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Zooarchaeological perspective on the Broad Spectrum Revolution in the Pleistocene-Holocene transitional period, with evidence from Shuidonggou Locality 12, China

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Based on optimal foraging theory, prey animals from the Shuidonggou Locality 12 (SDG12) are divided into three types according to body size and defense traits: high-ranked large game, low-ranked slow small game, and low-ranked fast small game. Application of the Reciprocal of Simpson's Index to the three types of animals from SDG12 yields a relatively high level of evenness, which implies a broader meat diet of the SDG12 hominids. Compared to values of taxonomic evenness from Mediterranean sites, it is suggested that this dietary expansion probably resulted from the occurrence of the Broad Spectrum Revolution rather than from climatic changes in the Shuidonggou area. Comparative studies between the Natufian phases in Hayonim Cave and the SDG12 validate this argument.

Broad Spectrum Revolution, Shuidonggou Locality 12 (SDG12), zooarchaeology, transitional period between Pleistocene and Holocene

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In 1968, Binford [1] described rapid diversification in hunting and food processing, including grinding nuts and usage of small mammals, by hominids in middle and high latitude Europe at the end of the Paleolithic or Mesolithic roughly 12–8 ka BP. In 1969, Flannery [2] furthered Binford's observation with the "Broad Spectrum Revolution (BSR)" hypothesis, proposing that the emergence of the Neolithic was prefaced by a period when dietary breath increased. He argued that the broader diet raised the carrying capacity of an environment increasingly constrained by climate instability at the end of the Pleistocene [2, 3]. Thereafter, Bar-Yosef [4] demonstrated shifts in the types of plants consumed during the transitional period between the Paleolithic to the Neolithic in West Asia, according to evidence from food storage equipment and botanical remains. Wringht [5] believed that plants, especially nuts and large-seeded plants, were necessary for the revolution of human subsistence during the transitional period, and Unger-Hamilton [6, 7] considered that the stone knives of Mesolithic Natufian culture were used to harvest crops. The BSR was thus shown to have occurred in Europe, west Asia and Southwest Asia by evidence of plant use. With zooarchaeological methods, Stiner analyzed bone assemblages from

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sites in the southern part of Levant, and provided evidence on the breadth of meat consumed by hominids in this area, which offered a novel perspective for the study of the BSR [8].

At the Shuidonggou Locality 12 (SDG12) site, dated to 11 ka BP, a variety of tools have been unearthed, including millstones, grinding rods and pestles, which to some extent demonstrates that humans were crushing and grinding seeds; while a polished bone tool with a deep groove, into which stone blades could be set, was probably used as a knife for harvesting crops [9]. Such grinding stones and composite tools have not been found at SDG1, SDG2, SDG7, and SDG8, which are all sites at least ten thousand years older than SDG12. Because the act of grinding increases the time and effort spent processing food, it is likely that hominids of SDG12 had already broadened their plant diet, as humans would not be selecting these time-consuming foods if easily processed plant resources were abundant [10]. Although residues of grass seeds were detected on some knapped stones, no millstones, grinding rod or pestles were unearthed from SDG2 [10], which signifies more efficient processing of plant seeds at SDG12 than SDG2 by humans. Hence, it is possible that some elements of early agriculture, such as grinding stones and composite tools, were present at SDG12. In addition to plant use, it is also important to elucidate how hominids used animal resources at the SDG12 site, because it will offer further clues as to whether the BSR occurred in the Shuidonggou area during the transitional period of the terminal Pleistocene to the early Holocene.

1 Materials

The Shuidonggou site is located 28 km southeast of Yinchuan, Ningxia Hui Autonomous Region. With an average elevation of about 1200 m, this site is geographically situated at the eastern edge of the Yinchuan basin and the western margin of the Mu Us Desert. Locality 12 of the Shuidonggou site (38°19′40″N, 106°29′49″E) lies downstream of the Biangou River and adjacent to the Chunwang Brickyard, which is about 4 km north of Locality 1. In this region, six terraces have been identified so far, with SDG12 and other localities are mainly situated on Terrace II. Initially discovered in the summer of 2005, SDG12 was excavated in 2007 and a large number of stone artifacts, bone tools and fragmented animal bone were unearthed [11]. Stone artifacts from SDG12 include microlithic cores, microblades, scrapers, millstones, grinding rods, stone pestles and some partially polished stone tools; bone tools from this site include some exquisite awls, needles and composite bone tools [9]. In addition to these cultural components, more than 10000 pieces of animal fossils were unearthed from SDG12 that can be taxonomically identified as rabbit (*Lepus* sp.), badger (*Meles meles*), wildcat (*Felis microtus*), deer (Cervidae), gazelle (*Procapra przewalskyi*), boar (*Sus* sp.), horse (*Equus przewalskyi*), buffalo (*Bubalus* sp.), bird (Aves), reptile (Reptilia) and rodent (Rodentia).

It was proposed that SDG12 is essentially buried in its primary context and only slightly disturbed by flowing water [11]. Examination of the surface modifications on animal bones from this site further indicates the absence of water in the accumulation of bones because no scratches were detected. Evidence of carnivore activity at this site can be found in two gnawed specimens, which accounts for roughly 0.1% of the whole assemblage and is far below corresponding figures in faunal assemblages accumulated by carnivores [12]. Similarly, only two bones, accounting for about 0.1% of the total bones, from this site have marks that could be confidently attributed to rodents. Typically, in faunal assemblages accumulated by rodents, bones gnawed by these animals usually account for around 22%–100% of the whole assemblage. Thus the low ratio of gnawed bones in this assemblage unequivocally rules out rodents as the agents of bone accumulation [13]. Of all the animal bones from SDG12, approximately 5.1% (92 pieces) are cut-marked. Although this proportion may appear low, in archaeological sites in Europe and Africa where humans have been confirmed to be responsible for accumulation of animal bones, the ratio of cut-marked bones is generally below 5% [14, 15]. Among the few taphonomically-studied faunas of China, cut-marked bones from the Lingjing site (Middle Paleolithic), the upper cultural layer (Upper Paleolithic) and the lower cultural layer (Middle Paleolithic) of the Ma'anshan site account for about 13% [16], 4.74% and 13.17% [17] of the corresponding assemblages respectively. Therefore, the seemingly small number of cut-marked bones from SDG12 does not diminish the dominant role played by humans in accumulation of the faunal remains. With more than 10000 stone artifacts, numerous bone tools associated with fossils from the site, and evidence of fire use by humans, we conclude that archaeological remains from SDG12 were probably the result of human activities.

2 Animal species abundance of SDG12

Ecologists have hypothesized that foraging humans generally follow two rules: the pursuit of efficiency and the success of production. Thus, whether a food resource will be exploited is not decided by its local abundance, but by the return rate, which is the predator's calorie acquisition per unit time. Predators always prefer to maximize their net energy intake, that is, obtaining enough food in the shortest period of time, which is the principle of optimal foraging theory [18]. For example, although it is more difficult to prey on large animals, they could in turn yield more energy and thus have a relatively higher return rate. However, smaller, faster animals are not only more difficult to hunt and process, they also have lower energy yields, which may cause predators to give up in favor of prey with higher return rates. When animal resources of high-ranked species decrease, predators will broaden their hunting choice, which will consequently produce a more diversified or balanced diet that includes more animals of lower return rate. Typically, the archaeological meat diets of humans are reconstructed based on the Linnean taxonomic system. Therefore, the most direct zooarchaeological proxy to detect occurrence of the BSR seems to be evenness in genus or species counts from faunal assemblages [8].

Bone fragments from SDG12 could be attributed to eleven species, and bones from both SDG2 and SDG7 could be taxonomically identified to seven species, which indicates that new species have been incorporated into the meat diet of later hominids of the SDG area. The number of identified specimens (NISP) of the faunal remains from SDG12 is 1821 (*Lepus* sp.,1045; *Meles meles*, 103; *Felis microtus*, 2; Cervidae, 19; *Gazella przewalskyi*, 404; *Sus* sp., 5; *Equus przewalskyi*, 52; *Bubalus* sp., 124; bird, 53; reptile, 1; other rodents, 13), and of this total, the proportion of rabbits is highest (around 57.39%), followed by gazelles (about 22%); proportions of remaining species are usually lower than 10% (Figure 1). The Reciprocal of Simpson's Index (RSI) or $1/\Sigma(pi)^2$ can measure the species diversity of the bone assemblage, of which p represents the proportion of each prey type for array i in an assemblage [19, 20]. At the highest value (i), the level of evenness of all species is the highest; while at the lowest value (l), all the bones belong to one species, which indicates the lowest level of evenness. The measurement of taxonomic evenness is to discern whether predators tend to favor some prey over others, and whether the ratio of neglected prey would increase when the paleoenvironment changed. The value of the RSI of SDG12 is 3.05 (the highest value is 11), which is lower than 4.85 of SDG7 (the highest value is 7), indicating that the level of evenness of the latter is higher than the former. If higher levels of taxonomic evenness of meat diets provide direct zooarchaeological evidence for the occurrence of the BSR, do lower RSI values indicate that the BSR did not occur in SDG12?

The method mentioned above provides a way to tabulate the evenness of human-selected game. What we are actually concerned with is not the taxonomic evenness of the fauna, but the human behavioral changes regarding prey selection. Thus, it is reasonable to compare human prey selections derived from species diversities without considering time and space. Stiner [8] measured taxonomic evenness of the Mediterranean faunal series including 32 assemblages from northern Israel (200–11 ka BP), the western coast of Italy (110–9 ka BP) and the south-central coast of Turkey (41–17 ka BP), and discovered a very weak correlation between the levels of evenness and time. According to Stiner [8], Linnean taxonomy is a powerful tool in biology. However, a forager's selection of prey does not necessarily follow the rules of biological systematics because they are more interested in the energetic return rate of game. Some distantly related taxa based on the Linnean taxonomy are nearly equivalent from the viewpoint of handling cost because of their predator-avoidance behavior. For example, rabbits and partridges, although different in Linnean classification, are both similar in body size, both quick and agile, thus have similar costs of hunting and handling from a human perspective. Since predators' prey selection is not bound by Linnean taxonomy, the variation in relative abundances of species or genera does not seem to be sensitive to behavioral changes in prehistoric human predators [8].

In conclusion, it is suggested that the higher level of taxonomic evenness based on Linnean taxonomy could not directly support the occurrence of the BSR as assumed [8]. Points representing the RSI values of SDG12 and SDG7 in Figure 2 nearly coincide with points from the Mediterranean sites, indicating similar levels of taxonomic evenness of the corresponding sites. We also suggest that the meat-diet changes based on Linnean taxonomy between SDG7 and SDG12 do not provide direct evidence as to whether the BSR occurred in the Shuidonggou area.

3 New classification of prey animals from SDG 12

The Linnean taxonomic system is insensitive to the physical

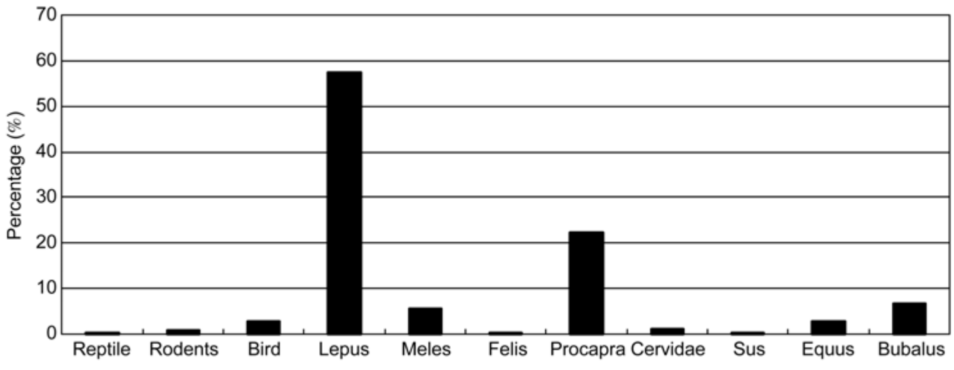

Figure 1 NISP of fauna from the SDG12 site.

and behavioral differences of prey animals. Based mainly on body size, Stiner [8] and other scholars divided prey animals into high and low payoff categories; and among the latter category, they further distinguished fast and slow animals according to their differing defense mechanisms. Within this new system, the Simpson indexes of the 32 sites show clear tendencies (Figure 3): the evenness values of the three kinds of prey animals from most sites around 10 ka are relatively higher, even representing the highest values among the whole array, which indicates that early humans exploited the low-ranked animals to some extent under a mild climate [8, 21]. This is probably because of the relative paucity of previously dominant resources due to human demographic expansions [21–23].

According to this classification, large ungulates of high return rate from SDG12 comprise deer, gazelles, wild pigs and buffalos. And among the animals of low return rate at the site, fast animals such as rabbits and birds were discovered, but slow animals such as tortoise and shellfish were absent. The Simpson index of SDG12 is 1.84, which is much higher than that of SDG7. This indicates that at SDG12, there is an even distribution of large animals, small quick game, and small slow game. In other words, compared to SDG7, humans at SDG12 have adapted to increase the breadth of their diet, and thus promoted evenness of their meat intake. The geological age of SDG12 is 11 ka, which is the transitional period between the Pleistocene and the Holocene; and pollen analysis indicates that the climate at that time was warm and moist. At the time of SDG7

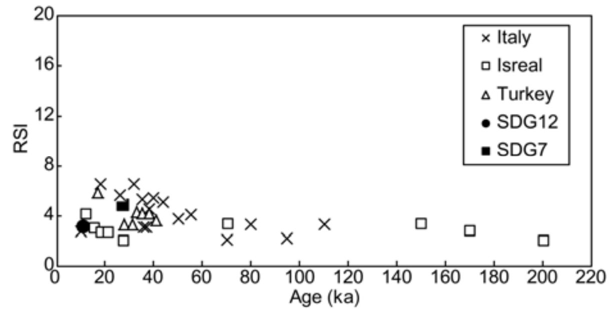

Figure 2 Evenness in the representation of Linnean genera.

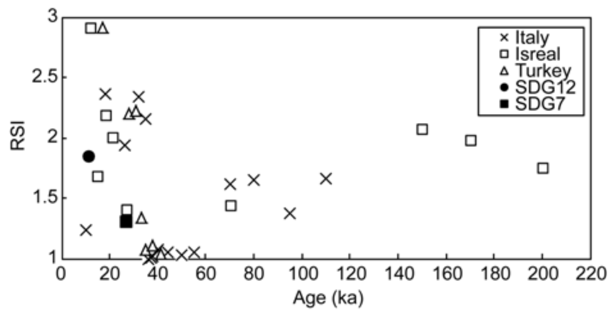

Figure 3 Evenness as shown by RSI (Reciprocal of Simpson's Index) in the presentation of three prey categories based on body size and defense mechanisms (large game, small slow game, and small quick game).

deposition, plant coverage around Shuidonggou area was low and the climate changed to cold and dry [24]. Theoretically speaking, when the climate was mild, there would have been relatively plentiful resources near the archaeological sites and humans may have had a much greater chance of acquiring game of higher return rates, which would have decreased the evenness index of the site. Our current knowledge from SDG12 conflicts with theoretical expectations. As a result, we can conclude that the differential distributions of the three kinds of prey animals from SDG12 and SDG7 are irrelevant to climatic changes, and the higher evenness of the SDG12 assemblage may signify the occurrence of the BSR at that site.

Because of the scarcity of archaeological sites bearing animal bones from the Shuidonggou area, we are currently unable to expand our samples in temporal and spatial scales. However, compared with the work of Stiner, the evenness values of SDG12 and SDG7 conform well to data from faunas of the equivalent age (Figure 3). This may suggest that the evenness indexes for the faunal remains from SDG12 and SDG7 are comparable to that in the Levant area, which indicates, at least to some extent, the occurrence of the BSR at Shuidonggou, just as in the prehistoric Levant.

4 Small animals from SDG12

Paleolithic records of small animal exploitation can be traced back to the early Middle Paleolithic in the Mediterranean Basin. In previous research, Stiner subdivided small animals into three categories: slow game of high return rate, such as tortoise and shellfish; fast terrestrial mammals of low return rate, such as hare and rabbit; and fast flying animals such as birds. Based on the Simpson Indexes, Stiner discovered that distribution of the three types of animals in this area become more evenly patterned over time, which further indicated the emergence of the BSR at the end of the Later Paleolithic [8].

However, because of the absence of small, slow game at SDG12, the Simpson value tabulated as the analysis of the Levant faunas is only 1.1 at this site, which is relatively low when compared to values from the Mediterranean Basin. Does this evidence negate the appearance of meat expansion at SDG12? We can answer this question from the perspective of environmental differences. The Shuidonggou site is located at the eastern edge of the Yinchuan basin and the western margin of the Mu Us Desert. This area has low rainfall and is only sparsely vegetated. With an average annual temperature of 8°C and an annual precipitation of 200 mm, Shuidonggou area is classified as a desert steppe environment [24]. Extant tortoises in China mainly inhabit coastal areas and the diversity and quantity of these animals is significantly higher than that in adjacent inland areas [25]. All the 32 sites studied by Stiner and Munro [8] are situated in the Mediterranean and adjacent to water sources, which is conducive to breeding of tortoises. Even in the Middle Paleolithic periods when large animals were relatively plentiful in this area, humans still frequently preyed on tortoises because of their ease of being caught by predators. As a result, the total absence of slow moving animals from SDG12 is probably a product of the scarcity of water around Shuidonggou, and does not necessarily disprove human dietary expansion at this time.

The human diet at SDG12 is lacking in small, slow game such as tortoises and shellfish; however, small, fast-moving animals, such as rabbits and birds constitute the majority of the assemblage and account for about 61.07% of the fauna, which is similar to that in the Natufian assemblages from the Levant. Natufian is about 12800–10200 BP and is most representative of the Mesolithic cultures in western Asia. The cultural components of Natufian include microlithics, polished bone tools, primitive agriculture, ornaments, arts and intentional burials. It has been confirmed that the BSR and resource intensification had once occurred in this period [26]. Stiner [8] studied animal bones from the Hayonim cave of the Natufian culture. When she divided the animals into ungulates, carnivores and small animals, she discovered that among all five phases of the Natufian culture, small animals constituted about 60% of the assemblage. This is similar to SDG12, yet different from SDG7 in which small animals accounted for 13% of total bones (Figure 4).

Studies show that demographic pulses have been triggered several times from Southwest Asia to Europe; and the upsurge of bird bones and dwindling number of tortoises in the archaeological sites are the earliest evidence for human population expansions during the Later Paleolithic [21–23]. Heavy exploitation of rabbits is an indicator of the demographic uprising of the later periods, and this pattern was witnessed in archaeological records from Iberia, Northern Africa and Eastern and Northern Europe [27–29]. For example, in Portugal, people rarely hunted rabbits in the Middle Paleolithic and they had only just begun to incorporate rabbits into their diet during the Later Paleolithic; whereas humans there hunted a large number of rabbits in the Mesolithic periods [28]. Rabbits have been a steady food source for humans. Rabbits generally mature at 6–7 months with a normal gestation of 30 days. A rabbit can give birth nine times a year and the average size of the litter is usually between 4 and 12 babies, which means that in one season a single female rabbit can produce as many as 800 offspring. The sudden appearance of a large number of rabbit bones in the archaeological sites of the terminal Pleistocene and the early Holocene was probably the result of human diet expansions due to demographic pulses, and therefore may offer important evidence for the occurrence of the BSR. The proportion of rabbit bones in SDG12 is 52.72%, which is much higher than that in SDG7 of an earlier age. This again indicates to some extent the presence of the BSR in early human meat resources.

5 Conclusions

The evenness value of large animals, small fast game, and small slow game from SDG12 are higher relative to that from SDG7. There is no significant difference between the even distributional patterns observed from the Levant faunas and SDG12; and the number of rabbit bones increased dramatically, which could provide sustainable resources for early humans at SDG12. In terms of cultural remains, there are great discrepancies between SDG12, SDG7 and SDG2 of earlier ages. Between the latter two sites, there has been no discovery of microlithics, polished bone tools and grinding stones. The presence of millstones, grinding rods and stone pestles from SDG12 indicates the exploitation of plants by humans at this site. Humans during this period may not only have expanded the breadth of their meat resources, but may also have included some plants in their diet. Research on the analysis of plant remains and residues preserved on artifacts from the site will soon be published. Further, increased breadth in the diet of SDG12 humans may provide some indication as to the interactive relationship between humans and their environment. Indexes of paleoenvironments show that changes in the dietary breadth of humans at Shuidonggou are not related to climatic cycles. In contrast, just as we have demonstrated in other parts of the world, this phenomenon may signify the demographic

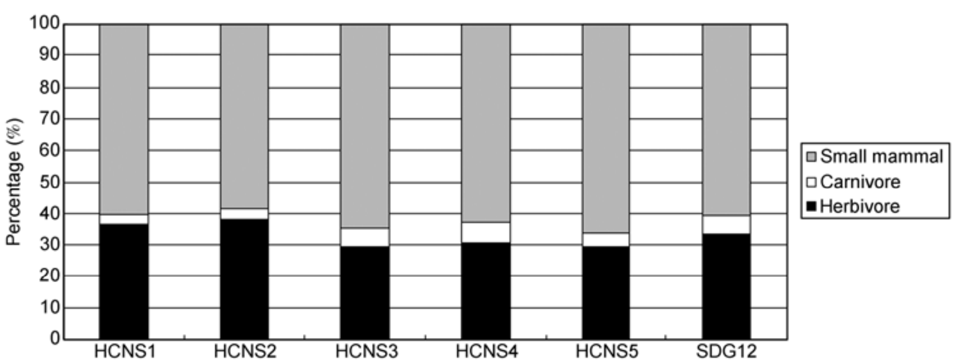

Figure 4 Relative abundance of major prey groups of SDG12 and Hayonim Cave Natufian Series (HCNS).

expansions of early humans. With substantial population increases, resources of high value were becoming increasingly unavailable for humans. As a result, in addition to the intensified use of high-ranked animals, humans were forced to adapt and exploit a wide range of meat resources. Consequently, lower value animal prey was incorporated into their diets, which may have given rise to the BSR in this area.

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