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Spatial autocorrelation analysis and the social organisation of crop and herd management at Çatalhöyük

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Abstract

This article uses spatial autocorrelation analysis in order to explore the social organisation of crop and herd management at the Neolithic site of Çatalhöyük in south-central Turkey. Evidence for spatial clustering across the settlement is sought at different scales (house, neighbourhood, radial wedge, sector, sub-mound) in the different periods of occupation from Early to Late. The data used are sheep carbon and nitrogen isotopes, densities of weed species in archaeobotanical assemblages and the densities of weed species in sheep dung. The results are interpreted in relation to existing work both on crop and herd management and consumption at Çatalhöyük and on the social organisation of the settlement. Complex nested and cross-cutting social groupings shared many aspects of production and consumption activities across the site resulting in limited spatial clustering of values. The impacts of taphonomic factors on these results are considered. Especially by the Late period of occupation at Çatalhöyük, there is some evidence of distinct labour and consumption organisation linked to houses and house groupings.

Özet

Bu makale, Türkiye'de İç Anadolu Bölgesi'nin güneyinde bulunan Neolitik yerleşim yeri Çatalhöyük'te mahsul ve sürü yönetiminin sosyal organizasyonunu araştırmak için mekansal otokorelasyon analizinin kullanılmasından bahsetmektedir. Erken dönemden Geç döneme kadar uzanan farklı iskan dönemlerinde, yerleşim genelinde farklı ölçeklerde (ev, mahalle, radyal plan, bölge, aşağı yerleşme) mekansal kümelenme için kanıt aranmaktadır. Kullanılan veriler; koyun karbon ve azot izotopları, arkeobotanik örneklerdeki ve koyun gübresindeki yabani ot türlerinin yoğunluklarıdır. Sonuçlar, Çatalhöyük'te hem mahsul ve sürü yönetimi ve tüketimine, hem de yerleşimin sosyal organizasyonuna ilişkin mevcut çalışmalara dayanarak yorumlanmıştır. Karmaşık, iç içe geçmiş ve kesişen sosyal gruplar, yerleşim genelinde üretim ve tüketim faaliyetlerinin birçok yönünü paylaşmış ve bu da değerlerin sınırlı mekansal kümelenmesine neden olmuştur. Bu sonuçlar üzerinde tafonomik faktörlerin etkileri göz önünde bulundurulmuştur. Özellikle Çatalhöyük'teki Geç iskan döneminde, evler ve ev gruplarıyla bağlantılı farklı emek ve tüketim örgütlenmesine dair bazı kanıtlar bulunmaktadır.

The aim of this paper is to shed further light on the social organisation of Neolithic Çatalhöyük, with particular reference to animal and plant production and consumption. The paper first summarises recent evidence concerning the spatial organisation of the settlement in terms of nested segments and cross-cutting sodalities, and then asks to what extent the management of plant resources and domestic sheep accord with this scheme. In the latter endeavour, spatial autocorrelation analysis is used to supplement other analyses that have sought to identify significant spatial patterning. Comparisons are also made with evidence from other sites, in particular Körtik Tepe and Tell Halula (Saña et al. 2014; Benz et al. 2016; 2018).

Çatalhöyük is a 9,000-year-old tell site on the Konya plain in central Turkey (fig. 1). First excavated by James Mellaart in the 1960s (see, for example, Mellaart 1967), a second project began in 1993 (Hodder 1996; 2000). The

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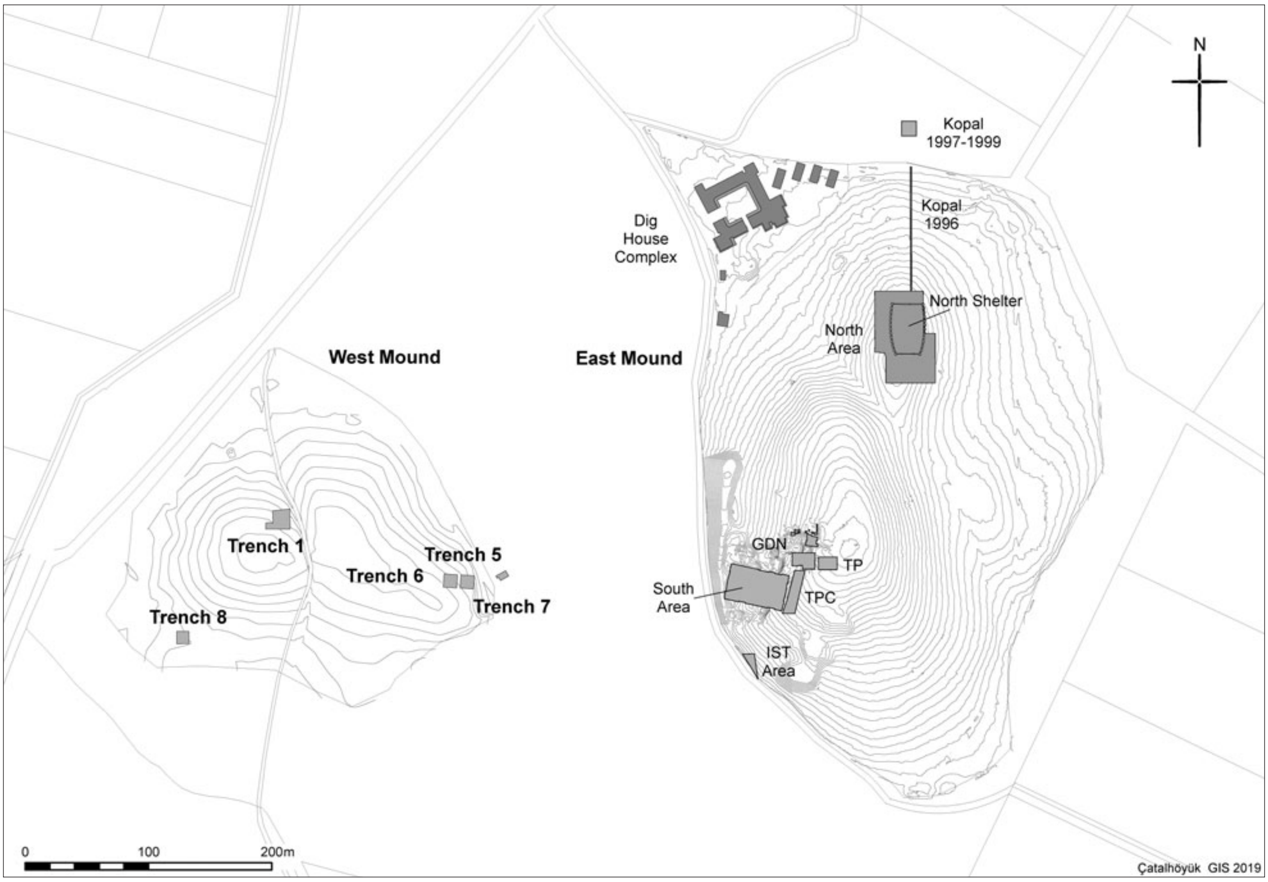

Fig. 1. Map of excavation areas on the East and West Mounds at Çatalhöyük (source: Camilla Mazzucato).

site is of international significance because it is large (13.5ha) at an early date, had dense population, has rich symbolism and sub-floor burial, and was occupied for 1,500 years; the Neolithic Çatalhöyük East Mound dates from 7100 to 5900 BCE with the Chalcolithic Çatalhöyük West Mound overlapping in time from the last quarter of the seventh millennium BC and continuing on until 5600 BCE (Orton et al. 2018). The well-preserved buildings and rich art in the Neolithic mound give a unique insight into early village life. The site allows study of many of the main questions dealing with the early formation of settled villages/towns and the early intensification of agriculture. The site was inscribed on the UNESCO World Heritage List in 2012.

There has been much debate about the size of the population that lived at Çatalhöyük at its height (Cessford 2005; Bernardini, Schachner 2018). It is undeniable that the settlement was large and that the exploitation of the surrounding mixed wet and dry environment (Ayala et al. 2017) would have presented challenges. In particular, how was the agricultural use of the Konya plain managed in terms of social organisation? While a diversity of views has been presented about the social organisation of the site (for example, Wason 2004; Düring, Marciniak 2006; Düring 2007; Kuijt 2018), current evidence allows us to infer a composite multi-levelled framework which can then be examined in terms of the management of agricultural resources.

A nested settlement pattern and cross-cutting ties

The smallest social unit identified at Çatalhöyük is the individual building. In contrast to earlier sites in central Anatolia such as Aşıklı Höyük (Özbaşaran et al. 2018) and Boncuklu (Baird et al. 2012) a wider range of activities took place in these buildings, including burial, art and ritual, manufacture (for example of stone and bone tools and beads), storage, processing of animal and plant products, cooking, consumption and discard. These buildings can be interpreted as houses in which a range of different activities were carried out. The floors and walls of the houses were repeatedly replastered, up to 450 times (Matthews et al. 2013), and houses were often rebuilt on the same footprint over time, although there were often breaks between the occupation of one house and the next (Plug et al. 2021). Nevertheless, there is much evidence of continuity of identity and memory construction in the repeated refloorings and in the stacks of buildings (Hodder 2019).

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Some buildings have large amounts of burials in them (up to 62 in Building 1: Cessford 2007a) while others have few or none. It thus seems likely that people were buried preferentially in certain buildings. Those buildings with large numbers of burials are also the buildings with most symbolic elaboration (Hodder 2016). These buildings, termed 'history houses', acted as burial and ritual foci for a larger group of buildings. Because we do not know where the people who were buried in a building lived during their lives, we cannot be sure whether the history-house groupings were local neighbourhoods or whether they were scattered over the settlement. The clustering of history houses in certain parts of the settlement suggests the latter may be the more likely. Groupings of history houses occur in both the South Area (Mellaart's Shrines 10, 8, 1) and the North Area (Buildings 1, 129, 77), which seems to suggest that the houses affiliated to individual history houses were more widely dispersed.

Nevertheless, local groups of houses certainly existed, as identified by specific distinctive cultural markers. Bleda Düring and Arkadiusz Marciniak (Düring, Marciniak 2006; Düring 2007) have proposed that the household in the Anatolian Neolithic was not an independent and self-sufficient unit, but rather was part of a larger social association that inhabited clustered neighbourhoods, especially in the early period of occupation at the site. There is much evidence to support this idea, despite the strong evidence for house autonomy in construction and use. The term 'neighbourhood' has often been used to describe the settlement pattern at Çatalhöyük with its tight clustering of buildings packed together; but, as already noted, we cannot be sure that spatially close or adjoining buildings constituted a social unit – social units may have been dispersed across the settlement and spatial proximity may not have indicated social proximity. The notion of 'neighbourhood' is used here to describe a grouping of nearby buildings that has some social or cultural coherence.

There are many examples of these local groupings, some seen in shared walls. At times, adjacent buildings were physically connected, as seen in the access crawl hole between Buildings 5 and 139 (Hodder forthcoming). Shahina Farid (2007) notes that Spaces 112 and 105 were jointly constructed. Similarly, Buildings 23 and 18 were placed on a common foundation raft; moreover, they shared a party wall with an opening between them. Building 55 shares a portion of its wall in the southeast corner with Building 58. The northern walls of Buildings 55 and 58 were both protected from the adjacent midden by the same retaining wall. The eastern wall of a niche in Building 58 was also the western wall of Building 67. To the east of Building 3 there was a structure in Space 41, and a door (Feature 633) existed between it and Building 3, at least in an early phase of Building 3. Building 52 was placed over two earlier buildings. The fact that they were demolished as a pair and rebuilt as one structure suggests some degree of neighbourly relationship between them.

There is now much evidence for local clusters of houses with distinct architectural or other features. We increasingly recognise that there are similarities between local groups of buildings. These local neighbourhoods are distinguished by distinctive and idiosyncratic practices (Mazzucato 2019). For example, two pot emplacements were found in the floor just east of the ladder in Building 42 (Hodder 2014a). The location of these emplacements recalls those near the ladder in the Buildings 65-56-44-10 sequence (Regan 2014) which is nearby. Freya Sadarangani (2014) argues that the layouts of Building 54 and close-by Building 57 were similar, as if paired, even though they have been allocated to different levels. Building 57 had a very unusual free-standing plaster and mud-core pillar in the main room. There is a possibly similar pillar in Building 45; both Building 57 and Building 45 are of the same Level North H date. Building 58 is similar in layout to Space 229, in that both have walls around western platforms. This is an unusual feature and only found in these two nearby buildings. Building 58 is also similar to Building 57, in that they both have upstanding rectangular ovens protruding from their southern walls; this type of oven is again unusual.

In the North Area we discovered a small elongated space or room, Space 67, to the east of a main room, Space 68 (Farid 2014). Space 67 contained elaborate features, such as a splayed figure (interpreted as a relief bear) in the southeastern corner. This location of an eastern side room with elaborate features is highly unusual, but a similar room was found in the nearby Building 5. In Building 5 an elongated space occurred to the east of the main room, again with an entry from the main room at the northern end (Cessford 2007b). Again there were complex features in this Space 155, including plaster basins, red painting and the scars of complex features and/or sculptures on the eastern wall face. In the TPC Area adjacent to the South Area, two nearby houses (Buildings 121 and 122, both in Level TP M) have very distinctive wall painting, including white geometric lines (Marciniak 2005).

There is also evidence for groupings of adjacent houses with related burial practices. The highest numbers of burials we have found at the site occur in three adjacent buildings in the North Area: Buildings 1, 77 and 131. Milena Vasić and colleagues (2021) note that this group, as well as Building 129 which was built on top of Building 131, also has the largest concentration of secondary burials. Buildings 1 and 131 also had burials of young people with very high numbers of beads (Vasić et al. 2021). Another possible example related to this grouping and adjacent Building 114 is the deposition of stone maceheads in

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burials. As Vasić and colleagues note (2021), these artefacts are not common on site, and they are largely absent from burials. Only four examples have been recovered from burial features in 25 years of excavation; complete maceheads were found in burials in Building 5 (below Building 1) and Building 114, whilst two fragments were recovered from the infill of two burial features in Building 131. In the South Area two groups of adjacent houses are suggested by the burial data (Vasić et al. 2021). Collars of boar tusks are extremely rare on site, but two individuals with sets of two and five collars were buried in neighbouring buildings (E.VII.12 and Building 50) in the South Area. The early houses 160-161-43-17-6 also form a distinctive group. These buildings see the repeated placement in burials of wooden planks, carnivore scat and carnivore pellets, which are distinctive practices rarely seen elsewhere on site. The fact that they occur in four burials located in three neighbouring buildings makes them even more exceptional. The fact that these buildings are not all exactly contemporary is of interest: it suggests that these local neighbourhood groups existed through time, with practices passed down between buildings in the group. The same has been noted for the North Area Buildings 1-5-114-129-131 group, since Building 5 is below Building 1.

So far in our nested hierarchy of spatial groupings at Çatalhöyük we have the individual building and then various forms of house grouping, whether the history-house group (perhaps dispersed across the mound) or the neighbourhood group. Other groupings of houses may be those that share the use of open areas or 'middens', or share the use of a terrace, but neither of these latter types of groupings has been identified as having distinct material-culture traits.

The next level of nesting is provided by wedges of buildings or open spaces radiating out from central high points on the northern and southern eminences of the East Mound (Hodder 2006). There are linear arrangements of abutting walls (see fig. 2) suggestive of a radial arrangement (Hodder 2006). Amy Bogaard and colleagues (2021) discuss the possibility that these radial 'wedges' may have extended out into the landscape and may have been the basis for the division of the landscape into zones of shared exploitation. Similar radial arrangements of houses have been identified at Aşıklı Höyük (Özbaşaran et al. 2018).

At the next level there are large sectors bounded by linear open spaces. In the North Area in particular there appear to be 'alleyways' that separate zones of clustered housing. Micromorphological evidence (Matthews et al. 2013) suggests that these 'alleyways' were used for refuse and outdoor activities, and there is no evidence of intensive trampling suggestive of 'streets'. Rather, these linear open areas seem to define zones of houses, although we have found no evidence of cultural practices that distinguish these groupings.

At a still higher level, the East Mound at Çatalhöyük is divided into two eminences or sub-mounds: North and South (fig. 1). There is now some evidence for cultural, social and economic differences that correlate with the two sub-mounds. Of course, the data are from limited areas of these eminences, and so we can talk only about the differences between the excavated areas. Camilla Mazzucato (2019) has shown a range of differences in architecture and symbolism between North and South, including nuanced preferences for the main highest platform to be in the northwest (in the North Area) versus the east (South Area) in the main rooms. Vasić and colleagues (2021) note a number of slight differences between the ways in which people were buried in the North and the South in the Middle period, although the sample sizes are often very small.

The highest level of grouping is the mound as a whole. Despite all the variability identified above, there is remarkable uniformity across the site in terms of architectural layout, domestic practices and artefact assemblages. While there are exceptions, most houses have the same internal plan, with entrance, ovens and hearth, production and manufacture residues, and child burial to the south and west, and higher whiter platforms with a wider range of burial and with more associated ritual and symbolism to the north and east. The range of activities that took place in the houses are similar, as are pottery, chipped stone and ground-stone forms. Whatever mechanisms were used to ensure this level of conformity over many centuries, they were effective at inserting site-wide rules of behaviour back into the lowest level of social unit, the individual house.

The nested system of groupings is summarised in figure 3. But there were also ties and affiliations that cross-cut this scheme. We have already suggested that the history-house groups based on shared burial may have cut across local neighbourhood groupings. There is much evidence of other cross-cutting links (Hodder 2006). Many of the most distinctive symbolic traits at Çatalhöyük are not at all localised but are scattered across the site. For example, pairs of opposed wall relief 'leopards' are found rarely and widely distributed. Benches with bull horns arrayed down each side are rarely and widely found, in both South and North Areas (for example in Mellaart's Shrine 10 and in Building 52). Similarly, the relief splayed figure, thought by Mellaart to be a goddess and identified by the current project as a bear, is found scattered across the South Area, but an example has also been found in the North Area in Space 67, as noted above (Farid 2014). Barbara Mills (2014) has interpreted such cross-cutting links as representing sodalities such as hunting or medicine societies. It seems that some history houses could also have been involved in social groupings that transcended the nested system.

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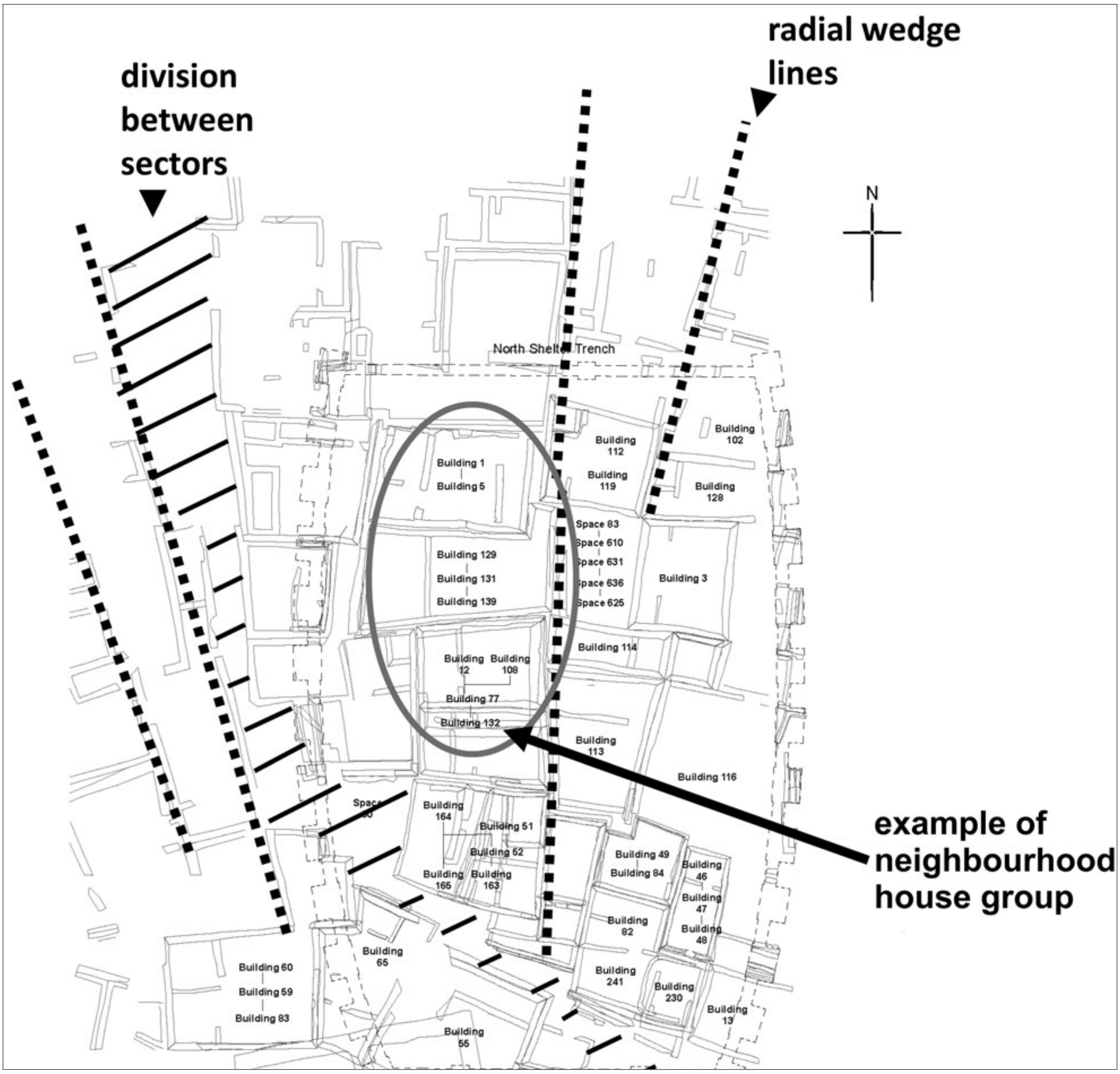

Fig. 2. Different scales of house groupings in the North Area at Çatalhöyük in Levels North F–H. Sectors, Radial wedges and a neighbourhood house grouping are identified. The latter grouping of Buildings 5-1, 139-131-129, 132-77 is described in the text and includes buildings with large numbers of burials, large numbers of secondary burials, burials of young people with a very high number of beads, maceheads in burials and an access hole between Buildings 5 and 139.

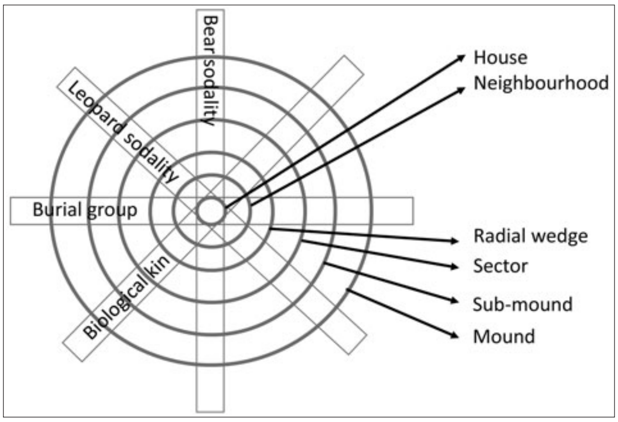

Fig. 3. Schematic diagram of nested scales of social grouping around an individual at Çatalhöyük in the Middle period of occupation. Diagram based on Kroeber's (1917: 185, fig. 3) description of Zuni social structure.

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The most intriguing evidence for cross-cutting ties is provided by research on biodistance and palaeogenetics at Çatalhöyük. Analysis of dental traits indicates that individuals interred together in the houses at Çatalhöyük were not phenotypically similar, likely indicating that they were not close biological relatives. Marin Pilloud and Clark Spencer Larsen (2011) suggest these results indicate that social structure was not based on biological kin but was practically organised. Thus, people may have been buried according to shared social/economic/political activities or individuals may have been adopted or fostered out after birth so that they had both biological and non-biological parents. The first DNA-based study of Çatalhöyük humans has provided some initial support for this pattern (Chyleński et al. 2019; Yaka et al. 2021): mtDNA profiles were studied from ten individuals buried in four neighbouring buildings (Buildings 80, 89, 96, 97) belonging to Levels South N–O. All ten individuals were found to carry distinct mtDNA lineages, suggesting that individuals buried in the same buildings were either non-kin groups or large patrilocal groups.

It would appear, then, that there is evidence to support the view that the social organisation of Çatalhöyük involved nested segments from the house to the local neighbourhood to the radial wedge to the sector to the sub-mound to the mound as a whole. Cross-cutting these were perhaps burial and ritual practices based on history houses (although these may have been the same as the neighbourhood groups), mixed biological groupings and larger-scale sodalities (fig. 3). Conceptually, the system recalls Zuni social structure as described by Alfred Kroeber (1917), although a more up-to-date account of Hopi social organisation in relation to Çatalhöyük is provided by Mills (2014).

However, the scheme as described above and as summarised in figure 3 is too fixed and structured in three senses. First, it ignores the detailed evidence of continual change and realignment in the organisation of daily activities. Kevin Kay (2020) has conducted detailed stratigraphic studies of the sequences of activities in houses. There is continual change in the location and number of hearths and ovens, platforms, burials and storage bins. This suggests ever-changing bustle and flux as relations between houses based on burial and food sharing are transformed.

Second, the nested groupings do not fit perfectly into each other. The cross-cutting ties that have been observed occur frequently. For example, the neighbourhood group identified as an example in figure 2 is largely contained within one radial wedge within one sector. But one of its defining characteristics is burials with maceheads. A burial with a macehead was also found in the adjacent Building 114, in a different radial wedge. Similarly, the four buildings in the North Area discussed above as having similar architectural features (Buildings 45, 54, 57, 58; not shown in fig. 2) are all immediately adjacent to each other, but there is a possible sector boundary separating Building 45 from the rest; Building 45 is also on a different alignment from the other three. Space 67 and Building 5 (see above) are close to each other but perhaps in different radial wedges. The different scales of grouping interweave in complex ways and there is much cross-cutting.

Third, the scheme in figure 3 ignores change through time. It works best for the Middle period of occupation of the site (table 1). For example, architectural connections between houses and co-builds are more common earlier in the sequence, and ground-floor doors into open spaces are more common later. Mazzucato and colleagues (2021) have explored the relationships between architectural and material-culture similarities between houses, on the one hand, and geographical proximity, on the other: while spatial proximity or neighbourhoods seem important for the Early and Middle periods, they seem less critical in the Late period. Work by Serena Love (2013) on the clays used in house construction finds distinct patterns of clay used in the Late Building 65-56-44 sequence in contrast to earlier levels when houses in the same time period tend to share clay sources. These results tie in with other evidence for a major change around 6500 cal. BC towards a more dispersed and fragmented settlement in which individual buildings are more independent and self-sufficient (Hodder 2014c).

Existing evidence for crop and herd management and the organisation of consumption

So how does the evidence for crop and herd management and consumption fit into this scheme?

The arrangement summarised in figure 3 suggests a high degree of reciprocity between nested segments and in the cross-cutting ties. Any individual could claim membership of multiple groups and could potentially share food, for example, with both biological and residential family members. So we might expect a high degree of shared resource management and consumption. But there is also evidence that individual units in the nested scheme produced and shared preferentially. At the smallest scale of the individual house, each house had its own oven or hearth at some point during its occupation. To some degree, production and consumption were house based. Most houses have side rooms and storage spaces; they have evidence of the final stages of processing glume wheats, for the intensive processing of animal bones for meat, fats, grease and marrow, and for a wide range of tool manufacture and use. Most houses have at least one burial, and most have some trace, however slight, of wall painting. So houses had an independent role in most spheres of life. Katheryn Twiss and colleagues (2021) note a distinctive cluster of pathological caprine metapodia in the South Area's Building 104, and Nerissa Russell and colleagues

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Temporal groupings of levels	*South*	*North*	*TP, TPC, GDN*	*IST*	*Mellaart*	*Cal. BC*
Final			TP Q–R		I	6300–5950
			TP O–P		II	
Late	South T	North H–J	TP N	IST	III	6500–6300
	South S		TP M			
	South R		TP L		IV	
	South Q					
	South Pb				V	
	South Pa					
Middle	South O	North F–G			VIA	6700–6500
	South N				VIB	
	South M				VII	
Early	South L				VIII	7100–6700
	South K				IX	
	South J				X	
	South I				XI	
	South H				XII	
	South G					

Table 1. Çatalhöyük East: temporal groupings of levels.

(2013) report a distinct set of sheep pathologies associated with the 65-56-44-10 sequence of buildings. The residents of Buildings 65-56-44 also had unusual access to, or atypical consumption of, wolf remains (Twiss et al. 2021).

But is there also evidence that neighbourhood groupings of adjacent houses produced and consumed together? The archaeobotanical evidence for weed assemblages associated with cropping suggests that buildings that were directly adjacent (Buildings 79 and 80), located in the same neighbourhood (Buildings 1 and 52) and/or in the same sector of the settlement (Buildings 63 and 122) shared particular similarities in weed flora (Bogaard et al. 2021), suggesting some form of supra-household organisation of land use. Neighbouring or nearby houses were linked with cultivation areas that were also proximate in the surrounding arable landscape, and so shared detailed similarities in growing conditions and arable weed composition. These groupings seem to continue through time, since nearby buildings with similar weed compositions may not be precisely contemporary. The inference that nearby buildings were linked with the same cultivation areas does not necessarily mean that their occupants pooled labour and resources. But even if the occupants of each building cultivated their own 'plots' within a 'wedge' or other grouping of neighbourhood fields, they would inevitably form a kind of 'community of practice' (Lave, Wenger 1991) or cooperative group with a detailed collective understanding of local variation in hydrology and soils.

As regards consumption, an important discovery in recent research has been that, in the small number of buildings with sufficient samples, the group of people buried together in a house (whether from neighbouring houses or from a more dispersed group) also ate together and/or obtained food resources from the same part of the landscape mosaic. Jessica Pearson and colleagues (2021) report statistically significant evidence for dietary differences between those buried in different buildings based on the variation of carbon and nitrogen human isotope values. The results are statistically significant for the Middle and Late levels. Kay's (2021) study of the detailed stratigraphies in houses has shown definitively that many houses have phases in which they do not have ovens. This suggests that to some extent food preparation was shared between groups of houses.

As regards consumption amongst larger neighbourhood groups of houses, Pearson and colleagues (2021) have assessed the carbon and nitrogen isotope values of humans buried in adjacent groups of houses to see whether there were distinct neighbourhood diets. When six house clusters were compared overall, regardless of period, the

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isotope values were found to be significantly different (p=0.001). However, when the data were separated into Middle and Late periods, significant differences were not found within a particular period.

Evidence from reconstructions of the size of feasting groups (Demirergi et al. 2014; Twiss et al. 2021) also suggests relatively small-scale groupings for the most part, although some larger groupings of over 100 people also occurred.

At a larger scale of grouping, differences have been noted between the North and South sub-mounds in terms of the grazing patterns of sheep, but these are best explained in terms of chronological trends (Pearson et al. 2021) since our data from the two sub-mounds cover overlapping but different periods of time. There appear to be intriguing differences in the rate of adoption of agricultural innovations between the two sub-mounds. There is a gradual shift through time across the whole site from emmer to 'new type' as the major glume wheat (Bogaard et al. 2021), but this shift seems to have occurred earlier in parts of the North than in the South. A change from pea to lentil, on the other hand, occured earlier in the South than the North. Similar results are found in the faunal data (Twiss et al. 2021; Wolfhagen et al. 2021a). Domesticated cattle were probably present in Levels North H–J but not in contemporary South P–Q, and this highlights the possibility that the North and South Areas employed different economic and/or land-use strategies. As regards cooking practices, consumption cuts on animal bone increase in the North Area into the Late period but decrease in the South. The baking of meat seems to have continued in the North while in the South there was a switch to stews (Twiss et al. 2021).

Spatial autocorrelation analyses

The existing evidence thus suggests that, despite an overall site-wide homogeneity and conformity of practices consistent with a high degree of sharing and reciprocity in a very interconnected and crosscut field, some separation of crop and herd management and consumption by groups of houses is evident, at different scales from individual house groups to larger entities.

The value of spatial autocorrelation analysis is that it allows the systematic exploration of spatial patterning in production and consumption indices. It explores spatial proximity effects within single variables directly, rather than within multivariate analyses, and it allows assessment of statistical significance (Hodder, Orton 1976).

The measure of spatial autocorrelation used was Global Moran's I (as implemented in the spdep package in R: Cliff, Ord 1981). Given a set of spatial locations and an associated attribute value to each of these locations, Moran's I tests if locations with similar attribute values are clustered, dispersed or randomly distributed. The Global Moran's I value varies from -1 in cases of maximum dispersion to +1 in cases of maximum clustering. A random distribution is indicated by a value of 0 (Cliff, Ord 1981). Each location is weighted to define how much impact it has on its neighbours. In this study, a weights matrix based on inverse distance was used, decreasing impact on a neighbour with increasing distance from it. Spatial autocorrelation analysis was used to see if it might be possible to confirm or refute the existing evidence for some degree of collective crop and herd management at Çatalhöyük.

Previous spatial autocorrelation analyses (Mazzucato 2013; Hodder 2014b) identified areas of high and low densities of artefacts in the North and South Areas. The high-density 'hot spots' and low density 'cold spots' grouped together two to four houses and adjacent open areas or middens. In some cases, these high- and low-density areas continued for more than one level of occupation. In a spatial autocorrelation analysis of adult human carbon isotopes in the North Area a distinct diet was associated with Building 60 (Hodder 2014b: 158).

Sheep isotopes

The initial question was whether the carbon and nitrogen isotope values for domestic sheep through the sequence at Çatalhöyük could be used to explore whether herds were collectively grazed. Samples of sheep bones were taken from the Early, Middle and Late periods and from a variety of contexts including many in open areas or middens. The assumption was that if sheep from the whole community were collectively grazed, or if individual herds were grazed over a diversity of landscapes, there should be no spatial patterning of isotope results. Isotope values for individual sheep bones from the site should not be correlated with values for bones nearby. Rather, the values should be randomly distributed spatially.

Previous research on sheep isotopes has shown that Çatalhöyük sheep were largely grazed on the Konya plain itself, with only small proportions showing traces of being grazed in the surrounding uplands (Bogaard et al. 2014). But the plain itself included a mosaic of wetlands and drier areas around the site itself, large expanses of alluvium and more distant expanses of poorer marl-based soils.

The spatial autocorrelation analysis was based on the isotope measurements for sheep bones from excavated units that had been assigned to period of occupation (Early, Middle, Late), and the spatial location used was the midpoint of the unit from which they were derived. A total of 182 samples could be identified (56 Early, 40 Middle, 86 Late). In many instances, several samples had been taken from different bones in the same midden unit. These bones would have the same midpoint location. The inverse distance for objects at the same location was set to 1. The isotope values are normally distributed (Pearson, Grove 2013).

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$\delta^{13}C$	*Moran I*	*p value*	*$\delta^{15}N$*	*Moran I*	*p value*
Early	***0.052***	0	Early	***0.049***	0
Middle	-0.025	0.494	Middle	-0.035	0.575
Late	***0.181***	0	Late	***0.093***	0

Table 2. Spatial autocorrelation (Moran I) for C and N isotopes of sheep bones in different periods at Çatalhöyük. Significant results are shown as bold italics.

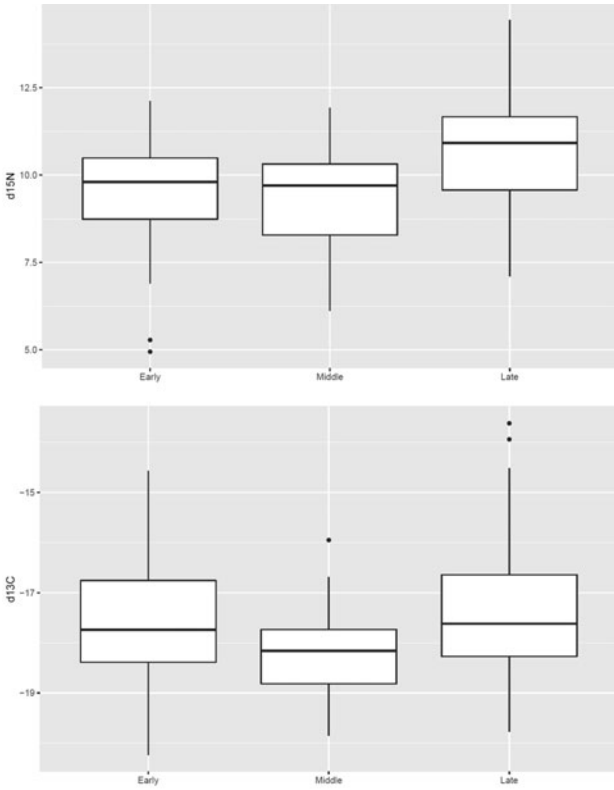

Fig. 4. The distribution of carbon and nitrogen isotope values for sheep bones analysed at Çatalhöyük.

The results for Moran's I were: .05 for both nitrogen and carbon in the Early period; -.03 and -.02 for nitrogen and carbon respectively in the Middle period; .09 and .18 for nitrogen and carbon respectively in the Late period. In terms of statistical significance, the p values for the Early and Late periods are highly significant but the values for the Middle period are not significant (table 2 and fig. 4).

Although highly significant for the Early and Late periods, the I values for all periods do not deviate far from 0. In general terms, the values suggest that sheep were not grazed in distinct parts of the landscape or that there was much sharing of sheep products. However, it is also possible that individual herding practices have become blurred. For example, although, as noted above, there are variations in grazing land across the Konya plain, there are many areas with similar soils. In addition, it remains possible that herds were associated with social groups but grazed openly, across diverse landscapes (Pearson et al. 2007). There is also the possibility of blurring through time. Each of the Early, Middle and Late periods covers several hundred years. Recent work on detailed dating of the Çatalhöyük sequence allied with Bayesian modelling has demonstrated the continual changes of use of buildings and open areas and middens (Bayliss et al. forthcoming). Nearby bones sampled for isotope analysis may not be closely contemporary.

In this context, the significant higher I values in the Early and Late periods are of interest. There were more C_4 plants consumed in the Early and Late periods, and this variability may have allowed significant differences to emerge. We can explore this pattern more fully for the Late period, for which samples are larger. Pearson and colleagues (2021) have noted, on the basis of sheep isotopes, that sheep were grazed over a wider range of contexts in this period (particularly in relation to carbon). Sheep dietary information from the archaeobotany of dung deposits also points to more diversity in foraging habitats in the Late period (with both 'riverine' and 'steppic' signatures) (Bogaard et al. 2021). This increased variability may have allowed greater discrimination between herds or subherds in the spatial autocorrelation analyses. For the Late period in the South there are two clusters of samples. These correspond to two sets of open areas or middens: one associated with Buildings 42 and 53, and the other associated with the column of Buildings 65-56-44 (only Buildings 42 and 56 are shown in figure 5, but the sampled sheep bones cover multiple levels within the Late period). The uniformity of the values in the former cluster contrasts with the greater diversity in the latter, and in particular with the larger number of low carbon values in the open areas associated with the Buildings 65-56-44 sequence. That a distinct pattern of values occurs for open areas associated with multiple superimposed buildings strongly suggests a distinct pattern of sheep management that was stable through time.

While there is spatial clustering of values in the Late South Area, the samples from the Middle and Early South are less widely spread spatially and so there is perhaps less ability to discern spatial patterning, especially since, as already noted, sheep were grazed over a wider range of contexts in the Late period. In the North area the samples

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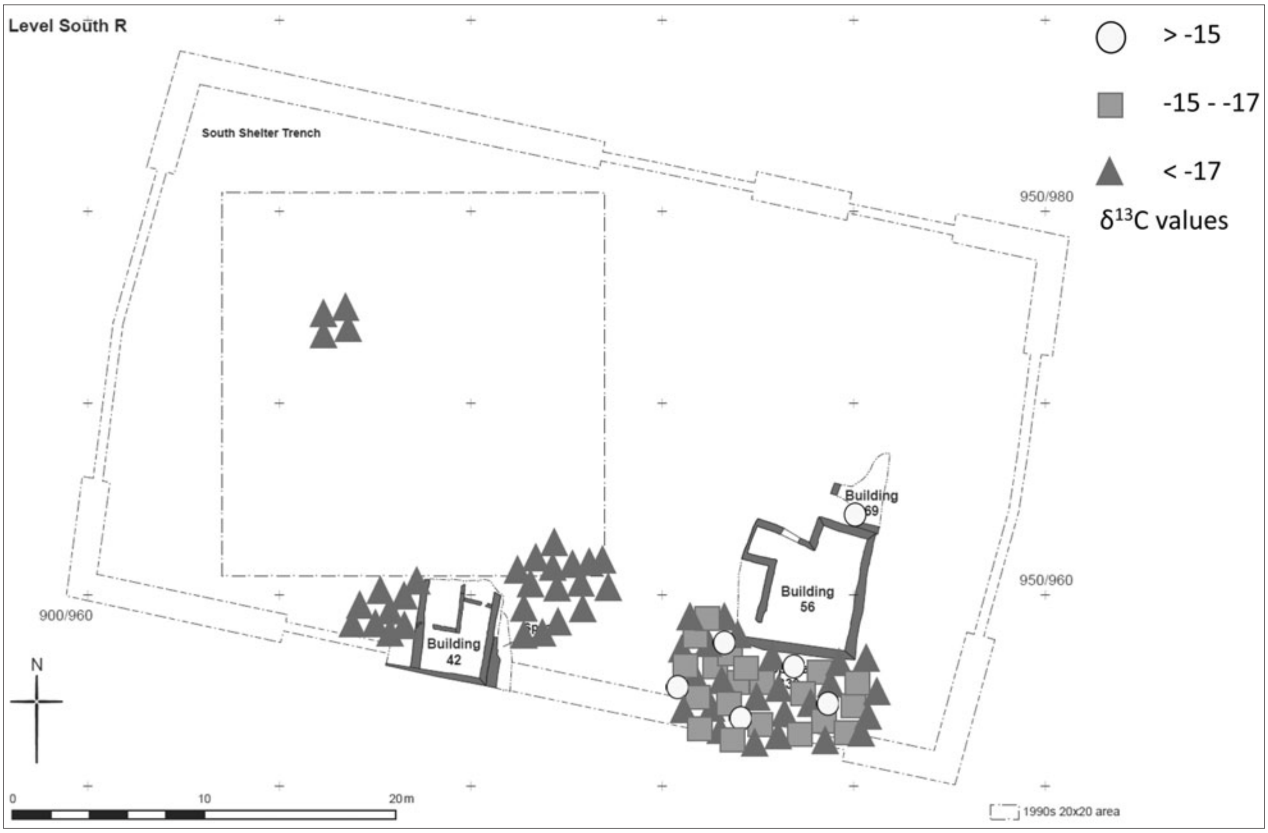

Fig. 5. Carbon isotope values in deposits associated with the sequence of Buildings 53-42 (only Building 42 shown) and Buildings 65-56-44 (only Building 56 shown).

are more widely spread spatially in both Middle and Late periods, although samples here are also smaller. There is a possible cluster of Late samples from Space 279, an open area with pits in Level North I associated with Buildings 70 and 71 (around grid reference 1041 1153). When the data were analysed separately for the South and North Areas, significant I values were identified for the South only; the small samples from the North produced insignificant values even for the Late period.

It is important to assess whether the distinction between the Late clusters of sheep isotope values in the two open areas associated with Buildings 53-42 and Buildings 65-56-44 could have resulted from taphonomic factors. For example, it is possible that the two sets of open areas are not exactly contemporary: the greater diversity in the 65-56-44 sequence could result from a greater length of time over which the samples accrued. While a precise answer to this question must await the detailed Bayesian modelling of dates being carried out by Alex Bayliss and colleagues (forthcoming), the greater diversity of samples in the Buildings 65-56-44 sequence occurs throughout Levels South Q, R, S, T; the diversity is not confined to part of this Late sequence.

Another confounding taphonomic process might be that the deposition of midden was somehow less diverse in the open areas associated with Buildings 53-42 than in the open areas associated with Buildings 65-56-44. As regards the nature of the two sets of open-area deposition, if anything it is the 53-42 open areas that are the most diverse. The 65-56-44 sequence sampled is a continuous build-up of open-area deposition to the south of the buildings and at one point there is a crawl-hole connection between the house and the midden. The 53-42 sequence, on the other hand, includes areas outside the houses as well as layers that interdigitate between house use and abandonment.

Another possibility is that the differences between the two areas result from deposition in different seasons. There is some evidence for increased variability in seasonality of different tasks in the Late period, including bird hunting and *Unio* collection (Wolfhagen et al. 2021b). It is possible that the animals sampled experienced multiple summers when the C_4 plants would have been most abundant. However, it is difficult to see how seasonal differences in midden development between periods would impact the isotopic values, since they likely average over too long a time to be affected by season of slaughter/deposition (and sampling avoided very young specimens). We do not have evidence that these middens were used in different seasons (Wolfhagen et al. 2021b).

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Weed data

A second set of spatial autocorrelation analyses were conducted for a range of weed species identified in archaeobotanical studies of a wide range of contexts; these were undertaken separately for the Early, Middle and Late periods of occupation at the site. This approach differs from that used by Bogaard and colleagues (2021), which employed correspondence analysis to explore variation between storage deposits in burned buildings only, with the results referred to above. Here, densities were used (as opposed to frequencies) and a wider range of deposits (though all relating to in-situ burning) was explored. This potentially allows for more detailed patterning to be observed across a larger number of samples. The identification of species as weeds is more secure in deposits that are evidently for storage; in other contexts the weed designation may be inappropriate. Nevertheless, evidence for any spatial clustering would be of interest. The expectation was that any spatial clustering of weed species might indicate distinct growing conditions on the landscape.

Perhaps partly because of the issues just identified, the vast majority of the spatial analyses of different types of 'weed' produced no significant results through all three periods. This was true of *Adonis*, *Atriplex*, *Bromus*, *Convolvulus arvensis* type, *Eremopyrum*, *Malva*, *Polygonum*, *Rumex*, *Sideritis* type, *Silene* and *Thymelaea*. Of interest, however, was that the cases with significant spatial clustering date to the Late period (see table 3). This was true of *Galium* (large-seeded) (just significant in the Late period), although the number of deposits with such weeds is small. Larger samples of deposits with *Hordeum murinum* and *Taeniatherum caput-medusae* also produced significant results for the Late period. There was significant evidence of clustering of *Vacaria pyramidata* in North Middle, as a result of a spatial clumping of high densities in the southern part of the North Middle. There was also a significantly high Moran value for *Vacaria pyramidata* in the Late period. What the spatial autocorrelation usefully adds to the earlier multivariate analyses is that there is additional significant clustering in weed composition, extending beyond 'storage' deposits to other forms of use deposit. The results are thus mutually enforcing, especially in relation to greater spatial clustering in the Late period. However, in most cases no significant patterning was detected; in some cases this is perhaps related to small sample sizes, but also perhaps the result of mixed or shared use of the landscape, a high degree of reciprocity in the processing and consumption of crops, or temporal blurring, as argued for the sheep isotopes.

Sheep dung

A third set of spatial autocorrelation analyses were applied to archaeobotanical data of wild species from sheep dung, with the assumption that these would give a direct insight into where sheep were grazed (Bogaard et al. 2021). The vast majority of medium-sized domestic ruminants at Çatalhöyük are sheep as opposed to goats. The analyses were based on the densities of *Sporobolus*, Cyperaceae

	Early	*Middle*	*Late*	*No. of deposits*
Galium (large-seeded)				
Moran I	*	-0.018	***0.013***	17
p value	*	0.189	0.049	
Hordeum murinum				
Moran I	-0.057	-0.009	***0.042***	39
p value	0.594	0.409	0.013	
Taeniatherum caput-medusae				
Moran I	-0.046	-0.052	***0.03***	77
p value	0.491	0.909	0.039	
Vacaria pyramidata				
Moran I	-0.019	***0.172***	***0.069***	74
p value	0.278	0	0	

Table 3. Spatial autocorrelation (Moran I) for weed densities in deposits of different date at Çatalhöyük. Asterisks indicate sample numbers too small for analysis. Samples included are those associated with in-situ burning and containing at least ten weed seeds. Significant results are shown as bold italics.

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indeterminate and *Bolboschoenus glaucus*, as these had a greater range of variation and large numbers over many samples. Only deposits relating to in-situ burning were considered. Samples from deposits internal to houses (floors and fire installations including ovens, hearths etc.) were separated from those external to houses (including floors and fire installations). Overall, 196 samples with at least ten seeds identified were available for study (30 Early, 59 Middle, 107 Late).

Notable was that all the external samples showed no significant autocorrelation; the significant results were for internal fire installations (table 4). As regards the dung data for internal installations, there was good significant clustering for *Sporobolus* in Late South and almost significant (p=.06) clustering for Middle North and South for *Bolboschoenus glaucus*. The good Late South results are to some degree caused by higher *Sporobolus* values in two samples from the same hearth in Building 75.

These results confirm to some extent the evidence for increased spatial segregation through time, but they also confirm other evidence discussed by Justine Issavi et al. (2021) for diverse and mixed activities in external open areas. There is better evidence for some degree of spatial clustering in the more limited and spatially and temporally structured activities within houses.

	Moran I	*p value*
Late South external		
Sporobolus	-0.09	0.491
Cyperaceae indeterminate	-0.094	0.562
Bolboschoenus glaucus	-0.089	0.461
Late South internal		
Sporobolus	***0.269***	0
Bolboschoenus glaucus	-0.138	0.485
Middle North and South internal		
Sporobolus	-0.002	0.277
Bolboschoenus glaucus	0.068	0.058

Table 4. Spatial autocorrelation (Moran I) for densities of wild plant seeds in dung samples from the Middle and Late periods in the North and South of Çatalhöyük. Samples included are those associated with in-situ burning (fire installations, such as ovens, hearths and fire spots, internal or external to houses) and containing at least ten dung-derived seeds. Significant results are shown as bold italics.

Conclusions

The spatial autocorrelation results reported in this paper are compatible with existing work both on crop and herd management and consumption at Çatalhöyük and on the social organisation of the settlement. Individuals had numerous others they could exchange and share with at many scales within a nested hierarchy of groupings as well as in cross-cutting sodalities. As a result, most residues of production and consumption are spread across the settlement in a fairly random manner. In addition, there are depositional and post-depositional processes that are likely to have smoothed out any original clustering. These processes include temporal blurring, changing variability in foraging habitats through time, variability in depositional processes in middens and uncertainties in identifying weed species in non-storage contexts. Other confounding factors include the relative uniformity of marl-based soils and vegetation across parts of the Konya plain in contrast to the wet and dry mosaic of alluvial environments near Çatalhöyük itself.

These confounding factors may have contributed to the predominantly non-significant Moran I values for many data sets. But it is also the case that 'random' patterning would be expected in the model of social organisation outlined in this paper. The complex nested and cross-cutting groupings would have involved exchanges and collaborations as labour and the products of labour were circulated. The elaborate channels of movement would have distributed archaeological traces through the settlement. Similar results have been obtained for Pre-Pottery Neolithic A Körtik Tepe, where human carbon and nitrogen isotopes show no segregation or clustering (Benz et al. 2016). At that site there is little evidence of clustering of individuals with similar diets in one household or area, and this is interpreted as an indication that 'access to food resources was open and diets varied individually rather than between households' (Benz et al. 2018: 144).

And yet at the later site of Çatalhöyük, some faint traces of a clustered patterning seep through the data. It of interest to note that by the time of Pre-Pottery Neolithic B Halula, animal herding was to some degree organised by household (Saña et al. 2014). Especially by the Late period of occupation at Çatalhöyük, but also apparent in some instances in the Middle period, there is evidence of distinct labour and consumption organisation linked to house groupings and larger-scale entities in the nested hierarchy. The sample sizes for the Early period in particular are often small and so, while we must await further research on the Early levels before the change through time can be confirmed, the development observed is compatible with claims for increased independence of house-based groups in the Late period (Hodder 2014c). The result is similar to the use of different cultivation areas in the surrounding landscape by house groups in *Linearbandkeramik* settlements in Germany (Bogaard et al. 2011).

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