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To cite this article: Vicki Cummings & James Morris (2018): Neolithic Explanations Revisited: Modelling the Arrival and Spread of Domesticated Cattle into Neolithic Britain, Environmental Archaeology, DOI: [10.1080/14614103.2018.1536498](https://doi.org/10.1080/14614103.2018.1536498)

To link to this article: <https://doi.org/10.1080/14614103.2018.1536498>



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Published online: 11 Nov 2018.



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## Neolithic Explanations Revisited: Modelling the Arrival and Spread of Domesticated Cattle into Neolithic Britain

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### ABSTRACT

Set against the new chronological framework for the introduction and spread of the Neolithic into Britain this paper considers the logistics of introducing domestic cattle from continental Europe. Cattle were the most extensively utilised domestic animal at the start of the Neolithic and understanding the processes behind their introduction is critical for exploring early Neolithic farming systems. We begin by exploring the realities of creating a viable new animal population and then moving that population to Britain across the water from Continental Europe. Using a series of simulated models we demonstrate that only a very small number of cattle need to have been introduced into Britain in order to enable the uptake and spread of domestic cattle across the whole island. This, in turn, may effect how we consider the mechanisms involved in the adoption of the Neolithic, and can better inform our understanding of the kinds of processes involved in the transition to the Neolithic.

### ARTICLE HISTORY

Received 1 February 2018  
Revised 12 September 2018  
Accepted 8 October 2018

### KEYWORDS

Domestic cattle; Mesolithic-Neolithic transition; early Neolithic; boats; population models

### Introduction

The start and the spread of the Neolithic into Britain and Ireland has been debated for many years, with discussion focussing on the mechanisms by which Neolithic things, practices and people reached these islands (Neolithic ‘things’ here relates to domestic animals, domestic plants, pottery, new stone tool technologies and monuments – our preferred terminology as it does not imply simultaneous uptake as the oft-used phrase ‘package’ implies). On the one hand there have been arguments for extensive colonisation and migration from the continent, most recently advocated by Sheridan (2004, 2010). Others, most notably Julian Thomas, have argued that the native people of Britain and Ireland were the key agents in the start of the Neolithic (Thomas 1988, 2013). The debate has changed again with the publication of the results of a dating programme which sought to date more accurately the arrival of the Neolithic practices into Britain and Ireland. It has been recently suggested that domesticates, pottery, monuments and new forms of stone tool first began to appear in south-east England around 4050 BC (see Whittle, Healy, and Bayliss 2011 for specifics): only later did these things appear in other parts of Britain around or after 3800 BC. While the new dates for the start and spread of Neolithic do not tell us whether incomers, natives, or a combination of both were involved in this process, it does give us a chronological framework which can be used to better inform our interpretations of this key transition period. In this

context, we consider the arrival and spread of domesticated animals into Britain and Ireland at the start of the Neolithic, in particular cattle. Following the classic Humphrey Case paper (1969) which considered the practical implications of the start of the Neolithic in Britain and Ireland, here we model the arrival and spread of cattle which can better inform our understanding of the beginnings of Neolithic farming systems along with the processes involved in the onset of the Neolithic more broadly.

### First arrivals

Although the presence of aurochs, the wild ancestor of cattle, has been reported from the Mesolithic in Britain, it has been demonstrated that domesticated cattle stock originated from populations on Continental Europe, probably from the Paris and Rhine Basins (Tresset 2003; Bollongino and Burger 2007; Edwards et al. 2011; Scheu et al. 2015), rather than through the domestication of native aurochs. This suggests that most or all British Neolithic domestic cattle had to have been imported from Europe. Moreover, once cattle were imported into Britain it was often thought that there was subsequently little inbreeding with aurochs although this picture may now be changing (see Park et al. 2015). What has been harder to ascertain is the number of animals imported from the Continent: were large numbers brought over or was there only ever the movement of small herds? It is this question

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which this paper aims to address, which, in turn, may better inform the debate on processes of Neolithisation.

The first issue to consider is genetic diversity. This may appear to be important, but the actual numbers of animals required to create a successful population without significant genetic problems are surprisingly small. A number of recent examples illustrate this. Modern populations of both albatrosses and cheetahs have very little genetic diversity stemming from a bottleneck event in terms of populations numbers, yet they survive with minimal health issues (Menotti-Raymond and O'Brien 1993; Milot et al. 2007). In terms of cows, the current herd of Chillingham cattle of Northumberland is all the offspring of just 13 individuals. This population suffered a significant reduction in numbers in the 1950s, and perhaps also in the past, but the modern population has sufficient genetic diversity as to cause no health issues (Hall and Hall 1988; Williams et al. 2016). The implications of this are clear: only small numbers of animals need ever to have crossed the English Channel in order to provide genetically viable populations for their establishment in Britain at the start of the Neolithic. However, we must add a note of caution that in examining genetic diversity in small populations we may see observer bias, in that we only see the populations that survive and not the ones that fail.

The next issue to consider is at what point during the year to move animals from a parent herd. Certainly cattle would have been easier to transport when they were small, i.e. when they were just weaned. Domestic herds from middle Neolithic France were weaned between 4 and 8 months after birth (Balasse and Tresset 2002), so if we assume calves were born in the spring, this would mean moving them in the autumn or winter. While this makes them lighter to transport, seas tend to be stormier at this time (Callaghan and Scarre 2009). Moreover, it also means they have to be fed through the winter, which is the most difficult time for maintaining cattle. It may have been the case that a population destined for Britain was wintered on the Continent and then transported in the spring once fodder was no longer required. The animals would be heavier but easier to look after once they landed in Britain and more robust in the long term. However, there is also the real possibility that calves were not just born in spring; the feral Chillingham cattle exhibit year-round breeding (Hall 1989), with winter births effected by changes in plant growth (Burthe et al. 2011). We are also able to estimate the height and weight of Neolithic cattle. Using scapular measurements from Boscombe Down, Grigson (1984) suggests early Neolithic cattle had an average shoulder height of 1.2 m, smaller than modern domestic breeds. Good analogies for the size of early Neolithic cattle would therefore be the Chillingham cattle with

an average weight of 280 kg or a large fully grown Dexter which weighs around 300 kg.

The only way animals could be moved to Britain was by boat, and there is a notable lack of surviving boats from this period (Glørstad 2013). However, boats from other periods and regions give a sense of what could easily have been in use at the time in question. Skin or leather boats (coracles/currachs) are known historically and are thought to be the most likely form of boat in the Neolithic (Robinson 2013; Mercer 2017). Recent examples are known to have carried around 20 sheep plus one person (Johnstone 1980, 139), although larger ones could feasibly have been made. A replica skin boat the *Brendan* crossed the Atlantic and had a capacity of roughly 1000 kg; larger examples are also possible (Mercer 2017). Logboats can carry up to 50 people and two lashed together would double the capacity as well as provide stability (Fry 2000), although whether they would have been sea-worthy has been questioned (Mercer 2017). There is also the possibility that Neolithic people used sewn-plank boats (e.g. Van de Noort et al. 2014). Until we find a well-preserved Neolithic boat we cannot be sure precisely what form they may have taken, but we may suggest using analogies of modern examples that it would not be unreasonable for the capacity of a Neolithic boat to be somewhere around 1 tonne or 1000 kg. A recent paper which modelled the feasibility of moving by boat from the continent to Britain and Ireland focussed on longer sea voyages, but one thing was clear: it would have been simply a case of waiting for favourable conditions to make the crossing over the Channel (Callaghan and Scarre 2009, 366). This could potentially have been achieved all year round, and a sail could have assisted paddled boats.

## Modelling populations

The creation of mathematical models to describe theoretical relationships and estimate the parameters of change has a long history in ecology (see Kingsland 1995). In discussing the multitude of parameters requiring measurement and definition in population modelling Levins (1966) summarised the problem of population models well – models are primarily a trade-off between generality, realism and precision. Williams, Nichols, and Conroy (2002) have suggested population models could be classified by their empirical strength and biological understanding, the more useful models having a good biological understanding supported by a detailed dataset. This raises interesting challenges for archaeologists wishing to understand past populations. For example, in its most simplistic form a model of population growth would be  $N_1 = (N_0 + B) - D$  where  $N_1$  is the number of individuals at a specific time,  $N_0$  is the number of individuals already present,  $B$  is the number of births and  $D$  the number

of deaths. If we were to apply the above equation to Neolithic cattle we would need to extract this information from the archaeological and zooarchaeological record – using MNI (Minimum Number of Individuals) calculations to estimate the number of cattle present and age at death data to estimate death rate, but number of births – the fecundity of the herd – would have to be estimated from modern populations. Modern domestic cattle have been bred for millennia to maximise milk and meat yields and therefore do not act as a good analogy. Instead, we can look at the birth rates amongst other groups of animals such as the Amsterdam Island cattle, a feral domestic breed left unmanaged (Berteaux and Micol 1992). Their herd fertility, with a 1:1 sex ratio at birth is 0.37 female calves per cow per year (Berteaux and Micol 1992); to put it another way there is a 37% chance of a breeding female producing a female calf in any one year. The Chillingham cattle have a rate of 0.29 (Hall and Hall 1988). The use of modern data is not without a precedent in archaeological demographics, for example, Fournié, Pfeiffer, and Bendrey (2017) recently used modern goat fecundity in modelling brucellosis transmission in Neolithic goat populations.

In terms of Neolithic cattle management and herd age structure, southern Britain is well served by Serjeantson's (2011) synthesis. This demonstrates a number of individuals dying at 1–15 months and 1–3 years and could be a result of keeping animals predominantly for a dairying economy, a suggestion supported elsewhere in the archaeological record (Cramp et al. 2014; Gron et al. 2015; Smyth and Evershed 2015). However, here we should add a note of caution; these survival rates are based on only a small number of examples (Windmill Hill: Grigson 1999, and Runnymede, not yet fully published but discussed in Serjeantson 2011) and therefore also date from the established Neolithic, rather than the earliest of sites. A more difficult aspect to model relates to other factors which would have affected survival rates such as predation and disease. However, work on modern wildlife populations has shown that the effects of environmental stochasticity are reduced in species with long adult lives (Lande, Engen, and Saether 2003, 62–63). For example, an extensive study of the red deer population on the Isle of Rhum has shown that annual fecundity is a much more important variable than environmental stochasticity (Benton, Grant, and Clutton Brock 1995). Environmental stochasticity produced only a small reduction in the long-term growth rate compared to fecundity.

Therefore, using archaeological data and modern analogies it is possible to use the above equation to calculate the number of cattle at any given time. This kind of model represents a closed system, where animals do not emigrate from or immigrate into the system. A similar real-life scenario would be the cattle on Amsterdam Island where five cattle were left in 1887 (Berteaux

and Micol 1992). However, a key consideration when using such models is that a single calculation represents just one possibility. This is because the birth rates and number of deaths used do not represent absolutes but rather the *probability* of such events occurring. Because of this many ecological models use Monte Carlo methods, the modelling of complex situations via repeated sampling. Within archaeological research, Monte Carlo modelling has been mainly used in the synthesis of radiocarbon results (Shennan et al. 2013; Crema et al. 2016), although recently it has been applied to the regional and temporal patterns in Roman brooches (Cool and Baxter 2016) and the onset of marine fish consumption (Orton, Morris, and Pipe 2017).

### Material and methods

With modern computer power and software development there is now a host of choice for researchers wishing to investigate population models (see, for example, Joyce and Verhagen 2016). One of the most popular models used to investigate population growth is a Leslie matrix (Leslie 1945). A Leslie matrix is a closed system with normally just the female population considered; it is thus a catalogue of age-dependent fecundities and survival rates. The matrix is divided into age classes (the matrix can be used for animals and plants) then individuals either move to the next age class or die each year. The survival rate describes the proportion of the population that moves onto the next age class. The fecundity rate, which is represented by the top line of the matrix, indicates the rate of births per capita for each age class (Table 1). The starting population of each age class can be included allowing populations to change over time to be calculated, however, it must be remembered that a Leslie matrix will just represent female animals, as males do not affect the survival and reproduction of females, except in cases of insemination (not envisaged for the Neolithic). This means that in archaeological examples certain assumptions about male vs. female kill-offs need to be made (see below).

Advances in computer hardware and software have allowed for the development of individual-based computer modelling (abbreviated as IBM or IBCM in ecological literature), also referred to as agent-based models, and it offers an attractive alternative for archaeologists. Individual-based modelling shifts the focus from populations to individuals, recognising that the properties, behaviours and outcomes for individuals determine the properties of the system they compose (Chapron and Arlettaz 2006; Grimm and Railsback 2005; MacPherson and Gras 2016). Individual-based models are analysed using Monte Carlo techniques, recognising that the data used is populistic and that birth and death events are a stochastic process

**Table 1.** Table showing the Leslie matrix used in the simulations. The top line represents birth rates of female calves for each age group. Survival rate is represented in the line for the next age group. For example, in year 0 the survival rate is 0.7, this means 70% of the year 0 populations will transition to year 1.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Year 0	0	0	0	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Year 1	0.7	0	0	0	0	0	0	0	0	0	0
Year 2	0	0.8	0	0	0	0	0	0	0	0	0
Year 3	0	0	0.95	0	0	0	0	0	0	0	0
Year 4	0	0	0	0.95	0	0	0	0	0	0	0
Year 5	0	0	0	0	0.95	0	0	0	0	0	0
Year 6	0	0	0	0	0	0.95	0	0	0	0	0
Year 7	0	0	0	0	0	0	0.9	0	0	0	0
Year 8	0	0	0	0	0	0	0	0.8	0	0	0
Year 9	0	0	0	0	0	0	0	0	0.9	0	0
Year 10	0	0	0	0	0	0	0	0	0	0.9	0

(Law, Murrell, and Dieckmann 2003). Given the aim of this research is to consider the arrival and growth of Neolithic cattle populations an IBM approach was adopted. This allows multiple simulations of different sizes of cattle populations along with varying fecundity and death rates.

To enable repeatability modelling was conducted in R v3.5.0 (R Core Team 2018), using the *population* package (Chapron 2018). The package allows IBM model simulations to be run on a post-breeding Leslie matrix model, meaning that the census of the population is after the 'birth-pulse', so in the model the age of newborn individuals is 0. The package therefore combines the ability of disparate zooarchaeological and ethnographic data to be combined in a simple Leslie matrix model with the ability to test the simulations using Monte Carlo runs.

The package requires three key pieces of information for each age class; the initial population, the survival rates and the birth rates. The focus of the research was to test different hypothetical population sizes of cattle, brought across to Britain in one action; initial population was therefore the key variable to be changed in the simulations. Four key sources of information, already discussed above, were used for the survival, birth rates and age of first reproduction. Zooarchaeological data in the form of tooth wear analyses from Serjeantson's (2011) southern Britain regional review were used. There are of course biases in this dataset, which is primarily from established, rather than very early Neolithic sites. In addition assumptions about male vs female kill-off patterns need to be made. It is likely that Neolithic people would have brought over more female than male cattle as early-middle Neolithic sites show a high proportion of female to male cattle, for example, Hambledon Hill has a ratio of 10:1 cows to bulls (Tresset 2003). The sex ratio combined with the high number of calf deaths on early Neolithic sites (Serjeantson 2011, 24) would suggest milking was an important factor in cattle husbandry.

Therefore a key assumption of the survival data is that the high number of first-year deaths reported in the early zooarchaeological assemblages represents male rather

than female kill-offs. However, a survival figure for the first year of life is still required for the Leslie matrix; it would be highly unrealistic to assume that all female calves survive. However, we can supplement this with ethnographic information. Amongst the Chillingham cattle 73% of calves survived to one month of age and only 50% of calves reached mature breeding age between 1953 and 1984. Breeding age is also another assumption that needs to be made using zoological analogies. Observations of the Amsterdam Island cattle indicated the earliest age of reproduction was 2–3 years old, but the age of first breeding does vary among cattle, with most studies on modern farm cattle. The Chillingham cattle produce their first calf between 3.5 and 5 years. Therefore for the simulations a conservative figure of 4 years was assumed for first breeding age. It is not possible to calculate fecundity for Neolithic cattle, therefore a modern analogy of Amsterdam Island (Berteaux and Micol 1992) was used as it represents a population with minimal human interference compared to the Chillingham cattle.

An element of environmental stochasticity can be added to the model by treating the survival and birth rates given as a mean, and adding a range. This essentially adds to the model a variation to the survival and birth rate, the actual survival and birth rate used for each individual within the model will be randomly chosen from a defined range from the rates entered – accounting for random stochasticity, both 'good' years and 'bad' years. For all the runs undertaken in this research a standard range of 0.1 was used for both survival and birth rates. Therefore the birth rate of 0.37, is treated as the mean within a range of 0.27–0.47, when the model is run a birth rate for each individual will be chosen at random from this range. We also assumed that all cattle would either have died naturally or been killed by 10 years, although they may well have lived longer in reality. In this sense, we have attempted to model for a worst-case scenario. Animals may well have lived and bred beyond 10 years old and well-managed herds may have suffered little predation if carefully tended.

The Leslie matrix produced for the simulations (Table 1) therefore represents a 'possible' picture of



early Neolithic cattle, based on a mixture of zooarchaeological and modern zoological analogies. It is important at this stage to stress that we are not suggesting the matrix represents a 'true' picture of early Neolithic cattle, rather it represents a useful model against which hypothetical changes in the initial starting population can be tested. Each model consisted of 5000 simulation runs which for the long-term (100 years plus) models required extensive computational time. The hardware used in this paper were produced on an Intel i7 quad core 3.6 GHz machine running Windows 10, runs of 200 years with 100 animals took approximately 20 minutes using the parallel processing function.

The new chronology for the start and spread of the Neolithic was used to help determine how long to run each simulation for. Whittle, Healy, and Bayliss (2011) argued that Neolithic things and practices first appeared in the south-east of England, centring on the decades around 4050 cal BC. In their model not all aspects of the Neolithic appeared at this point but it is important to note the overall lack of animal bone assemblages which informed this model (see Whittle, Healy, and Bayliss 2011, 800). Neolithic things and practices did not spread beyond south-east England for 150 years until around 3900 cal BC when they were found for the first time in south-central England. Once again, they argue there was a delay in the spread of Neolithic things beyond this point for another 100 years. In terms of running our simulated population models, this gives us several hundred years to consider the growth of domestic animal herds. Simulations were therefore run for 200 years to investigate how cattle population growth may relate to the spread of Neolithic culture.

## Results

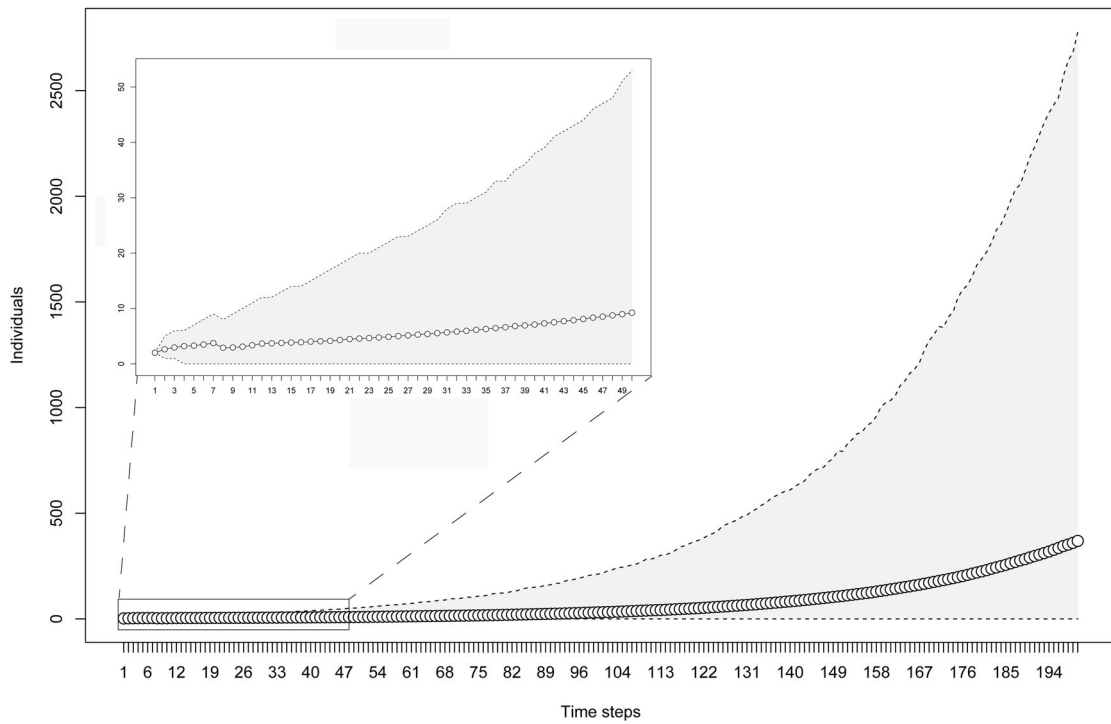
Using the population R program several different simulations were run (see appendix for R code). All the simulations are concerned with female cattle, therefore the initial starting populations are for cows only. It is likely that Neolithic people would have brought over many more females than males. Since milking was important to early Neolithic people this would also mean that we would expect female cattle to survive longer than male cattle due to their usefulness in supplying secondary products.

As the aim of the simulations was to investigate the smallest possible female population that could be transported to Britain and survive, a series of simulations were run with decreasing populations. As the model has the earliest breeding opportunity at four years old, the first simulation is for a small population of two cows (Figure 1). This is because, as discussed below, Neolithic craft could have fitted up to three fully grown cattle. This simulation, as expected, showed

large numbers of population failures, 22% in the first 10 years and 66% after 200 years. Those populations that did succeed had very slow growth. After 50 years the mean number of individuals had grown to 15 cows per group with a range of 2 to 83 cows. At the end of simulation (after 200 years) the mean had grown to 853 cows, with a range of 5 to 3595 cows. Increasing the number to seven cows, all four-year-olds at time of transport resulted in 31% of populations failing after 200 years, with a mean of 1487 cows and a range of 26 to 11,881.

The modelling of just two or seven cows being brought to Britain at the start of the Neolithic is unlikely to have provided enough animals for people more widely to have acquired these animals by 3800 BC so the next simulation increased the number of individuals to 30 moved in a single event. For this simulation, each group started with 5 one-year-olds, 10 two years olds, 10 three-year-olds and 5 four-year-olds. This was in attempt to model a small and young group of cows with females of breeding age and younger animals about to become of breeding age. In this scenario, we assumed that mature cows were not brought as part of the group. This simulation shows that in the first 50 years the simulated populations grew slowly, with a mean of 142 individuals at the end of this period. None of the simulated populations suffered failure, but a number did struggle and shrink slightly resulting in a minimum of 25 cattle after the 50 years. At the opposite end of the spectrum some simulated populations thrived, with a maximum of 148 cattle after 50 years. After 100 years there were 448 cattle (min 50, max 1784), but after this point there was a rapid expansion in population so that after 150 years there was a population of 1,924 (min 92, max 11,610) individuals. After 200 years the population hit a mean of 5,177 (min 238, max 31,035) animals (Figure 2). We ran the model again with the same birth, survival and death rates but with a starting population of 100 animals, 25 animals of year groups 1 to 4. In this run, simulated animal numbers were 987 (min 340, max 2514) at 50 years, 3113 (min 1019, max 8699) at 100 years, 10,293 (min 2387, max 41,159) at 150 years and 34,065 (min 3199, max 144,214) at 200 years. As already stated, these simulations are likely to be on the conservative side, as they take the breeding rate of unmanaged cattle.

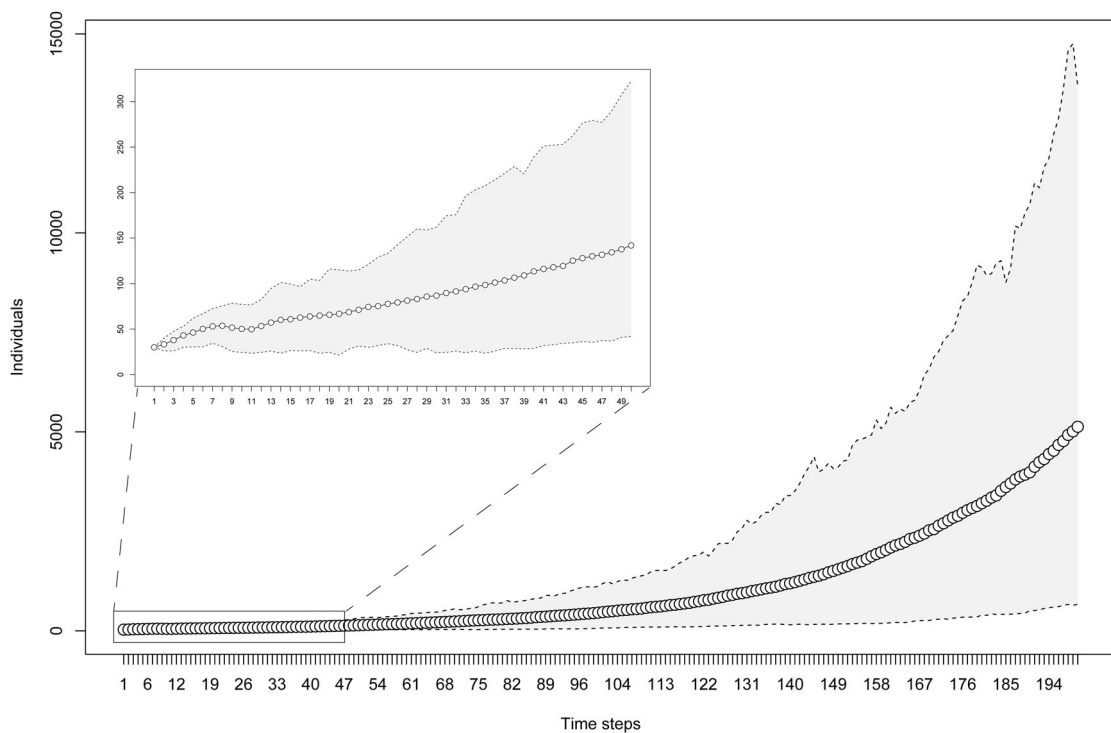
In this regard, it is worth comparing the figure we modelled for Neolithic cattle with those generated for a modern population. Here we took the known birth, survival and death rates for East African cattle herds (Dahl and Hjort 1976) which were kept in small herds containing a maximum of about 25 individuals. In these runs, with a starting population of 30 individuals, to mirror and provide context for the above simulation, cattle numbers grew to a mean of 57,516 (min



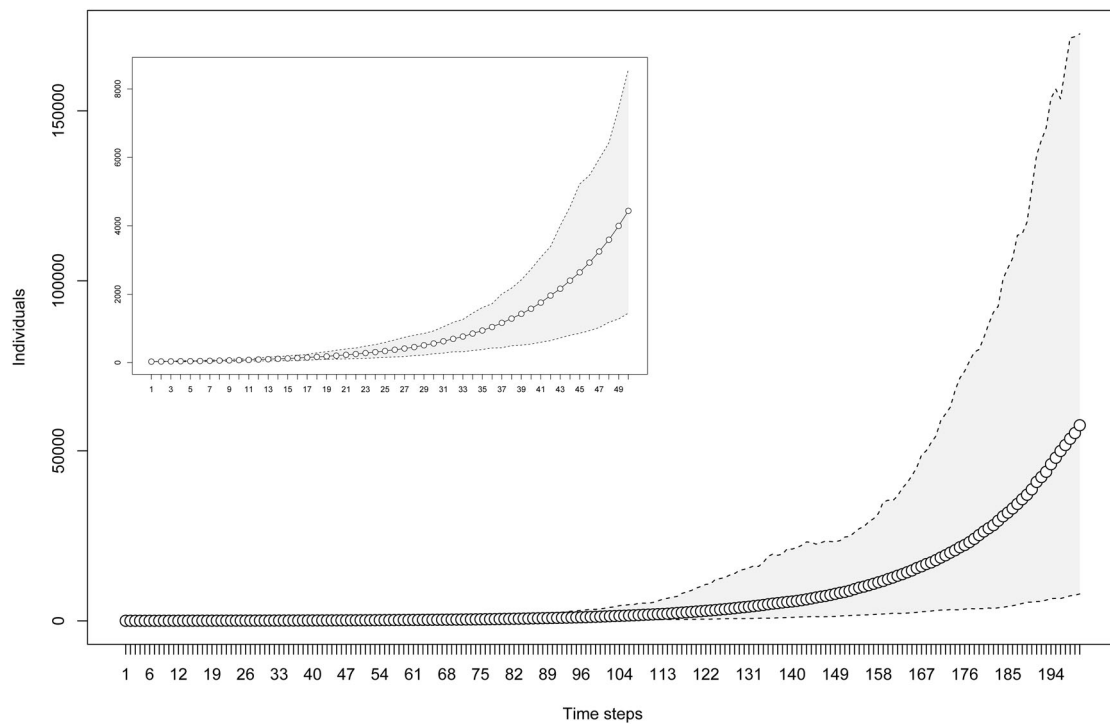
**Figure 1.** This diagram illustrates the population growth for the simulations starting with two cows over 200 years. Circles indicate the mean number of individuals. The grey area indicates the maximum and minimum numbers to a 95% confidence interval.

5,531, max 220,959) after 200 years (Figure 3). This represents an 11-fold difference in mean numbers compared to our simulations using data from unmanaged wild cattle. In the simulations, there was only a 0.03 difference in the cattle fecundity: the key difference was in the age-specific survival data, with the majority of the east African cattle surviving until old adulthood.

This could indicate that the Neolithic toothwear data is not revealing the true age structure of the cattle herds. Certainly, we view our Neolithic simulations as very conservative in terms of mean cow numbers. We should also consider that in the East African example the environment is much more arid that would have been the case for Neolithic Britain.



**Figure 2.** The population growth model for Neolithic cattle run over 200 years with a starting population of 30 individuals. Circles indicate the mean number of individuals. The grey area indicates the max and min numbers to a 95% confidence interval.



**Figure 3.** The population growth model for East African cattle run over 200 years with a starting population of 30 individuals. Circles indicate the mean number of individuals. The grey area indicates the max and min numbers to a 95% confidence interval.

### Neolithic practicalities

If we envisage a small population of cattle numbering around 30 individuals arriving into south-east England in the years around 4050 cal BC, by the time the Neolithic spread beyond this area into south-central England in 3900 cal BC our model suggests there should have been around 2000 head of cattle. That would effectively translate to 66 groups each owning a herd of 30 cattle, or 166 groups having a smaller herd of 12 cattle each. We cannot know for certain what size herd people would have maintained in the Neolithic: these figures are simply presented here to illustrate the fact that cattle ownership could have been quite widespread by 3900 BC in south-east England, given the possible population growth. Within another 50 years cattle numbers could have grown, our model suggests to 172 groups each owning 30 cows. Within another 50 years (3800 cal BC) under this model cattle numbers would grow to 18,477, enough for people beyond the confines of southern England to acquire herds in a scale consistent with the proposed wider uptake of the Neolithic modelled by Whittle, Healy, and Bayliss (2011). That number translates to over 615 groups having a herd of 30 cows. If we increase the starting population to 100 at 4050 cal BC, then by 3900 cal BC nearly 700 groups could own 15 cows each. Of course, we have no idea of the population levels in the Neolithic, but this gives an indication that even with a very small founding population of cows, most communities could easily acquire a herd without recourse to importing animals from the

continent by 3800 cal BC. Perhaps the limiting factor here is not the cattle population but the human population with suitable animal husbandry knowledge to look after this number of animals.

These figures give us, for the first time, a sense of the numbers of boats or crossings required for the successful importation of Neolithic animals into Britain. If a weaned cow weighed around 100 kg and a fully grown Neolithic cow weighed something in the region of 300 kg and the carrying capacity of a Neolithic boat can be estimated as around 1000 kg, we can make some suggestions regarding crossings and trips. It would be possible to fit three fully grown adult cows, presumably bound at the hooves to keep them immobile, plus one or two people in a boat, or nine just-weaned animals plus crew. With a starter population of 30 animals, an extended family group with three boats moving juvenile animals could have been responsible for the introduction of domesticated cattle into Britain, or one boat making ten trips with mature animals. With a larger starting population of 100 animals, this would either involve more boats, more voyages, or the importation of animals over several years. In either scenario, this does not require the large build-up of animals on the Continent, nor the mass movement of people or animals across the sea. This surely has implications for our understanding of the start and development of the Neolithic in Britain. It is also worth noting that the simulation with just two cows resulted in a successful population, all be it small, in 33% of cases. Increasing this to seven juvenile cows resulted in a successful population of cattle in 69% of the simulations,



showing that the importation of cattle into Britain could have been a very small-scale affair and possibly even a one-off event.

## Implications

This model suggests that a very small number of domestic animals may have been required for the initialisation of the British Neolithic cattle population, when there is sufficient time to enable the small starter population to grow. Our ‘slow start’ model works in tandem with the timings of the spread of Neolithic practices as produced by the *Gathering Time* project (Whittle, Healy, and Bayliss 2011). As a consequence we can now argue that there was the potential that very small numbers of people and boats were required to found the entire British population of cattle, possibly just a few families. We could go further and suggest that it may have been this initial slow growth of cattle numbers which partly explains the staggered start of the Neolithic beyond south-east England (cf. Zvelebil and Rowley Conwy 1986). Certainly 150 years is enough time for small founder populations of animals to grow into much larger numbers, and at 3900 cal BC there could have been enough cattle available for people in south-central England to acquire their own founder herds, but crucially here, from *within Britain*: in this scenario there is no need for cattle to be introduced from the continent. Of course this does not mean that animals were not acquired from there; there may well have been kinship or exchange networks in place between people in south-central England and Continental Europe, and the movement of people and animals at this point remains a feasible possibility. However, the recent identification of some aurochs’ DNA in British cattle may suggest that people did not resort to this and instead drew upon local aurochs populations to supplement numbers (Park et al. 2015).

Our model shows that 100 years later, at roughly 3800 cal BC, there would have been a much larger number of cattle within Britain available. The *Gathering Time* model suggests that the uptake of Neolithic things and practices was much more widespread beyond southern England after 3800 cal BC, including in central and south-west England, southern Scotland, and perhaps Ireland (Whittle, Healy, and Bayliss 2011). This wider uptake could well have been facilitated by the wider availability of cattle. Our model using 30 starter cows shows a very conservative estimate of over 18,000 individuals, which may have been more than enough to act as founder herds for many groups, possibly every community in Britain and Ireland. Again, it is not necessary to seek recourse to a continental origin for these animals, although it does not exclude the possibility. It suggests that the limiting factor in the expansion of Neolithic groups would not be cattle,

but the number of people to look after them. What we do know is that Neolithic cattle were imported from the continent where established regimes based on a dairying economy appear to have been in place for many hundreds of years (e.g. Gilles et al. 2016). In our model, we have assumed that people in Britain wanted access to dairy products from the onset, and this, in part, indicates why the initial growth of animal numbers was quite modest. The production of dairy products is one of the aspects of owning domesticates which sets them apart from their wild counterparts and may have made them extremely desirable (Legge 1981, 2008; Ray and Thomas 2003; Schulting 2013).

It is worth briefly mentioning that we have not considered domesticated sheep or pigs which were also introduced into Britain and Ireland from the continent. The arguments made here about numbers are, however, translatable to these other species, and since they are considerably smaller, only a single boatload of sheep or pigs need ever have set sail from Continental Europe to be the source of all British and Irish domesticates. It is of considerable interest, however, that there is now evidence for the movement of wild deer populations at the start of the Neolithic, as suggested for Ireland (Woodman and McCarthy 2003; Carden et al. 2012) but also apparently taking place in Scotland (Stanton, Mulville, and Bruford 2016). It seems that the importation of new domesticates inspired people to move other species around as well.

## Conclusion

This paper does not answer the question of whether or not the Neolithic was initiated in Britain by colonisers from Continental Europe, through a process of indigenous adaption, or a combination of the two (Cummings and Harris 2011). Indeed, both scenarios are valid within the model used. What it does change is the debate on the *nature* of the interactions between people on the continent and in Britain and Ireland. We have been able to investigate the growth of cattle herds as a drawn-out process because of the new chronology offered for the start and spread of the Neolithic over several hundred years (Whittle, Healy, and Bayliss 2011). Indeed, we no longer need to envisage any kind of social upheaval or pioneering spirit on the continent for the British Neolithic to get underway, certainly in terms of one of the most challenging aspects of this transition and that is the importation and establishment of domestic animals. Our model has demonstrated that only a very small number of domesticated animals need ever have been imported into Britain for these new domestic species to become established. This, in turn, need only ever have involved a small number of boats and people.

## Acknowledgements

The authors would like to thank Jessica Smyth and Rosalind Gillis for accepting this paper at the Neolithic Studies Group meeting in London and for their subsequent help in bringing this to publication. The University of Central Lancashire is thanked for supporting this research via sabbaticals and we are grateful to Rick Peterson and David Robinson for discussing aspects of this paper. Comments from two external reviewers were also extremely helpful.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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