# Cycles of change in Jomon settlement: a case study from eastern Tokyo Bay

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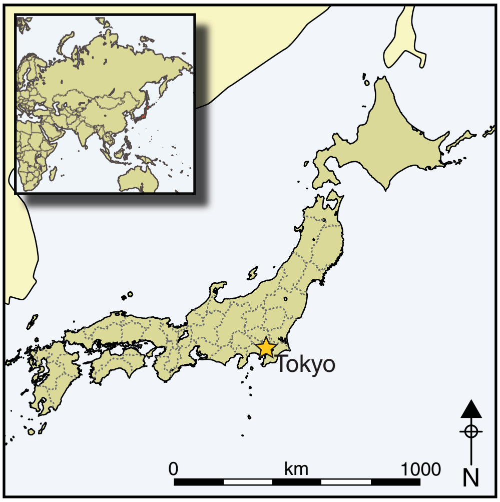


*Japanese archaeology benefits from the large number of rescue excavations conducted during recent decades that have led to an unparalleled record of archaeological sites. That record is here put to use to interrogate changing settlement patterns in the north-eastern corner of Tokyo Bay during several millennia of the Jomon period (Early, Middle and Late Jomon: 7000–3220 cal BP). Jomon hunter-gatherer occupation is characterised by large numbers of settlements, some of them substantial in size, containing hundreds of individual pit-house residential units. Detailed analysis of the rank-size distribution of these settlements reveals a pattern in which periods of settlement clumping, with few large settlements, alternate with more dispersed settlement patterns on a regular cycle of approximately 600 years. The regularity of this cycle might suggest a correlation with cycles of climatic change, such as Bond events. Closer scrutiny shows, however, that such a correlation is unconvincing and suggests that cyclical change in Jomon settlement patterns may instead be due to other factors.*

*Keywords:* Japan, Tokyo Bay, Jomon period, 7000–3220 cal BP, settlement change, clustered settlement patterns, dispersed settlement patterns

Method

## Introduction

The distinction between nucleated and dispersed settlement patterns has long been a topic of interest amongst geographers, historians and archaeologists (Roberts 1996). Typically, nucleation and dispersal have been viewed as two ideal extremes across a spectrum of possible spatial distributions that residential units might take in different geographical and cultural settings. Even in the same landscape, a diverse range of patterns can be identified across time, often showing how the settlement history of a region can be characterised by continuous shifts along such a spectrum (Bintliff 1982; Jones 2010).

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Interests in these temporal variations within the same region led to the development of several theoretical models (e.g. Renfrew & Poston 1979; Jones 2010; Griffin 2011) designed to identify the primary reason why new settlement patterns emerge. In particular, they aimed to determine whether these transformations were reactions to similar forces, or whether they were convergent responses to different environmental, social and economic catalysts. While climatic events have often been regarded as one of the most plausible external causes of change in settlement patterns (e.g. Chatters & Prentiss 2005), a number of studies (Renfrew & Poston 1979; Griffin 2011) instead suggest that the internal dynamics of a settlement system (e.g. social conflict, resource overexploitation, etc.) could equally lead to sudden and radical transformations in the human landscape.

While both sets of models undoubtedly offer valuable insights about the generative processes behind long-term changes of settlement patterning, they ultimately still require formal testing against the observed archaeological record. Unfortunately, the great majority of archaeological datasets are simply not good enough to sustain formal statistical comparisons with these model expectations. For example, the coarse-grained chronology and the qualitative assessments of most prehistoric settlement systems can typically offer only approximate correlations and potentially biased interpretations of the empirical data. This problem is particularly relevant to the study of settlement amongst prehistoric complex hunter-gatherers and it is worth addressing in that context, not least because ethnographic data suggest that these societies might offer an extraordinary laboratory for understanding how human adaptation can lead to a wide variety of settlement strategies (e.g. Watanabe 1986). Focusing on these groups might provide crucial insights for understanding how and why settlement patterns change, but in most cases the available dataset is too small and the temporal resolution too coarse to provide valuable insights using existing analytical methods.

This paper seeks to contribute to this research agenda by studying the settlement history of the Jomon hunter-gatherers of Japan (15 700–2300 cal BP), particularly the Early–Late periods (7000–3220 cal BP). The rich record provided by Japanese rescue archaeology and an unusually fine-grained, pottery-based relative chronology enable us to examine long-term changes of hunter-gatherer settlement pattern at a level of detail that is almost unmatched in other areas of the world. The archaeological data associated with these hunter-gatherers are still, however, affected by high levels of chronometric uncertainty that hinder the understanding of Jomon settlement history. This paper will overcome some of these issues by using statistical techniques that can handle the uncertainties of the relative chronological framework adopted for settlement data, thereby maximising the information-content of the analytical output.

More specifically I will (1) quantitatively test a hypothesis that suggests a cyclical alternation between two distinct settlement patterns in eastern Tokyo Bay; and (2) establish a more precise chronology of when these alleged changes occurred. The results in turn will lay the foundation for a future assessment of any possible correlations between changes in settlement and the onset of key climatic events that might have acted as catalysts. While any such correlation will not automatically mean that environmental changes were causative agents of the observed archaeological phenomena, nevertheless it sets up a more robust inferential framework for investigating the possible cultural responses adopted by Jomon communities to environmental changes.

## Problems and perspective in Jomon settlement archaeology

There are three compelling reasons why Jomon archaeology offers an extraordinary laboratory for investigating long-term settlement dynamics. First, Jomon culture lasted for over 10 000 years, and its basic subsistence underpinnings—based on hunting, gathering, and fishing—seem to have remained largely unchanged (but see Bleed & Matsui 2010; Crawford 2011). Second, the availability of an exceptionally detailed chronological sequence based on pottery styles (Kobayashi 2008), offers a temporal framework that is unrivalled by any other prehistoric hunter-gatherer group. These two features, when combined with the richness and the wide coverage of rescue excavation data (Tsude 1995), support the claim that this is one of the best contexts for investigating prehistoric hunter-gatherers (Rowley-Conwy 2001).

Jomon settlement studies have focused on a wide range of topics, including long-term population dynamics (Imamura 2010), settlement layouts (Taniguchi 2005; Kaner 2011), territoriality (Taniguchi 1993; Tsumura 2006), relationship to subsistence strategies (Habu 2001, 2008) and settlement hierarchy (Tsumura 2002). Many of these works suggest, implicitly or explicitly, a settlement history characterised by cycles of change (see also papers in Suzuki & Suzuki 2010). The most notable evidence supporting this notion is the continual appearance and disappearance of *kanjo-shuraku,* settlements formed by hundreds of residential units deployed in a circle around a central plaza (Taniguchi 2005). Other indications include the fluctuations in the number of pithouses (Imamura 2010) and large-scale shell middens (Habu *et al.* 2011), while some studies suggest that subsistence strategy shifted between intervals with stronger or weaker reliance on plant resources (Imamura 1999).

These lines of evidence led Uchiyama (2006) to hypothesise that Jomon settlement history was characterised by a cyclical structure involving an alternation between two distinct patterns, which he labelled 'clumped' and 'dispersed'. The former type was characterised by a few large settlements and many small ones, while the latter comprised a more uniform distribution of settlement sizes. Uchiyama suggested several possible driving forces behind these transitions, primarily pointing to climatic changes, but without dismissing the role of human-induced environmental degradation and inter-societal conflict. The empirical support for his hypothesis was, however, primarily based on the comparative evaluation of existing studies, mostly characterised by rather simple qualitative descriptions. This lack of formal assessment of spatial patterning and, more crucially, of any precise evaluation of the timing of possible transitions between clumped and dispersed patterns has until now made it difficult to establish whether or not climatic changes played a driving role.

## Settlement history in eastern Tokyo Bay

In order to test Uchiyama's hypothesis, I analysed the settlement history of eastern Tokyo Bay (Figure 1) between the Early and Late Jomon periods (7000–3220 cal BP). This choice was driven by the rich archaeological record of the study area, associated with a fine-grained relative chronology that has been recently matched to an absolute sequence (Kobayashi 2008; see also Crema 2012), and supported by an extremely high density of rescue excavations.

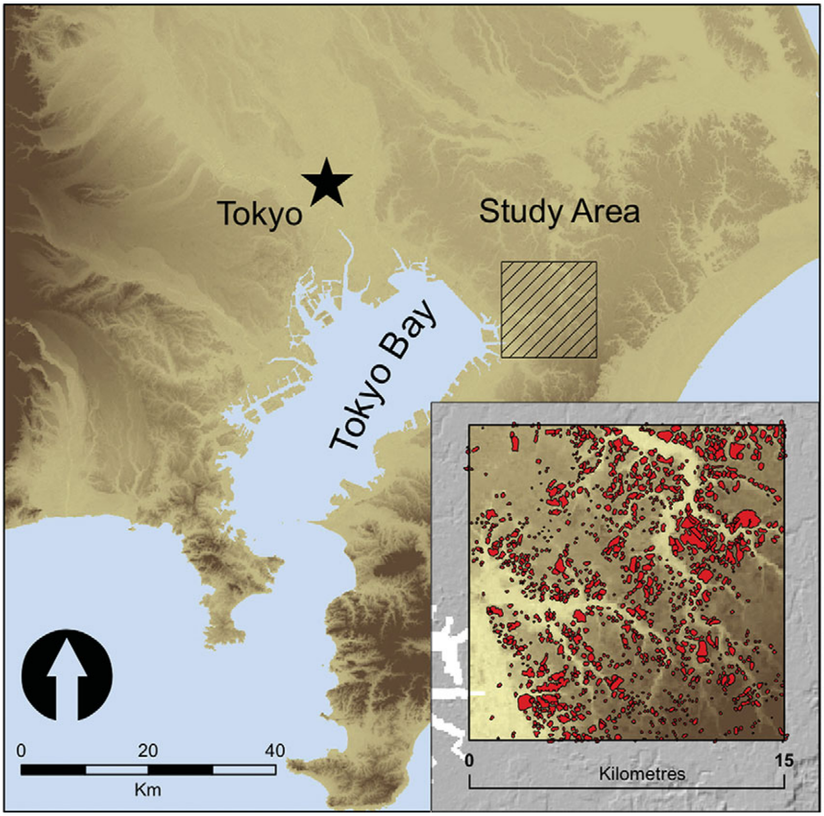


*Figure 1. Location of the study area and distribution of all archaeological sites therein attributed to the Jomon period.*

For the purpose of this study I chose a particularly well-explored sub-region of 15 × 15km, within which archaeologists have identified 1418 pithouses across 119 different sites.

Jomon pithouses are usually indirectly dated using potsherds recovered from the habitation floor, but the quality and quantity of the diagnostic sherds mean that different residential units can be shown to have different time-spans of existence. More precisely, some pithouses can be attributed to a single sub-phase (<50–100 years) whilst others can only be assigned to a much wider time-range (>1000 years). These time-spans do not represent the duration of the occupations, which are presumably less than 10–15 years (Watanabe 1986), but rather the temporal interval within which these pithouses might have existed.

My choice of case study also highlights a particularly problematic aspect of Jomon settlement archaeology: the knock-on consequences of arbitrary decisions made about what constitutes an archaeological site, as driven by the contingencies of rescue excavation. In many cases, a single 'site' spans the aggregate extent of multiple episodes of occupation over several millennia and different cultures, or might simply define the zone in which an emergency excavation has taken place (e.g. excavations related to the construction of a golf club). As a result, the assumption that site-equals-settlement is often false, and ignoring this question of definition may bias any further interpretation.

## Identifying clumped and dispersed patterns

In order to determine whether settlement in eastern Tokyo Bay oscillated between clumped and dispersed patterns we need to: **1)** select an analytical method that can distinguish quantitatively between more clumped and more dispersed settlement patterns; **2)** address the possible biases introduced by the fact that we cannot automatically equate the extent of modern archaeological sites with the size of past human settlements; and **3)** develop a method that handles the temporal uncertainty arising from the indirect dating of pithouses by pottery sequences.

Rank-size analysis offers a well-suited statistical environment for approaching the first problem. The technique has been used in a variety of archaeological contexts (e.g. Savage 1997; Drennan & Peterson 2004; Griffin 2011), but rarely for the study of hunter-gatherer settlement patterns. This is perhaps due to a mistaken sense that a method drawn from urban economic geography would be inappropriate for the study of hunter-gatherers. However, while a direct analogy with the settlement hierarchies of fully urban systems would undoubtedly be misleading, the method itself can be applied to almost any sort of long-tailed statistical distribution, and indeed to phenomena outside the domain of settlement studies (e.g. Bentley 2003). Thus, the possibility of intra-annual mobility patterns and the comparatively less permanent nature of hunter-gatherer settlements should not be treated as conceptual limitations. They should instead be addressed in the interpretation of the rank-size analysis rather than in its application.



In the case of Jomon settlements, it is possible to estimate the size of a settlement directly, using the identified number of pithouses. While the presence of recovery bias (e.g. partial excavations) will undoubtedly introduce some error in calculating the size of a given settlement, the large number of extensive excavations and the goal of the analysis to seek the presence of variation over time, rather than establishing a precise description of the settlement pattern at a given moment in time, ensures that this procedure is robust enough for the purpose of this study.

The creation of rank-size plots is, however, not sufficient to distinguish clumped and dispersed systems. One solution is to calculate an *A*-coefficient as proposed by Drennan and Peterson (2004). This method provides a single index that measures deviation from a theoretical rank-size distribution known as Zipf's law (Zipf 1949). The Zipfian distribution is characterised by a straight-line relationship between logged ranks and logged settlement sizes (i.e. a power law, where the straight line has an exponent of $-1$ such that the size of a settlement of rank $r$ is equal to the product between the size of the largest settlement and $r^{-1}$). The *A*-coefficient has a positive value (with a maximum of 1) when lower-ranked settlements are larger than expected by a Zipf's law distribution, and negative values in the opposite case (see Figure 2). When the rank-size distribution is close to the theoretical Zipf's law distribution the coefficient will be close to 0. Adopting this measure thus allows us to switch from an ambiguous and purely categorical definition of 'clumped' *versus* 'dispersed' patterns, to a continuous spectrum of values, where the Zipf's law distribution acts as a middle-point. Put simply, positive values of the *A*-coefficient will indicate a dispersed pattern and negative values will suggest a clumped pattern.

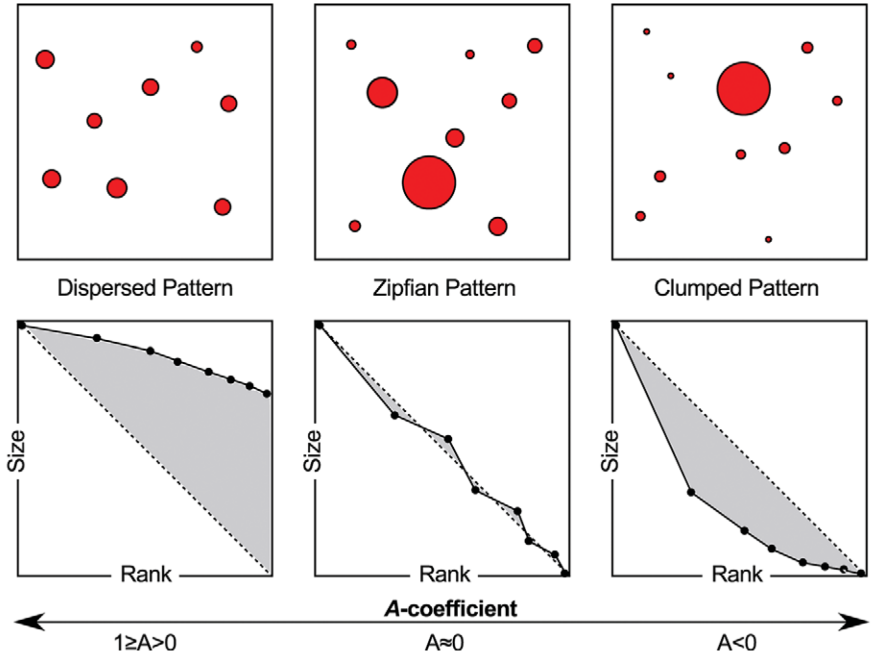


*Figure 2. Schematic demonstration of how a formal distinction between clumped and dispersed patterns can be established via an* A*-coefficient that measures deviation from a theoretical, Zipfian rank-size distribution. Positive values (up to 1) indicate dispersed patterns, whilst negative values indicate clumped patterns.*

The potential mismatch between the spatial extent of an archaeological site and the size of a Jomon settlement can be addressed by exploring how different defining criteria affect the ultimate analytical outcome. The starting assumption here is that if different definitions of what constitutes a settlement lead to different results, we need to find more robust justifications for our choices. Conversely, if the results do not vary much when we change how we define the settlement itself, then we can proceed more confidently with our interpretation of the results. Such a sensitivity analysis has been conducted as follows: 1) each site has been decomposed to its smaller constituents (i.e. single excavation plots); 2) the centroid (i.e. the geometric centre) of each of these has been extracted; and 3) these centroids have been aggregated using a clustering algorithm which ensures that those centroids close together are merged into one. For the purpose of this study six alternative datasets have been generated using a spatial clustering method that allows input of a distance-based parameter that can consider six increasingly aggressive approaches to merging the site centroids.

The problem of temporal uncertainty has been approached by combining aoristic analysis (Ratcliffe & McCullagh 1998) and Monte-Carlo methods (see Robert & Casella 2004 for a review). The former consists of slicing the time-continuum into equal intervals (*time-blocks*), and then computing the probability of the existence of a pithouse in a given time-block based on its possible *time-span* of existence as suggested by pottery finds. Monte-Carlo methods can then be used to simulate the exact time-block where the event might have occurred based on the probabilities obtained from the aoristic analysis. Detailed discussion on the combination of the two techniques can be found elsewhere (Crema 2012), but here it is sufficient to state that this method leads to the creation of *n* datasets where the chronological definition of all pithouses is refined to unique time-blocks. By assessing the distribution of the *A*-coefficients for each of these *n* simulated datasets, we can obtain a probabilistic description of the settlement pattern for each time-block.

For the purpose of the present study, the interval between Early and Late Jomon has been subdivided into 37 time-blocks, starting from 7000–6900 cal BP and ending with 3400–3300 cal BP. We can label each block with a lower case 't' and a subscript indicating the starting date of the block (e.g. the time-block between 4600 and 4500 cal BP will be referred to as $t_{4600}$). The time-span of each pithouse has been estimated based on the relative pottery-based chronology provided by the excavation reports and, where possible, confirmed via visual re-assessment of the published pottery drawings. The discrepancy between Kobayashi's sequence (2008) and the commonly adopted sequences in the Chiba Prefecture has been solved according to the cross matching proposed by Ouchi (2008). In those cases where the attributions are particularly uncertain or debatable, I have chosen to be particularly conservative and have assigned the widest possible time-spans.

A total of 6000 simulation runs have been conducted (1000 for each alternative dataset generated from the clustering algorithm), so that for each time-block 6000 possible settlement patterns have been generated.



## Long-term population dynamics in eastern Tokyo Bay

The combination of methods described above offers a robust benchmark comparable to other studies on Jomon population dynamics (e.g. Imamura 2010; Crema 2012), as well as an opportunity to explore population dynamics by generating a time-series of pithouse and settlement counts. Figure 3a combines the time-series of pithouse-counts for each of the 1000 simulation runs (light grey) with the general trend (the average time-series, superimposed as a solid black line). Despite the temporal uncertainty associated with this data (the width of the envelope generated by the grey lines) we can identify a strong increase starting at the end of the sixth millennium cal BP, followed by a decline in the mid fifth millennium cal BP and a renewed increase during the second half of the same millennium. A more robust assessment of the temporal variation in pithouse counts can be obtained by computing the rates of change between consecutive *time-blocks*. Figure 3b illustrates this, with the two-sided bars indicating the average rate of change for each transition, along with their 95% confidence intervals. This method allows us to distinguish changes in pithouse counts that are characterised by high levels of uncertainty (e.g. $t_{4900}$–$t_{4800}$) from those where we can safely identify episodes of increase (e.g. $t_{4800}$–$t_{4700}$) or decline (e.g. $t_{4600}$–$t_{4500}$). The results broadly confirm and refine the dynamics observed in previous studies (Imamura 2010), with one main population peak during the second half of the Middle Jomon period (5470–4420 cal BP), and two minors peak at the end of the seventh millennium and the second half of the fifth millennium cal BP.

The number of settlements follows a similar pattern, although some minor differences can be noted. Figure 3c shows the combined time-series of all six sets generated from the cluster analysis with the average trend of an intermediate clustering parameter superimposed in solid black. While variations in the clustering parameters determined a wider envelope

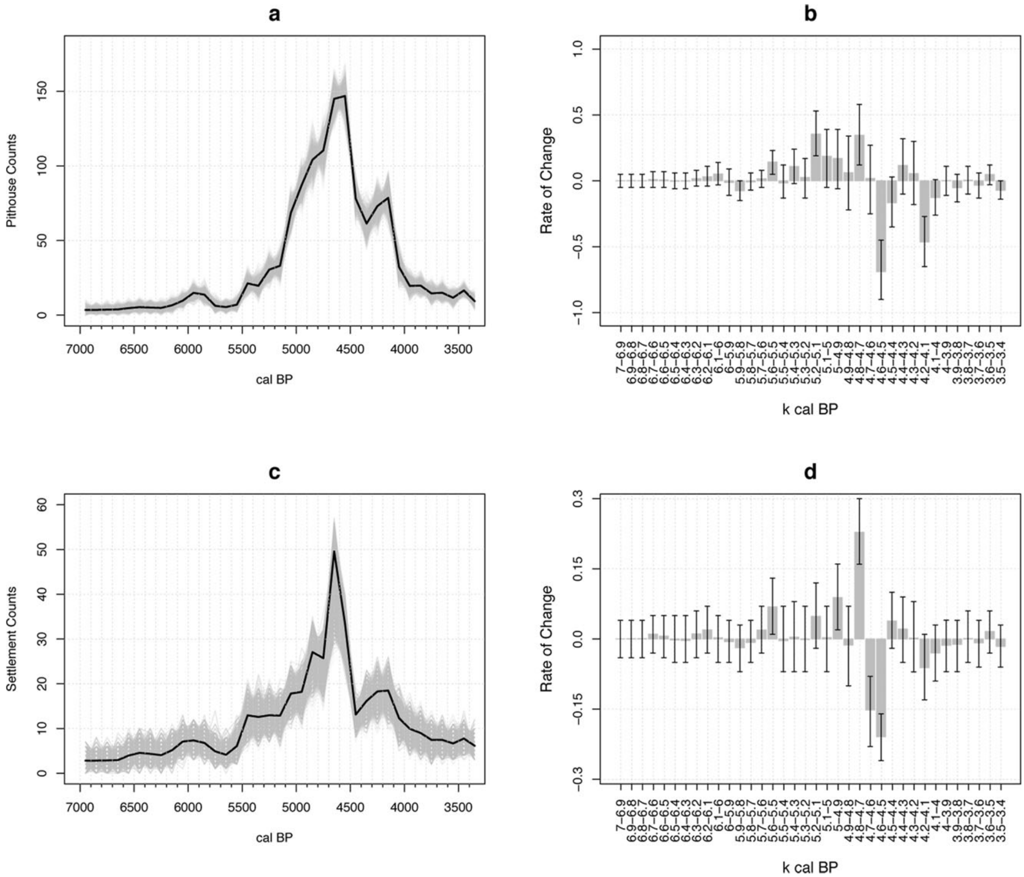


*Figure 3. Alternative representations of settlement dynamics in eastern Tokyo Bay:* (**a**) *time-series of pithouse counts per 50-year block;* (**b**) *rate of change in pithouse counts over the same period;* (**c**) *time-series of settlements per 50-year block;* (**d**) *rate of change in settlement counts (the x-axis labels of the rates of change refer to the start date of each time-block). Plots* **c** *and* **d** *have been obtained using the number of clusters identified by the DBSCAN clustering algorithm (Ester* et al. *2009). The grey lines in* **c** *show the simulated time-series for all six settings of the distance threshold parameter (from 0 to 250m with an interval of 50m), while the solid line is the average trend obtained with that parameter set to 150m. The rates of change in* **d** *refer to the same aggregation criterion (150m).*

of possible values, the overall pattern of temporal variation remained consistent though all the six sets with a major central peak during the first half of the fifth millennium cal BP and two smaller ones at *c.* 6000 and 4300–4200 cal BP. The rate of change analysis (Figure 3d) shows, however, some difference between the dynamics of pithouse and settlement counts. For example, settlement counts show an increase at the transition $t_{4500}$–$t_{4400}$, in contrast to a decline observed in the pithouse counts (Figure 3b). Similarly, the sharp decline in the number of settlements observed at $t_{4700}$–$t_{4600}$ cannot be identified in the pithouse counts.

## Cycles of settlement change

These divergences in the two time-series suggest that the size distribution of Jomon settlements was characterised by substantial changes in eastern Tokyo Bay. The *A*-coefficient

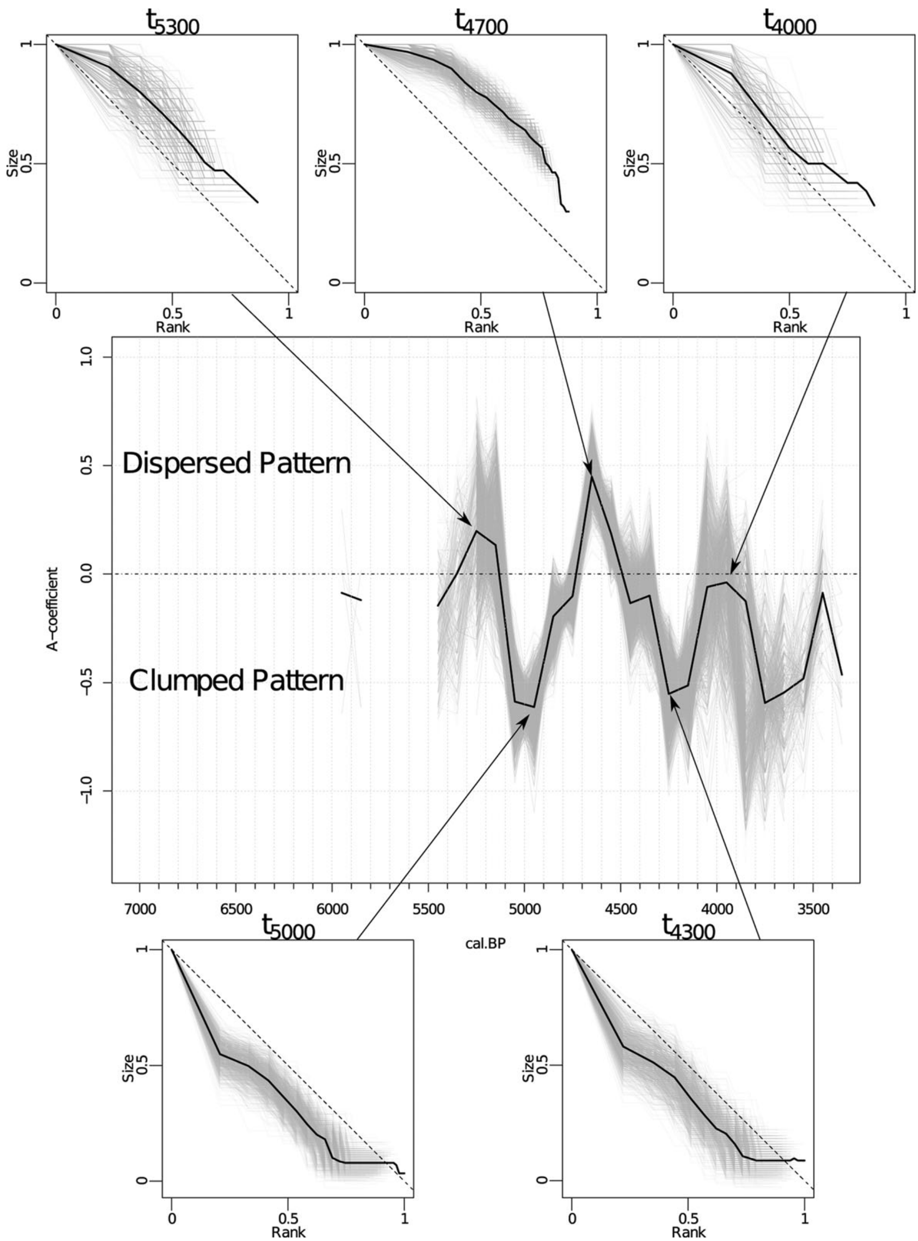


*Figure 4.* A*-coefficients of settlement patterns for successive time periods in eastern Tokyo Bay, along with examples of standardised rank-size plots for peak periods. The solid lines represent the average trend of the* A*-coefficient and the rank-size obtained from the counts of clusters (settlements) for a DBSCAN distance threshold parameter of 150m. The time-series suggests episodes of clumped pattern at $t_{5000}$ and $t_{4300}$, and dispersed pattern at $t_{5300}$, $t_{4700}$ and $t_{4000}$. Note that when the number of clusters for a given period was smaller than 5, the* A*-coefficient was not computed.*

analysis shown in Figure 4 confirms these expectations. Again, the plot combines all the time-series, with the average trend for an intermediate clustering parameter shown in solid black. The results indicate how settlement patterns fluctuated in an almost regular fashion, with episodes of both dispersed (e.g. at time-blocks $t_{5300}$ and $t_{4700}$) and clumped patterns (e.g. at $t_{5000}$ and $t_{4400}$). The formal treatment of spatial and temporal uncertainty also points to the limits of what we can know from the available data. For example, the number of settlements during the Early Jomon period (7000–5470 cal BP) is too small to determine the shape of the rank-size distribution, effectively leaving a blank space in the time-series. On the other hand, variation in the clustering algorithm did not show any consistent differences, indicating how ambiguities in site definition do not affect the outcome of spatial analysis in a major way. Figure 4 shows also the rank-size plot for peak values of the *A*-coefficient, further confirming the continuous shift in the hierarchy of settlement sizes.

## Discussion

The analysis presented here strongly supports Uchiyama's (2006) hypothesis: the settlement history of eastern Tokyo Bay was indeed characterised by repeated transitions between clumped and dispersed patterns. Similar radical transformations in the spatial distribution of residential units have been observed in a variety of cultural contexts, from the earliest agricultural communities in the Santa Valley in Peru (Drennan & Peterson 2004) to the Pueblo communities in the Mesa Verde region in the US Southwest (Ortman *et al.* 2012).

Interestingly, in the case of eastern Tokyo Bay, the temporal pattern of settlement transitions exhibits high regularity, with autocorrelation analysis indicating a significant cycle of *c.* 600 years (Crema 2013). Given the regularity of certain climatic cycles (e.g. Bond events; Bond *et al.* 1997), it is tempting to question whether the observed pattern is the result of (a) convergent responses to similar environmental events recurring multiple times or (b) the cyclical onset of some internal processes independent of climatic changes (e.g. overexploitation of resources). We should be cautious to avoid a false dichotomy, however, as similarity in the rank-size distribution does not necessarily imply similarity in the underlying structure and generative process.

The available archaeological evidence reinforces the latter point. For example, the relationship between settlement pattern on one hand, and overall residential density on the other, appears to vary over time: peaks in the overall number of pithouses can be correlated with both dispersed (at 4700–4600 cal BP) and clumped (at 4300–4100 cal BP) settlement systems. The two spatial configurations are also associated with different subsistence strategies. Analyses of faunal remains suggest that Middle Jomon period (5470–4420 cal BP) subsistence practices were quite consistent, with all settlements relying on a similar, balanced set of resources. By contrast, the larger settlements of the Late Jomon period (4420–3220 cal BP) appear to exhibit greater diversity in subsistence practice, with evidence for local specialisation in certain subsistence resources to the detriment of others (Toizumi & Nishino 1999).

An overview of existing palaeoenvironmental studies does not seem to support the idea that the recurrence of similar climatic events is the driving force behind the observed changes in the settlement pattern. A recent review paper by Kudo (2007) on the climate history of the Kanto region suggests two major environmental events at *c.* 5900 and 4500 cal BP. These are characterised mainly by episodes of cooling and coastal regression, and appear to confirm previous studies (Imamura 1999; Habu 2001) suggesting a correlation between environmental changes and the decline in the number of archaeological sites observed towards the end of the Early and Middle Jomon periods. The data analysed in this study does show some evidence for a decline in the number of residential units at *c.* 5900 and 4500 cal BP (see Figure 3b), but in contrast another decrease recorded during the second half of the Late Jomon period (*c.* 4200–4100 cal BP) cannot at present be correlated with any known major climatic event.

Similarly, fluctuations in the rank-size distribution do not always match the key dates suggested by Kudo. The sharp decline in the number of pithouses at *c.* 4500 cal BP is preceded by a decline in settlement counts and a transition from clumped to dispersed settlement pattern at *c.* 4700 cal BP. This suggests that some radical transformations in the settlement pattern occurred *before* the overall decline in residential density and before Kudo's 4500 BP event, refuting the idea that the latter was driving the shift in the rank-size distribution. These lines of evidence do not rule out the role of environmental change, but nonetheless point to the need for a closer re-examination of the available archaeological evidence.



It is worth remembering that such a re-examination will require precise assessments of the relationship between key archaeological and environmental events. The analysis proposed here adopts Kobayashi's chronological sequence, one of the few and most complete attempts to establish a link between Jomon pottery phases and absolute chronology. This sequence does not express the uncertainty of the start and end date of each phase, however, nor does it consider the possibility that the pottery phases could be overlapping, rather than abutting. Ideally, the adoption of Bayesian analysis (e.g. Buck *et al.* 1992) of these pottery phases, combined with the techniques already used in this paper, would provide a yet more accurate assessment of when key archaeological events occurred. Similarly, chronology of existing palaeo-environmental evidence would benefit from closer consideration of the intrinsic uncertainty associated with age-depth models (see Parnell *et al.* 2008).

## Conclusion

The observed cycles of Jomon settlement change and the detailed examination of the mid fifth millennium cal BP evidence in eastern Tokyo Bay suggest that we should reconsider the relationship between shifts in settlement pattern and the role of climate change, even if the available dataset is still insufficient to dismiss fully the latter as a catalyst. The dynamics observed in eastern Tokyo Bay suggest also that an alternative hypothesis should be considered, where forces originating from *within* the system (i.e. endogenous causes) may have driven transitions between clumped and dispersed patterns. Both simulation studies (Renfrew & Poston 1979; Griffin 2011; Crema in press) and ethnographic accounts (Woodburn 1968; Endo 1997) suggest how episodes of group fission and/or fusion can easily lead to the emergence of radically different settlement patterns without the onset of climatic events. In light of these models, phenomena such as human-induced resource overexploitation, perhaps triggered by high population density, should be carefully considered as a possible explanation of the radical changes observed in Jomon settlement history. Regardless of the outcome, a research endeavour formally tackling these and other alternative explanations would undoubtedly offer a promising agenda.

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