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Geographic information system in zooarchaeology: A novel technique in analysis of the faunal remains from the Ma'anshan site, Guizhou, China

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Abstract: Geographic Information System has now found its way into many fields of archaeological research; however, its integration with zooarchaeology is only occasionally practiced, especially in China. In this study, we tentatively adopt this technique in an analysis of the faunal remains from the Ma'anshan site(ca.43-16 kaBP), Guizhou Province of China. Associated with thousands of stone artifacts and dozens of formalized bone tools, this site is exceptional in its excellent preservation of a fairly large bone assemblage. With the assistance of a geoprocessing tool from ArcGIS's Spatial Analyst extension, skeletal remains of Class III animals(including *Bubalus* sp. and *Megatapirus augustus*) from the site are quantified in bulk with maximum precision; meanwhile, patterns in bone element abundance of the two species are visually accentuated. The current study indicates that GIS can be a unique and most potent tool in standardizing and simplifying procedures in analyzing animal bones, especially those of extremely large collections from the Paleolithic sites of China.

Keywords: Geographic information system; Zooarchaeology; Ma'anshan site; Upper Paleolithic; Subsistence strategies

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1. Introduction

It is widely recognised now that the first major impact of Geographical Information System(GIS) upon archaeological society was in the early 1990s[1]; and as this system matured sufficiently to allow non-specialists to use it relatively easily in the first decade of this century, a variety of disciplines within European and American archaeology have adopted GIS[2, 3]. The majority of the archaeological applications of GIS during the past years are, however, regionally-based, especially in landscape archaeology and cultural resource management. The integration of GIS methods to address finer-scale archaeological problems, such as artifact analysis, has just recently become a primary interest of researchers[2]. Particularly, both physical anthropologists and zooarchaeological scholars have attempted to use GIS-based approaches to quantify severely fragmented bones from archaeological sites with ease and greater precision[4-12]. Marean et al.[11] piloted the study by using GIS to estimate the minimum number of elements(MNE), one of the few derived archaeozoological measurements essential both to disentangling taphonomic processes and to an overall interpretation of human subsistence behaviours in prehistoric and later times[13-28]. Their method, although proved to be quite useful, may be viewed as complicated to implement as it required extensive GIS processing and template preparation[4, 6]. In addition, the main merits of the application developed by Marean and his colleagues is actually based on an early version of Arcview, which is now simply inapplicable in new computing systems. A growing number of scholars have, therefore, taken steps to address these issues in attempts to optimize the advantages of the later versions of the ArcGIS package and ultimately to ease the process of recording and quantification in the analysis of skeletal remains[4-9]. Arguably, the work of García-Moreno et al. [4] might stand as a key example in such efforts. Different from other uses, these authors developed a novel methodology, in which the Equal to Frequency tool in ArcGIS's Spatial Analyst extension is first applied to the calculation of MNE of the horse remains from the well-known archaeological site of Schöningen 13II-4. While following this thread of logic, the purpose of the current paper is two-fold: first, to clarify on a critical point of the tool used by García-Moreno et al. [4] and further to make a refinement to their method; secondly, to assess the advantages this method offered over conventional ones by incorporating it into an analysis of the faunal remains from the Ma'anshan site, a typical Upper Paleolithic site of Southern China[29, 30]. This study is presently the first time a GIS-assisted approach is practiced in Chinese Zooarchaeology.

2. Materials and methods

2.1. The Ma'anshan site and the faunal remains therefrom

The Ma'anshan site is located 2 km southeast of Tongzi County, northwest Guizhou

Province(Fig.1). Its geographic coordinates are 28°07'18"N, 106°49'37"E, and its altitude is 960 m. This site was systematically excavated in 1986[30] and 1990[31]. An area of roughly 25m^2 was excavated to a depth of ca. 2.20 m in the eastern part of the cave in 1986; and another area of 23 m^2 by 2.30 m deep was excavated in 1990 in the center of the cave. Sieving was not performed during the excavations since the clay was very sticky and there was a lack of water in the vicinity; nevertheless, a faunal assemblage of 15 mammal genera(>10 kg) with a high NISP was recovered[29], as much effort was made to collect artifacts and animal remains, including micromammal and bird bones, bone tools, and long bone fragments from the sediments by carefully compressing the sticky sediment between the fingers[30].

The stratigraphic interpretation of the site was attempted by two groups of authors, and in this paper we choose to follow Zhang's proposal[30], which is also adopted by later studies[29, 32, 33]. In this scheme, eight archaeological levels were recognized, with an erosional surface dividing the sequence into two cultural units–the more brecciated strata 7~8 and the finer-grained strata 3~6 (for more detailed information of the stratigraphy of the site, please refer to [29]). Radiocarbon ages obtained for the upper unit indicate that these layers were accumulated between cal 35 kaBP and cal 18 kaBP, while the U-series age for the lower unit is rough 53 kaBP[29, 33].

Stone artefacts and pieces of formal bone tools from the upper unit are mostly <40 mm in length, while lithics from the lower unit are >40 mm and no organic tools were uncovered. Apart

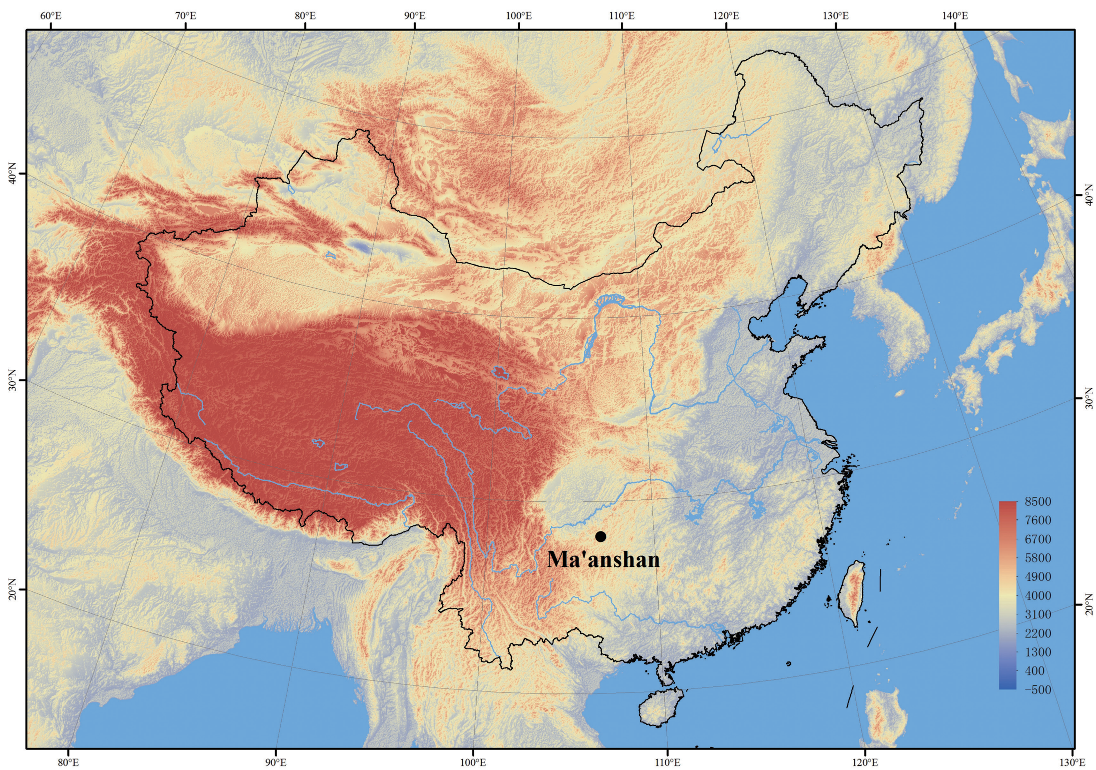

Fig.1 Geographical location of the Ma'anshan site

from the difference in tool size, the composition of the lithic assemblages from both units is quite similar, where the scraper is the predominant element in retouched tools, followed by chopping and pointed tools; unretouched flakes bearing traces of utilisation are also common[30].

In terms of faunal remains from the site, a major difference between the two units is clearly observed: *Bubalus* sp. dominates the faunal spectrum in the lower unit, while *Cervus unicolor* is most represented in the upper unit; in addition, there is no evidence for human exploitation of birds and micro-mammals in the lower unit, while 334 bones of such animals were recovered from the upper unit[29]. Following Brain [34] and others, faunal remains from the Ma'anshan site were grouped into 4 body-size classes[29]; for consistency, we adopt the same system of division in the following analysis. However, for illustrative purposes, we will focus only on the Class III animals from the Ma'anshan site, including *Bubalus* sp. and *Megatapirus augustus*(NISP 884 for the upper unit and 363 for the lower unit). For both stratigraphic units of Ma'anshan, an overwhelming majority of Class III animal bones are from the former species, whereas few fragments could be securely attributed to the latter.

2.2. The GIS-based method to claculate MNE

With an aim to decipher human behavior and the taphonomic history of the bone assemblage under observation, zooarchaeologists routinely employ MNI(the minimum number of individuals) and MAU(the minimum number of animal units) in their analyses, both of which are readily derived from an analytical estimation of the minimum number of elements(MNE) (Fig.2). Traditionally, there are at least two different ways employed by scholars to fulfill such a goal: the fraction summation approach and the overlap approach[11], although both methods have some drawbacks, such as the cumbersome procedures to follow and the large discrepancies in results between individual investigators.

Researchers have recently made progresses in using tools from the GIS packages to overcome the weaknesses of the traditional methods while maintaining their strengths[4-11]. Among them, the method proposed by García-Moreno et al. [4] is especially welcomed for its intuitional reasoning and simplicity. The basic logic in the process of calculating of MNE is to count the number of overlapping fragments at a specific location of a bone element; the Equal to Frequency tool of ArcGIS software, which evaluates on a cell-by-cell basis the number of times("OutRas" in Fig.3) the values in a set of rasters("InRas1", "InRas2" and "InRas3") are equal to another raster("ValRas")[35], is thus particularly relevant in this regard. By using the Equal to Frequency tool, García-Moreno et al. [4] well acquired an estimate of the MNE of each skeletal element of horse(*Equus mosbachensis*) from the Schöningen site with improved efficiency.

The overall workflow configured in the current paper is as follows: first, the digital template of multiple views(lateral, medial, cranial, caudal, etc.) of a complete skeletal element of an animal species should be drafted by using popular raster image processing softwares(e.g. Adobe Photoshop CS6); second, each bone fragment from the site, if identifiable to a specific portion of

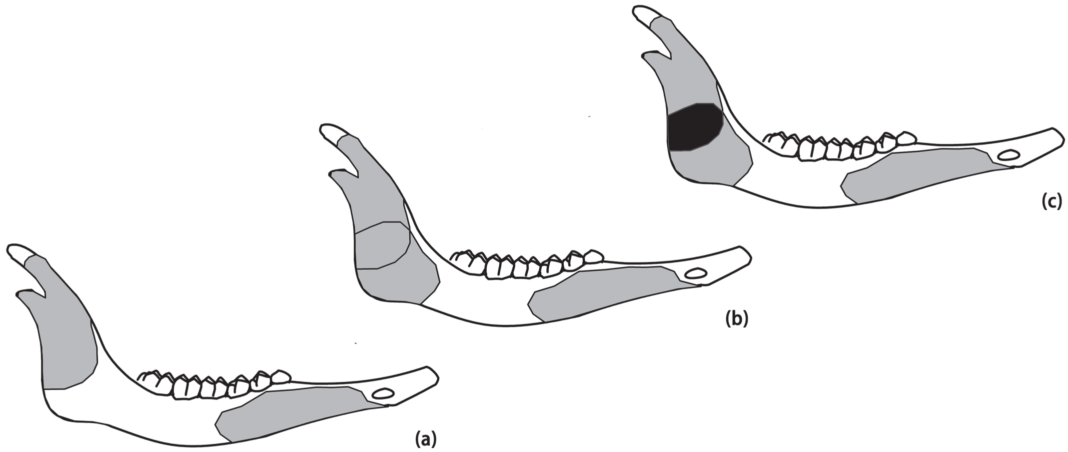

Fig.2 Schematic illustration of the principle of MNE quantification

(a) two mandible fragments of a mammal taxon drawn onto the element, where the MNE count is 1 (although there are two pieces of bone); (b) a third fragment, sharing some identical features with one of the first two bones, is added to the mandible template; (c) the overlapping part between the two fragments(in black colour) now raises the MNE count from 1 to 2

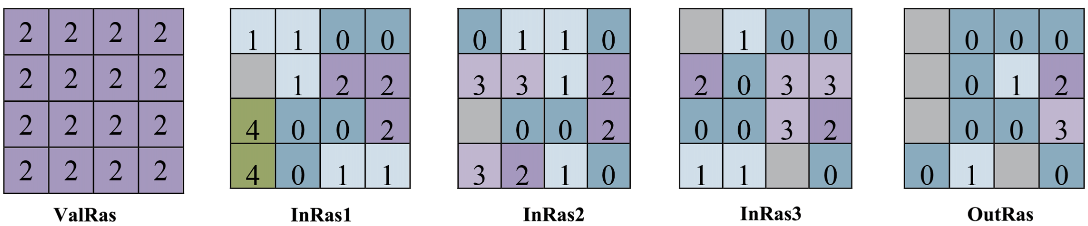

Fig.3 Schematic illustration of the computing process of the Equal to Frequency tool (modified after ESRI, 2014)

the bone element(distal epiphysis of a femur, for instance) for the animal species concerned, is digitally dawn on the pre-prepared template, with every view of the bone considered separately; third, using identical color scheme for bone fragments in step 2, a raster image of the same size and resolution as the template in step 1 is also drawn; last, all fragments identified to a specific element of the animal species(InRas in ArcGIS), along with the raster image produced in step 3(ValRas in ArcGIS), are imported as raster layers into the ArcGIS software and then manipulated by the Equal to Frequency tool of the Spatial Analyst extension. In this way, the number of fragments overlapping at any point of the complete bone template could then be determined by a resulting raster layer(OutRas in ArcGIS) in the output interface of the ArcGIS tool. The procedure outlined above is largely in accordance with that of García-Moreno et al[4]. Nevertheless, there are clearly some key points that needs to be addressed. According to García-Moreno et al[4] , the resulting raster layer appearing in the last step of the workflow should be divided by three in order to get a correct estimate of the MNE of the bone element in study. However, our experience indicates that this is not always true; or more precisely, it is generally not the case. In principle, while only pixel values in band R of the ValRas are considered, every InRas of RGB mode is computed three times(one for each colour band) in the Equal to Frequency tool of ArcGIS. Therefore, when all three bands of each InRas having identical pixel values with that of the ValRas it will then causes up to three times overestimation of the number of overlapping fragments. In this case, a division of the OutRas by three becomesan imperative; otherwise, it is definitely not necessary to do so. Particularly, when encountering an extraordinarily large assemblage, it may become rather difficult to manipulate such a large number of raster layers in ArcGIS; under the circumstance, an alternative way here is to have grayscale images instead of RGB ones integrated into the Equal to Frequency tool, which could greatly expedite the computing process of the GIS system. This is certainly the case for the present study, since the faunal assemblage from Ma'anshan comprises thousands of bone fragments identifiable to taxon and/or skeletal element.

3. Results

In order to compare the patterns of skeletal part representation of the Class III animals between the two units, bone fragments identifiable by both of us to a specific element of *Bubalus* sp. or *Megatapirus augustus* are quantified by employing the Equal to Frequency tool embedded in the ArcGIS package. In this way, for example, we may get, with a greater extent of ease and accuracy, an estimate of the MNE value for humerus of *Bubalus* sp. from the lower unit of the site; in addition, the pattern of bone survivorship within the skeletal element is also visually attenuated in the GIS-generated picture(Fig.4).

With the MNE numbers for each element of the animals acquired, they are further processed to meet the defining requirements of minimum anatomical units(MAU) and then standardized as percentages of the most common element of the animal at the site(MAU%)(Tab.1, Fig. 5), following the most popular methodology initially set forth by Binford [36]. For comparison, MAU% values for each element obtained by using the traditional fraction summation approach[29] are also included. However, it must be noted that the MNE values for the cranium of Class III animals from both stratigraphic units are virtually based on isolated, complete teeth and it is thus heuristically unnecessary to apply a GIS technique for their estimate. In view of this, we choose instead to adopt the corresponding numbers of the traditional method[29]. As is indicated in Table 1, MNE values in the current study are, by and large, somewhat bigger than their counterparts obtained by the traditional approach. This tendency has also been observed by Lyman[15]. There are also some bone elements for which the MNE values from both methods are exactly the same. Upon a close examination, however, it becomes quite clear that all these exceptions are of the result of

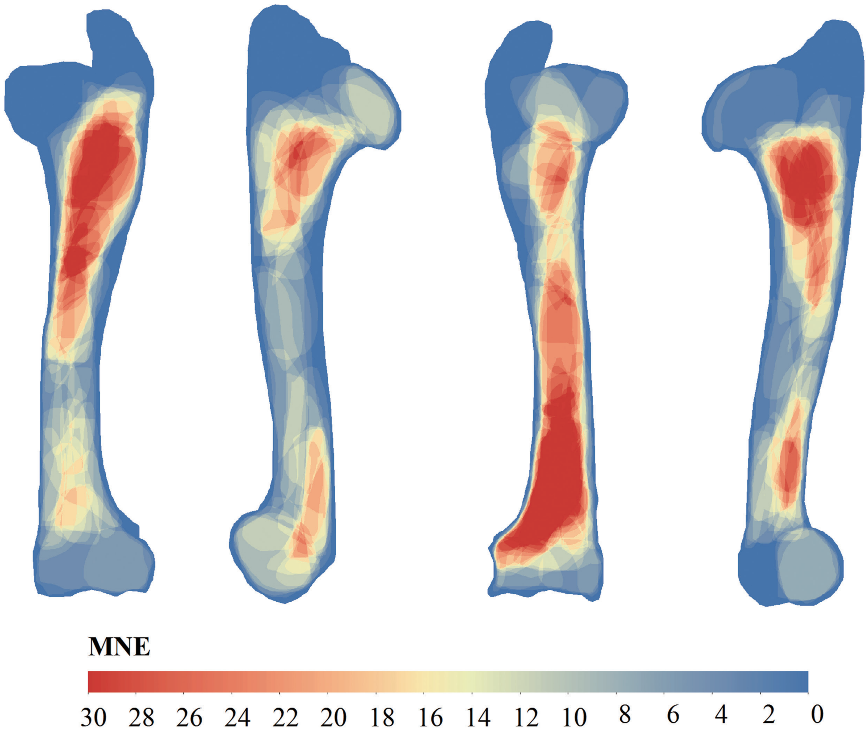

Fig.4 The MNE value for humerus of *Bubalus* sp. from the lower unit of Ma'anshan site

Tab.1 Skeletal element data (NISP, MAU and MAU%) for Class III animals from the upper and lower units of Ma'anshan site. Note: Numbers in columns marked by "*" are values obtained via the traditional method, as published in Zhang et al[29]

	Upper unit						Lower unit					
	NISP	MNE	MNE*	MAU	MAU%	MAU%*	NISP	MNE	MNE*	MAU	MAU%	MAU%*
Cranium	66	27	27	6	100	100	80	16	16	8	42.11	48.34
Mandible	7	3	2	1.5	25	16.67	33	8	8	4	21.05	24.17
Rib	51	10	8.32	0.38	6.41	5.33	81	15	11.44	0.58	3.04	2.66
Scapula	2	1	1.1	0.5	8.33	9.17	3	1	0.5	0.5	2.63	1.51
Humerus	32	3	3	1.5	25	25	187	30	23.4	15	78.95	70.69
Radius/Ulna	29	5	4	2.5	41.67	33.33	184	38	33.2	19	100	100
Pelvis	2	1	1	0.5	8.33	8.33	7	4	3	2	10.53	9.06
Femur	13	2	2	1	16.67	16.67	58	13	11.8	6.5	34.21	35.65
Tiba	24	7	6	3.5	58.33	50	107	17	14.86	8.5	44.74	44.89
Astragulus	18	4	4	2	33.33	50	28	12	11	6	31.58	36.25
Metapodial	48	9	8.8	2.25	37.5	36.67	92	16	14.76	4	21.05	22.3
Phalange1	38	20	18.48	2.5	41.67	38.5	16	7	5.52	0.88	4.61	4.15
Phalange2	30	14	12.8	1.75	29.17	26.7	8	7	6	0.88	4.61	4.5
Phalange3	2	2	1.6	0.25	4.17	3.3	0	0	0	0	0	0
Total	362						884					

small sample size. A Wilcoxon signed ranks test unambiguously indicates that the difference of the MAU% values for each bone element between the two methods is not significant, both for the upper unit(z=-1.581, p=.114, two-tailed) and for the lower one(z=-.471, p=0.638, two-tailed).

In terms of skeletal part profiles, there are both similarities and differences between the Class III animals from the upper and lower units. As clearly shown in Fig.5, bone assemblages from both units are generally similar, with a poor representation of vertebrae, ribs, scapulas and pelvises, and a sheer absence of atlas and axis vertebrae. This pattern could either be an outcome of hominin transport decisions[e.g., 21, 37] or of density-mediated bone destruction[13, 38, 39]. The major difference between the two units is best evidenced by the anatomical biases to the upper/middle limbs(humerus, radius, femur, tibia) in the lower unit, where MAU percentages for some limbs are even higher than those for head elements(especially when one considers that the latter parts are estimated from teeth rather than bones). Moreover, MAU values for the foot bones(metapodials, carpals/tarsals and phalanges) of Class III animals in the same unit are obviously lower than those for the upper/middle limbs, which is in sharp contrast with the pattern in the upper unit, where the values of the extremities are equal to or higher than those of the upper/middle limbs. It is well known now that the bulk densities of the metapodials of Class III mammals are largely similar to those of the midshafts of major limb bones[13, 39] and the density of animal tooth is even higher[13]. The observed discrepancy between the estimated MAU values for bone elements and their expected frequencies in terms of bulk density, therefore, could not be explained by differential destruction of the less dense bone elements of the animals. Instead they provide a correct representation of selective transport by hominins at Ma'anshan. We thus could conclude, along with other evidence from taphonomic investigation[29, 33], that inhabitants in the lower unit of the Ma'anshan site preferentially carried back marrow-rich limbs bones on the one hand and abandoned foot bones at kill sites on the other; while the occupants in the upper unit favored moving a wider range of elements back to the cave. The seeming discordance between

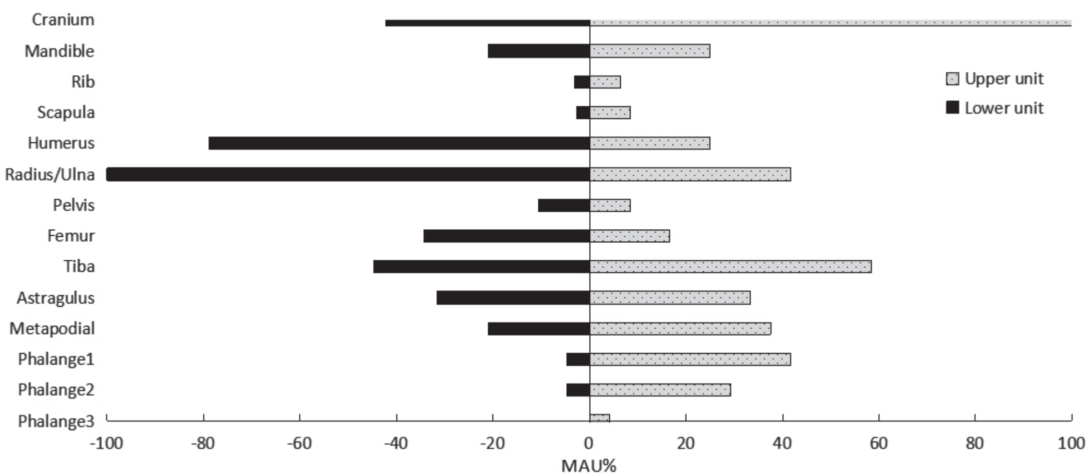

Fig.5 The skeletal element profiles of Class III animals from the upper and lower units at the Ma'anshan site

elements from this unit is more likely a taphonomic effect of preservation rather than that of differential transport by hominins.

4. Discussion and Conclusions

It has long been speculated that when prehistoric hunter-gatherers acquired a prey of larger size, they were probably had to make a difficult decision as to which body parts of the animal should be left behind at the kill site and which parts should be transported to their residential sites for further processing and consumption[37, 40]; ethnographic and ethoarchaeological studies thereafter, to a large extent, have satisfactorily confirmed the validity of this assumption[25, 26, 41-44]. Traditionally, scholars adopt MNE, MAU or some other measures to evaluate the relative abundance of skeletal parts of an animal in archaeological context[13-15, 17, 36] The recent integration of GIS technique with this procedure by a small number of scholars has further prompted authors to achieve their goals with greater ease. The accuracy and significance of GIS technique in calculating MNE is, however, not unanimously appreciated in the field of zooarchaeology. Lyman [15], for example, has criticized this approach for its tendency to overestimate the number of bone elements; Parkinson et al.[9], on the contrary, find a slight underestimate of MNE relative to the traditional method. The present study indicates that compared to the numbers from Zhang et al. [29], bone counts based on the GIS technique for various elements of Class III animals are generally larger. This difference could be, at least partially, explained by several observations. First, in earlier faunal analysis at the Ma'anshan site, each fragment was recorded as a certain percentage of a predefined anatomic landmark of the element. However, since only specific landmarks are routinely entered into the database, a specimen with half the length of the linear aspera of a femur as well as some adjacent cortical portions, might well be labeled as 1/2 linear aspera. This innate problem will unavoidably lead to a lower estimate of the numbers of bone elements. In contrast to the traditional approach, the GIS technique has taken cortical parts free of explicit landmarks into consideration and hence increased, more or less, the counts of the bone elements. Second, due to the absence of highly precise provenances for finds from the site(the sticky sediments of the site had virtually prohibited an in situ recovery of most bones and lithics), manual conjoining of the bone fragments was virtually not practiced in earlier studies[29, 33]; possibly contributing to a relatively small count of the elements in direct tallies of bones. Therefore, although the outcome of our analysis shares certain similarities with Lyman's[15], we are still confident in proposing that the GIS approach should be viewed as a new and alternative way to a better estimate of MNE for various elements of the animals from archaeological sites. Particularly, in consideration of its efficiency and capability for bulk processing and visual enhancement of the skeletal part profiles, this technique will eventually outweigh others in achieving MNE values and their derivatives(MAU, MAU%) for various elements of prehistoric animals, which could largely expedite the process of fragment quantification and thus encourage researchers to move to a more standardized protocol for the investigation of taphonomic processes at archaeological sites.

Based principally on MNE values from the GIS-assisted technique, the skeletal element abundance at the two cultural units of Ma'anshan site exhibits rather different patterns, which is largely a product of hominin transport practices. For occupants in the lower unit, they were more selective in transport of the skeletal remains of Class III animals; for hominins in the later period, they instead favored carrying almost a complete array of bone parts back to the cave. This distinction, as we have addressed before, may bear greater significance in terms of human adaptations in prehistoric periods[29, 33].

In addition to its distinctive contributions to the current study, GIS technique could potentially be extended to other fields in zooarchaeology as well, for example, the analysis of distributional patterns of bone surface modifications(cut marks, percussion marks, burning marks, carnivore tooth marks, etc.) on animal bones from archaeological sites in China. This appears to be more promising than ever before for disentangling the complex taphonomic history at sites and thereafter for achieving a holistic understanding of human subsistence strategies in prehistoric China.

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地理信息系统在动物考古学研究中的应用：以贵州马鞍山遗址出土的动物遗存为例

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摘要：目前，地理信息系统（GIS）在多学科领域的融合方面已经发挥了极为明显的作用。但是，在动物考古学研究中，尤其是在东亚地区，这一手段的使用还明显有所欠缺。本文尝试将这一技术手段应用于贵州马鞍山遗址（距今约 43~16 kaBP）出土动物遗存的研究之中。在上千件石制品与数十件骨制品之外，马鞍山遗址还出土有大量的动物化石，从而使其成为检验与实践地理信息系统的一个良好媒介。本文以 ArcGIS 软件包中的空间分析工具为技术依托，重点对遗址出土的大型动物（包括 *Bubalus* sp 和 *Megatapirus augustus*） 的骨骼单元分布模式进行了更为准确的统计与分析。本项研究表明，相对于传统方法而言，GIS 系统在大型动物遗存的量化统计方面具有独特而重要的价值；此外，这一技术手段还有望在第四纪其他学科的研究中得到发挥与应用。

关键字：地理信息系统；动物考古学；埋藏学；马鞍山遗址；旧石器时代晚期；生存策略

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