenced through frequent association with ritual sites (figure 1), and in the material culture. Exactly when it was domesticated and the route it took to Europe remains a subject of speculation, but Caesar’s writings (Gallic War, V, 12) confirm it was present in Britain, at the edge of Europe, by the Iron Age.

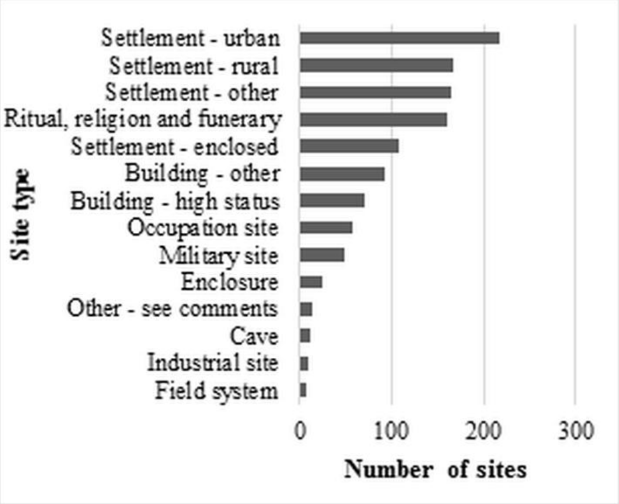

Figure 1 Site types recorded in our database. After settlements, Ritual, religion and funerary sites are most frequent, indicating the chicken's significance in this respect

Understanding why an animal is selected for domestication and the implications this has for the society, culture and ecosystem into which it is introduced, requires a sufficiently broad archaeological dataset.

This paper discusses the challenges of assembling such a dataset. We discuss means of acquiring sources and visualising and supplementing gaps in information. We examine how the key factors of reliable dating, context and identification are influenced by where, when and how a site was excavated. Each of these factors have important associated recovery and reporting biases. We offer suggestions for mitigation, including use of a simple and objective auditing strategy. Given that assembling and sharing databases is becoming increasingly common in zooarchaeology, it is important that those using them can appreciate general biases inherent in zooarchaeological databases; can identify high versus low confidence entries; and can replicate the methods by which this weighting is achieved.

2. Materials and Methods

2.1 Materials

The primary purpose of compiling a database of archaeological information is to answer specific research questions. Our research is concerned with the presence or absence of domestic chicken in Europe up to 500AD. We chose to compile our information using Microsoft™ Access (2010-2016 versions). Relational databases facilitate easy extraction of data, which can be exported to other applications.

The archaeological data was gathered from various sources. Most of the data for all countries came from bibliographic cross-referencing or online searches combining scientific names and synonyms for particular species, and for relevant epochs in both English and European languages. The British Library is an excellent resource for books and journals unavailable elsewhere. Many reports and articles are readily accessible online. Within the UK, many of the unpublished reports from commercial excavations are available on the Archaeological Data Service (ADS) online [www. http://archaeologydataservice.ac.uk]. These include some regional summaries of information. The original reference was consulted where easily available. The French Natural History Museum has collated much of the French zooarchaeological record and broad detail is available on its Inventaire National du Patrimoine Naturel [https://inpn.mnhn.fr]. The sources are referenced and can sometimes be found on regional archaeological websites. Many researchers upload their articles to Academia.edu or Researchgate.net. Requests for materials can also be sent direct to the author, with mixed results. Email enquiries to local historical or archaeological societies for literature both in the UK and France yielded positive results.

All sites included were assigned co-ordinates in latitude and longitude. This enables use of the data in geographical information systems (GIS) software for spatial mapping, data visualisation and extraction of some missing variables. We use ArcGIS (v.10.2.2) for this purpose. It also enables use of the data in cross-disciplinary techniques, such as biogeographical modelling or ecological niche models (Pitt et al. 2016).

2.2 Zooarchaeological recording and associated caveats

To meet our research aims, the minimum criteria for inclusion of a source included recording of geographic location to at least place name, the presence to at least family taxonomic level of bird species (see Morales (1993) for discussion of issues with “general categories”), and a pre-500AD date. We recorded geological and environmental data, where available, and included all fauna. We use sites lacking chicken, but with evidence of other birds, to infer absence of chicken. Four levels of the database recorded factors associated with 1. site, 2. phase, 3. context, and 4. species evidence. These were linked to sub-tables containing ancillary information, including detailed species information, habitat, chronology and associated culture. The design of the database included information to enable us to assess anticipated issues, such as dating method, context type, and additional comments regarding bones. Ultimately, the performance and usefulness of any database is limited by the quality and quantity of its entries.

2.2.1 Quantity of data

While modern political boundaries have little bearing on the actions of our ancestors, they do affect the quality and quantity of available archaeological evidence. On a broad spatial scale, such as ‘Europe’, this varies greatly. The UK and France have stricter policies regarding preservation of the historic environment and this is apparent in the quantity and availability of data there (figure 2). Although our database is dominated by sites from these two countries, we did not attempt to include all sites from those countries, but rather aimed to achieve a broad geographical and deep time coverage. It would be an almost impossible task to find details of every site in Europe containing birds, particularly within the time-scale available for our project, so time and effort was employed locating sites in areas of Europe where we lacked data.

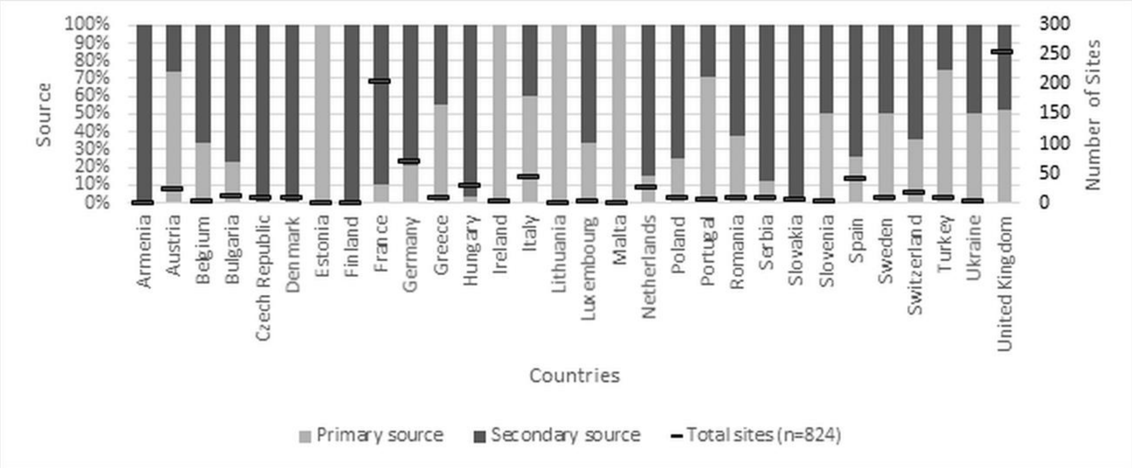

Figure 2 Frequency of sites in our database by country (line markers) and source used (bars in per cent)

Contacts have been made over the duration of the project in countries for which little faunal information was recovered using our search methods, and these have confirmed that in most cases it simply has not been recorded, or at least not reported.

Archaeological reporting varies greatly in its scope and detail. This is especially the case with zooarchaeological reporting. The three primary factors affecting quality of data of any archaeological database are likely to be secure dating, confident interpretation and accurate recording/reporting. In an ideal world, each site would be visited and each assemblage reviewed by the database author. In practice this is unfeasible. Due to the nature of archaeology, most sites no longer exist and the resulting assemblages are not always accessible. The written report is, therefore, the only practical source of data for compiling databases of evidence on broad spatial and temporal scales.

Written reports come in several forms, ranging from primary sources, such as monographs, unpublished site reports or isolated bone reports, to secondary evidence, such as books and journal articles on related themes or species-specific gazetteers. Primary sources were used where available (figure 2). In the absence of being able to verify the details of every site and assemblage, the report was assumed to be accurate although issues such as potential contamination or disturbance were noted.

Combining such diverse information into a single usable database presents a challenge. Not all reports contain the same information, but some factors may still be worth recording if reported, such as geology (which affects vegetation). This can be supplemented using readily available GIS shapefiles. These files tend to be at coarse resolution, so accuracy can be tested using the evidence at local site level to determine whether this variable can be used in other analysis techniques, such as ecological niche models. As with all databases, there is a fine balance between recording enough and recording more than is useful.

2.2.2 Quality of data

Understanding an archaeological site is primarily governed by three inter-related factors. They are confident dating, secure stratigraphy, and accurate interpretation of the evidence. Where, what and how a site is excavated affects this outcome. The study aims influence the reporting; and databases are limited by the report content.

‘Where’ is important, for several reasons. Soil conditions on a site affect the preservation of animal bones. Poor preservation hinders identification to species and means that smaller bones would be less likely to survive or be recovered. This is particularly challenging for research focused on presence of birds and/or small mammals (Payne 1972). If GIS layers are shown to be accurate then they can be used to predict where bone preservation is likely to be poor, thereby identifying areas of potential false absences.

‘Where’ also determines the extent of later disturbance on a site. Many of the earliest recorded examples of Red Junglefowl and/or chicken in Europe, such as Bora Gran d'en Carreres (ca. 14000BC) and Reclau Viver (ca. 5000BC), Spain (Petit 2005); Borduşani-Popină (ca. 4250BC), Romania (Gal and Kessler 2003) and Loona (ca. 3000BC), Estonia (Mannermaa and Lougas 2005) all note dating or stratigraphic issues.

Bird bones are small; so individual bones can be transported through different layers by bioturbation. Unless specifically noted, this is difficult to recognise. Chicken bones are found in very small frequencies (sometimes single bones) on pre-Roman sites. This is unsurprising for a newly-introduced exotic species. For this reason, excavation technique, which can vary by country, is important. Legislation in some countries may request particular approaches. An open-area approach excavates large areas by context, and is favoured by many western European countries, while the USA and several countries in Asia prefer a box-grid approach, excavated vertically in spits (Drewett 1999). Both methods have advantages and disadvantages; however, limited frequency and potential for assisted stratigraphic mobility of small animal bones highlights the importance of understanding context security if possible, and the method of dating. Open area excavation lends itself better to this. In an ideal situation the bone will have been radiocarbon dated and found in a sealed context, although this is rarely the case.

Another problem is that ‘what’ has been excavated may not actually be chicken. Recent literature has highlighted issues with identification of early evidence of chicken (Kyselý 2010; Peters et al. 2015; Eda et al. 2016). The primary cause is similarity in appearance to other Galliformes. Identification of bones to species is limited by the knowledge of the bone specialist. Most countries only have a few avian bone specialists. Knowledge and identification techniques have, however, improved in recent decades, and a wealth of easily accessible resources, including books, electronic articles, electronic reference collections and special-interest forums have extended the discipline beyond the domain of a few individuals. Advances have also been made in genetics and morphometrics, both excellent methods for identifying to species, which have gradually reduced in cost of both time and money. Even so, these methods are only generally used to verify important dubious examples.

With modern excavations ‘how’ a site is dug corresponds to the reason for excavation. Research excavations in the UK are generally funded by universities, often as training digs, which means they are usually excavated in great detail, but by inexperienced archaeologists. British commercial excavations are funded by developers, are excavated by professional archaeologists, and are under tight time pressures to complete. This can result in different study aims. As recently as a decade ago, animal bone was often not considered important enough in commercial archaeology to always retain or to fully analyse (authors personal experience). This situation has been somewhat rectified by new guidelines from Historic England (Baker and Worley 2014).

Where faunal remains are considered, often only mammals are reported, and occasionally only primary domesticates, presumably because primary domesticates tend to be larger and less easy to overlook during excavation. Recovery method is also a factor. Sieving, in addition to hand collection, is likely to result in the recovery of greater quantities of smaller bones and artefacts, but costs additional time and money. It would simply not be possible to sieve every context on every site.

2.2.3 Consequences of quantity and quality issues

These factors result in huge variation in the presence and scope of faunal information reported. It is often unclear whether absence of faunal remains reflects true absence, recovery bias, or project scope. Despite this, due to reliance on secondary sources, we have to trust the identification of the report author. Additional detail in the report including associated bone groups, bone size, bone preservation, bone elements, comparison to similar species, and even large quantities of the same species provides some reassurance that the identification is correct and the bone has not been found where it lies due to taphonomic or other factors. In terms of our database, limited reporting of avian remains greatly reduced the quantity of eligible reports. The total number of sites included was 824, including a 13 per cent sample of sites with birds, but no chickens, for comparison.

3. Strategy for mitigation

Given the issues outlined in section 2, we designed and implemented a simple, replicable audit strategy (table 1) to allow future updates to the database. We identified objective components of the written report to ascertain how well the key inter-related factors of dating, interpretation and accuracy are reported at each site. Our strategy divides the information into four 'quality' groups- 'Poor', 'Adequate', 'Reasonable' and 'Good'. Each key factor has levels 1-3, with '1' being the most detailed and/or accurate and '3' the least.

Level	Dating	Context	Recording accuracy
1	Scientifically-dated animal bone Reason: Dating accuracy	Sealed context Reason: No intrusion; dating accuracy	Associated-bone-group or well-described elements Reason: Accurate species identification
2	Bone(s) recovered from a closely-dated cut feature Reason: Dating by cultural association is more likely to be accurate; reduced chance of intrusion	5+ chicken/bird bones. Reason: Larger quantities of bones belonging to a single species make it less likely to be intrusive	Species smaller than a chicken recorded Reason: Small bones have been retrieved and analysed, rather than false absence
3	Well-dated or well-stratified site Reason: Context information is not always available, despite the site being well-dated by e.g. C14, coins, distinctive artefacts	Total fauna = 100+ bones Reason: Implies deliberate deposition	Above average bone preservation Reason: Better preserved bones are easier to correctly identify to species
Good	2 or more level 1 criteria		
Reasonable	2 or more level 2 or better		
Adequate	2 or more level 3 or better		
Poor	<2 of any level, or over-riding issue (provide detail in comments)		

Table 1 Audit strategy, including reasons and method for applying scores

Two or more of each category level are required to achieve the respective score. Otherwise, a well dated bone may still not be a correctly-identified chicken; or may be intrusive to that site or feature. Requiring all three criteria in a level would be so constrictive as to render the upper scores almost unattainable. The upper score is still only achieved by very few sites, which can be considered to be secure evidence, with the majority falling into the 'reasonable' and 'adequate' categories (table 2).

Audit score	Poor	Adequate	Reasonable	Good	Total
No. of sites	129	332	352	11	824

Table 2 Frequency of sites by audit category

4. Discussion

Applying the strategy does not invalidate any sites, but allows us to weight potential reliability or error. This enables tailored use of appropriate information for analyses of different types and scales. For example, mapping locations where a species has been reported is not limited at all by quality or accuracy of data. Spatial mapping of this information allows us to easily visualise where and when chickens are reported to have been present (figure 3).

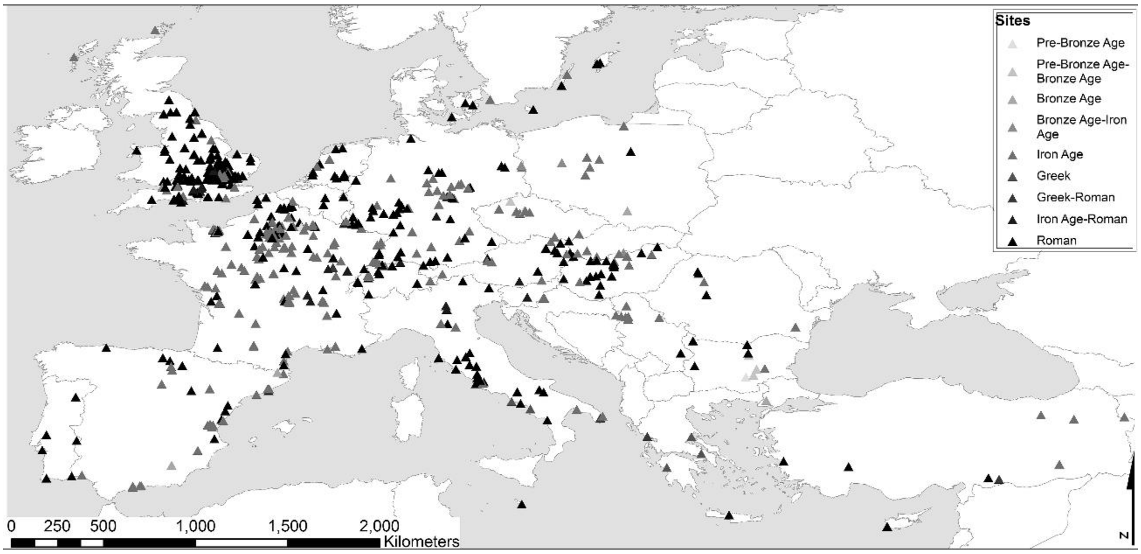

Figure 3 Distribution of database sites

We performed a preliminary analysis of our strategy by assessing the hypothesis that there will be higher frequency of chicken fragments on Roman compared to Iron Age sites (figure 4). It is a logical assumption based on the chicken becoming more established in Europe, and increased use as a food source, as attested by recipes of the time (Apicius, De re coquinaria, ca. 385AD).

Given the highly mobile nature of chicken bones, most future analyses will need to exclude sites with over-riding issues, including dubiously early dates, unless these are verified in the future; and sites with noted disturbance and intrusion. Otherwise the quality of sites used will depend on the type and scale of the analysis.

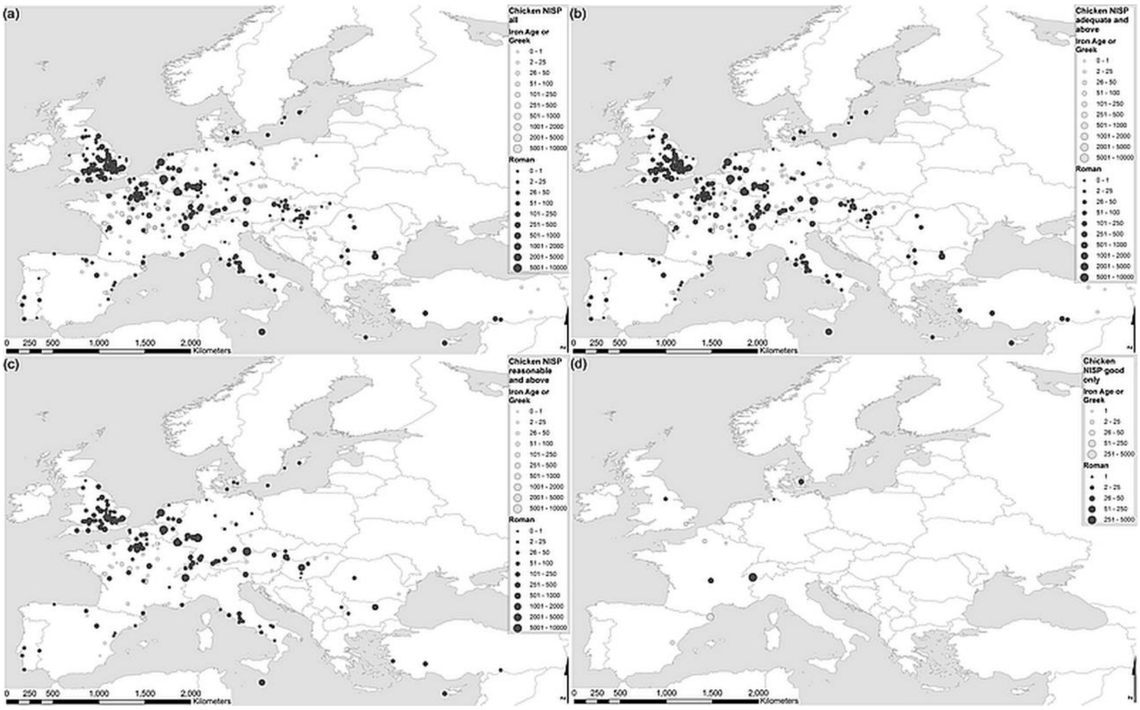

Figure 4 Increase in frequency of chicken bones from the Iron Age or Greek to Roman periods using records based on audit scores (a) all, (b) adequate or above, (c) reasonable or above, (d) good. 'Reasonable' or above provide the clearest indication of the expected outcome, while using only 'good' records provides an insufficient sample for this kind of broad scale analysis

5. Conclusions

Issues which would potentially affect the future use of our database have been highlighted in this paper. Caveats related to quality of data, including secure dating, secure contexts, and secure species identification, are applicable to most zooarchaeological databases of any species. Assembling data over broad temporal and spatial scales, or including small vertebrates, presents additional complications. Quality and quantity of archaeological reporting tends to be influenced by when, where, how and why the excavation occurred. We offer suggestions for mitigating some of these issues. We present a simple audit strategy which offers an objective means by which to evaluate quality of data taken from diverse sources, based on key factors. We suggest that information can be supplemented, visualised and assessed using GIS, which is becoming increasingly used in archaeology but can be used to much better effect to enhance the archaeological record.

We are in the early stages of using the data for analyses, so precisely how well our mitigation works is a subject for future discussion. We appreciate it is only one solution, which is somewhat governed by our research aims, and welcome suggestions for improvement. We hope that some of our observations and conclusions can help inform future similar endeavours.

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Appendix II: Database sites and references

Table of database sites, organised alphabetically by country. See *Glossary* for description of site types. Sites containing more than one site type indicates a change of use at multi-phase sites. Negative dates represent BCE, positive dates are CE.

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
Armenia	Argishtikhinili, Armavir	-800	-800	1	Settlement - urban	Yes	(Liarsou, A., 2013)
Austria	Bernhardsthal, Mistelbach	90	250	1	Settlement - rural	Yes	(Riedel, A., 1996)
Austria	Göttlesbrunn	-260	-150	1	Building - other	Yes	(Pucher, E., 2006)
Austria	Gracarca bei St. Kanzian	-900	-701	1	Settlement - other	No	(Galik, A., 1998)
Austria	Gurina bei Dellach	-15	50	1	Settlement - urban	No	(Galik, A., 1998)
Austria	Heiligtum, Frauenberg bei Leibnitz	-150	-28	1	Ritual, religion and funerary	Yes	(Grill, C., 2009)
Austria	Kiabichl, Faggen	-500	-401	1	Settlement - other	Yes	(Tecchiati, U., 2012)
Austria	Magdalensberg	-100	99	1	Settlement - urban	Yes	(Hornberger, M., 1970)
Austria	Mauerbach, near Vienna	50	199	1	Building - high status	Yes	(Riedel, A., 1999)
Austria	Michelstetten	-190	99	2	Settlement - rural	Yes	(Holzer, V., 2009; von Schmitzberger, M., 2009; Heiss, A. G. and Kohler-schneider, M., 2009)
Austria	Moserfeld, Moserstein, Dürrnberg	-550	-461	1	Ritual, religion and funerary	Yes	(Abd El Karem, M., 2012)
Austria	Nickelsdorf	100	299	1	Building - high status	Yes	(Riedel, A., 2004)
Austria	Putzenfeld, Dürrnberg	-460	-110	1	Settlement - other	Yes	(von Schmitzberger, M., 2012)
Austria	Ramsautal, Dürrnberg	-450	-201	4	Settlement - other	Yes	(Pucher, E., 1999; Swidrak, I., 1999; von Schmitzberger, M., 2012)
Austria	Roseldorf-Sandberg, west Weinviertel	-250	-151	2	Ritual, religion and funerary	Yes	(Holzer, V., 2009; Abd el Karem, M., 2011)
Austria	Sanctuary of Jupiter Heliopolitanus, Carnuntum	175	225	1	Ritual, religion and funerary	Yes	(Gál, E., 2013)
Austria	Schleinbach, Mistelbach	-2300	-1600	1	Settlement - other	No	(Pucher, E., 1996)
Austria	Sennbühel, Bregenz	0	99	1	Ritual, religion and funerary	Yes	(Deschler-Erb, S., 2011; Ertel, C., 2011)
Austria	Simonbauerfeld, Dürrnberg	-150	-15	1	Settlement - other	Yes	(Abd el Karem, M., 2008)
Austria	Steinbühel Villa, Bregenz	80	199	1	Building - high status	Yes	(Deschler-Erb, S., 2011)
Austria	Traismauer/Augustiana	0	399	1	Settlement - urban	Yes	(Riedel, A., 1993)
Austria	Tropfstein cave and Tunnel cave, Kugelstein bei Deutschfeistritz	0	499	1	Ritual, religion and funerary	Yes	(von den Driesch, A. and Pöllath, N., 2000; Modl, D. and Kraschitzer, J., 2014)
Austria	Walpersdorf Nord	-550	-401	1	Settlement - other	Yes	(Pucher, E., 1998a)
Austria	Wolfholz, Brunn am Gebirge, Nr. Vienna	0	399	1	Occupation site	Yes	(Pucher, E., 1998b)
Belgium	Mithraeum, Grijpenveld, Tienen	250	275	1	Ritual, religion and funerary	Yes	(Lentacker, A. et al., 2002; 2004)
Belgium	Place du Marché aux Légumes, Namur	0	299	1	Settlement - rural	Yes	(Liarsou, A., 2013)
Belgium	Zennegat, Mechelen	-1890	-1740	1	Other	No	(Meylemans, E. et al., 2011)
Bulgaria	Bagatchyna	-4000	-1001	1	Other	No	(Boev, Z., 1996)
Bulgaria	Bela Voda	200	399	1	Building - high status	Yes	(Beech, M. J., 2007; Boev, Z. and Beech, M. J., 2007)
Bulgaria	Colonia Ulpia Traiana Ratiaria	100	399	1	Settlement - urban	Yes	(Beech, M. J., 2007; Boev, Z. and Beech, M. J., 2007)
Bulgaria	Early Bronze Age settlement near Dyadovo village (vicinity of the town of Nova Zagora)	-3050	-3050	1	Settlement - other	Yes	(Boev, Z., 2006)
Bulgaria	Galabovo	173	289	1	Settlement - other	Yes	(Boev, Z., 2004)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
Bulgaria	Hotnitsa, Orlovka, Tarnovski Visochini Hills	-4900	-3001	1	Settlement - rural	Yes	(Boev, Z., 2009)
Bulgaria	Iatrus, Krivina	300	475	2	Military site; Settlement - other	Yes	(Bartosiewicz, L. and Choyke, A. M., 1991; Beech, M. J., 2007)
Bulgaria	Kabyle ancient town	-700	399	1	Settlement - urban	Yes	(Boev, Z. and Ribarov, G., 1993)
Bulgaria	Nicopolis ad Istrum	109	450	2	Settlement - urban	Yes	(Beech, M. J., 2007; Boev, Z. and Beech, M. J., 2007)
Bulgaria	Sozopol	-3000	-2001	1	Settlement - other	No	(Boev, Z., 1996)
Bulgaria	Urdoviza	-3000	-2001	1	Settlement - other	No	(Boev, Z., 1996)
Bulgaria	Yabalkovo Village	1079	1079	1	Settlement - other	Yes	(Boev, Z., 2009)
Bulgaria	Yassa Tepe, Kabile	-1000	-1	1	Settlement - other	Yes	(Boev, Z., 1996)
Czech Republic	Ostrov-Zápy	-850	-801	1	Other	Yes	(Kysely, R., 2010)
Czech Republic	Polešovice	-800	-30	1	Settlement - other	Yes	(Benecke, N., 1994)
Czech Republic	Poříčany	-550	-460	1	Other	Yes	(Kysely, R., 2010)
Czech Republic	Praha-Michle	-460	-401	1	Settlement - other	Yes	(Benecke, N., 1994; Kysely, R., 2010)
Czech Republic	Rubín	-510	-390	1	Settlement - enclosed	Yes	(Kysely, R., 2010)
Czech Republic	Těšetice	-800	-460	1	Settlement - other	Yes	(Benecke, N., 1994; Kysely, R., 2010)
Czech Republic	Toušeň-Hradištko	-620	-460	1	Other	Yes	(Kysely, R., 2010)
Czech Republic	Tuchoměřice	-550	-260	1	Settlement - other	Yes	(Benecke, N., 1994)
Denmark	Dalshøj	-200	499	1	Building - other	Yes	(Møhl, U., 1957; Watt, M., 2009)
Denmark	Ellekilde	250	250	1	Ritual, religion and funerary	No	(Gotfredsen, A. B., 2013)
Denmark	Grave 1, Vråby	70	199	1	Ritual, religion and funerary	Yes	(Gotfredsen, A. B., 2013)
Denmark	Grave 4, Munkehøjgård	150	199	1	Ritual, religion and funerary	Yes	(Gotfredsen, A. B., 2013)
Denmark	Grave, A3663, Kærup Nord	250	250	1	Ritual, religion and funerary	Yes	(Gotfredsen, A. B., 2013)
Denmark	Kirkebakkegård	200	250	1	Ritual, religion and funerary	No	(Gotfredsen, A. B., 2013)
Denmark	Sorte Muld, Svaneke	200	499	1	Settlement - rural	Yes	(Møhl, U., 1957; Watt, M., 2009)
Denmark	Varpelev Vest	200	250	1	Ritual, religion and funerary	No	(Gotfredsen, A. B., 2013)
Estonia	Loona, Saaremaa Island	-4000	-2001	1	Settlement - other	Yes	(Mannermaa, K. and Lõugas, L., 2005)
Finland	Otterbote	-1500	-401	1	Occupation site	No	(Stora, J. and Lougas, L., 2005)
France	16-28 rue des Tuileries 69009 Lyon	-520	-450	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	17 Rue de Reverdy, Chartres	-55	476	1	Settlement - urban	Yes	(Lepetz, S. et al., 2013)
France	38 Rue Henri Barbusse, Paris	-55	476	1	Settlement - urban	Yes	(Lepetz, S. et al., 2013)
France	65 Rue du Souvenir, Lyon	-475	-425	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Acy-Romance Necropolis	-199	-1	1	Ritual, religion and funerary	Yes	(Meniel, P., 2012)
France	Aigueperse, le clos Clidor	-175	-70	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Aix-en-Provence, Entremont	-123	-90	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Alençon, les Grouas	-125	-75	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Argentomagus, Mersans	-50	199	2	Settlement - rural	Yes	(Liarsou, A., 2013)
France	Argentomagus, Saint-Marcel	-150	14	2	Settlement - enclosed; Settlement - urban	Yes	(Allain J. et al., 1966; Krausz, S., 1998)
France	Artonne-La Mothe	-480	-101	1	Occupation site	Yes	(Foucras, S., 2010)
France	Augustomagus, Impasse du Courtillet, Senlis	0	299	1	Settlement - urban	Yes	(Durand, M., 1993; Lepetz, S., 1996)
France	Aulnat complex, Clermont-Ferrand	-350	-75	4	Settlement - urban; Settlement - other; Ritual, religion and funerary	Yes	(Foucras, S., 2010)
France	Basse vallée du Dan, Blainville-sur-Orne	50	399	5	Settlement - other	Yes	((Anon.) Universite de Caen, 2015)
France	Bath quarters, Aregenua, Vieux	0	399	3	Settlement - urban	Yes	(Lepetz, S., 1996)
France	Beauvais, les Aulnes du Canada	-150	476	2	Settlement - rural	Yes	(Méniel, P., 1990; Callou C. (ed.), 2015)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
France	Besançon, Collège Lumière	-150	-28	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Besançon, Parking de la Mairie	-124	-40	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Besançon, Résidence Saint-Jean, rues Ronchaux et Renan	-50	50	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Bobigny, Hôpital Avicenne	-150	-125	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Bobigny, Vache-à-l'Aise	-200	-151	1	Occupation site	Yes	(Seigle, M., 2014; Callou C. (ed.), 2015)
France	Bourges, Port-Sec-Sud	-500	-401	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Bourges, Saint Martin des Champs	-550	-460	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Bourguignon-les-Morey	-550	-460	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Bruebach, Rennwasen	-460	-260	1	Occupation site	Yes	(Seigle, M., 2014)
France	Bruechel, Geispolsheim	-800	-461	1	Settlement - other	No	(Callou C. (ed.), 2015)
France	Bucy-le-Long, le Grand Marais	-550	-460	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Budant a la route de Pauvres, Ville-sur-Retourne	-150	399	3	Ritual, religion and funerary	Yes	(Stead, I. M. et al., 2006)
France	Buisson-Saint-Cyr, Baron	-50	499	3	Building - other	Yes	(Lepetz, S., 1996; Van Goidsenhoven, W., 2010)
France	Bure, Voie Gasselle	-550	-460	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Bussy-Saint-Georges, Champ Fleuri	-460	-261	1	Building - other	Yes	(Seigle, M., 2014)
France	Caesaromagus, Hôtel-Dieu, Beauvais	0	476	1	Settlement - urban	Yes	(Lepetz, S., 1996)
France	Calvisson, la Liquière	-610	-580	1	Settlement - enclosed	No	(Columeau, Philippe, 1978; Dedet, B. and Py, M., 2008; Seigle, M., 2014)
France	Camp d'Aunedonnacum, Aulnay	20	30	1	Military site	Yes	(Lignereux, Y. and Peters, J., 1997)
France	Camp de Myard, Vitteaux	-800	-461	1	Settlement - other	No	(Callou C. (ed.), 2015)
France	Carsac	-800	-461	1	Building - other	No	(Liarsou, A., 2013)
France	Cave de la Maison des Chapelains, Cosne-Cours-sur-Loire	-27	476	1	Other	Yes	(Callou C. (ed.), 2015)
France	Cergy, ZAC des Linandes	-150	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Châlon-en-Champagne	-460	-260	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Chambly, la Marnière	-150	-28	1	Enclosure	Yes	(Seigle, M., 2014)
France	Changis-sur-Marne, la Pelle à Four Sud	-400	-71	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Clermont-Ferrand, Av. Albert Elisabeth	-175	25	1	Enclosure	Yes	(Foucras, S., 2010)
France	Clermont-Ferrand, le Pâtural	-350	-101	1	Settlement - rural	Yes	(Foucras, S., 2010)
France	Clos de la Lombarde, Narbonne	75	425	1	Building - other	Yes	(Liarsou, A., 2013)
France	Clos-au-Duc, Rue de la Libération, Evreux	75	299	1	Ritual, religion and funerary	Yes	(Lepetz, S. et al., 2013)
France	Compiègne, le Font Pernand	-460	-260	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Corent Oppidum	-175	-25	1	Settlement - enclosed	Yes	(Foucras, S., 2010)
France	Couesmes, La Tesserie	-150	-28	1	Building - other	Yes	(Cotté, Olivier, 2011)
France	Curtil Brenot, Ouroux-sur-Saône	-1050	-801	1	Building - other	No	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Delle de Derrière l'Eglise, Giberville	-27	476	1	Occupation site	Yes	(Callou C. (ed.), 2015)
France	Drancy, rue Delplacé	-150	-28	1	Industrial site	Yes	(Seigle, M., 2014)
France	Echiré, Chemin Chevaleret	-200	-71	1	Building - other	Yes	(Seigle, M., 2014)
France	Entzheim-Geispolsheim, Aéroparc	-550	-260	3	Settlement - rural	Yes	(Seigle, M., 2014)
France	Epieds-en-Beauce, Chantaupiaux	-550	-401	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Escrennes, chemin de St Eutrope	-525	-460	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Espace Mangin, Fréjus	-50	399	4	Settlement - urban	Yes	(Rodet-Belarbi, I., 2005)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
France	Estrées-Saint-Denis	0	399	2	Ritual, religion and funerary	Yes	(Lepetz, S., 1996)
France	Etigny, le Brassot	-70	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Fesques, le Mont du Val aux Moines	-200	-71	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Feurs, centre ville	-160	-20	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Fontenay-le-Comte, les Genâts I	-150	-71	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Gensac-la-Pallue	-550	-460	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Grisy-sur-Seine	-150	-28	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Herblay, ZAC Olympium	-125	-50	1	Building - other	Yes	(Seigle, M., 2014)
France	Hornaing, Douai	-150	99	3	Settlement - rural	Yes	(Meniel, P., 1992; Van Goidsenhoven, W., 2010)
France	Hôtel-Dieu, Paris	-27	476	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Ilôt La Boucherie, Amiens	1	499	3	Settlement - urban; Ritual, religion and funerary	Yes	(Lepetz, S. et al., 2013)
France	Institut des Jeunes Sourds, Paris	-27	476	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	La Beauve, Meaux	300	399	1	Ritual, religion and funerary	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	La Blanche- Voye, Beaumont-sur-Oise	0	499	4	Settlement - other	Yes	(Morize, D. and Vermeersch, D., 1993; Lepetz, S., 1996)
France	La Bute Grise, Plailly	0	399	1	Building - other	Yes	(Lepetz, S., 1996)
France	La Campagne, Basly	-620	-550	1	Settlement - enclosed	Yes	(Baudry, A., 2005)
France	La Cime des Bruyères, Pulvérières	-140	-110	1	Ritual, religion and funerary	Yes	(Foucras, S., 2010; Blaizot, F. et al., 2014)
France	La Corneille, Bretteville-l'Orgueilleuse	100	399	2	Settlement - rural	Yes	((Anon.) Universite de Caen, 2015; Callou C. (ed.), 2015)
France	La Fauche Verdon, Luigné	-550	-401	1	Occupation site	Yes	(Levillayer, A. et al., 2013)
France	La Fosse Touzé	-550	-450	1	Settlement - enclosed	No	((Anon.) Universite de Caen, 2015)
France	La Lampe, Fontenay-en-Parisis	-260	380	4	Settlement - enclosed	Yes	(Daveau, I. and Yvinec, J.-H., 2001; 2002)
France	La Noue Mauroy, Acy-Romance	-150	-28	1	Ritual, religion and funerary	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	la Roche Blanche, Gergovie	-70	-28	2	Settlement - enclosed; Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	La Saussaye, Touffreville	-120	-30	1	Settlement - enclosed	Yes	((Anon.) Universite de Caen, 2015)
France	Langres, Marché couvert	0	99	1	Settlement - rural	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Lattara (Lattes), Hérault	-400	150	1	Settlement - urban	Yes	(Petit, L. G., 1997)
France	Le Bas de Vieux	0	399	3	Building - other	Yes	((Anon.) Universite de Caen, 2015)
France	Le Bissonnet, le Fond du Val, enclos n1	-450	-30	1	Settlement - rural	Yes	((Anon.) Universite de Caen, 2015)
France	Le Bois d'Empreville, Athies-sous-Laon	0	350	1	Building - other	Yes	(Lepetz, S., 1996)
France	Le Bois Harlé et La Queue de Rivecourt, Longueil-Sainte-Marie	100	199	1	Settlement - rural	Yes	(Lepetz, S., 1996)
France	Le Bufosse, Verneuil-en-Halatte	0	399	3	Building - other	Yes	(Lepetz, S., 1996)
France	Le Cendre, oppidum de Gondole	-80	-20	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Le Chemin Haussé, parcelle AH30p, Vieux	0	299	1	Building - other	Yes	((Anon.) Universite de Caen, 2015)
France	Le Clos de l'Epinette	-450	-50	1	Settlement - rural	Yes	((Anon.) Universite de Caen, 2015)
France	Le Forum - Le Champ des Crêtes	-30	399	2	Settlement - urban	Yes	((Anon.) Universite de Caen, 2015)
France	Le Montant de l'Obit, Menil-Annelles	-150	-28	1	Ritual, religion and funerary	Yes	(Stead, I. M. et al., 2006)
France	Le Motel, Fresnes-lès-Montauban	200	299	1	Ritual, religion and funerary	Yes	(Lepetz, S., 1996)
France	Le Moulin à Vent, Montmartin	0	399	2	Building - other	Yes	(Lepetz, S., 1996)
France	Le petit cabaret, Cizay-la-Madeleine	-550	-401	1	Occupation site	Yes	(Levillayer, A. et al., 2013)
France	Le petit noyer, Cannes-Écluse	-150	-28	1	Building - other	Yes	(Liarsou, A., 2013)
France	Le Port, Salses-le-Château	-500	-460	1	Settlement - rural	Yes	(Seigle, M., 2014)

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France	Le tribunal, Boulogne	250	299	1	Settlement - urban	Yes	(Vadet, A., 1986)
France	Les Esquillons, Houdancourt	-460	-28	1	Occupation site	No	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Les Fontinettes, Cuiry-lès-Chaudardes	-4900	-4701	1	Settlement - rural	Yes	(Callou C. (ed.), 2015)
France	Les Hauts de Buergelen, Illfurth	-620	-460	1	Settlement - other	Yes	(Seigle, M., 2014)
France	Les Neuf, Rémy	41	99	1	Building - high status	Yes	(Lepetz, S., 1996)
France	Les Petites Corvées, Lavau	-1200	399	2	Ritual, religion and funerary	Yes	(Callou C. (ed.), 2015)
France	Les Plaines, Cournon-d'Auvergne	-460	-28	1	Settlement - other	Yes	(Callou C. (ed.), 2015)
France	Les Tamaris, Seclin	-50	-1	1	Settlement - rural	No	(Révillion, S. et al., 1986)
France	L'Etoile II - Site I	-260	-30	1	Settlement - other	Yes	((Anon.) Universite de Caen, 2015)
France	Levroux, les Arènes	-150	-28	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Levroux, Terrain Lacotte	-150	-80	1	Settlement - rural	Yes	(Liarsou, A., 2013)
France	L'Hôtel de Ville, Saint-Quentin	0	125	1	Settlement - urban	Yes	(Lepetz, S., 1996)
France	Lieusaint	-600	-501	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Mainxe, la Croix des Sables	-150	-28	1	Occupation site	Yes	(Seigle, M., 2014)
France	Martigues	-400	-101	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Mas Sauvy, Villeneuve-de-la-Raho	80	120	1	Settlement - rural	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Menneville, Derrière le Village	-550	-401	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Mercin et Vaux	300	399	1	Building - high status	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Meung-sur-Loire, l'Herbaudière	-150	-28	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Mez-Notariou, Ouessant	-800	476	2	Ritual, religion and funerary	No	(Callou C. (ed.), 2015)
France	Milly-la-Forêt, le Bois Rond	-550	-460	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Mirebeau-sur-Bèze, la Fenotte	-200	-71	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Mithraeum, Septeuil	300	399	1	Ritual, religion and funerary	Yes	(Lentacker, A. et al., 2004)
France	Mittelhausen, Liesbuehl	-460	-260	1	Industrial site	Yes	(Seigle, M., 2014)
France	Molesme, Sur-les-Creux	-150	-28	1	Building - other	Yes	(Seigle, M., 2014)
France	Monchy-le-Preux	375	425	1	Building - other	Yes	(Lepetz, S., 1996)
France	Mont Saint Vaast, Arras	41	54	1	Military site	Yes	(Lepetz, S., 1996)
France	Montereau-Fault-Yonne	-800	-461	1	Building - other	Yes	(Liarsou, A., 2013)
France	Montfaucon, Travers de St Hilaire	-400	-201	1	Building - other	Yes	(Seigle, M., 2014)
France	Montierchaume, le Travoir	-150	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Nanterre, les Guignons	-200	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Nasium Oppidum, Boviolles	-150	-30	1	Settlement - enclosed	Yes	(Bonaventure, B. et al., 2014)
France	Nemetacum, la ville, Arras	0	399	6	Settlement - urban; Military site; Ritual, religion and funerary	Yes	(Jacques, A. et al., 1988; Lepetz, S., 1996)
France	Nievre sanctuary	0	399	2	Ritual, religion and funerary	Yes	(Argant, A. et al., 2008)
France	Nîmes, le Mont Cavalier	-500	-401	1	Settlement - enclosed	No	(Columeau, Philippe, 1978; Dedet, B. and Py, M., 2008; Seigle, M., 2014)
France	Nissan-lez-Ensérune, oppidum d'Ensérune	-400	-201	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Oedenburg	20	399	4	Military site; Settlement - urban	Yes	(Reddé, M. et al., 2005)
France	Orléans, la Charpenterie	0	99	1	Occupation site	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Orléans, Rue de la grille	0	99	1	Occupation site	Yes	(Liarsou, A., 2013)
France	Parcs d'activités, parcelle ZL 13, Fleury-sur-Orne	-250	-120	1	Settlement - other	Yes	((Anon.) Universite de Caen, 2015)
France	Périgueux, rue Saint-Georges	-200	-151	1	Settlement - urban	Yes	(Seigle, M., 2014)

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France	Pfulgriesheim, lotissement communal	-460	-260	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Pommiers, l'Assault	-70	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Pont-à-Chin	-650	-450	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Pouillé, le Grand Paisilier	-200	-71	2	Settlement - enclosed; Enclosure	Yes	(Seigle, M., 2014)
France	Prasville, Vers Chesnay, les Fontenelles	-320	-71	3	Building - other; Settlement - enclosed; Settlement - rural	Yes	(Seigle, M., 2014)
France	Projet Décathlon, Cagny	-550	-460	1	Settlement - enclosed	No	((Anon.) Universite de Caen, 2015)
France	Puy de Dôme Mercury Temple	125	150	1	Ritual, religion and funerary	Yes	(Meniel, P., 2014)
France	Quartier du Théâtre, Vieux	100	399	1	Settlement - other	Yes	((Anon.) Universite de Caen, 2015)
France	Rahon, Champ de la Manche	-150	-28	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Roanne, 28 rue de Charlieu	-150	-28	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Roanne, quartier Saint-Paul	-160	10	3	Settlement - urban	Yes	(Seigle, M., 2014)
France	Rochefort, Gerzat	-175	99	1	Settlement - enclosed	Yes	(Alfonso, G., 2007; Foucras, S., 2010)
France	Roissy-en-France, le Château	-400	-261	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Roissy-en-France, ZAC du Moulin	-120	476	2	Settlement - rural	Yes	(Seigle, M., 2014; Callou C. (ed.), 2015)
France	Romans-sur-Isère, Contournement Ouest	-500	-450	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Rosheim, Mittelweg	-460	-260	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Rovon, le Pas de l'Échelle	-460	399	3	Cave	Yes	(Laroche, C. et al., 2013; Seigle, M., 2014)
France	Rue Alfred Maury, Meaux	0	199	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Rue de la Fraternelle, Lyon	-537	-537	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Rue de l'Abbé-de-L'Epée, Paris	-27	476	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Rue de Lutèce, Paris	100	399	1	Settlement - other	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Rue du Docteur Horand, Lyon	-525	-450	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Rue Gay-Lussac, Paris	-27	476	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	rue Lavalard, Amiens	175	225	1	Settlement - other	Yes	(Lepetz, S., 1996)
France	Rue Monsieur-Le-Prince, Paris	-27	476	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Rue Pierre et Marie Curie, Paris	0	399	1	Settlement - urban	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Rue Rambuteau, Mâcon	0	299	1	Industrial site	Yes	(Lepetz, S. et al., 2013)
France	Rues Sergent Michel Berthet - Saint-Pierre de Vaise Berthet II, Lyon	-550	-460	1	Settlement - urban	Yes	(Seigle, M., 2014)
France	Saint-Apollinaire, Pré Thomas	-50	-10	1	Enclosure	Yes	(Seigle, M., 2014)
France	Saintes	-27	37	1	Occupation site	Yes	(Liarsou, A., 2013)
France	Saint-Hippolyte, Château de la Roche	-150	476	2	Occupation site	Yes	(Seigle, M., 2014; Callou C. (ed.), 2015)
France	Saran, ZAC du Champ Rouge	-70	-28	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Sarliève, Grande Halle	-350	-75	1	Settlement - rural	Yes	(Foucras, S., 2010)
France	Schwobenfeld, Geispolsheim	-460	-320	1	Settlement - other	Yes	(Putelat, O. and Landolt, M., 2013)
France	Sierentz, Landstrasse	-150	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Sous Blousseru, Juniville	-150	-28	1	Ritual, religion and funerary	Yes	(Stead, I. M. et al., 2006)
France	Sublaines, le Grand Ormeau	-400	-151	1	Building - other	Yes	(Seigle, M., 2014; Callou C. (ed.), 2015)
France	Tagnon, la Fricassée	-460	-260	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Tartigny	-300	-201	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Terres noires, Lewarde	0	399	1	Settlement - rural	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Toulouse, nécropole St-Roch	-150	-28	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)

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France	Vallangoujard, Epiais-Rhus	-70	-28	1	Occupation site	Yes	(Liarsou, A., 2013; Callou C. (ed.), 2015)
France	Varennes-sur-Allier, 33 rue Claude Labonde	-175	-150	1	Occupation site	Yes	(Foucras, S., 2010)
France	Varennes-sur-Seine, le Marais du Colombier	-400	-350	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Vaux-de-la-Celle, Genainville	-27	499	1	Ritual, religion and funerary	Yes	(Liarsou, A., 2013)
France	Vénissieux, ZAC du Vieux Bourg	-530	-260	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Verberie, le Buisson Campin	-200	-151	1	Building - other	Yes	(Seigle, M., 2014)
France	Vermand, le Champ des Lavoirs	-260	-150	1	Settlement - enclosed	Yes	(Lemaire, P. et al., 2000)
France	Vernou-sur-Brenne, la Butte du Trésor	-150	-28	1	Occupation site	Yes	(Seigle, M., 2014)
France	Vicus Les Sablins, Etaples	0	299	2	Settlement - urban	Yes	(Sennequier, G. and Tuffreau-Libre, M., 1977; Vadet, A., 1985; Lepetz, S., 1996)
France	Vicus, Les Châtelets, Vendeuil-Caply	50	299	1	Settlement - urban	Yes	(Sestier, P., 1990; Piton, D., 1993; Lepetz, S., 1996)
France	Vieille-Toulouse, le Planho	-100	-1	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
France	Viermeux, oppidum de Cusset	-70	-28	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	villa de l'Arribèra deus Gleisiars, Lalonquette	275	350	1	Building - high status	Yes	(Callou C. (ed.), 2015)
France	Villa d'Eros, Epiais-Rhus	100	199	1	Building - high status	Yes	(Lepetz, S., 1996)
France	Villedieu-sur-Indre, Mehun	-150	-28	1	Occupation site	Yes	(Seigle, M., 2014)
France	Villeneuve-Saint-Germain, les Grandes Grêves	-150	-28	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Villers-Saint-Paul, la Barrière	-320	-201	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Ville-saint-Jacques, le Bois d'Echalas	-400	-261	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Villiers-le-Sec, Place de la Ville	-260	-151	1	Enclosure	Yes	(Seigle, M., 2014)
France	Vinneuf	-1100	-1001	1	Occupation site	No	(Callou C. (ed.), 2015)
France	Vix, Mont Lassois	-550	-260	2	Settlement - enclosed	Yes	(Seigle, M., 2014)
France	Vrigny, les Cumines Basses	-550	-401	1	Settlement - rural	Yes	(Seigle, M., 2014)
France	Wolphus, Zouafques	300	399	1	Building - other	Yes	(Lepetz, S., 1996)
France	ZAC du Parc d Activités, Delles des Marquets, Delle de la Rance, Fleury-sur-Orne	-120	99	2	Building - other	Yes	((Anon.) Universite de Caen, 2015)
France	ZAC Object Ifs Sud Ensemble 5	-450	-30	3	Settlement - other	Yes	((Anon.) Universite de Caen, 2015)
France	ZAC Object Ifs Sud Ensemble 6	-450	-30	2	Settlement - enclosed	Yes	((Anon.) Universite de Caen, 2015)
France	ZAC Object Ifs Sud Ensemble 7	-120	-30	1	Occupation site	No	((Anon.) Universite de Caen, 2015)
Germany	"Auf dem Katzenberg" Roman fort	300	450	1	Military site	Yes	(Wenzel, S., 2011)
Germany	"Lopodunum" Kellereigasse, Ladenburg	70	260	1	Settlement - urban	Yes	(Wussow, J. et al., 1999)
Germany	Abusina	100	299	1	Military site	Yes	(Liarsou, A., 2013)
Germany	Altenburg Rheinau Oppidum	-150	-15	1	Settlement - enclosed	Yes	(Moser, B., 1986)
Germany	Altenstadt Fort, Upper German Limes	100	260	1	Military site	Yes	(Davies, R. W., 1971; Benecke, N., 1994)
Germany	Am Goldnenacker, Lahnau-Waldgirmes	0	10	1	Settlement - other	Yes	(Benecke, N., 1997)
Germany	Am Hetelberg, Gielde	100	199	1	Settlement - other	Yes	(Donnerbauer, H. J., 1968; Hanik, S., 2005)
Germany	Am Laubenberg, Oberdorla	-460	-30	1	Settlement - other	Yes	(Döhle, H-J., 2006)
Germany	Auf dem "Erbbrink", Seinstedt	100	299	1	Settlement - other	Yes	(Boessneck, J. and Ciliga, T., 1966)
Germany	Boyneburg	-550	-260	2	Settlement - other; Settlement - enclosed	Yes	(Becker, C., 1999; Müller, J., 1999)
Germany	Breisach-Muensterberg	-600	-401	1	Settlement - enclosed	Yes	(Benecke, N., 1994)
Germany	Büßleben, Erfurt	-800	-50	1	Occupation site	No	(Hans-Volker, K., 2009)
Germany	Butzbach, Upper German Limes	90	235	1	Military site	Yes	(Davies, R. W., 1971)
Germany	Cart burial, Neuwied, Heimbach-Weiss	-110	-71	1	Ritual, religion and funerary	Yes	(Schoenfelder, M., 1994)

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Germany	Celtic oppidum and Roman temple complex, Wallendorf	-130	399	3	Settlement - enclosed; Ritual, religion and funerary; Settlement - other	Yes	(Wustrow, C., 2004)
Germany	Colonia Ulpia Traiana, Xanten	0	299	3	Settlement - urban	Yes	(Peters, J., 1994; Nolte, N., 2010)
Germany	Dienstedt	275	325	1	Settlement - other	Yes	(Barthel, H-J., 1987b)
Germany	Eggolsheim	200	399	1	Settlement - other	Yes	(Liarsou, A., 2013)
Germany	Federsen Wierde	100	299	1	Settlement - other	No	(Liarsou, A., 2013)
Germany	Goettingen	-150	-30	1	Settlement - other	Yes	(Döhle, H-J., 2006)
Germany	Gommern	-800	-460	1	Settlement - other	No	(Döhle, H-J., 2006; Müller, H-H and Prilloff, R-J, 2006)
Germany	Großfahner, Erfurt	-460	14	1	Settlement - enclosed	Yes	(Barthel, H-J., 1987a)
Germany	Haarhausen, Ilm Kreis	275	299	1	Settlement - other	Yes	(Barthel, H-J., 1987b; Benecke, N., 1997)
Germany	Helfta, Eisleben	-460	-60	1	Settlement - other	Yes	(Döhle, H-J., 2006; Müller, H-H and Prilloff, R-J, 2006)
Germany	Hemmoor II, Cuxhaven	175	250	1	Ritual, religion and funerary	Yes	(Willers, H., 1901; Ewerson, J., 2003)
Germany	Heuneburg, Hundersingen	-550	-260	1	Settlement - enclosed	Yes	(Benecke, N., 1994)
Germany	Hildesheim-Bavenstedt	200	499	1	Settlement - other	Yes	(Hanik, S., 2005)
Germany	Hofheim Roman Fort, Hofheim am Taunus	40	110	1	Military site	Yes	(Haverfield, F., 1912; Davies, R. W., 1971)
Germany	Hörafing	100	299	1	Ritual, religion and funerary	Yes	(Lauwerier, R. C. G. M., 1988)
Germany	Hufingen	-27	476	1	Settlement - rural	Yes	(Liarsou, A., 2013)
Germany	Kablow, Kreis Koenigs Wusterhausen	0	299	1	Settlement - other	Yes	(Teichert, M., 1971)
Germany	Karlstein, Kreis Berechtesgadener Land	-460	-30	1	Settlement - other	Yes	(Benecke, N., 1994)
Germany	Kastel Oppidum	-150	399	2	Settlement - enclosed; Settlement - other	Yes	(Wustrow, C., 2004)
Germany	Kempten	0	99	1	Ritual, religion and funerary	Yes	(Lauwerier, R. C. G. M., 1988)
Germany	Kiesgrube Kieser, Gotha	-150	-70	1	Settlement - other	Yes	(Prilloff, R.-J. and Huck, T., 2002)
Germany	Klause II, Glauberg	-460	-401	1	Building - other	Yes	(Knipper, C. et al., 2014)
Germany	Kleinkayna, Gemeinde Grosskayna	-150	-28	1	Settlement - other	Yes	(Ewerson, J., 2003; Döhle, H-J., 2006; Müller, H-H and Prilloff, R-J, 2006)
Germany	Kurstraße, Bad Nauheim	-300	-1	1	Settlement - other	Yes	(Benecke, N., 1997)
Germany	Kyffhäusergebirges, Bad Frankenhausen	-620	-460	1	Cave	Yes	(Teichert, M. and Lepiksaar, J., 1977; Teichert, M., 1978; 1981; 1985a; 1985b; Kysely, R., 2010)
Germany	Lauriacum Z, Lorch	-27	476	1	Building - high status	Yes	(Liarsou, A., 2013)
Germany	Leuna	200	299	1	Ritual, religion and funerary	Yes	(Gandert, O. F., 1953; Schulz, W., 1953)
Germany	Lorenzberg, Epfach	0	399	2	Settlement - urban	Yes	(Boessneck, J., 1964)
Germany	Lossow, Frankfurt (Oder)	-800	-460	1	Settlement - enclosed	Yes	(Hilzheimer, M., 1923; Benecke, N., 1994)
Germany	Manching Oppidum, Ingolstadt	-260	-28	1	Settlement - enclosed	Yes	(Boessneck J. et al., 1971)
Germany	Martberg Gallo-Roman temple complex	200	399	1	Ritual, religion and funerary	Yes	(Kroll, H., 2013)
Germany	Mithraeum, Wiesloch vicus	100	199	1	Ritual, religion and funerary	No	(Hensen, A., 1994; von den Driesch, A. and Pöllath, N., 2000)
Germany	Mithras sanctuary and Roman Fort, Künzing	75	250	2	Settlement - enclosed; Ritual, religion and funerary	Yes	(Schmotz, K., 2000; von den Driesch, A. and Pöllath, N., 2000)
Germany	Mogontiacum, Mainz	0	299	3	Ritual, religion and funerary	Yes	(Hochmuth, M. et al., 2005)
Germany	Nersingen, Neu-Ulm	-550	-460	1	Settlement - other	Yes	(Benecke, N., 1994)
Germany	Nonnenbuckel, Heilbronn-Neckargartach	-550	-150	1	Ritual, religion and funerary	Yes	(Hees, M., 2002)
Germany	Nörten-Hardenberg	-480	-60	1	Settlement - other	No	(Döhle, H-J., 2006)
Germany	Pipinsbug bei Osterode	-550	-401	1	Settlement - other	Yes	(Döhle, H-J., 2006)
Germany	Remda, Kreis Rudolstadt	-150	-30	1	Settlement - other	Yes	(Müller, H-H, 1965)

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Germany	Rieth, Oberdorla	100	399	1	Ritual, religion and funerary	No	(Teichert, M., 1962)
Germany	Roman cemetery, Rheinzabern	0	399	1	Ritual, religion and funerary	Yes	(Wustrow, C., 2004)
Germany	Roman villa, Borg	-300	399	5	Building - high status; Building - other	Yes	(Miron, A. and Wustrow, C., 1997; Wustrow, C., 2004)
Germany	Rothbühl, Gerolzhofen	-50	-1	1	Building - other	Yes	(Benecke, N., 1997)
Germany	Rottweil, Area Flaviae II	0	199	1	Settlement - urban	Yes	(Liarsou, A., 2013)
Germany	Saalburg, Upper German Limes	90	260	1	Military site	Yes	(Davies, R. W., 1971)
Germany	Schirndorf	-600	-501	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J., 2000)
Germany	Sponeck, Sasbach am Kaiserstuhl	200	399	1	Military site	Yes	(Liarsou, A., 2013)
Germany	Suenninghausen, Kreis Warendorf	-500	-1	1	Settlement - other	Yes	(Benecke, N., 1994)
Germany	Tangermünde	-600	-1	1	Settlement - other	No	(Döhle, H-J., 2006; Müller, H-H and Prilloff, R-J, 2006)
Germany	Temple complex and cemetery Wederath, Belginum	100	399	1	Ritual, religion and funerary	Yes	(Wustrow, C., 2004)
Germany	Vemania	275	399	1	Military site	Yes	(Liarsou, A., 2013)
Germany	Wallerfangen	-800	-460	1	Settlement - enclosed	Yes	(Benecke, N., 1994)
Germany	Waltersdorf, Schönefeld	200	499	1	Settlement - other	Yes	(Liarsou, A., 2013)
Germany	Widderstatt bei Jüchsen, Lkr. Meiningen	-550	-260	1	Settlement - other	Yes	(Döhle, H-J., 2006)
Germany	Wohnpark Moritzstraße, Erfurt	-150	-30	1	Building - other	Yes	(Döhle, H-J., 2006)
Germany	Wüste Kunersdorf, Kreis Seelow	-200	299	2	Settlement - other	Yes	(Teichert, M., 1968; Kysely, R., 2010)
Greece	Artemision of Olympia	-560	-480	1	Ritual, religion and funerary	Yes	(Benecke, N., 2006)
Greece	Eleftherna, Rethymnon	-870	399	3	Settlement - other; Settlement - urban	Yes	(Nobis, G., 1998)
Greece	Hellenistic–Early Roman house, Nea Paphos	-50	14	1	Building - other	Yes	(Tepe, E., 2012)
Greece	Kassope Roman city	-350	-30	1	Settlement - urban	Yes	(Friedl, H., 1984)
Greece	Kastro	-800	-701	1	Settlement - other	No	(Klippel, W. E. and Snyder, L. M., 1991)
Greece	Lerna	-2750	-1250	3	Occupation site; Settlement - enclosed	No	(Reese, D. S., 2008; 2013)
Greece	Northeastern house, Nea Paphos	75	175	1	Building - other	Yes	(Tepe, E., 2012)
Greece	Southeast Gate, New Halos	-260	-220	1	Settlement - urban	Yes	(Prummel, W., 2005)
Greece	Thebes	-300	-250	1	Ritual, religion and funerary	Yes	(Liarsou, A., 2013)
Hungary	Ács-Vaspuszta, Pannonia	-27	425	2	Military site	Yes	(Bökönyi, S., 1974)
Hungary	Albertfalva, Budapest	0	299	2	Military site; Settlement - other	Yes	(Bökönyi, S., 1974; Fitz, J., 2003; Szirmai, K., 2003; Damian, A. et al., 2008)
Hungary	Balatonaliga, Balatonvilágos	-11	420	1	Settlement - other	Yes	(Bökönyi, S., 1974)
Hungary	Balatonfüred	-11	420	1	Ritual, religion and funerary	Yes	(Bökönyi, S., 1974)
Hungary	Balatonkeresztúr–Réti-dűlő	-2300	-30	2	Settlement - other	Yes	(Gál, E., 2007)
Hungary	Balatonlelle–Kenderföldek	100	399	1	Settlement - other	Yes	(Gál, E., 2007)
Hungary	Békés-Városerdő	-2200	-1401	1	Settlement - other	No	(Bökönyi, S., 1974; Schramm, P., 2012)
Hungary	Bogád	300	399	1	Ritual, religion and funerary	Yes	(Bökönyi, S., 1974)
Hungary	Bokor Street-Nagyszombat Street, Aquincum	40	476	1	Settlement - urban	Yes	(Gál, E., 2005)
Hungary	Filatorigát, Aquincum	40	476	1	Settlement - urban	Yes	(Gál, E., 2005)
Hungary	Garadna	0	399	1	Settlement - other	Yes	(Bökönyi, S., 1974)
Hungary	Haus der Tribuni Laticlavii, Aquincum	100	260	1	Ritual, religion and funerary	Yes	(von den Driesch, A. and Pöllath, N., 2000; Nemeth, M., 2003)
Hungary	Intercissa, Dunaujváros	98	430	1	Military site	Yes	(Gál, E., 2008)
Hungary	Ipari Park II, Salgótarján	-650	-450	1	Settlement - other	No	(Bartosiewicz, L. and Gal, E., 2010)
Hungary	Jászfelsőszentgyörgy	-600	-501	1	Building - other	Yes	(Bökönyi, S., 1974; Benecke, N., 1994)
Hungary	Káposztások, Balassagyarmat	-600	-401	1	Settlement - other	Yes	(Bartosiewicz, L. and Gal, E., 2010a; 2010b; Gál, E., 2012)

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Hungary	Matraszõlõs	-450	-27	1	Ritual, religion and funerary	Yes	(Bökönyi, S., 1974)
Hungary	Pók Street, Aquincum	40	476	1	Ritual, religion and funerary	Yes	(Gál, E., 2005)
Hungary	Sajópetri 46 (Hosszúdűlő and Hosszú-rét)	-300	-201	1	Settlement - other	Yes	(Timar, L., 2008; Bartosiewicz, L. and Gal, E., 2010)
Hungary	Salla	10	499	1	Settlement - other	Yes	(Gál, E., 2005)
Hungary	Scarbatina Forum, Sopron	-27	106	1	Settlement - urban	Yes	(Damian, A. et al., 2008)
Hungary	Sóderbánya, Ludányhalászi	-1200	-701	1	Settlement - other	Yes	(Tugya, B., 2010; Bartosiewicz, L. and Gal, E., 2010; Gál, E., 2012)
Hungary	Szakàley – Rèti Földek	-27	106	1	Settlement - rural	Yes	(Damian, A. et al., 2008)
Hungary	Szentendre	-460	-30	1	Settlement - other	Yes	(Benecke, N., 1994)
Hungary	Szilvásvárad	100	499	1	Settlement - other	Yes	(Bökönyi, S., 1974)
Hungary	Tác-Fövenypuszta/Tac Gorsium	75	399	1	Settlement - other	Yes	(Bökönyi, S., 1974; Schilling, L., 2011)
Hungary	Testvérhegy, Aquincum	320	330	1	Ritual, religion and funerary	Yes	(Gál, E., 2005)
Hungary	Tiszalúc- Dankadomb	-1800	-1600	1	Occupation site	No	(Bökönyi, S., 1974)
Hungary	Tokod Roman fort	100	399	1	Military site	Yes	(Bökönyi, S., 1974)
Hungary	Túróczi-tanya, Jászfelsőszentgyörgy	-600	-401	1	Settlement - rural	Yes	(Bartosiewicz, L. and Gal, E., 2010; Gál, E., 2012)
Ireland	Ballinderry crannog no. 2, Co. Westmeath	-400	-101	1	Settlement - other	No	(Stelfox, A. W., 1942)
Ireland	Beaker Settlement, Newgrange	-250	-2500	1	Ritual, religion and funerary	No	(van Wijngaarden-Bakker, L. H., 1986)
Italy	Acropolis, Timpone della Motta	-850	-601	2	Building - high status; Ritual, religion and funerary	No	(Elevelt, S. C., 2012)
Italy	Alife	0	399	3	Building - high status	Yes	(Carannante, A. et al., 2014)
Italy	Benacci-Caprara necropolis, Bologna	-800	-775	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J., 2000)
Italy	Bolsena (Poggio Moscini)	-200	99	1	Settlement - other	Yes	(Ghisleni, M. et al., 2011)
Italy	Broglio di Trebisacce, Sector 10	-1700	-720	2	Settlement - other	No	(Elevelt, S. C., 2012)
Italy	Cantiere Mitello, Otranto	-400	-200	1	Settlement - urban	Yes	(De Grossi Mazorrin, J. and Minniti, C., 2008)
Italy	Casale di Rivalta	-500	-401	1	Settlement - other	Yes	(De Grossi Mazorrin, J., 2000)
Italy	Cassa di Risparmio, Modena	-99	-1	1	Settlement - urban	Yes	(De Grossi Mazorrin, J., 1988)
Italy	Castrum Minervae, Taranto	-400	-100	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J. et al., 2009)
Italy	Chianciano Terme, Sienna	0	499	2	Settlement - other; Other	Yes	(Ghisleni, M. et al., 2011)
Italy	Colle Santiano, Invillino	0	450	1	Building - other	Yes	(Stork, M. and von den Driesch, A., 1987)
Italy	Colosseum, Rome	80	499	4	Building - other	Yes	(De Grossi Mazorrin, J. and Minniti, C., in prep.)
Italy	Cuma	-500	-301	1	Ritual, religion and funerary	Yes	(Brun, J-P. et al., 2015)
Italy	Elvas, Brixen	0	199	1	Building - other	Yes	(Boschin, F. and Weissteiner, M., 2008)
Italy	Heraion, Capaccio-Paestum	-350	-250	1	Ritual, religion and funerary	Yes	(Dewaiily, M., 1997)
Italy	Herdonia	300	425	1	Settlement - urban	Yes	(Buglione, A., 2007)
Italy	House of Amarantus, Pompeii	0	79	1	Building - other	Yes	(Robinson, M., 2002)
Italy	House of Ganymede, Pompeii	-6	79	1	Building - other	Yes	(Liarsou, A., 2013)
Italy	La casa di via Conca d'Oro a San giorgio di Valpolicella	-200	-1	1	Building - other	Yes	(Tecchiati, U., 2006)
Italy	La necropoli di Povegliano Veronese, Ortaia	-175	-1	1	Ritual, religion and funerary	Yes	(Meniel, P., 2012; Vitali, D. et al., 2014)
Italy	La villa dei Quintili a Monteporzio, Frascati	0	199	1	Building - high status	Yes	(De Grossi Mazorrin, J., 1987)
Italy	Mausoleo di Tortora	0	99	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J., 2003)
Italy	Meta Sudans, Rome	0	99	1	Other	Yes	(De Grossi Mazorrin, J. and Minniti, C., 1995)
Italy	Mithraeum, Crypta Balbi, Rome	300	499	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J., 2004)
Italy	Mola di Monte Gelato	-27	499	2	Building - high status; Settlement - other	Yes	(Cartwright, C., 1997; West, B., 1997; King, A., 1997; 2007)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
Italy	Necropoli di Porta Nocera, Pompeii	-75	-25	1	Ritual, religion and funerary	Yes	(Lepetz, S., 2013)
Italy	Necropolis of Monte Cucco, Castel Gandolfo	-900	-850	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J., 2000)
Italy	Ossaia	0	399	1	Building - high status	Yes	(Ghisleni, M. et al., 2011)
Italy	Piazza Dante, Vaste	-330	-30	2	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J. and Solinas, A. M., 2010)
Italy	Piazzale di Porta San Lorenzo, Intramural area	-100	225	3	Settlement - urban	Yes	(De Grossi Mazorrin, J., 1996)
Italy	Pievina, Cinigiano	-100	450	2	Settlement - rural; Building - other	Yes	(Ghisleni, M. et al., 2011)
Italy	Poggio Colla, Mugello	-550	-301	1	Ritual, religion and funerary	No	(Trentacoste, A., 2013)
Italy	Poggio Gramignano (Lugnano in Teverina)	0	499	3	Building - high status; Ritual, religion and funerary	Yes	(MacKinnon, M., 1999; Ghisleni, M. et al., 2011)
Italy	Populonia	-300	-1	2	Settlement - urban	Yes	(De Grossi Mazorrin, J., 1985; De Grossi Mazorrin, J. and Minniti, C., 2010)
Italy	Roca, Melendugno	-1300	-1000	1	Settlement - enclosed	No	(Pagliara, C. et al., 2007)
Italy	Romagnoli Tomb, Bologna	-800	-775	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J., 2000)
Italy	San Claudio	-600	-501	1	Settlement - other	Yes	(De Grossi Mazorrin, J., 2000; Trentacoste, A., 2015)
Italy	San Giusto, Lucera	375	450	1	Settlement - rural	Yes	(Buglione, A., 2007)
Italy	Settefinestre Roman villa	-30	235	2	Building - high status	Yes	(King, A., 1985)
Italy	Tenuta di Vallerano	0	199	1	Settlement - rural	Yes	(Minniti, C., 2000)
Italy	Veio	-325	-301	1	Settlement - urban	Yes	(Cuchinotta, C. et al., 2010)
Italy	Via Gaetano Sacchi, Rome	138	192	1	Settlement - urban	Yes	(De Grossi Mazorrin, J. and Coppola, F., 2008)
Italy	Vicus, Castelporziano	-27	399	4	Settlement - urban	Yes	(Rendell, H. M. et al., 2006; MacKinnon, M., 2010)
Lithuania	Kretuonas 1C	-2100	-1501	1	Settlement - rural	No	(Daugnora, L. and Girininkas, A., 1995; Daugnora, L. et al., 2002)
Luxembourg	Goeblange-Nospelt	-70	-28	1	Ritual, religion and funerary	Yes	(Seigle, M., 2014)
Luxembourg	Lamadelaine	-100	-1	1	Ritual, religion and funerary	Yes	(Lambot, B. et al., 1996; Meniel, P., 2012)
Luxembourg	Temple district, Dalheim vicus	70	299	2	Ritual, religion and funerary	Yes	(Oelschlagel, C., 2004)
Malta	Tas Silġ	-125	-1	1	Ritual, religion and funerary	Yes	(De Grossi Mazorrin, J. and Battafarano, M., 2012)
Netherlands	Bovenkarspel-Het Valkje	-1350	-650	1	Settlement - other	No	(Ijzereef, G. F. et al., 1981; Brinkkemper, O., 2013)
Netherlands	Broekpolder, Vlaardingen	-370	476	2	Building - other; Settlement - rural	Yes	(Clason, A. T., 1967)
Netherlands	Canabe Legionis, Nijmegen	70	120	1	Settlement - other	Yes	(Lauwerier, R. C. G. M., 1988)
Netherlands	Castra, Nijmegen	70	120	1	Military site	Yes	(Lauwerier, R. C. G. M., 1988)
Netherlands	Cemetery, Tiel-Passewaaij	60	270	1	Ritual, religion and funerary	Yes	(Groot, M., 2007)
Netherlands	Druten-Klepperhei	-250	199	3	Occupation site; Building - high status	Yes	(Willems, W. J. H., 1986; Lauwerier, R. C. G. M., 1988)
Netherlands	Dwelling mound, Wijnaldum-Tjitsma	175	350	1	Settlement - other	Yes	(Zeiler, J., 2013; Prummel, W. et al., 2013)
Netherlands	Elst Temple	50	299	1	Ritual, religion and funerary	Yes	(Lauwerier, R. C. G. M., 1988)
Netherlands	Enkhuizen-Kadijken	-1400	-1201	1	Settlement - other	No	(Brinkkemper, O., 2013; Roessingh, W., 2013)
Netherlands	Forum Hadriani	120	270	1	Settlement - urban	Yes	(Zeiler, J. T. and de Vries, L. S., 2008)
Netherlands	Hekelingen	-2250	-2130	1	Settlement - other	No	(Clason, A. T., 1967)
Netherlands	Hoogkarspel-Tolhuis	-700	-700	1	Building - other	Yes	(Clason, A. T. and Prummel, W., 1979; Roessingh, W., 2013)
Netherlands	Jelsum terp, Leeuwarderadeela	-27	476	1	Building - other	Yes	(Prummel, W. et al., 2011)
Netherlands	Margriet, Hugo de Grootstraat, Nijmegen	300	399	1	Ritual, religion and funerary	Yes	(Lauwerier, R. C. G. M., 1988)
Netherlands	Meinerswijk Castellum, Arnhem	100	250	1	Military site	Yes	(Willems, W. J. H., 1986; Lauwerier, R. C. G. M., 1988)
Netherlands	Oude Tielseweg, Tiel-Passewaaij	120	170	1	Settlement - rural	No	(Groot, M., 2007)
Netherlands	Paddepoel	-200	250	1	Settlement - rural	Yes	(Knol, E., 1983)
Netherlands	Passewaaijse Hogeweg, Tiel-Passewaaij	-60	350	5	Settlement - rural; Building - other	Yes	(Groot, M., 2007)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
Netherlands	Praetorium Agrippinae, Valkenburg (Z.H.)	40	260	1	Military site	Yes	(Glasbergen, W., 1972; Clason, A. T. and Prummel, W., 1979; Liarsou, A., 2013)
Netherlands	Tritsum	-500	99	1	Settlement - rural	Yes	(Clason, A. T. and Prummel, W., 1979; Knol, E., 1983; Kysely, R., 2010)
Netherlands	Valkhof, Nijmegen	25	350	2	Occupation site; Settlement - enclosed	Yes	(Lauwerier, R. C. G. M., 1988)
Netherlands	Velsen I Roman Castellum	16	43	1	Military site	Yes	(Prummel, W., 1993; Bosman, A. and de Weerd, M., 2004)
Netherlands	Vlaardingen	-2380	-2240	1	Settlement - other	Yes	(Clason, A. T., 1967)
Netherlands	Voorne-Putten	-725	-25	3	Building - other	No	(Prummel, W., 1989)
Netherlands	Waterworks of Amsterdam, Zandvoort	-300	-300	1	Occupation site	Yes	(Clason, A. T., 1967)
Netherlands	Westerveld, Ussen	-12	199	1	Building - other	Yes	(Bakels, Corrie et al., 1997)
Netherlands	Zandwerven, Opmeer	-2500	-2201	1	Settlement - other	No	(Clason, A. T., 1967)
Poland	Biskupin	-747	-597	1	Settlement - enclosed	Yes	(Wazny, T., 1993; Benecke, N., 1994; Gotfredsen, A. B. and Makowiecki, D., 2004; Bochenski, Z. et al., 2012)
Poland	Borsuka Cave	-2225	-1970	1	Cave	Yes	(Wilczyñski, J. et al., 2012)
Poland	Brudnice	200	299	1	Ritual, religion and funerary	Yes	(Bochenski, Z. et al., 2012)
Poland	Komorowo	-970	-461	1	Settlement - enclosed	Yes	(Gotfredsen, A. B. and Makowiecki, D., 2004)
Poland	Kotlin	-800	-620	1	Settlement - other	Yes	(Benecke, N., 1994)
Poland	Kruszwica (Fst. 5)	-550	-460	1	Settlement - other	Yes	(Benecke, N., 1994)
Poland	Slupca	-620	-460	1	Settlement - enclosed	Yes	(Benecke, N., 1994)
Poland	Tolkmicko (Fst. 1)	-620	-460	1	Settlement - enclosed	Yes	(Benecke, N., 1994)
Portugal	Alcáçova de Santarém	-800	499	6	Settlement - enclosed; Settlement - urban	Yes	(Davies, S. J. M., 2006)
Portugal	Castro Marim	-650	50	3	Settlement - urban	Yes	(Davis, S. J. M., 2007)
Portugal	Monte Molião, Lagos	-400	199	3	Settlement - enclosed; Settlement - urban	Yes	(Arruda, A. M., 2011; Detry, C. and Arruda, A. M., 2013)
Portugal	Prazo, Freixo de Numão	300	399	1	Building - high status	Yes	(Monteiro-Rodrigues, S. and Angelucci, D. E., 2004; Costa, C., 2008)
Portugal	Quinta das Longas, Elvas	340	399	1	Building - high status	Yes	(Goncalves, V. S. et al., 2003; Cardoso, J. L. and Detry, C., 2005)
Portugal	Tróia, Grândola	175	450	1	Industrial site	Yes	(Nabais, M., 2014)
Portugal	Zimbro II, Freixo de Numão	-25	399	1	Building - high status	No	(Costa, C., 2008)
Romania	Borduşani-Popină	-4700	-28	2	Settlement - other	Yes	(Tomescu, I., 2003; Bălăşescu, A. et al., 2003; Gál, E. and Kessler, E., 2003a; 2003b; Bréhard, S. and Balasescu, A., 2012)
Romania	Ciuleneş, Mintiu Gherlii	-1800	-1301	1	Settlement - other	Yes	(Molnar, Z. S. et al., 2013)
Romania	Hârsova Tell	-4350	-4001	1	Settlement - rural	Yes	(Gál, E., 2002; Bréhard, S. and Balasescu, A., 2012)
Romania	Largiana, Romanasi, Sălaj	135	275	1	Military site	Yes	(Gál, E., 2005)
Romania	Magyarfenes, Vlaha	-800	-460	1	Settlement - other	Yes	(Molnar, Z. S. et al., 2013)
Romania	Porolissum, Sălaj	150	270	2	Ritual, religion and funerary; Settlement - urban	Yes	(Gál, E., 2005)
Romania	Sanctuary of Liber Pater, Apulum	100	299	1	Ritual, religion and funerary	Yes	(Gál, E., 2005)
Romania	Sângeorgiu de Mureş	-460	-28	1	Occupation site	No	(Kelemen, I., 2010)
Serbia	Bare, Voganj	-150	-75	1	Settlement - other	Yes	(Jovanovic, B., 2009; Radmanović, D. P. et al., 2013)
Serbia	Bregovi Atovac, Kuzmin	-150	-1	1	Settlement - other	Yes	(Jovanovic, B., 2009; Radmanović, D. P. et al., 2013)
Serbia	Čarnok, Vrbas	-150	-1	1	Settlement - enclosed	Yes	(Radmanović, D. P. et al., 2013)
Serbia	Gladno Polje, Remesiana	300	350	1	Ritual, religion and funerary	Yes	(Јовановић, J. and Булатовић, J., 2013)
Serbia	Gomolava, Hrtkovci	-950	-1	2	Settlement - other	Yes	(Radmanović, D. P. et al., 2013)
Serbia	Gradina, Vašica	-150	-1	1	Settlement - other	Yes	(Radmanović, D. P. et al., 2013)
Serbia	Mitrovačke livade, Sremska Mitrovica	-150	-1	1	Settlement - other	Yes	(Radmanović, D. P. et al., 2013)
Serbia	Židovar	-150	-1	1	Settlement - enclosed	Yes	(Jevtić, M. and Ljuština, M., 2008; Radmanović, D. P. et al., 2013)

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Slovakia	Bajč (fst. Vlkanovo)	-460	-30	1	Ritual, religion and funerary	Yes	(Benecke, N., 1994)
Slovakia	Fort Iža	161	179	1	Military site	Yes	(Hajnalová, M. and Rajtár, J., 2009)
Slovakia	Nebojsa, Galanta	-460	-30	1	Ritual, religion and funerary	Yes	(Benecke, N., 1994)
Slovakia	Nitriansky-Hradok	-2000	-801	1	Occupation site	No	(Liarsou, A., 2013)
Slovakia	Nové Košariská	-800	-460	1	Ritual, religion and funerary	Yes	(Benecke, N., 1994)
Slovenia	Brežice-Sejmišče	-260	-151	1	Ritual, religion and funerary	Yes	(Hincak, Z. and Guštin, M., 2011)
Slovenia	Cvinger near Vir pri Sticni	-50	-1	1	Settlement - enclosed	Yes	(Stergar, P. et al., 2014)
Slovenia	Dobova - Kosovka	-300	-101	1	Ritual, religion and funerary	Yes	(Hincak, Z. and Guštin, M., 2011)
Slovenia	Škocjan Caves	-500	-30	1	Cave	No	(Riedel, A., 1977)
Spain	Alorda park	-400	-200	1	Settlement - enclosed	Yes	(Hernandez Carrasquilla, F., 1992; Valenzuela Lamas, S., 2008; Valenzuela Lamas, S. et al., 2009)
Spain	Aloria	200	399	1	Settlement - rural	Yes	(Castaños, P., 2001)
Spain	Alto de la Carcel, Arellano	0	399	2	Building - high status	Yes	(Marriekurrena, K. and Altuna, J., 1993)
Spain	Arcaya Roman town	0	99	1	Settlement - urban	Yes	(Castaños, P., 2008)
Spain	Augusta Bilbilis	-50	125	1	Settlement - urban	Yes	(Castaños, J. et al., 2006)
Spain	Ca n'Oliver, Cerdanyola del Vallès	-500	-201	1	Settlement - enclosed	Yes	(Albizuri, S., 2011b)
Spain	Cabezo de San Pedro	-700	-200	1	Settlement - other	Yes	(Liarsou, A., 2013)
Spain	Cabezo Redondo	-2000	-1800	1	Building - other	No	(Liarsou, A., 2013)
Spain	Can Roqueta II, Sabadell	-2300	-1301	1	Ritual, religion and funerary	No	(Albizuri, S., 2011a)
Spain	Castillo de Dona Blanca, Cádiz	-750	-500	1	Settlement - urban	Yes	(Hernandez Carrasquilla, F., 1993; Morales Muñiz, A. et al., 1994)
Spain	Cerro de la Tortuga	-600	-550	1	Ritual, religion and funerary	Yes	(Becker, C., 2013)
Spain	Cerro de la Virgen, Orce	-2800	-1550	1	Settlement - other	Yes	(von den Driesch, A., 1973)
Spain	Cerro de Santa Ana, Entrena	-400	-200	1	Settlement - rural	Yes	(Miguel, F. J. and Morales Muniz, A., 1983; 1986)
Spain	Cerro del Real, Galera	-1200	-801	1	Settlement - other	Yes	(von den Driesch, A., 1973)
Spain	Cerro del Villar	-750	-501	2	Occupation site; Industrial site	Yes	(Aubet, M. E., 1999; Garcia Petit, L., 1999; Montero, M., 1999; Rodrigues, C. G., 1999; Burjacks, F. and Ros, M. T., 1999)
Spain	Cova 120, La Garroxta	-3200	-801	2	Cave	Yes	(Bibiana, A. et al., 1986; Petit, L. G., 2005)
Spain	El Barranquete	-2300	-2000	1	Ritual, religion and funerary	No	(Liarsou, A., 2013)
Spain	El Castellet de Bernabé, Llíria, Valencia	-500	-401	1	Settlement - enclosed	Yes	(Iborra Eres, M. P., 2004)
Spain	El Cormulló dels Moros, Albocàsser, Castellón	-200	-1	1	Settlement - enclosed	Yes	(Iborra Eres, M. P., 2004)
Spain	El Puntal des Llops, Olocau, Valencia	-400	-201	1	Settlement - enclosed	Yes	(Iborra Eres, M. P., 2004)
Spain	El Torrello del Boverot, Almassora, Castellón	-170	-140	1	Settlement - other	Yes	(Iborra Eres, M. P., 2004)
Spain	El Tossal de Sant Miquel, Llíria, Valencia	-400	-201	1	Settlement - urban	Yes	(Iborra Eres, M. P., 2004)
Spain	Illa d'en Reixac	-600	-201	1	Settlement - rural	Yes	(Petit, L. G., 2005; Belarte, M. C. and Valenzuela-Lamas, S., 2013)
Spain	La Bastida de les Alcusses, Moixent	-400	-301	1	Settlement - enclosed	No	(Iborra Eres, M. P., 2004)
Spain	La Morranda, El Ballestar, Castellón	-200	-1	1	Settlement - rural	Yes	(Iborra Eres, M. P., 2004)
Spain	La Seña, Villar del Arzobispo	-500	-301	1	Settlement - rural	Yes	(Iborra Eres, M. P., 2004)
Spain	La Villa de Cornelius, L'Ènova	0	199	1	Building - high status	Yes	(Descals, R. A. and de Madaria, J. L., 2006)
Spain	Los Castellazos, Mediana de Aragón	-300	-200	1	Settlement - urban	Yes	(Hernandez Carrasquilla, F., 1992)
Spain	Los Villares, Caudete de las Fuentes	-700	-501	1	Settlement - other	No	(Iborra Eres, M. P., 2004)
Spain	Mas Castellar de Pontos	-600	-201	1	Settlement - other	Yes	(Petit, L. G., 2005; Petit, L. G. and Pons, E., 2010; Colominas, L. et al., 2013)
Spain	Molí d'Espígol, Tornabous	-500	-1	1	Settlement - enclosed	Yes	(Petit, L. G., 2005)

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Spain	Morro de Mezquitilla	-800	-600	1	Settlement - urban	Yes	(Becker, C., 2013)
Spain	Necropolis 'Poblado', Coimbra del barranco ancho, Jumilla	-380	-225	1	Ritual, religion and funerary	Yes	(Paz, M., 1993; Albizuri, S. et al., 2012)
Spain	Necropolis, Plaça de la Vila de Madrid	150	250	1	Ritual, religion and funerary	Yes	(Colominas Barbera, L., 2007; Garcia Petit, L., 2007)
Spain	Poblado de la Hoya	-450	-350	1	Settlement - enclosed	Yes	(Hernandez Carrasquilla, F., 1992)
Spain	Puig Castellar	-550	-300	1	Settlement - rural	Yes	(Belarte, M. C. and Valenzuela-Lamas, S., 2013)
Spain	Reclau Viver, Serinya	-5200	-2201	1	Cave	Yes	(Petit, L. G., 2005; Zilhao, J., 2006)
Spain	Toscanos	-740	-600	1	Settlement - urban	Yes	(Becker, C., 2013)
Spain	Ucero	-400	-200	1	Ritual, religion and funerary	Yes	(Hernandez Carrasquilla, F., 1992)
Spain	Veranes	300	499	1	Building - high status	Yes	(Eduardo Corona-M., 2008)
Spain	Vinarragell, Burriana, Castellón	-700	-550	1	Settlement - rural	Yes	(Iborra Eres, M. P., 2004)
Sweden	Apalle	-1200	-701	1	Settlement - other	No	(Ullén, I., 1996; Ericson, P. G. P. et al., 1997)
Sweden	Eketorp Castle, Degerhamn	300	399	1	Settlement - enclosed	Yes	(Boessneck, J. et al., 1979)
Sweden	Raä89, Huseby Klev	-2900	-1301	1	Settlement - other	No	(Nordqvist, B., 2005)
Sweden	Simunde	-1400	399	2	Ritual, religion and funerary	Yes	(Wehlin, J. and Schönbäck, B., 2012)
Sweden	Skedemosse	-1500	499	2	Other	Yes	(Hagberg, U. E., 1967)
Sweden	Styrmansberg, Fröjel	0	199	1	Settlement - enclosed	Yes	(Stenberger, M., 1955)
Sweden	Styrmansberg, Gotland	0	199	1	Settlement - enclosed	Yes	(Stenberger, M., 1955; Welinder, S., 1998)
Sweden	Uppåkra, Lund	0	399	1	Settlement - rural	No	(Nilsson, L., 2002; Jennbert, K., 2011)
Sweden	Vallhagar	200	499	1	Settlement - other	Yes	(Stenberger, M., 1955)
Switzerland	Basel-Münsterhügel, Basel	-80	40	2	Settlement - enclosed	Yes	(Stopp, B., 2009)
Switzerland	Biberist-Spitalhof Roman Villa	75	260	2	Building - high status; Ritual, religion and funerary	Yes	(Deschler-Erb, S., 2006)
Switzerland	Cave sanctuary, Zillis	260	399	1	Ritual, religion and funerary	Yes	(Rageth, J., 1994; 2001)
Switzerland	Cellar, Osttorstrasse, Augusta Raurica	225	275	1	Building - other	Yes	(Deschler-Erb, S., 2012)
Switzerland	Civil settlement West, Vindonissa, Windisch	0	40	1	Ritual, religion and funerary	Yes	(Baerlocher, J. and Deschler-Erb, S., 2011)
Switzerland	En Chaplix, Aventicum, Avenches	70	120	1	Ritual, religion and funerary	Yes	(Deschler-Erb, S., 2013)
Switzerland	Ersigen-Murain	0	299	1	Building - high status	Yes	(Miron, A. and Wustrow, C., 1997; Olive, C. and Deschler-Erb, S., 1999; Liarsou, A., 2013)
Switzerland	Gelterkinden	-460	-260	1	Settlement - other	Yes	(Benecke, N., 1994)
Switzerland	Insula 30, Augusta Raurica	-27	476	1	Settlement - urban	Yes	(Liarsou, A., 2013)
Switzerland	La Tène	-200	-71	1	Settlement - urban	Yes	(Seigle, M., 2014)
Switzerland	Martigny mithraeum	200	399	1	Ritual, religion and funerary	Yes	(von den Driesch, A. and Pöllath, N., 2000; Fegerl, K., 2008)
Switzerland	Mont Vully	-125	-75	1	Settlement - enclosed	Yes	(Seigle, M., 2014)
Switzerland	Mormont	-100	-100	1	Ritual, religion and funerary	Yes	(Méniel, P., 2011)
Switzerland	Southern Cemetery, Vindonissa, Windisch	70	120	1	Ritual, religion and funerary	Yes	(Deschler-Erb, S., 2013)
Switzerland	Sus, Zernez	-480	-28	1	Building - other	Yes	((Anon.) Société suisse de préhistoire, 1936)
Switzerland	Tschugg	-27	476	1	Building - high status	Yes	(Liarsou, A., 2013)
Switzerland	Villa d'Orbe-Bosceaz Mithraeum	175	299	1	Building - high status	Yes	(Lentacker, A. et al., 2004)
Turkey	Buyuktepe Höyük, Gumushane	-1000	-201	1	Settlement - other	Yes	(Howell-Meurs, S., 2001)
Turkey	Dülük Baba Tepesi	-600	-1	3	Ritual, religion and funerary	Yes	(Pöllath, N. and Peters, J., 2011)
Turkey	Ephesus, Hangaus II	-2	299	1	Building - high status	Yes	(Liarsou, A., 2013)

Country	**Site name**	**Date from**	**Date to**	**No. of phases**	**Site type**	**Chickens**	**Source(s)**
Turkey	Korucutepe	-2600	-1200	3	Settlement - rural	Yes	(Boessneck, J. and von den Driesch, A., 1974)
Turkey	Sagalassos, Ağlasun	0	450	2	Settlement - urban	Yes	(De Cupere, B., 2001)
Turkey	Sos Höyük, Yiğittaşı, Erzurum	-3000	-201	1	Settlement - other	Yes	(Sagona, A. and Sagona, C., 2000; Howell-Meurs, S., 2001; Longford, C. et al., 2011)
Turkey	Tušhan, Ziyaret Tepe	-800	-701	1	Building - high status	Yes	(Greenfield, T. et al., 2013)
Turkey	Zeugma	100	253	3	Settlement - urban	Yes	(Aylward, W., 2013; Charles, B., 2013; Gale, R., 2013)
Ukraine	Ol'vija (Olbia)	-600	-1	1	Settlement - urban	Yes	(Benecke, N., 1994)
Ukraine	Panskoye I	-250	-201	1	Settlement - rural	No	(Kasparov, A., 2002; Sceglov, A. N., 2002)
United Kingdom	12 Pieces Lane, Waterbeach	100	138	1	Industrial site	Yes	(Newton, A., 2011)
United Kingdom	16-22 Coppergate, York	43	410	1	Occupation site	Yes	(O'Connor, T. P., 1986)
United Kingdom	165 Great Dover Street, Southwark (Watling St.)	175	299	1	Ritual, religion and funerary	Yes	(Reilly, K., 2000)
United Kingdom	24-30 Tanner Row	150	399	2	Settlement - urban	Yes	(O'Connor, T. P., 1988)
United Kingdom	27 Jewry Street, Winchester	175	399	1	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	33 Sheep Street, Cirencester	43	399	3	Settlement - other; Settlement - urban	Yes	(King, R., 1990)
United Kingdom	51-57 Rayne Road, Braintree	100	410	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	6 Driffield Terrace, York	250	399	2	Ritual, religion and funerary	Yes	(Foster, A. and Jaques, D., 2012)
United Kingdom	9-11 Monson Street, Lincoln	150	275	1	Settlement - other	Yes	((Anon.) Allen Archaeology, 2010)
United Kingdom	Abbotstone Down, Alresford	-100	99	1	Settlement - enclosed	Yes	(Hambleton, E., 2008)
United Kingdom	Aldwick, Barley, nr Royston	-800	42	1	Settlement - rural	Yes	(Cra'ster, M. D., 1961)
United Kingdom	Alington Avenue, Dorchester	-100	410	5	Enclosure; Building - other; Occupation site; Ritual, religion and funerary	Yes	(Maltby, M., 1988)
United Kingdom	Annetwell Street, Carlisle	43	410	1	Settlement - urban	Yes	(Allison, E. P., 1991)
United Kingdom	Appleford Field, Appleford	100	399	1	Settlement - rural	Yes	(Hinchliffe, J. and Thomas, R., 1980)
United Kingdom	Arbeia, South Shields Roman Fort	222	350	1	Military site	Yes	(Hodgson, N., 1994; Stokes, P., 2000)
United Kingdom	Ashville Trading Estate, Abingdon	-800	399	4	Settlement - rural	Yes	(Parrington, M., 1978)
United Kingdom	Aslockton, Vale of Belvoir	-800	42	1	Settlement - other	No	(Dobney, K. and Ervynck, A., 2007; Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Asthall, Burford	150	410	1	Settlement - urban	Yes	(Booth, P. M., 1992)
United Kingdom	Bagendon Oppidum	20	50	1	Settlement - enclosed	Yes	(Balfour-Browne, F. L., 1961; Clifford, E. M., 1961; Jackson, J. W., 1961)
United Kingdom	Baldock	-100	410	3	Settlement - enclosed; Settlement - urban	Yes	(Hamilton-Dyer, S., 2007)
United Kingdom	Baleshare, North Uist	-800	-401	1	Settlement - rural	No	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Balksbury Camp, Andover	-900	399	4	Occupation site; Building - other; Settlement - rural; Settlement - enclosed	Yes	(Wainwright, G. J. and Davies, S. M., 1995)
United Kingdom	Bancroft, Milton Keynes	-400	410	6	Settlement - rural; Settlement - enclosed; Ritual, religion and funerary; Building - high status	Yes	(Levitan, B., 1994; Holmes, J. and Rielly, K., 1994; Hambleton, E., 2008)
United Kingdom	Banwell Roman villa	300	399	1	Building - high status	Yes	(Maltby, M. and Coy, J., 1979)
United Kingdom	Barnack	100	410	1	Settlement - rural	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Barnsley Park	43	410	1	Building - high status	Yes	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Barrow Hills, Radley	-2000	-1501	1	Ritual, religion and funerary	No	(Barclay, A. and Halpin, C., 2002)
United Kingdom	Barton Court Farm	-100	410	3	Building - other	Yes	(Miles, D., 1984)
United Kingdom	Basilica, Caerwent Roman Town	43	399	1	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	Bath Gate Cemetery, Cirencester	145	410	2	Occupation site; Other	Yes	(Thawley, C., 1982a)
United Kingdom	Battlesbury Bowl, Warminster	-800	-200	2	Settlement - rural	No	(Hambleton, E. and Maltby, M., 2008)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
United Kingdom	Biddenham Loop	-2500	99	2	Settlement - other; Building - other	Yes	(Luke, M. et al., 2009)
United Kingdom	Bierton	-100	42	1	Settlement - rural	Yes	(Hambleton, E., 2008)
United Kingdom	Billesley Manor	100	399	1	Settlement - other	Yes	(Palmer, S. C., 2003)
United Kingdom	Billingborough	-900	99	3	Industrial site; Enclosure; Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Birdlip Quarry	160	380	1	Building - other	Yes	(Holbrook, N., 2006; Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Birdoswald, Hadrians Wall	117	350	2	Military site	Yes	(Izard, K., 1997)
United Kingdom	Bishops Canning Down	-1600	-1001	1	Settlement - rural	No	(Maltby, M., 1992)
United Kingdom	Blackfriars Street, Carlisle	79	410	2	Settlement - urban	Yes	(Rackham, D. J., 1990)
United Kingdom	Blackhorse Rd, Letchworth	-800	410	2	Enclosure	Yes	(Legge, A. et al., 1988)
United Kingdom	Bonners Ln, Leicester	43	410	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Bottom Pond Farm, Owslebury	-300	99	8	Settlement - rural	Yes	(Maltby, M., 1987)
United Kingdom	Bourton-on-the-Water	43	410	1	Settlement - other	Yes	(Maltby, M., 1998)
United Kingdom	Box Roman villa	125	325	1	Building - high status	Yes	(Fisher, C., 1987)
United Kingdom	Boxmoor House School	43	410	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Braintree	43	410	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Brampton Kiln Field	175	299	1	Industrial site	Yes	(Jones, G., 1977)
United Kingdom	Brancaster Roman Fort	175	299	1	Settlement - urban	Yes	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Braughing Bath House	-100	42	1	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Brean Down	-1000	-701	2	Occupation site	Yes	(Bell, M., 1990)
United Kingdom	Breckness Broch, Orkney	-400	-101	1	Building - other	Yes	(Ballin Smith, B. et al., 2004)
United Kingdom	Bremetennacum, Ribchester	78	350	1	Military site	Yes	(Davies, R. W., 1971)
United Kingdom	Brentford	43	410	1	Settlement - rural	No	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Broad Street, Abingdon	350	399	1	Occupation site	Yes	(Parrington, M., 1975; Parrington, M. and Balkwill, C., 1975)
United Kingdom	Broch of Midhowe, Rousay, Orkney	-200	199	1	Settlement - rural	Yes	(Platt, M., 1934)
United Kingdom	Bu, Orkney	-600	99	1	Building - other	No	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Buckingham Street, Aylesbury	43	410	1	Occupation site	Yes	(Allen, D., 1982)
United Kingdom	Budbury	-800	-401	1	Settlement - enclosed	Yes	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Burderop Down	-1000	-701	1	Settlement - rural	No	(Maltby, M., 1992)
United Kingdom	Burgh	-100	43	1	Enclosure	No	(Jones, R. T. et al., 1988)
United Kingdom	Burton Latmer, Higham Road and Bungalow	150	399	1	Settlement - rural	Yes	(Matlby, M., 2013)
United Kingdom	Bury Wood Camp	-350	-150	1	Settlement - enclosed	Yes	(Bunting, G. H. et al., 1963)
United Kingdom	Caesaromagus NE, Chelmsford	43	399	2	Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Caesaromagus SE, Chelmsford	43	199	1	Building - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Caister-on-Sea	200	399	1	Military site	Yes	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Caistor Hall Hotel, Caistor St Edmund	250	399	1	Settlement - rural	Yes	(Emery, G., 2007)
United Kingdom	Caldecotte, Milton Keynes	50	399	1	Settlement - rural	Yes	(King, A., 1999)
United Kingdom	Caldicot, Gwent	-2000	-1	2	Occupation site	No	(McCormick, F. et al., 1997)
United Kingdom	Camulodunum, Colchester	43	410	5	Settlement - urban; Other	Yes	(Luff, R. and Brothwell, D., 1993)
United Kingdom	Cat's Water Subsite, Fengate, Peterborough	-800	42	1	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Catterick Site 434	100	399	2	Military site; Settlement - urban	Yes	(Payne, S., 1990)
United Kingdom	Cattlemarket, Chichester	43	410	6	Settlement - urban	Yes	(Down, A., 1989)
United Kingdom	Causeway Ln, Leicester	43	399	2	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Chignall Roman Villa, Chignall	43	410	4	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)

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United Kingdom	Cleveland Farm, Ashton Keynes	43	410	1	Settlement - rural	Yes	(Knight, S. et al., 2007)
United Kingdom	Colchester (1930's excavations)	0	199	2	Settlement - urban; Other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	County Museum, Aylesbury	-400	-101	1	Occupation site	Yes	(Bonner, D., 1998)
United Kingdom	Covells Drain, Swavesey	200	399	1	Field system	Yes	(Murrell, K., 2007)
United Kingdom	Crosskirk Broch, Caithness	0	199	1	Building - other	Yes	(Fairhurst, H., 1984)
United Kingdom	Crown Hotel, Jewry Street, Winchester	200	299	1	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	Danebury	-550	-50	4	Settlement - enclosed	Yes	(Cunliffe, B., 1991); Cunliffe, B. and Poole, C., 1991
United Kingdom	Dean Bottom	-2800	-801	2	Enclosure	No	(Maltby, M., 1992)
United Kingdom	Derby NW Sector	43	410	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Deva, Chester legionary fortress	74	399	1	Military site	Yes	(Davies, R. W., 1971)
United Kingdom	Dicket Mead, Lockleys, Welwyn	200	399	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Ditches Hillfort, North Cerney	-100	399	2	Settlement - enclosed	Yes	(Trow, S. D., 1988)
United Kingdom	Dodderhill Roman Fort	55	66	1	Military site	Yes	(Davis, S. J. M., 1988)
United Kingdom	Downing College Sports Field, Cambridge	-100	99	1	Building - other	Yes	(Armour, N., 2001)
United Kingdom	Dragonby, nr Scunthorpe	-100	410	2	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Ducklington	250	410	1	Settlement - rural	No	(Chambers, R. A., 1975)
United Kingdom	Dunstable	43	199	1	Ritual, religion and funerary	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	East Road, Caerwent	330	330	1	Settlement - urban	Yes	(Liarsou, A., 2013)
United Kingdom	Eastern Cemetery, Tower Hamlets	43	499	2	Ritual, religion and funerary	Yes	(Barber, B. and Bowsher, D., 2000)
United Kingdom	Edix Hill, Barrington	-150	42	1	Settlement - other	No	(Davis, S. J. M., 1995)
United Kingdom	Elms Farm, Heybridge	-50	499	5	Settlement - other	Yes	(Johnstone, C. and Albarella, U., 2002)
United Kingdom	Elms Farm, Leicester	-400	42	1	Enclosure	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Eton Socon	43	399	2	Field system	Yes	(Gibson, C., 2005; Sykes, N., 2005)
United Kingdom	Exeter	55	499	3	Settlement - urban	Yes	(Liarsou, A., 2013)
United Kingdom	Northern Extramural Area, Alcester	43	399	2	Settlement - urban	Yes	(Booth, P. and Evans, J., 2001)
United Kingdom	Farmoor	43	410	1	Settlement - other	No	(Wilson, B. and Bramwell, D., 1979)
United Kingdom	Fenny Lock, Milton Keynes	-400	399	2	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Fishbourne, Chichester	43	290	3	Building - high status	Yes	(Cunliffe, B., 1971; Allen, M., 2009)
United Kingdom	Flagstones, Dorchester	-100	42	1	Field system	No	(Smith, R.J.C. et al., 1997; Bullock, E. and Allen, M. J., 1997)
United Kingdom	Folly Lane, Verulamium, St Albans	-100	399	2	Occupation site; Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Former County Hospital, Dorchester	60	410	4	Settlement - urban	Yes	(Barnett, C., 2008; Grimm, J., 2008; Hamilton-Dyer, S., 2008; Sidell, J., 2008; Stevens, C., 2008)
United Kingdom	Foxholes Farm, nr Hertford	-100	42	1	Enclosure	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Foxton (St Neots-Duxford Pipeline)	43	410	2	Field system; Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Gadebridge Park, Hemel Hempstead	43	410	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Gas House Lane, Alcester	200	410	2	Settlement - urban	Yes	(Cracknell, S. and Allen, D., 1996)
United Kingdom	George Street, Aylesbury	-400	-101	1	Occupation site	Yes	(Allen, D. and Dalwood, C. H., 1983)
United Kingdom	Godwin Ridge shrine	-100	42	1	Ritual, religion and funerary	No	(Evans, C., 2013)
United Kingdom	Gorhambury, nr St Albans	20	399	3	Settlement - enclosed; Building - high status	Yes	(Locker, A., 1990; Neal, D. S., 1990)
United Kingdom	Grandford, nr March	43	399	3	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Great Chesterford, nr Saffron Walden	200	399	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Great Dunmow	100	299	1	Settlement - urban	Yes	(Luff, R. M., 1988)
United Kingdom	Great Holts Farm, Boreham	200	399	2	Building - high status	No	(Albarella, U., 1997b)

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United Kingdom	Great Staughton AML 1547, nr St Neots	43	410	1	Building - high status	Yes	(Bramwell D., 2000)
United Kingdom	Greyhound Yard, Dorchester	60	450	5	Settlement - urban	Yes	(Maltby, M., 1990)
United Kingdom	Groundwell Barn, Blunsdon St Andrews	-500	-301	1	Enclosure	No	(Coy, J., 1982)
United Kingdom	Grove Farm, Enderby, Leicester	-400	42	1	Building - other	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Gussage All Saints	-800	42	3	Building - other	Yes	(Harcourt, R., 1979)
United Kingdom	Hemel Hempstead Station, Hemel Hempstead	43	410	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Henley's Garage, Winchester	75	399	3	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	High Barns Road, Roxton	-50	50	1	Settlement - enclosed	Yes	(Timby, J. et al., 2007b)
United Kingdom	High St (33-47), Leicester	200	399	1	Occupation site	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Hindlow Cairn, nr Glossop	-2500	-801	1	Ritual, religion and funerary	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Hod Hill	43	99	1	Military site	Yes	(Fraser, F. C., 1968; Davies, R. W., 1971)
United Kingdom	Holt, Denbighshire	85	135	1	Military site	Yes	(Davies, R. W., 1971)
United Kingdom	Houghton Down	-369	399	2	Settlement - enclosed; Settlement - rural	Yes	(Hamilton, J., 2000a; Cunliffe, B. and Poole, C., 2000b)
United Kingdom	Hyde Abbey, Winchester	175	399	2	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	Ickleton Rd, Chesterford	-100	42	1	Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Insula IX, Silchester	300	399	1	Settlement - urban	Yes	(Fulford, M. et al., 2006)
United Kingdom	Isca, Caerleon	74	99	3	Military site	Yes	(Hamilton-Dyer, S., 1993)
United Kingdom	Ivinghoe Beacon	-800	-401	1	Settlement - enclosed	Yes	(Hambleton, E., 2008; Albarella, U. and Pirnie, T., 2008)
United Kingdom	Ivy Chimneys, Witham	43	410	3	Enclosure; Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Kingscote	75	360	1	Settlement - other	Yes	(Maltby, M., 1998)
United Kingdom	Kirtling Green to Wixoe Pipeline	43	250	1	Settlement - rural	No	(Lyons, T., 2012)
United Kingdom	Latimer, nr Amersham	200	410	2	Building - high status; Building - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Lincoln Road, Enfield	100	399	1	Occupation site	Yes	(Ivens, J. and Deal, G., 1977)
United Kingdom	Lincoln sites	43	399	3	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Linton Village College, Linton	150	410	1	Occupation site	No	(Faine, C., 2009)
United Kingdom	Little Barford (St Neots-Duxford Pipeline)	150	410	2	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Little Chester, Derby	50	399	3	Military site	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Little Lane, Leicester	100	399	2	Settlement - urban	Yes	(Gidney, L. J., 1991)
United Kingdom	Little Stonegate, York	43	410	2	Settlement - urban	Yes	(Liarsou, A., 2013)
United Kingdom	Little Waltham, nr Chelmsford	43	410	1	Occupation site	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	London Rd, Godmanchester	100	399	2	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Longdoles Field, Claydon Pike	-400	410	3	Settlement - rural; Building - high status	Yes	(Miles, D et al., 2007)
United Kingdom	Longthorpe II, nr Peterborough	43	199	1	Military site	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Longthorpe, nr Peterborough	44	62	1	Military site	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Low Park Corner, Chippenham	-400	99	2	Settlement - enclosed; Settlement - rural	No	(Atkins, R., 2013)
United Kingdom	Magiovinium, nr Fenny Stratford	43	299	2	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Maiden Castle	-800	42	1	Settlement - enclosed	Yes	(Wainwright, G. J and Cunliffe, B. W., 1985; Sharples, N., 1991)
United Kingdom	Maiden Castle Road, Dorchester	43	410	1	Settlement - other	Yes	(Smith, R.J.C. et al., 1997; Bullock, E. and Allen, M. J., 1997)
United Kingdom	Manor Farm, Borwick	-1740	-1640	1	Ritual, religion and funerary	No	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Market Road, Chichester	200	399	1	Settlement - urban	Yes	(Raymond, F., 2004)
United Kingdom	Meare Lake Settlement	-800	42	1	Settlement - rural	Yes	(Harrison, C.J.O., 1987)
United Kingdom	Meare Village East	-150	99	1	Settlement - rural	Yes	(Coles, J., 1987)
United Kingdom	Meare Village West	-100	42	1	Settlement - rural	Yes	(Bulleid, A. and St. George Gray, H., 1948; Backway, C., 1986)

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United Kingdom	Merton Rise and Marnel Park, Basingstoke	-100	100	1	Settlement - rural	Yes	(Grimm, J., 2009)
United Kingdom	Micheldever Wood	-300	-101	1	Enclosure	Yes	(Fasham, P. J., 1987)
United Kingdom	Middle Duntisbourne	0	42	1	Settlement - rural	Yes	(Hambleton, E., 2008)
United Kingdom	Middle Farm, Dorchester	-2500	-1001	1	Settlement - enclosed	No	(Smith, R.J.C. et al., 1997; Bullock, E. and Allen, M. J., 1997)
United Kingdom	Milton Keynes	43	410	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Nazeingbury Essex, nr Broxbourne	43	410	1	Building - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Neigh Bridge, Somerford Keynes	25	225	2	Field system; Settlement - other	Yes	(Miles, D et al., 2007)
United Kingdom	Nettlebank Copse, Wherwell	-470	42	2	Settlement - rural	Yes	(Cunliffe, B. and Poole, C., 2000a)
United Kingdom	New Royal Spa, Bath	43	399	3	Occupation site; Building - high status	Yes	(Higbee, L., 2007; Humphrey, A. and Jones, K. G., 2007)
United Kingdom	New Wimpole (St Neots-Duxford Pipeline)	-100	99	1	Occupation site	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Newarke St, Leicester	43	410	3	Settlement - urban; Occupation site; Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Norman Cross, Stilton, nr Peterborough	200	399	1	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Nornour, Cornwall	-100	240	1	Settlement - rural	Yes	(Butcher, S. A., 1978)
United Kingdom	Northchurch villa, nr Berkhamsted	100	399	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Northfleet Roman Villa	70	410	3	Building - high status	Yes	(Grimm, J., 2010; Andrews, P. et al., 2011; Barnett, C. et al., 2011)
United Kingdom	Northgate House, Winchester	-800	399	5	Settlement - urban	Yes	(Nicholson, R., 2011; Strid, L., 2011)
United Kingdom	Oakham, Rutland	43	410	1	Other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Old Down Farm, Andover	-700	120	4	Settlement - enclosed	Yes	(Davis, S. J. M., 1981)
United Kingdom	Orton Hall Farm, Orton Township	50	399	3	Settlement - rural; Building - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Orton Longueville (Monument 97)	-100	299	2	Building - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Outgang Road, Market Deeping	-400	42	1	Occupation site	No	(Albarella, U., 1997a)
United Kingdom	Ower	0	410	3	Settlement - enclosed; Industrial site	Yes	(Woodward, P. J., 1986a)
United Kingdom	Park and Ride site, Butt Lane, Milton	-300	-60	1	Settlement - enclosed	Yes	(Hounsell, D., 2009)
United Kingdom	Park St, nr St Albans	43	410	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Paston Reserve, Peterborough	100	299	1	Enclosure	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Pennyland, Milton Keynes	-800	-101	1	Settlement - rural	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Pooles Cavern, Buxton	43	199	1	Cave	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Poundbury, Dorchester	-2500	410	4	Settlement - enclosed; Settlement - rural	Yes	(Sparey Green, C., 1987)
United Kingdom	Puckeridge and Braughing, Bishop's Stortford/Stevenage	-100	42	1	Settlement - enclosed	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Racecourse Cemetery, Derby	43	410	1	Ritual, religion and funerary	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Racecourse, Derby	100	299	1	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Rayne, nr Braintree	43	410	1	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Renhold Water End East	43	399	2	Settlement - rural	Yes	(Timby, J. et al., 2007b)
United Kingdom	Rockley Down	-1000	-701	1	Enclosure	No	(Maltby, M., 1992)
United Kingdom	Rookery Hill, Bishopstone	-800	42	1	Settlement - enclosed	Yes	(Hambleton, E., 2008)
United Kingdom	Rope Lake Hole	-100	299	3	Settlement - other; Building - other	Yes	(Woodward, P. J., 1986b)
United Kingdom	Rothwell Haigh, Leeds	300	350	1	Enclosure	Yes	(Cool, H. E. M. and Richardson, J.E., 2013)
United Kingdom	Roxton Road West	43	199	1	Settlement - rural	Yes	(Timby, J. et al., 2007b)
United Kingdom	Saltersford Water Treatment Plant, Grantham	200	299	1	Ritual, religion and funerary	Yes	(Dobney, K. and Jaques, D., 1994)
United Kingdom	Saunderton, nr Princes Risborough	43	410	1	Building - high status	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Segontium Roman Fort, Caernarvon	75	399	1	Military site	Yes	(Davies, R. W., 1971)

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United Kingdom	Sheepen, Colchester	44	61	1	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Skeleton Green, Puckeridge	-100	42	1	Settlement - rural	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Slonk Hill, Shoreham	-600	399	2	Settlement - rural	Yes	(Sheppard, P., 1978)
United Kingdom	Springhead roadside settlement	50	410	3	Settlement - other; Occupation site	Yes	(Andrews, P. et al., 2011; Barnett, C. et al., 2011)
United Kingdom	Springhead Roman town (south)	100	199	1	Settlement - urban	Yes	(Campbell, G., 1999; Wilson, R., 1999; Boyle, A. and Early, R., 1999)
United Kingdom	Springhead sanctuary complex	0	199	3	Occupation site; Ritual, religion and funerary	Yes	(Grimm, J., 2007; 2010; Andrews, P. et al., 2011; Barnett, C. et al., 2011)
United Kingdom	St Georges Road, Dorchester	43	410	1	Enclosure	Yes	(Smith, R.J.C. et al., 1997; Bullock, E. and Allen, M. J., 1997)
United Kingdom	St Michael's Field, Cirencester	43	399	3	Settlement - urban; Military site	Yes	(Thawley, C., 1982b; Maltby, M., 2010)
United Kingdom	St Peters School, Coggeshall	200	399	1	Enclosure	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Stansted Airport, Stansted	-900	-701	1	Enclosure	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Stirling Way, Witchford	43	199	1	Settlement - rural	Yes	(Atkins, R., 2011)
United Kingdom	Stonea, nr March	100	399	2	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Strood Hall	43	410	2	Settlement - rural	Yes	(Timby, J. et al., 2007a)
United Kingdom	Suddern Farm	-750	-301	2	Settlement - enclosed	Yes	(Cunliffe, B. and Poole, C., 2000c; Hamilton, J., 2000b)
United Kingdom	Swallow Street, Bath	43	410	1	Settlement - urban	Yes	(Yalden, D. W. and Albarella, U., 2009)
United Kingdom	Temple of Mithras, Walbrook, London	240	308	1	Ritual, religion and funerary	Yes	(Knox, E. M, 1998; Macready, S. and Sidell, J., 1998; Minos, C., 2014)
United Kingdom	The Beeches, Cirencester	270	399	2	Building - other	Yes	(Levitan, B., 1986; McWhirr, A., 1986)
United Kingdom	The Park, Lincoln	43	399	2	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Third Drove GOS16, Gosberton	43	410	1	Settlement - rural	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Thistleton, Rutland	43	410	1	Settlement - urban	Yes	(Branwell, D., 1971; Harcourt, R., 1971)
United Kingdom	Thorpe Thewles	-500	50	3	Settlement - enclosed; Settlement - rural	Yes	(Heslop, D. H., 1987)
United Kingdom	Three Locks Golf Course, Stoke Hammond	100	410	1	Building - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Thrupp House Farm, Radley	-800	42	1	Building - other	Yes	(Everett, R. and Eeles, B.M.G., 1999)
United Kingdom	Tolpuddle Ball, Dorchester	-400	410	3	Settlement - enclosed; Settlement - rural	Yes	(Hearne, C. M. and Birbeck, V., 1999)
United Kingdom	Tort Hill East, Stilton, nr Peterborough	100	399	2	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Tort Hill West, Stilton, nr Peterborough	-100	42	1	Settlement - rural	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Trentholme Drive	43	410	1	Ritual, religion and funerary	Yes	(Wenham, L., 1968)
United Kingdom	Trimontium, Newstead	75	150	1	Military site	Yes	(Curle, J., 1911)
United Kingdom	Udal X-XII, Grenitote, North Uist	-2340	42	5	Occupation site; Ritual, religion and funerary; Other; Building - other	Yes	(Serjeantson, D., 2013; 2014)
United Kingdom	Uley Shrines, West Hill	-200	420	6	Ritual, religion and funerary	Yes	(Woodward, A. and Leach, P., 1993)
United Kingdom	Upper Delphs, Haddenham, nr Ely	-400	-101	1	Enclosure	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Vercovicium, Housesteads Roman Fort, Hadrian's Wall	122	410	1	Military site	Yes	(Davies, R. W., 1971; van der Veen, M., 2009)
United Kingdom	Verulamium, St Albans	43	410	1	Settlement - urban	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Victoria Road Cemetery	75	150	1	Ritual, religion and funerary	Yes	(Maltby, M., 2010)
United Kingdom	Victoria Road East, Winchester	75	399	4	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	Victoria Road West, Winchester	75	399	4	Settlement - urban	Yes	(Maltby, M., 2010)
United Kingdom	Vinovia, Binchester Roman Fort	80	410	1	Military site	Yes	(Mulkeen, S. and O'Connor, T. P., 1997; (Anon.) Wessex Archaeology, 2008; Petts, D., 2012)
United Kingdom	Waddon Hill	43	60	1	Military site	Yes	(Davies, R. W., 1971)
United Kingdom	Wardy Hill, Coveney	-100	42	1	Enclosure	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Warrens Field, Claydon Pike	-400	-101	1	Settlement - enclosed	Yes	(Miles, D et al., 2007)

Country	Site name	Date from	Date to	No. of phases	Site type	Chickens	Source(s)
United Kingdom	Watchfield, Shrivenham	43	250	1	Settlement - rural	Yes	(Birbeck, V., 2001)
United Kingdom	Wavendon Gate, Milton Keynes	43	399	3	Settlement - enclosed	Yes	(Letts, J. B., 1995; Reilly, K., 1995; Williams, R. J. et al., 1995; Dobney, K. and Jaques, D., 1995)
United Kingdom	Wellwick Farm, Wendover	135	155	1	Ritual, religion and funerary	Yes	(Rackham, J., 2003; Zeepvat, R. J., 2003)
United Kingdom	Whitcombe	-100	42	1	Settlement - rural	Yes	(Buckland-Wright, J. C., 1990)
United Kingdom	White Horse Stone	-800	-101	1	Settlement - other	Yes	(Kitch, J., 2006)
United Kingdom	Wicken Bonhunt, Wicken Bonhunt	43	410	1	Occupation site	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Wigber Low, White Peak	-2500	-801	1	Ritual, religion and funerary	No	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Wimpole Hall, Wimpole	43	410	1	Settlement - other	Yes	(Albarella, U. and Pirnie, T., 2008)
United Kingdom	Winklebury Camp, Basingstoke	-600	-201	1	Settlement - enclosed	Yes	(Jones, R., 1977)
United Kingdom	Wroxeter Roman baths and macellum	90	299	2	Settlement - urban	Yes	(Meddens, B. and Noddle, B., 2000)
United Kingdom	Wycomb, A40 bypass	69	410	2	Settlement - urban	Yes	(Maltby, M., 1998)
United Kingdom	Wycomb, Syreford Mill	-100	410	1	Settlement - rural	No	(Maltby, M., 1998)
United Kingdom	Wyndyke Furlong, Abingdon	43	410	1	Field system	No	(Wilson, B. and Locker, A., 1999)

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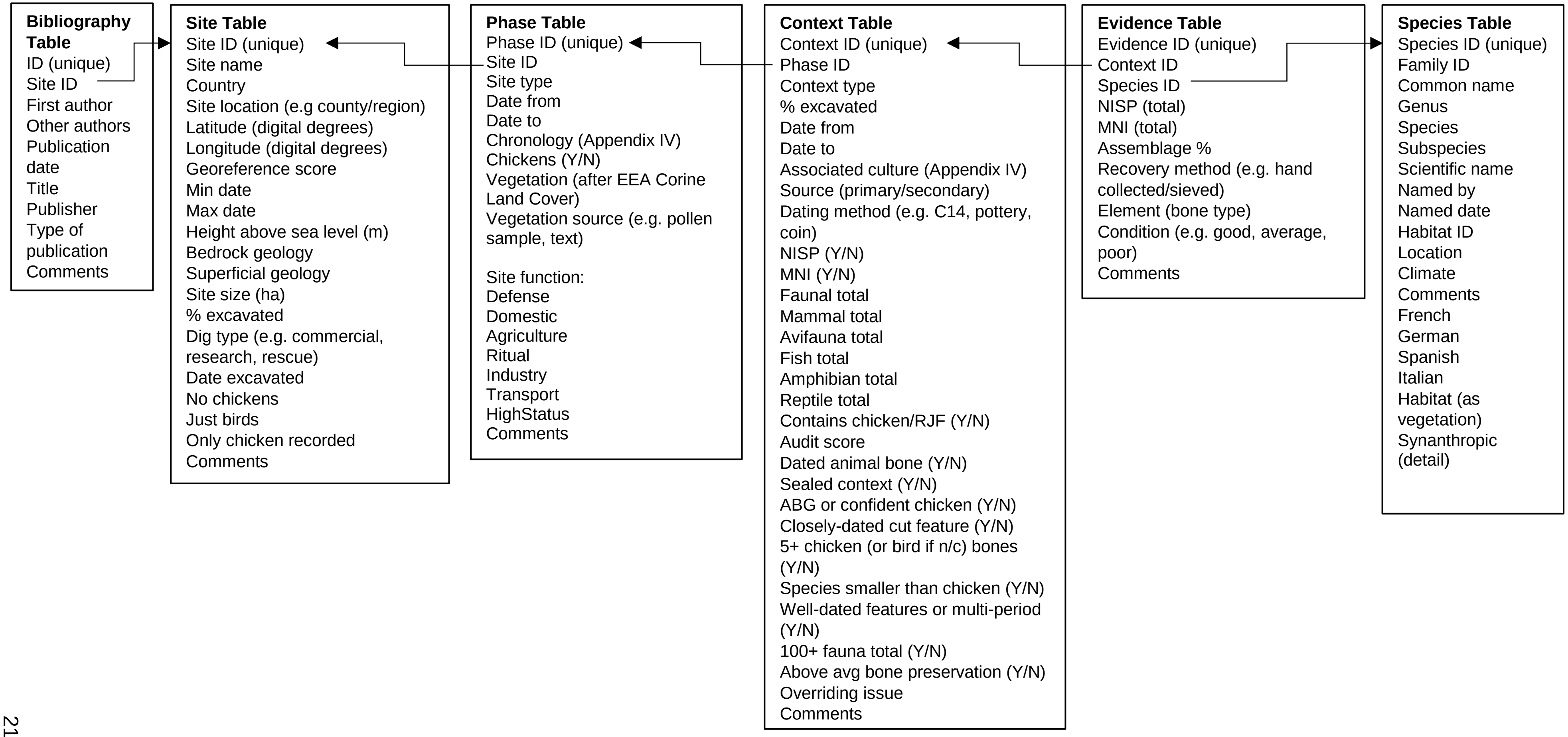
Appendix III: Database structure

Diagram indicating the structure and content of the database described in Chapter 2. Arrows indicate relational links.



Bibliography Table
ID (unique)
Site ID
First author
Other authors
Publication date
Title
Publisher
Type of publication
Comments

Site Table
Site ID (unique)
Site name
Country
Site location (e.g county/region)
Latitude (digital degrees)
Longitude (digital degrees)
Georeference score
Min date
Max date
Height above sea level (m)
Bedrock geology
Superficial geology
Site size (ha)
% excavated
Dig type (e.g. commercial, research, rescue)
Date excavated
No chickens
Just birds
Only chicken recorded
Comments

Phase Table
Phase ID (unique)
Site ID
Site type
Date from
Date to
Chronology (Appendix IV)
Chickens (Y/N)
Vegetation (after EEA Corine Land Cover)
Vegetation source (e.g. pollen sample, text)

Site function:
Defense
Domestic
Agriculture
Ritual
Industry
Transport
HighStatus
Comments

Context Table
Context ID (unique)
Phase ID
Context type
% excavated
Date from
Date to
Associated culture (Appendix IV)
Source (primary/secondary)
Dating method (e.g. C14, pottery, coin)
NISP (Y/N)
MNI (Y/N)
Faunal total
Mammal total
Avifauna total
Fish total
Amphibian total
Reptile total
Contains chicken/RJF (Y/N)
Audit score
Dated animal bone (Y/N)
Sealed context (Y/N)
ABG or confident chicken (Y/N)
Closely-dated cut feature (Y/N)
5+ chicken (or bird if n/c) bones (Y/N)
Species smaller than chicken (Y/N)
Well-dated features or multi-period (Y/N)
100+ fauna total (Y/N)
Above avg bone preservation (Y/N)
Overriding issue
Comments

Evidence Table
Evidence ID (unique)
Context ID
Species ID
NISP (total)
MNI (total)
Assemblage %
Recovery method (e.g. hand collected/sieved)
Element (bone type)
Condition (e.g. good, average, poor)
Comments

Species Table
Species ID (unique)
Family ID
Common name
Genus
Species
Subspecies
Scientific name
Named by
Named date
Habitat ID
Location
Climate
Comments
French
German
Spanish
Italian
Habitat (as vegetation)
Synanthropic (detail)

Appendix IV: Database chronology

Table of chronological dates for periods and cultures used for the database, with sources. Periods which comprise multiple periods or span two parts of a single period (e.g. Neolithic or Bronze Age, or Bronze Age-early/middle), use the earliest and latest dates for those periods in Europe.

Period	Related cultures	Sources
Neolithic **(6000-2000 BCE)**	Early Neolithic (5200-4000 BCE), Middle Neolithic (4200-2500 BCE), Late Neolithic (3500-2000 BCE), Early Chalcolithic (5300-3000 BCE).	Mannermaa and Lougas 2005; Milisauskas 2013; Historic England 2017
Neolithic or Bronze Age **(6000-700 BCE)**	-	-
Copper Age **(4900-3000 BCE)**	Chalcolithic (4900-3000 BCE), Gumelnița (5000-3900 BCE), Eneolithic, Vlaardingen (2750-2150 BCE).	Clason 1967; Harding 2008; Boev 2009; Bréhard and Balasescu 2012
Late Neolithic – Early Bronze Age **(3200-1500 BCE)**	Aegean Bronze Age/Early Helladic (3000-2000 BCE), Anatolia Early Bronze Age I (3000-2801 BCE), Anatolia Early Bronze Age II (2800-2501 BCE), Anatolia Early Bronze Age III (2500-2201 BCE), Anatolia Middle Bronze Age I (2200-2001 BCE).	Sagona and Sagona 2000; Bahn 2001; Mannermaa and Lougas 2005; Sládek et al. 2006; RGZM 2015; Historic England 2017
Bronze Age **(3000-700 BCE)**	Aegean Bronze Age (3200-1100 BCE), Minoan (3000-1100 BCE), Helladic (3000-1050 BCE), Maradovce.	Bahn 2001; Bogucki and Crabtree 2004; Asher Silberman 2012; Liarsou 2013; Milisauskas 2013; RGZM 2015
Bronze Age/Iron Age **(3000 BCE-50 CE)**	-	-
Bronze Age-Early **(3000-1500 BCE)**	Late Chalcolithic (2500-1700 BCE), Beaker (2800-1800 BCE), Anatolia Middle Bronze Age II (2000-1501 BCE), Hatvan (2000-1500BC), Argar (2200-1550 BCE), Unetice.	Gimbutas 1965; Whitehouse 1983; Sagona and Sagona 2000; Bogucki and Crabtree 2004; Harding 2008; Lull et al. 2011
Bronze Age-Early/Middle **(3200-1000 BCE)**	Cyladic (3200-1600 BCE).	Sakoulas 2016
Bronze Age-Middle **(2200-1000 BCE)**	Middle Helladic (2000-1550 BCE), Middle Cycladic (2000-1600 BCE), Mycenaean (1300-1000 BCE), Late Helladic (1550-1050 BCE), Late Bronze Period/Heroic Age (1600-1100 BCE), Wietenberg, Gyulavarsánd-Ottomany.	Gimbutas 1965; Bogucki and Crabtree 2004; Pardo et al. 2009; Brinkkemper 2013; Bălan 2014; RGZM 2015
Bronze Age-Middle/Late **(2200-700 BCE)**	-	-
Bronze Age-Late **(1500-700 BCE)**	Hallstatt A&B, Urnfield (1200-800 BCE), Kyjatice (1200-700 BCE).	Gimbutas 1965; Bogucki and Crabtree 2004; Harding 2008; Bartosiewicz and Gal 2010; RGZM 2015; Historic England 2017
Late Bronze Age-Early Iron Age **(1500-400 BCE)**	Hallstatt (1200-460 BCE), Phoenician (1500-539 BCE), Aland Bronze Age (1500-400 BCE), Mycenaean (1300-1000BC), Lusatian. (Transition defined as 1000-700 BCE)	Gimbutas 1965; Bogucki and Crabtree 2004; Stora 2005; Cunliffe 2008; Asher Silberman 2012; Becker 2013; RGZM 2015; Sakoulas 2016
Iron Age **(1100 BCE-50 CE)**	-	-
Iron Age/Greek or Roman **(1100 BCE-500 CE)**	Przeworsk.	Szela 2009-2010
Iron Age-Early **(1100-400 BCE)**	Greek Proto-Geometric (1100-900 BCE), Neo-Assyrian (934-609 BCE), Hallstatt C & D (800-461 BCE), Iberian 1st Iron Age (800-500 BCE), Etruscan (800-301 BCE), Latial.	Mocsy 1974; Zimansky 1995; De Grossi Mazorrin 2000; Bahn 2001; Bogucki and Crabtree 2004; Cunliffe 2008; Pardo et al. 2009; Seigle 2014; RGZM 2015; Historic England 2017
Iron Age-Early/Middle **(1100-100 BCE)**	Late Halstatt/Early La Tene (550-261 BCE), Scythian (1000-300 BCE), Urartian.	Zimansky 1995; Bahn 2001; Bartosiewicz and Gal 2010; Seigle 2014; RGZM 2015
Greek **(900-30 BCE)**	-	-
Greek-Early **(900-480 BCE)**	Geometric (900-700 BCE), Archaic (700-480 BCE).	Benecke 2006; RGZM 2015; Sakoulas 2016
Greek-Early/Middle **(900-146 BCE)**	-	-

Roman Republic (509-27 BCE)	Mid-Roman Republic (275-150 BCE), Late Hellenistic or Greco-Roman (146-30 BCE).	Heather 2006; Rosenstein and Morestein-Marx 2010
Roman Republic/Empire (509 BCE-499 CE)	-	-
Iron Age-Middle (500-100 BCE)	Iberian 2nd Iron Age- Iberian culture (500-200 BCE), Early La Tene (ancienne/A&B- 460-261 BCE), Late Hallstatt/Early La Tene transition (500-400 BCE).	Pardo et al. 2009; Seigle 2014; Historic England 2017
Iron Age-Middle/Late (500 BCE-50 CE)	La Tene (480-28 BCE), Swedish Pre-Roman Iron Age (400-1 BCE), Middle La Tene (moyenne/C- 260-151 BCE).	Stenberger 1955; Mocsy 1974; Tyrberg 2002; Seigle 2014
Greek-Middle (480-146 BCE)	Greek Classical (480-323 BCE), Greek-Hellenistic (323-146 BCE), Messapian.	de Grossi Mazorrin and Solinas 2010; Asher Silberman 2012; Lombardo 2014; Sakoulas 2016)
Greek-Middle/Late (480-30 BCE)	-	-
Iron Age-Late (150 BCE-50 CE)	Late La Tene (finale/D- 150-28 BCE).	Bogucki and Crabtree 2004; Pardo et al. 2009; Seigle 2014; Historic England 2017
Late Iron Age/Late Greek/Late Roman Republic-Early Roman (150 BCE-117 CE)	Late-Roman Republic/Early Roman Empire (150 BCE-99 CE), Gallo-Roman France South (121 BCE onward), north (58 BCE onward); Greek Late or Hellenistic (323-30 BCE- includes Late Republican (200-30 BCE). (Transition defined as 58 BCE-70 CE for Iron Age, 60 BCE-50 CE for Greek and Roman Republic).	Bogucki and Crabtree 2004; Heather 2006; Pardo et al. 2009; Foucras 2010; Rosenstein and Morestein-Marx 2010; Sakoulas 2016
Greek-Late (146-30 BCE)	-	Sakoulas 2016
Roman Empire (27 BCE-500 CE)	Roman period non-Empire.	-
Roman-Early (27 BCE-117 CE)	Augustinian (27 BCE-14 CE).	Mocsy 1974; Pardo et al. 2009; Foucras 2010; Historic England 2017
Roman-Early/Middle (27 BCE-299 CE)	Swedish Early Roman Iron Age (0-199 CE).	Stenberger 1955
Roman-Middle (100-299 CE)		Mocsy 1974; Pardo et al. 2009; Foucras 2010; Historic England 2017)
Roman-Middle/Late (100-499 CE)	Swedish Late Roman Iron Age (200-399 CE).	Stenberger 1955
Roman-Late (300-499 CE)		Mocsy 1974; Pardo et al. 2009; Foucras 2010; Historic England 2017

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Appendix V: Paper published in Journal of Archaeological Science, 74, October 2016, 1-10

New perspectives on the ecology of early domestic fowl: An interdisciplinary approach

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Keywords: Red Junglefowl, Chicken, Domestication, Ecological niche models, Maxent

Abstract

Introduced into Europe during the Bronze- and Iron Ages as an exotic, non-native species, very little is currently understood about the origins and spread of early domestic fowl, Gallus gallus domesticus. Ecological niche modelling of extant Red Junglefowl, Gallus gallus, presents a unique opportunity to examine historical ecological implications associated with its descendant, the chicken, in early stages of domestication. We model the environmental conditions associated with Red Junglefowl populations both in south-east Asia, where the bird originates, and populations transported further afield as a consequence of human interaction. This allows us to establish the full extent of the ecological tolerance of the ancestor bird. We show that potential for suitable sets of environmental conditions for Red Junglefowl in Europe ranges from poor to limited, based on both current climate and when projecting to mid-Holocene (ca. 4000BCE) climate simulations. This suggests that human intervention played a vital contribution during early domestication to ensure the future widespread success of the chicken. These conclusions offer new insights into the archaeological evidence. We identify areas in the native range as the probable location of first domestication, and not China as has been suggested. We suggest that a dispersal route into Europe via the Mediterranean offers the best ecological potential to aid survival for a recently domesticated version of this species. Identifying the environmental tolerances of Red Junglefowl may also aid future conservation of this species, now highly endangered in its true wild form.

1.Introduction

With a population of over 20 billion (Chemnitz and Becheva, 2014) and near global distribution, the domestic fowl or chicken Gallus gallus domesticus is the most widespread domestic animal. Chickens have influenced many facets of human life, including ritual, religion, culture, and identity; in addition to their more commonly recognised uses as producers of meat, eggs and feathers.

While it is widely accepted that domestic fowl are descended from junglefowl, very little is understood regarding their origins and dispersal around the globe. Despite the success of the chicken, the junglefowl has also survived, offering an excellent opportunity to examine the ancestor in order to explore issues faced by recently domesticated species, including responses to new environments and the corresponding implications of animal husbandry.

There are four extant species of junglefowl, namely Red Junglefowl, *Gallus gallus*; Grey Junglefowl, *Gallus sonneratii*; Sri Lanka Junglefowl, *Gallus lafayetii*; and Green Junglefowl, *Gallus varius*. Originating in Southern and Southeast Asia, India and Indonesia, and predominantly occupying tropical rainforest environments, they have historically been confined to this range by geographical barriers (Fig. 1).

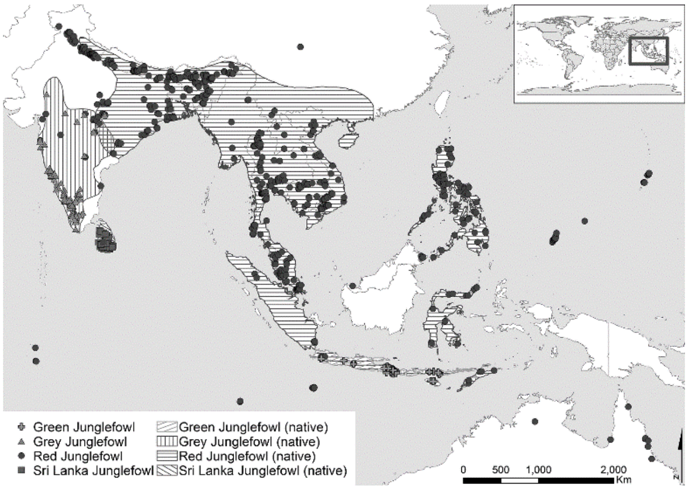

Fig. 1. Geographic range (hashed area, IUCN Redlist) with occurrence points (GBIF.org) for all four junglefowl species.

There are very few archaeological specimens found outside of the native range which are identified as Red Junglefowl, rather than chicken; although whether this is because bones bearing Gallus traits are automatically identified as chicken in areas outside the native junglefowl range is unclear. Early chickens are often noted to be of similar size to Red Junglefowl. Junglefowl (and chickens), however, are non-migratory with limited flight capability, rendering mountains and large bodies of water impassable. Inhospitable environments such as desert or semi-desert lacking corridors of environmental suitability further restrict natural dispersal to areas which would otherwise be suitable. Red Junglefowl have been transported by humans to most continents in more recent times, but there are no reported occurrences of the other three species outside their native ranges.

Of the four junglefowl species, genetic studies have identified the contribution of the Redand Grey Junglefowl to the domestic mix. Red Junglefowl is the dominant ancestor for early domestic fowl, with hybridization with Grey Junglefowl occurring millennia later. (Eriksson et al., 2008; Girdland Flink et al., 2014).

As yet, there is no clear chronology for the early domestication of the chicken, largely due to potential misidentification of the remains, lack of secure context or poor dating evidence (Harrison, 1980; Stewart, 2005, 2007; Bochenski, 2008). Multiple rather than single origins of domestication are now accepted (Liu et al., 2006; Kanginakudru et al., 2008; Xiang et al., 2014), with mtDNA providing support for localised domestication events in South Asia, Northeast India, Southwest China, and a further event in Southwest China and Southeast Asia (Miao et al., 2013). The earliest proposed domestication event is Nanzhuangtou, China ca. 8050BCE (Xiang et al., 2014); but this has been contested (Peters et al., 2015; Xiang et al., 2015; Eda et al., 2016). Eda et al. (2016) recently reappraised evidence at other early Chinese sites (West and Zhou, 1988) concluding that the earliest specimens are not chicken, but one or more of the other 53 Phasianidae species found in China. This leaves the oldest evidence from a secure archaeological context found in Asia at Harrapan Culture sites in the Indus valley, India, ca. 2500BCE (Zeuner, 1963; Fuller, 2006).

An eastward expansion of the domestic chicken via Oceania to South America has been demonstrated using archaeological evidence (Storey et al., 2007, 2008; Fitzpatrick and Callaghan, 2009) and DNA analysis (Gongora et al., 2008; Storey et al., 2012; Thomson et al., 2014). Despite its archaeological relevance as a proxy for human dispersal and cultural associations, there has been less consideration of its route westwards and into Europe, largely due to a lack of collated zooarchaeological evidence. Routes proposed include dispersal into Europe by way of a northern route into China, spreading to Europe via Russia (West and Zhou, 1988); or west via Phoenician trade routes (Becker, 2013). These correspond with some of the earliest proposed evidence outside of Asia, including Bulgaria, ca. 5550BCE (Boev, 2009), the Southern Levant, ca. 2500BCE (Perry-Gal et al., 2015) and Iberia, ca. 2000BCE (von den Driesch, 1973). Recent literature highlighting issues with other early evidence (Kyselý, 2010; Peters et al., 2015), suggests that these unusually early dates for European sites may require verification. Evidence is present in secure archaeological contexts from at least the Iron Age in Europe, ca. 500BCE (Hamilton, 2000; Kyselý, 2010; Strid, 2015). Placing archaeological evidence in the context of environmental suitability can be used to aid interpretation of these early specimens.

Ecological niche models (ENM) are frequently used in ecological research to better understand the environmental conditions that enable a species to persist. They predict the presence of suitable conditions, but not where the species will necessarily be found. Estimating the latter benefits from consideration of biotic and geographical factors, which falls outside the scope of ENM and this study. Various methods exist for performing ENM. However, maximum entropy modelling (Maxent) has been demonstrated to work well with presence-only data (as opposed to data with known presences and confirmed absences), such as the data available for this study (Phillips et al., 2004; Elith et al., 2006; Banks et al., 2013). It is a machine learning method which takes the average value for a set of random sample points within a calibrated region (study area where the species is found and able to survive within geographical boundaries and environmental tolerance). It calculates how this differs from known sets of environmental values at locations the species is known to occur to estimate the probability of occurrence given particular environmental conditions. This can then be projected to other regions of the world or other time-periods (Phillips et al., 2006).

Modelling the ecological niche of Red Junglefowl enables evaluation of how far the chicken today has conserved or shifted its fundamental niche. The fundamental niche indicates where the species can survive, as opposed to the realised niche, which relates to where the species is actually found. The former is of most importance to this study. Wild populations within the region of origin may not represent the full fundamental niche of the species. Geographical barriers limiting movement mean that any niche based on these observations more closely reflects a realised niche and ENM enables us to predict the consequences of removing these barriers to movement. Comparing the niches of native wild populations to populations which are known to have already been transported by humans to locations that would otherwise be geographically inaccessible, identifies how well Red Junglefowl acclimate to different environments and latitudes. The combination of both niches establishes the full suite of environmental tolerance for this species, including those that have been subject to human interaction and, inevitably, some level of artificial selection. Higher environmental suitability values indicate where the species is more likely to be able to survive and breed. First domestication of a species in an area of poor environmental suitability is unlikely to be successful. Lower suitability would necessitate increased assistance by other means, i.e. direct (feeding and housing) or indirect (selection during breeding) human intervention. The earliest examples of domestic fowl would have had limited chance to evolve distinct physiological and morphological traits from their ancestor. Therefore, identifying potential for suitable environmental conditions at archaeological sites with early evidence of chicken can inform not only the likelihood for the site being a location of first domestication, but also the extent of human effort required during early domestication to ensure survival of this newly domesticated, exotic species.

2. Materials and methods

ENM input requires a dataset of occurrence points and environmental variable layers for the relevant geographic extents.

We used observation data for Red Junglefowl post-1950 downloaded from the Global Biodiversity Information Facility (GBIF.org (11th February 2016)). Observations which were described as domestic, were unclearly georeferenced, exact duplicates, or were located outside of the boundary of the global terrestrial environmental layers were removed. This resulted in a presenceonly dataset of 2356 occurrence points for the ENMs. There is a danger with this type of dataset that sampling bias towards more easily accessible regions could bias the random background data for the ENM. However, Maxent contains inbuilt functionality to account for this (Phillips et al., 2009).

These occurrences vary from wild Red Junglefowl in National Parks or protected forests, to managed reserves, to birds inhabiting urban settings (including zoos, botanical gardens and residential properties). ‘Wild’ Red Junglefowl are most likely to be a hybridised version of wild birds, since hybridization between ‘true’ wild Red Junglefowl and domestic fowl has resulted in very limited populations retaining their original morphology, making the Red Junglefowl, in its original wild form, now highly endangered (Peterson and Brisbin,1998; Gering et al., 2015). As our aim was to understand the broadest ecological tolerance of the species, the observations were not subdivided by habitat type. PCA analysis (Fig. 2) did identify differences in response to environmental conditions depending on whether the bird is within its natural range or has been subject to human selection and transportation. Therefore, we divided the observations into two groups accordingly. Hereafter, observations located in suitable environments which are geographically accessible without human help are defined as ‘indigenous’, while all other observations are defined as ‘nonindigenous’. Once transported, ‘non-indigenous’ occurrences are subject to the same dispersal limitations as those within the natural range, due to lack of migration or capacity for flight.

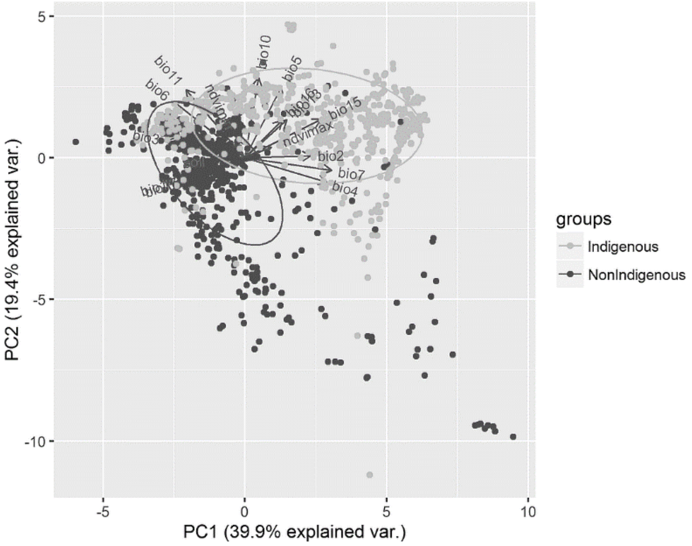

Fig. 2. Principal component analysis of all variables (present climate) and occurrences by geographic location. Green (pale grey in print) points represent occurrences within Asia (the continent of origin for Red Junglefowl), while purple (dark grey in print) points represent all other occurrences. Spatial clustering indicates differences in response to environmental conditions based on geographic location.

Recent changes affecting the habitat of Red Junglefowl due to human activity in the native region could affect interpretation when projecting to the past. With some exceptions, such as Mexico City, urbanisation occurs more frequently at low elevations. To assess the potential impact of this, altitude (CGIAR Consortium for Spatial Information, 2008) over the past 25 years at the location of known observations within its native range was analysed to gauge the impact of the spread of urbanisation. No significant changes in elevation are observed over this time period, indicating that the species has not been forced to alter their habitat by moving to higher elevations to survive.

The study area comprises calibrated and projected global ranges for the indigenous and non-indigenous Red Junglefowl. Calibrated ranges for the final models are defined by potential species movement (determined by convex hull based on known occurrences), and which are at least minimally environmentally suitable (ENM suitability value > 0, calculated using preliminary ENM within geographically accessible areas) (Fig. 3).

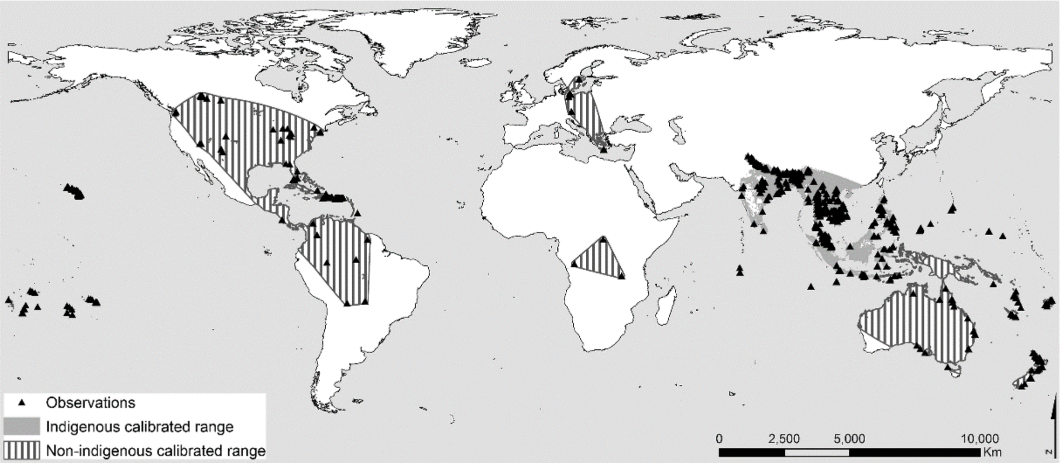

Fig. 3. Observation locations (points) and extent of indigenous (solid colour) and non-indigenous (striped) calibrated ranges.

As mentioned above, dispersal outside of the native range requires transportation by humans. For this reason, the global projection range is not limited geographically, as humans have transported the chicken a long way beyond its native range. However, it is limited environmentally. Maxent uses an exponential model for probabilities, which can result in large predicted suitability values for environmental conditions outside the range present in the study area (Phillips et al., 2006). To avoid spurious predictions, global projection was limited to areas of the world where the values of the environmental variables fall within the range of those in the calibrated area (Ficetola et al., 2007).

Environmental variables were selected based on relevance to the biological requirements of Red Junglefowl. Minimum and maximum temperatures determine thermal tolerance, which has been demonstrated to limit species distributions (Araujo et al., 2013; Khaliq et al., 2014), with minimum winter temperature shown to be the best predictor of variation in avian metabolic scope, outperforming all other thermal variables (Stager et al., 2016). Seasonal variation identifies tolerance for change by predominantly equatorial species. Precipitation variables explain the availability of drinking water. Soil type explains the availability of grit, used to macerate ground-foraged food in the crop due to a lack of stomach acid. Vegetation cover is critical for food, shelter and protection from predation. The latter was unavailable for past climate simulations, due to changes in vegetation cover between the time periods under consideration.

We used Bioclimatic (bioclim) variables for both current climate and the mid-Holocene (ca. 4000BCE) from the WorldClim database at 2.5 arc-minute resolution, or approx. 5 km at the equator (Hijmans et al., 2005). Current climate is likely to be similar to that experienced by early chickens in Europe, ca. 500BCE, a period which corresponds with the improving climate of the Middle Iron Age to Roman period, and is therefore used as a proxy. Projecting to the mid-Holocene enables comparison of suitability for a time period even closer to some of the earliest evidence for chicken. Annual average vegetation cover was compiled from the individual 0.1-degree resolution 1-month Terra/Modis Normalized Difference Vegetation Index (NDVI) (Nasa Earth Observations, 2015) for 2008, the mean year for the observation points. We used the 'Harmonized World Soil Dataset - Major Soil Groups' (FAO/IIASA/ISRIC/ISS-CAS/ JRC, 2009) to denote soil type; and degree of slope was calculated using the standard function in ArcGIS (v.10.2.2), based on the SRTM 250 m digital elevation model (CGIAR Consortium for Spatial Information, 2008). Final variable selection (Table 1) was chosen according to least correlation and greatest importance to the species. Importance was assessed using the Maxent jackknife test of variable importance from a preliminary model using all variables and occurrences.

Table 1
Environmental variables selected for final models.

Variable	Description	Purpose
Bio4	Temperature Seasonality (standard deviation *100)	Seasonality
Bio5	Max Temperature of Warmest Month	Thermal tolerance
Bio6	Min Temperature of Coldest Month	Thermal tolerance
Bio13	Precipitation of Wettest Month	Water availability
Bio14	Precipitation of Driest Month	Water availability
Bio15	Precipitation Seasonality (Coefficient of Variation)	Seasonality
Ndvimin	Terra/Modis NDVI, annual minimum (0-255)	Vegetation cover
Ndvimax	Terra/Modis NDVI, annual maximum (0-255)	Vegetation cover
Soil	Soil type (categorical variable)	Grit availability

Ecological niche models for this study were run using Maxent for 100 replicates with a subsample of 30% test data, random seed, and a regularization parameter of 2.5 to prevent overfitting. Each replicate uses different random sets of training and test data, and the results presented within this paper represent averages. Model performance was evaluated using AUC, the area under the receiver operating curve, which produces a value between 0 and 1 based on how well the model predicts presence at the training locations (see Phillips et al., 2006 for a full discussion of the validity of AUC in Maxent). A value of 0.5 would indicate no better than expected by chance, 0.7-0.9 indicates reasonable performance, and above 0.9 indicates very good performance (Swets, 1988). Thresholds for environmental suitability were calculated from the output summary using a sensitivity-specificity equality approach (see Liu et al., 2005 for evaluation of determining thresholds in niche modelling).

3. Results

Changing altitude of observations from 1950 to the present was analysed to assess potential modern influences on junglefowl range. Little change in altitude was observed, suggesting that movement to higher elevations to avoid urbanisation has not occurred.

The performance of the ENMs can be considered reasonable to good, with AUC values ranging from 0.76 to 0.95. Areas predicted to be suitable for the Red Junglefowl, both currently and in the past, based on indigenous occurrences, largely lie between the latitudes of the tropics of Cancer and Capricorn (Fig. 4).

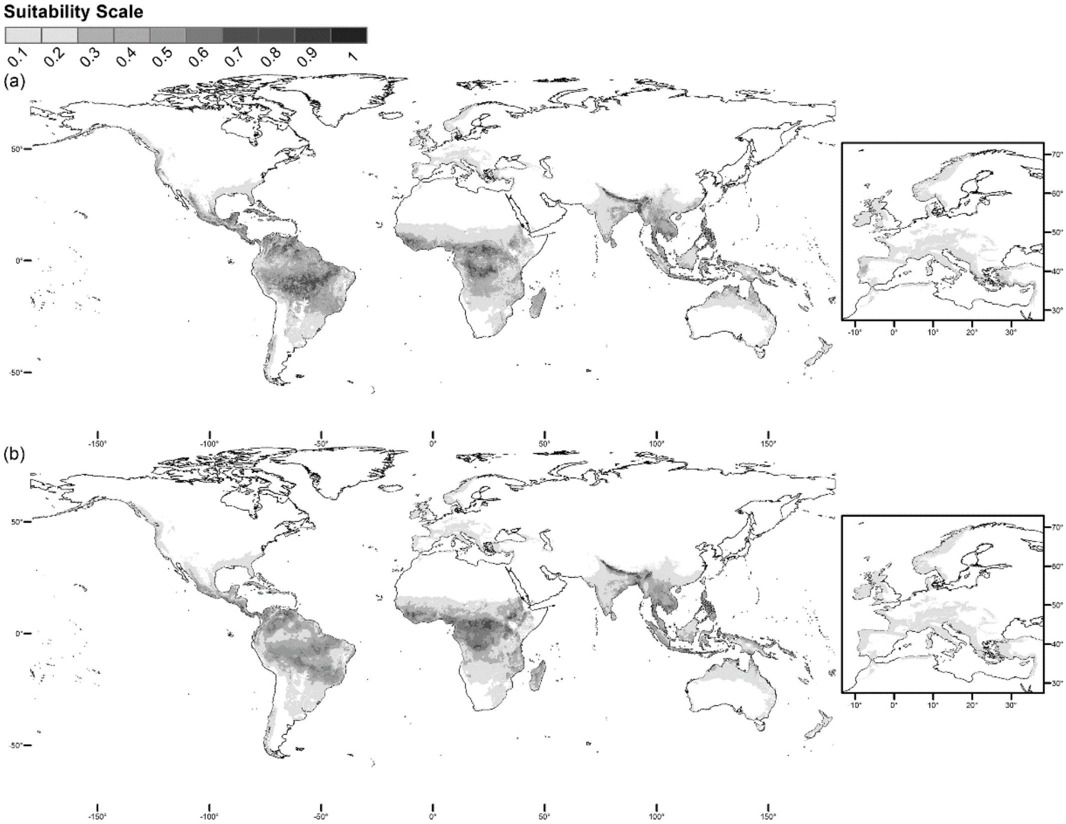

Fig. 4. Global projections of predicted environmental suitability for Red Junglefowl (n = 796) based on indigenous observations for current climate (a), past climate (b). Suitability threshold = 0.4; areas in white fall outside the range of calibration area.

The most suitable sets of conditions are found within its native range, central Africa, and the Amazon basin. For indigenous populations, precipitation and minimum vegetation cover are most important. Probability of suitable conditions increases with high rainfall in the wettest month, corroborating the exclusion of much of Europe from the global projection due to low rainfall relative to the tropics. An optimal vegetation cover is indicated by a positive relationship for increased levels of minimum vegetation, but a negative relationship when the maximum vegetation is too dense. Apart from very small pockets in Portugal, Greece, Montenegro and Albania, Europe is unlikely to contain suitable environmental conditions for indigenous Red Junglefowl, either now or when projected back to 4000BCE.

Models based on ‘non-indigenous’ occurrences reveal potential suitability at broader latitudes, with fewer large areas of high potential (Fig. 5). The most suitable sets of conditions are found in the South Pacific islands and New Zealand; Kenya, Tanzania and the southern coast of South Africa; eastern Madagascar; the Caribbean islands; and eastern Brazil.

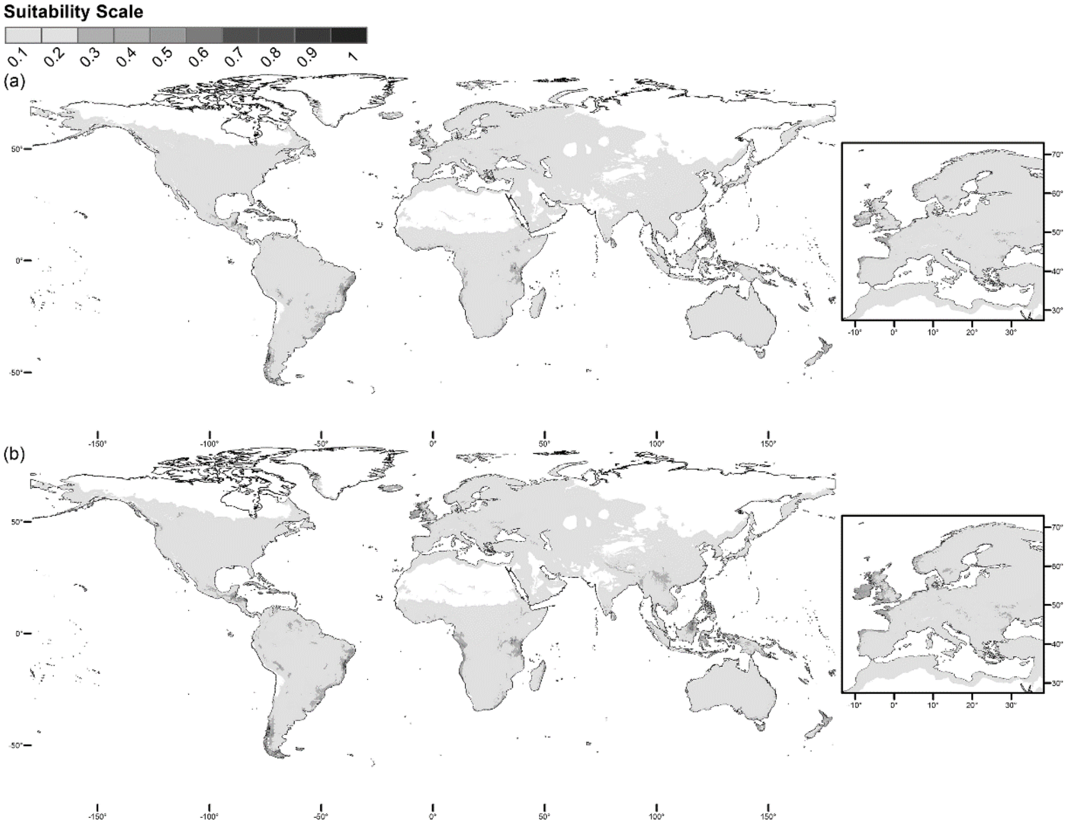

Fig. 5. Global projections of predicted environmental suitability for Red Junglefowl (n = 1559) based on non-indigenous observations for current climate (a), past climate (b). Suitability threshold = 0.2; areas in white fall outside the range of calibration area.

Above threshold potential for suitable conditions is present in Europe, with fairly good potential in northwest France, north-west Iberia, and the south coast of Ireland. Past projection predicts better potential at more northerly latitudes than current climate simulations. For non-indigenous populations, temperature seasonality and temperature range are most important. Seasonality increases with distance from the equator, requiring much greater tolerance within an annual cycle. Probability of suitable conditions decreases with warmer temperatures in the warmest month, and increases with warmer temperatures in the coldest month, reflecting thermal tolerance.

Geographically, only limited overlap of suitable niche is observed between the indigenous and non-indigenous ENMs (Fig. 6). Environmentally, niche similarity between the two was compared using ENMTools (Warren et al., 2010). “Schoener’s D” (Schoener 1968) and “Hellinger's I” (Warren et al., 2008) are similarity measures which compare suitability estimates from two or more ENM, then normalise the resulting score to a value of 0=1, where 0 indicates complete dissimilarity and 1 would indicate the niches were identical. Analysis returned overlap values of 0.76 and 0.86 respectively, suggesting that the niches are environmentally more similar than suggested by geographical overlap.

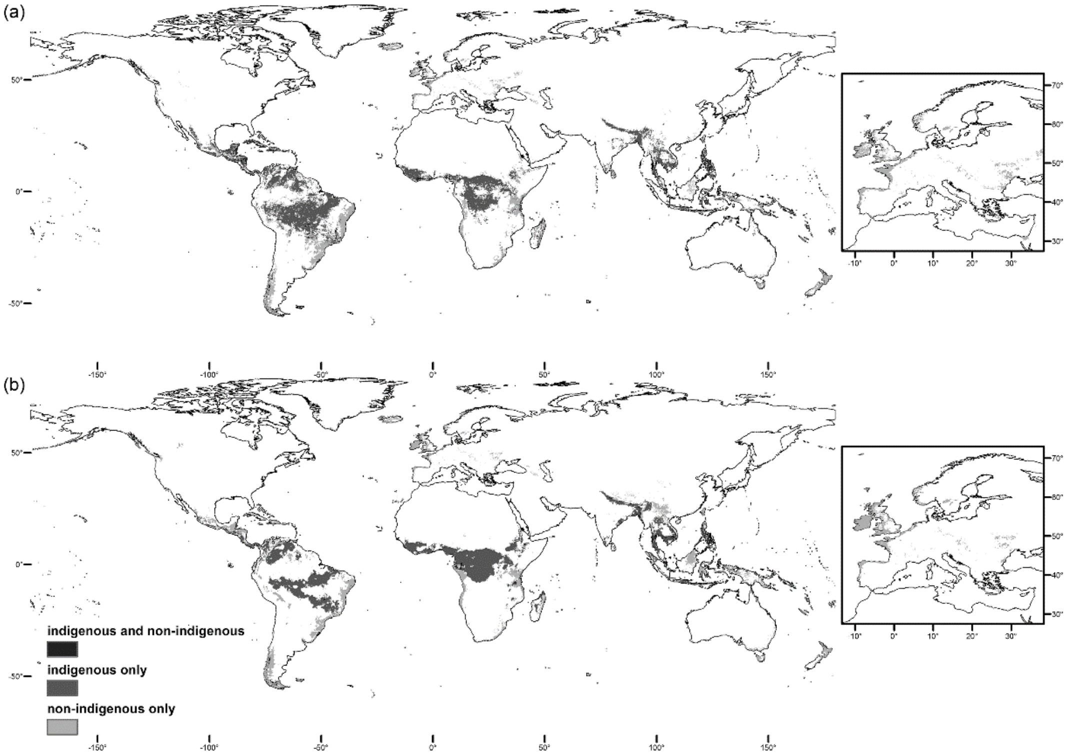

Fig. 6. Areas of environmental suitability predicted to be above threshold for (a) present climate and (b) climate in 6000BP.

Suitability values were extracted for each model at selected archaeological sites (Table 2). Sites chosen include those purported to have early examples of domestic fowl and/or which are found at the extremes of Europe (see Fig. 7 for locations):

1. Nanzhuangtou, China (ca. 8050BCE), Neolithic site with evidence for grain milling. One of the earliest sites proposed for chicken domestication worldwide (Xiang et al., 2014) but this has been contested (Peters et al., 2015; Eda et al., 2016).

2. Cishan, China (ca. 5000BCE). Type-site of the Cishan culture, which is associated with farming. A Neolithic settlement with dwellings, it is often cited as one of the earliest sites of chicken (West and Zhou, 1988). The evidence has been recently contested and reappraised (Yuan, 2010; Eda et al., 2016).

3. Hotnitsa, Bulgaria (ca. 5000BCE). Chalcolithic settlement andthe earliest in Europe reported to have chicken (Boev, 2009). A reappraisal of the material is in progress.

4. Mohenjo Dara, India (ca. 2500BCE). Large settlement of theHarrapan civilisation. Among the earliest sites accepted to contain definite evidence of chicken from secure archaeological contexts (Zeuner, 1963; Fuller, 2006).

5. Cerro de la Virgen (ca. 2500BCE). Argar Culture (Bronze Age) dwelling mound. Earliest claimed evidence of chicken in the Iberian peninsula (von den Driesch, 1973) and of interest here due to its early date and location at the far west of Europe.

6. Eleftherna, Rethymnon, Crete (ca. 850BCE). Settlement including an Early Geometric cemetery. Earliest evidence in Greece (Nobis,1998) and situated on Phoenician trade routes into Europe
7. Biskupin, Poland (ca. 650BCE) Halstatt (Iron Age) periodfortified settlement (Bochenski et al., 2012). Date and location may favour a northern dispersal route from Asia via Russia into Europe.
8. Alcaçova de Santar em, Portugal (ca. 800-300BCE), Fortified enclosure. Earliest reliable site in the Iberian peninsula with chicken from a secure context (Davis, 2006).
9. Houghton Down, Hampshire, UK (ca. 800-400BCE), Two nearly complete articulated skeletons from an Early Iron Age pit within a settlement. Early evidence of chicken in the United Kingdom, at the north-west extent of Europe (Hamilton, 2000).
10. Skedemosse, Oland, Sweden (ca. 15AD). Pre-Roman Iron Age€ fishing lake (Hagberg, 1967). Among the earliest evidence in Scandinavia for chicken, and located at the northernmost extent of Europe.

Table 2
Environmental suitability (scale: 0-1) for early archaeological sites containing faunal remains of domestic fowl. Above threshold values are highlighted in bold.

Model			Archaeological Site									
Climate	Occurences	Suitability threshold value	1	2	3	4	5	6	7	8	9	10
Present	Indigenous	0.39	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.19	0.00	0.00
Present	Non-indigenous	0.16	0.01	0.01	0.06	0.00	0.04	0.13	0.05	**0.28**	0.16	0.06
Past	Indigenous	0.41	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.06	0.00	0.00
Past	Non-indigenous	0.21	0.01	0.01	0.04	0.00	0.01	**0.24**	0.07	**0.32**	**0.26**	0.12

Our models based on indigenous occurrences indicate a complete lack of potential for suitable sets of environments at many of these locations. The poorest potential is found at the Chinese Neolithic sites and in India. Limited potential for suitable conditions may have been present in 4000BCE at Eleftherna in Crete, Alcaçova de Santarem in Portugal, and Houghton Down in the UK. However, for Eleftherna and Houghton Down, it is unlikely to be suitable today and thus at the time the material was deposited.

4. Discussion

The models based on environmental conditions suitable for indigenous Red Junglefowl are largely limited to a geographical band fairly close to the equator. This suggests that if a wild Red Junglefowl was to be taken from this region and left to survive in Europe, it would be unlikely to survive without help.

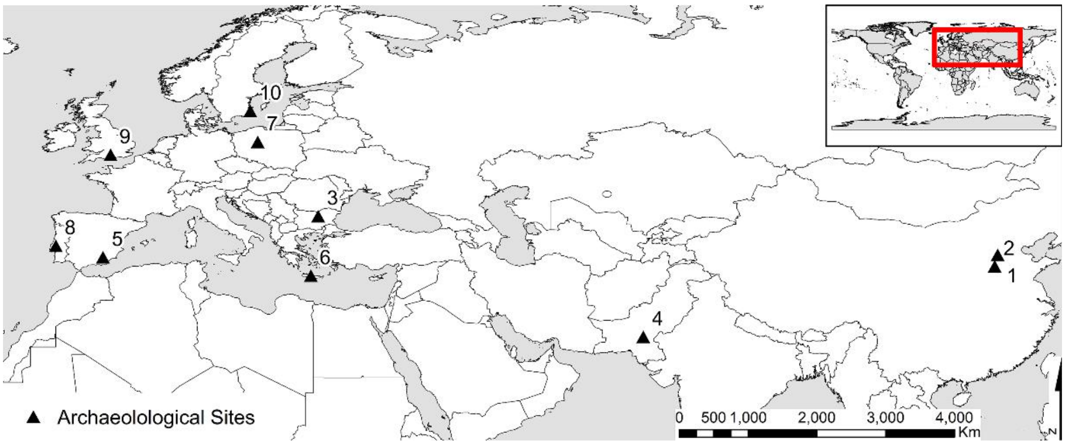

Fig. 7. Location of archaeological sites mentioned in Table 2.

Therefore, non-indigenous populations of Red Junglefowl are of great interest. Similar to the domestic chicken, these populations are likely to have been subject to some level of selection. The removal of natural barriers by virtue of human transportation has enabled these populations of Red Junglefowl to successfully inhabit environments geographically distinct from the natural habitat of the indigenous wild bird. The models indicate that they are able to survive and breed at very different latitudes and in colder climates to where the species originate. This suggests that Red Junglefowl has a broader fundamental niche than the suite of environmental conditions present in their native range suggests.

In terms of survival, environmental suitability values below the threshold for the species maximum tolerance are expected to require additional human intervention to ensure survival. The same would be true for a recently domesticated version of this species. The Red Junglefowl is a bird that is easily tamed, self-organises into hierarchical groups, and provides a good source of protein and feathers, and as such is an ideal species for domestication. However, despite millennia of domestication and selective breeding the chicken has retained traits that would make it difficult to maintain flocks in unsuitable environments, particularly without the aid of modern technology. Transporting and/or keeping a bird in enclosed environments is more challenging than for a species that does not fly, such as ungulate livestock. Keeping chickens in small confined spaces is not ideal in any case, as inability to exhibit natural behaviour, such as foraging, is displaced with abnormal behaviour, which can be aggressive (Baxter et al., 1983).

Therefore, first domestication in an area of poor environmental suitability would be unlikely to succeed. Geographical barriers limiting Red Junglefowl dispersal prior to domestication means the most likely location(s) for first domestication should be in environmentally suitable areas of the indigenous calibrated range. This would be challenging archaeologically. Gallus bones in this region are more likely to be interpreted as wild Red Junglefowl, and even if bones are found associated with domestic features, this would not necessarily indicate a domestic bird. Use of wild birds in early societies is well documented. Equally, as the tolerance of Red Junglefowl exceeds that of conditions within the native range, then archaeological bones found outside of this area (but within the ecological niche of non-indigenous Red Junglefowl) may not belong to domestic fowl, but wild birds selected for transportation that have subsequently escaped.

Poor environmental suitability values at locations of early archaeological evidence suggest that early chickens were either present in areas which were environmentally unsuitable for their ancestor, even at its broadest tolerance, that the sites are incorrectly dated, or that these are not chickens. Based on reappraisal of the some of the evidence, the reason may be that the remains represent a different galliform (Eda et al., 2016). If they are domestic fowl, then increased human provision would be needed to meet essential requirements, including food, water and/or shelter. The chicken was an expensive commodity, as attested by depictions in material culture and evidence of use in ritual proceedings (Sykes, 2012). Decreasing suitability values by moving into higher latitudes implies greater investment of effort and resources. Colder winters require storage of feed and additional shelter, and egg-laying is affected by daylight hours, causing an issue for reproduction as well as provisioning. This is exacerbated by the fact that wild junglefowl lay eggs only in spring and although the loss of seasonal reproduction is thought to have occurred fairly early in domestication, the date of this adaptation remains unclear (Girdland Flink et al., 2014).

In terms of dispersal routes, the models indicate that a northern route via China and Russia into Eastern Europe would be environmentally challenging. Areas predicted as suitable by models based on non-indigenous observations do, however, correspond well with Greek and Phoenician trade routes through the Mediterranean and up into southern Britain and Ireland (Becker, 2013). The start of these routes also link up with known Bronze Age commercial roads through the Near and Middle East (Covington, 2013). Suitable environmental conditions would likely improve potential for survival of an early domestic descendent of the Red Junglefowl into Europe via this route. A lack of potential for suitable sets of environments for much of the rest of Europe suggests that the chicken needed to adapt further by the time it reached parts of central and northern Europe, and/or would have required substantial human investment to survive in such climates outside of the environmental tolerance of its ancestor.

Analysis of the habitat of occurrences both within and outside of the native range may be able to answer questions regarding the extent of adaptation under domestication, as related to climate. Efforts are currently being made to reappraise the faunal evidence in Bulgaria and other early sites with domestic fowl. This may prove interesting, especially if sites with poor environmental potential are shown to be of correct date, as this may indicate a fairly rapid adaptation to climate on the part of the chicken in otherwise unsuitable conditions.

5. Conclusions

Our analyses confirm that the climate of Europe is not suitable for indigenous Red Junglefowl, or by extension, its descendant in early stages of domestication. A Red Junglefowl taken from Asia to Europe today is unlikely to find conditions suitable for unaided survival. This suggests that early domestic fowl could not just be transported and left to disperse, survive and breed. Rather, it provides an interesting example of the human investment required to sustain a new domestic species, especially since sites containing early examples of chicken are likely to have lacked suitable environmental conditions. Based on environmental considerations, first domestication is likely to have occurred in the native range of the species and not in areas such as northern China, where environmental conditions are likely to have been entirely unsuitable. Occurrences of Red Junglefowl outside of its natural range suggests that Red Junglefowl can, and have, acclimated to alternative environments. This suggests that the environmental niche of the species may be broader than might be suspected based on conditions within its native range. It also suggests that a dispersal route through the Mediterranean into Europe has the best potential for presence of environmental conditions to aid survival of a new domestic species.

Acknowledgments

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Glossary

Abiotic: non-living component affecting organisms in an ecosystem

Adaptation: adjustment in natural or human systems to become more suited to a new or changing environment.

AUC: Area Under the Curve. Used in statistical analysis for determining goodness of fit.

Biotic: living components affecting organisms in an ecosystem.

Building - high status: archaeological sites with evidence for high status structures, including villas, palaces etc. High status defined by artefacts or building materials, e.g. plaster, mosaics, and other structural features, such as heating.

Building – other: archaeological sites with evidence for structures, which are not clearly high status, including farmsteads, dwellings, mounds etc.

Cave: archaeological cave site with evidence for domestic occupation. ('Cult caves' are defined as *ritual, religion and funerary*).

Domestic: species containing traits which have been artificially selected for.

Eclipse plumage: seasonal moult of brightly coloured feathers in male bird species.

Ecological niche: a set of environmental conditions that allow a species to breed and survive.

Enclosure: archaeological sites containing a single (or partial) enclosure ditch, with no evidence for permanent settlement.

Evolution: changes in heritable traits of organisms, affecting populations not individuals.

Field system: archaeological sites containing a series of ditches and/or enclosure ditches, with no evidence for permanent settlement.

Fundamental niche: a set of environmental conditions within which a species could potentially survive and breed.

GIS: 'Geographic Information System', used for spatial analysis.

Industrial site: archaeological sites with evidence indicating a primary function of industry, including metal-working, granaries, pottery manufacture etc.

Military site: archaeological sites with evidence indicating a primary function of military use, such as forts, or as indicated in the text, based on literary information.

MNI: Minimum Number of Individuals; used in archaeological recording of faunal evidence, based on NISP.

Monophyletic origin: origin of a species from a single ancestor species.

NISP: Number of Individual Specimens; used in archaeological recording of faunal evidence.

Occupation site: archaeological site with evidence for human activity, but insufficient evidence to define the primary site function.

‘Other’ site: archaeological sites with either no information regarding function or site type, or unusual site types, which include road, lake, river channel, fountain.

Polyphyletic origin: origin of a species from a multiple ancestor species.

R: ‘free software environment for statistical computing and graphics’, see www.r-project.org.

Realised niche: a set of environmental conditions with the right combination of species and otherwise restricting factors that would enable a species to survive and breed.

Ritual, religion and funerary: archaeological sites with evidence indicating a primary function of ritual, religious, or funerary use, including evidence for ritual feasting, temples, sanctuaries, cult sites, cemeteries etc.

Settlement - enclosed: archaeological sites with evidence indicating permanent settlement, with evidence for full or partial enclosure by e.g. ditch, rampart, wall foundation, including hillforts, walled towns etc.

Settlement - other: archaeological sites with evidence indicating permanent settlement, but no information to define further (as e.g. enclosed, rural, urban, industrial or military).

Settlement - rural: archaeological sites with evidence indicating permanent settlement, which are associated with rural activity, e.g. field systems, banjo enclosures, with evidence for more than a single dwelling (single rural dwelling defined as *building-other*); or a series of dwellings in insufficient number to be defined as urban, including hamlets and villages.

Settlement - urban: archaeological sites with a high density of evidence indicating permanent settlement, interpreted as towns by the report author due to multiple dwellings, and/or indication of further activity, whereby domestic is the primary site function, although evidence for industry, trade, religion or military may also be present.

Synanthropic: wild species which benefit from association with human-created environments.

Synurban: species populations which demonstrate a preference for urban habitats.