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# Advances in East Asian Agricultural Origins Studies

## The Pleistocene to Holocene Transition

Edited by
Pei-Lin Yu, Ikeya Kazunobu and Meng Zhang

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Editors

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# About the Editors

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*Editorial*

# Introduction: New Discoveries and Theoretical Implications for the Last Foraging and First Farming in East Asia

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Worldwide, scientific understanding about domestication and the origins of food production is undergoing rapid change based on new data from discoveries in paleoclimates and environments, paleobiology, and archaeology. Two major periods of transition include the Pleistocene to Holocene of about 12,000–9000 BP, and another in the Middle Holocene (7000–4000 BP) [1]. The larger narrative of the transition from foraging to farming has been mainly built based on the archaeological record from Near East and Mesoamerica; in contrast, East Asia has been less integrated in worldwide archaeological research, in part because of language boundaries. Obviously, this region, well-known for cultivation of millet, rice, and other cultigens, cannot be ignored in order to do empirical generalization and theory building for this anthropologically oriented research question. In this Special Issue of *Quaternary* we focus on East Asia because of the broad array of habitats and deep time horizons that enable explorations of variability in agricultural origins and adoptions. The regions we now call northern and southern China, Inner Mongolia, Japan, and the Taiwan island have seen steady growth in the number of archaeological and other scientific investigations that are germane to the foraging to agriculture transition in both key periods, due to the rapid pace of salvage archaeology resulting from development projects and the strength of academic and museum programs that foster archaeological research [2–6]. Additionally and importantly, critical and productive re-examination of important legacy research documents, samples, and collections is facilitating the growth of new ways to investigate legacy data from prior explorations [3,4,7–9]. The multi-lingual publication rate is growing, as evidenced by the birth of new English language journals devoted exclusively to Asian archaeology and special issues (like this one) in multi-disciplinary publications, and the availability of open-source access is accelerating the growth of international readership, comparative approaches, and collaborations [3,9–11].

In the field of East Asian archaeology, methodological advances in chronometric analysis have fueled an increase in the sample of securely dated contexts and clarified the timing of change as well as allowed for critical comparison of regional sequences. Detailed evidence for paleoclimatic deteriorations and ameliorations allow us to posit testable correlations between climatic fluctuations and adaptive responses in subsistence, settlement, and social organization. Environmental analysis brings habitat and niche into focus, so that overlaps and differences can be identified in landscapes preferred by foragers and farmers. Detailed analysis of biomorphology, isotopic signatures, and genetic information can reveal domestication thresholds for a wide variety of crop species. Examining technological systems from the standpoint of social organization, such as implications of microblade-based societies, can sharpen distinctions between groups that at first glance appear to be homogeneous, or find commonalities between apparently different systems. Use wear and residue analysis are contributing to better knowledge about subsistence of the transition, and actualistic and experimental methods are important middle range approaches to open up new lines of hypothesis development regarding testable expectations for the contexts and evolutionary pathways of subsistence and technology. Finally, reference information from global and local ethnographies of foragers and farmer-gardeners, and from the sister discipline of human behavioral ecology, are providing rich insights into testable factors that influence decision-making in the rapidly changing adaptive theater of the Pleistocene to Holocene transition, and play an increasingly important role in our understanding of the origins of East Asian food production.

The origin and spread of agriculture in East Asia during the transitional period occurred within a varied theater of habitats and foraging adaptations. The mountain chains, plateaus, hilly flanks, and river-crossed plains of China offer a fascinating "laboratory" that includes centers of domestication as well as a variable pace and process of agricultural adoptions by foraging neighbors. In the north, the vast distances and high connectivity appear to facilitate the development of mobile socio-technological systems such as microblade-based societies that were maintained and evolved through frequent aggregations [12] and a supple adaptive capacity for climatic shifts [13] that offered both 'push and pull' for experimentation with cultivation. In the Middle Yangtze River valley and other complex riverine habitats, hunter-gatherers mapped onto abundant resource patches and in some cases semi-sedentized societally complex foraging remained a viable lifeway compared to rice agriculture [14]. The roles of women in procuring abundant wild aquatic resources through the use of standardized technological systems have been under-studied and are worthy of further investigation.

Moving offshore, the abundant littoral, estuarine, and oceanic resources of neighboring islets offered Paleolithic hunting and gathering societies a means of broadening the subsistence niche with aquatic resources, with later specialization through development of technology like boats, lines, and net systems to acquire pelagic foods of the deep ocean [15]. In the case of Taiwan, the arrival of Neolithic farmer-fishers from SE China with their millet and rice initially added competitive pressure for land and resources and narrowed foraging options; but ultimately this phenomenon also provided a means for some hunter-gatherers to broaden their niche by adding low-effort and mobility friendly cultigens to aquatic and hunted foods.

By comparison, in the Japanese archipelago the characteristics of many habitats fostered the continued adaptive value and maintenance of hunting and gathering in some areas. This is in contrast to the basins of Yangtze River and Yellow River, which were centers of agriculture. In this respect, it is also necessary to conduct comparisons with surrounding areas including northeastern and southern parts of China. Of the various cultivated plants of the Japanese archipelago, including soybeans, foxtail millet (*Setaria italica, awa* in Japanese), pearl millet (*Echinochloa esculenta*, *hie* in Japanese), and rice, the latter is the most important crop that contributed to the naissance of farming. Because of the prevailing culture of indigenous hunter-gatherers and fishermen in the Japanese archipelago, even if cultivated plants other than rice had been introduced the shift of peoples' livelihoods to agriculture would have been complex. Paddy rice cultivation became established in northern Kyushu by immigrants from the Korean Peninsula [16].

Two questions relate to the shifting of subsistence in the Japanese Archipelago: first, why did the culture of hunter-gatherers persist? The transition period from the Pleistocene to the Holocene at ca. 11,500 BP occurred at the early phase of the Jomon period (16,000–3000 BP, about 13,000 years total) in Japan. Jomon hunter-gatherers lived on various islands from Hokkaido to the main island of Okinawa over a range of 3000 km north and south. Recent studies have elucidated that azuki beans, soybeans, millet, and others were cultivated in some parts of the country during the middle Jomon period [17], but cultivation was just one of many activities of subsistence, along with hunting, gathering, and fishing. In fact, cultivated plants would have been less important than gathering forest nuts (walnuts, acorns, conker, chestnuts, beech, etc.). During the transitional period from the Pleistocene to the Holocene, it is possible that modes of hunting, gathering, and fishing were influenced by a warming climate, but the introduction of agriculture and its social effects have yet to be recognized. This may have been the case because the diverse natural resources of forests, rivers and sea in the Japanese archipelago were abundant, secure, and stable. In fact, it has been revealed that human cultures changed from the late Pleistocene to the early Holocene in Hokkaido [18]. In the eastern part of Hokkaido the discovery of many early Holocene pit dwellings are evidence that the number of settlements was increasing, suggestive of higher population densities, or growing sedentism, or both.

The second question concerns the adoption of agriculture (rice farming) in the Japanese Archipelago? Why was it not adopted in some cases, and what are the salient differences? Much later than in the rest of East Asia, in the tenth century BCE immigrants from the Korean Peninsula introduced rice cultivation to northern Kyushu. Thus the first farming cultures of the Japanese Archipelago were born, and varied relationships developed between farmers and hunter-gatherers. It is estimated that their relationships endured for different periods in the Fukuoka Plain, Osaka Plain, Kanto Plain, and Tohoku Region [19,20]. If examined at the level of individual archeological sites on Fukuoka Plain [20], clearly their relationship changed over time. For example, hunter-gatherers still lived in Hokkaido and Okinawa during the late period [21]. About 500 years elapsed between the introduction of rice farming in Kyushu and its spread to the Tohoku region of Japan. Moreover, rice farming was then limited to Kyushu, Honshu, and Shikoku, which indicates not only limitations to conduct rice cultivation in cold regions, but also the reluctance of indigenous hunter-gatherers—who were well-adapted to abundant natural resources—to convert to the farming lifestyle.

Taken individually, the new methods and discoveries in these case studies are provocative. Approaches of macroecology, human behavioral ecology, ethnoarchaeology, experimental archaeology, and others are applied to provide explanatory and referential frameworks on the foraging to farming transitions in East Asia. Results indicate very early experimentation in food production; growing evidence for the persistence of foraging; new perspectives on the roles of aggregations and gendered food procurement; and the surprisingly intertwined relationship between wild aquatic foods, niche, migration, and the agricultural experiment. Taken as a whole, the emerging picture of Paleolithic to Neolithic transitions in East Asia is revolutionary, overturning prior assumptions about both hunter-gatherers and farmers and revealing new aspects of the tempo and mode of the change. From forests, plateaus, grassy plains, and mountains to coasts, islands, and archipelagos, we are now positioned to take an unprecedented opportunity to understand and predict variability in the tempo and mode of the Paleolithic to Neolithic transition across one of the biggest landmasses on the planet. Clearly, the Russian Far East, Mongolia, Korea, Sakhalin, and Island Southeast Asia are important transitional regions experiencing rapid research growth, and these regions merit robust attention in their own right.

This Special Issue of *Quaternary*, "Advances in East Asian Agricultural Origins Studies: The Pleistocene to Holocene Transition", aims to present advances in research from established and upcoming researchers working in mainland China, Taiwan Island, and the Japanese Archipelago, with the purpose of evaluating the significance of Paleolithic cultural influences on the transition to Neolithic adaptations by comparing cultural evolutionary scenarios through time and across space. The array of approaches is multidisciplinary, including new archaeological excavation data, revisiting legacy data, fresh perspectives on paleoclimate and environments, and reference information from hunting and gathering peoples and small scale farmers. Quantitative, qualitative, and integrated data and methodologies are featured. A critical synthetic review chapter provides a global perspective on this rapidly growing field including theoretical and methodological considerations for the case studies.

The co-editors hope that growing our understanding of the East Asian transition from foraging to Neolithic agriculture—a hallmark of the Quaternary and among the most dramatic and influential processes in the history of modern humans—will help to deepen our understanding of variability of human adaption and decision-making against the backdrop of dramatic and unpredictable climate change that marks the transition from terminal Pleistocene to incipient Holocene. We also hope these articles help to inform the general trajectory of scientific inquiry into the foundational characteristics of Late Quaternary growth and migrations of human populations, societal complexity, subsistence and economic transformations of landscape, niche construction, migration, boundary defense, and other density-dependent phenomena that have had profound consequences for the planet's ecosystems and contemporary human societies.

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# Ethnoarchaeology of Introducing Agriculture and Social Continuity among Sedentarised Hunter–Gatherers: The Transition from the Jomon to the Yayoi Period

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**Abstract:** This study was conducted to elucidate the introduction of agriculture and social continuity from the Jomon to the Yayoi period, from an ethnoarchaeological perspective. The Yayoi period has been divided into two types: a broad spectrum economy that relied on many kinds of resources, such as rice, millet, and nuts, and a selective economy that specialised in rice and wild boar. However, it is not clear how the livelihoods shifted from the Jomon to the Yayoi period. In this study, ethnohistorical materials were examined first. Ethnohistorical reference materials gathered worldwide have revealed three relationships between hunter–gatherers and farmers: coexistence, fusion, and assimilation. Focusing on fusion, this study examined situations of hunting, gathering, and fishing, as inferred from ruins of the Late and Final Jomon period, and assessed their relationships with agriculture using ethnohistorical reference materials of the Early Edo period. There were not many social changes caused by the introduction of field farming; however, the introduction of paddy rice cultivation had different effects on society depending on the level of investment in obtaining water from streams and springs and creating irrigation features.

**Keywords:** dry-field farming; first farmers; Jomon; paddy rice farming; sedentarised hunter-gatherers; Yayoi

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## 1. Introduction and Study Location

Prehistoric hunter–gatherers who became sedentarised in western Asia are said to have begun farming and raising livestock more than 10,000 years ago [1]. Later, after farmers populated this area, hunter–gatherers and farmers coexisted [2]. The earliest clear evidence for the use of rice in the lower Yangtze region of Zhejian, China, is between 6900 and 6600 years ago [3], but this was not yet cultivated. At that time, indigenous hunter–gatherers formed a diverse array of relationships when they encountered migrant rice farmers.

In the case of the Japanese archipelago, a large shift is known to have occurred from prehistoric hunter–gatherers (Jomon people using Jomon earthenware, [4,5]) to prehistoric agricultural farmers (Yayoi people using Yayoi earthenware) except in Hokkaido. Regional differences are apparent, as the landmass extends around 2000 km from Hokkaido to Kyushu. People from the Korean Peninsula with knowledge of rice farming first settled in northern Kyushu (Figure 1). In Japan, rice cultivation was first adopted by new immigrant populations at the Nabatake archaeological site in the Fukuoka Plain of northern Kyushu during the Early Yayoi period, although this was not irrigated but rain-fed rice cultivation. Millet farming was also conducted there [6,7] The floodplain of the valley was wetland; the hills behind were evergreen forests. Under such circumstances, rice farming in the form of dry-field farming began on the lower slopes of the plain or at the edges of lowland areas. Later, in the Early Yayoi period, the Itazuke site village was established with pit dwellings and a circumjacent ring moat 5–6 m deep. Irrigated paddy rice cultivation was combined with millet fields producing *awa* (foxtail millet, *Setaria italica*) and *hie* (a kind of Japanese barnyard millet, *E. esculenta)*.

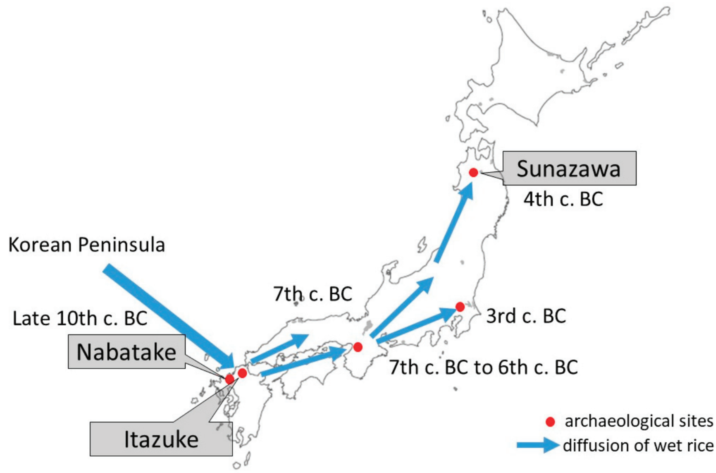



**Figure 1.** Diffusion of wet rice farming and archaeological sites in Japan ([8]. Used by permission).

On the other hand, according to Shitara [9], the economy in the Yayoi period can be divided into two types: an exhaustive economy that relied on many kinds of resources, such as rice, millet, and nuts, and a selective economy that specialised in rice and wild boar. However, the transition between livelihoods from the Jomon to the Yayoi period is not clear. The wet rice cultivation technique was accepted by hunter-gatherers from Honshu, Shikoku, and Kyushu over an approximately 700-year span [10]. For example, on the Fukuoka Plain, archaeological remains of paddy field farms from the latter half of the 10th century BC have been found in the downstream basin of northern Kyushu's plains. The transition process from hunter–gatherer to farmer can be classified into the following three categories [11]. In the first category, native hunter–gatherers and migrant farmers established a new settlement together in a downstream basin. Residents specialised together in paddy rice cultivation. In this case, sometimes a ring moat was built around the settlement, as in the Itazuke ruins of the Fukuoka Plain, and the settlement endured to become a local main village. In the second case, the two groups established a settlement together but later abandoned the settlement and moved to another place. The last case occurs in the context of food stress caused by a population increase, in which farmers who lived in a downstream basin moved upstream into areas populated by hunter–gatherers and started food production. Apparently, hunter–gatherers began farming after being influenced by immigrant farmers from the Korean Peninsula; that is, they were transformed gradually into farmers.

Herein, a dynamic model of the relationship between hunter–gatherers and farmers is presented based on the question of how sedentarised hunter–gatherers began farming during the transition period from hunter–gatherer to farmer in East Asia. It is said that field agriculture such as soybean and azuki bean cultivation had already been introduced in the Jomon period by the time of rice introduction [12,13], but the influence of legume cultivation on hunter–gatherer societies is not yet known. Similarly, the impact of the introduction of paddy rice cultivation on hunter–gatherer societies in the Yayoi period is not well understood. It is the objective of this paper to examine the sustainability and transformation of livelihoods and society after the introduction of agriculture, using ethnoarchaeological reference data from similar sites that are relevant to the ways that agriculture and other livelihoods were combined.

The author has selected sites from the Late and Final Jomon periods in the Japanese archipelago where the use of resources at the time of interest can be reconstructed. Sites were also selected from early modern *Matagi* settlements, which are not from the Early Yayoi period but show the influence of the introduction of paddy rice cultivation on a hunter–gatherer society. This is due to the fact that there is abundant information on livelihoods such as hunting, gathering, and farming in the *Matagi* settlements, which are located in almost the same locations as the Jomon sites.

The author conducted an ethnoarchaeological study on the use of people's natural resources in a remote mountain village called a *Matagi* settlement [14], which possesses both historical sites of the Late and Final Jomon periods, and archival materials on paddy rice cultivation or swidden agriculture in the 17th century. The *Matagi*, who believe in the mountain god named Yamano-kami, are hunters who combine gathering, fishing, small farming, and trading. The historical relationship between the *Matagi* and Jomon people is unclear. Actual practices and methods of resource control related to cave hunting and trapping of Japanese black bears have already been reported from ethnohistorical perspectives [15].

The study site is about 30 km upstream of the Miomote River in central Japan, which empties into the Sea of Japan. In the study site, a small flat river terrace surrounds the deep slope of the mountains in the upper Miomote River. The Motoyashiki archaeological site (Figures 1 and 2) dates to the Late and Final Jomon periods. The entire settlement (approximately 180 m east–west, and 90 m north–south) was investigated at the time of the Okumiomote Dam's construction. It consists of excavated pillar buildings, pit dwellings, buried earthenware (200), stone graves (89), and a processing facility for *tochi* (horse chestnut, *Aesculus turbinata*) including water features for leaching or removing lye from chestnuts. Large amounts of wood and wood products, bone and horn products, plant-dependent substances, and animal-dependent substances had already been excavated there, including Jomon pottery and stone tools [16].

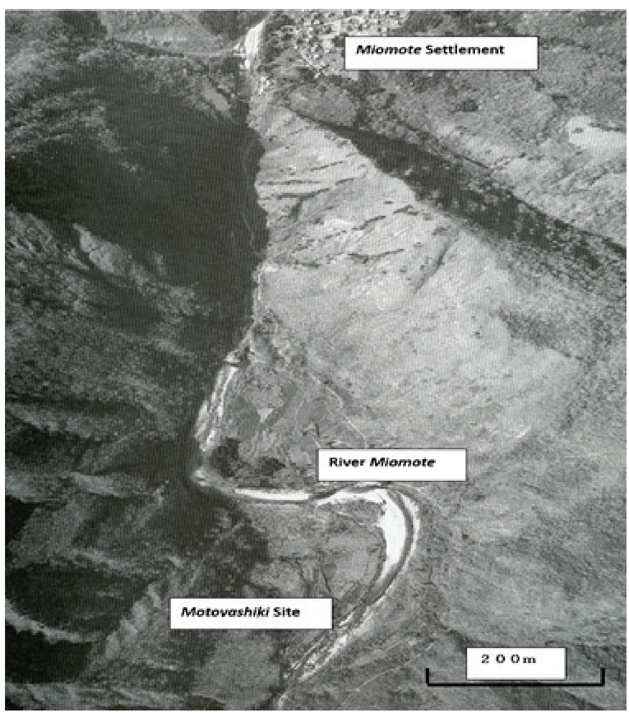



**Figure 2.** Study Area: Motoyashiki archaeological site at the late and final Jomon periods and Miomote settlement at the Early Edo period [16].

## 2. Theoretical Framework (Presumption): Transition from Jomon to Yayoi Period and Group Relationships

Studies of sedentarised hunter–gatherers have clarified two types of responses to introduced agriculture [17]. In the first, hunter–gatherers introduced agriculture into their life: they hunted and gathered while farming. In the second, hunter–gatherers maintained a coexistent relationship with farmers. In the second adaptive response, hunter–gatherers sometimes helped with farmers' activities (e.g., harvesting) and received food in return. Both types of incorporation of agriculture have been identified among the San people of the Kalahari Desert [18]. The Aka and Mbuti people in the Congo Basin, the Aeta of the Philippines, and the Mlabri of Thailand have established the latter type [19–23]. Nevertheless, it remains unknown why such a difference has arisen among hunter–gatherers.

Figure 3 presents a dynamic model of the relationship between hunter–gatherers and farmers by examining the ethnohistories of present-day hunter–gatherers (Figure 3). Earlier studies, mainly archaeological or ethnological, revealed characteristics of several individual cases which can be sorted into three types of relationships between hunter–gatherers and farmers—that is, coexistence and symbiosis, fusion, and assimilation. First, assimilation is the situation in which all cultural elements or habits of one group disappear after contact. In such a case, the //Gana San would marry into farming societies and lose their own language and traditions. Next, coexistence and symbiosis are conditions under which the hunting and gathering group was maintained even after contacting another group. For example, very few Tsila San hunter–gatherers intermarried with Kgalagadi farmers; rather, they worked in the farmers' fields and received food. Lastly, fusion is the condition by which external elements are added after contacting another group. In this case, trace characteristics of the existing group remain. For example, a //Gana San hunter–gatherer would marry a farmer, combine hunting, gathering, and farming, and use both languages. Why did such differences arise? Based on the example of hunter–gatherers in the Kalahari Desert, group size and population caused this variation, because Kgalagadi farmers migrated inside the hunter–gatherers' territory in the 18th century [18].

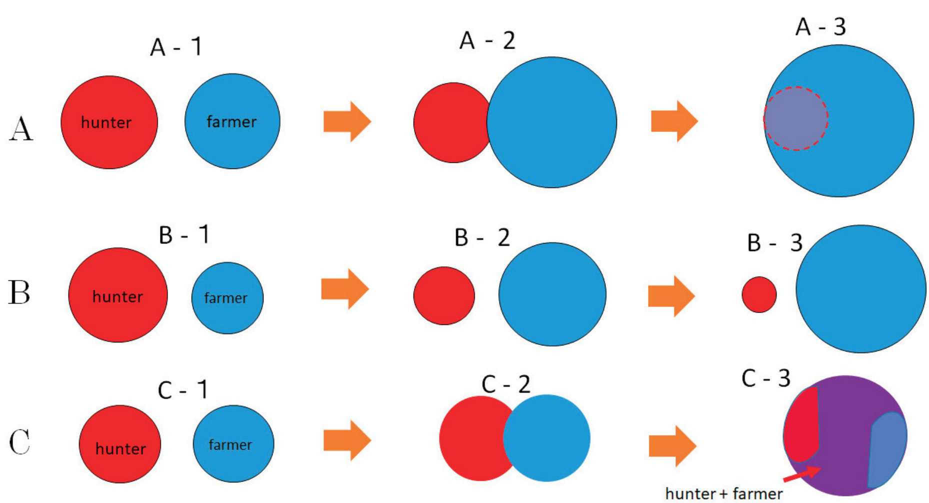



**Figure 3.** Dynamic model of relationships between hunter-gatherers and farmers: (**A**) assimilation; (**B**) coexistence/symbiosis; (**C**) fusion. Circle size represents the population size (made by K. Ikeya).

Coexistence and symbiosis occur when the respective population sizes of the two groups are similar. However, although the population of the Mlabri hunter–gatherers remained smaller than that of the farmers, they maintained their culture and identity [22]. Fusion occurred when the farmer group became larger than the hunter-gatherer group, although hunter–gatherers continued to maintain their cultural traditions strongly. Assimilation also occurred when the farmer group was larger than the hunter–gatherer group.

We may now ask, what type of relationship did hunter–gatherers and farmers establish during the transition from the Jomon to the Yayoi period? First, one must consider the time during which hunter–gatherers met farmers in northern Kyushu, approximately 600 BC. It is unknown whether the two groups coexisted with no mutual relationship, or whether they shared a symbiotic condition with some kind of trade or exchange. As already described, an assimilation type of relationship occurred in the Fukuoka Plain after hunter–gatherers encountered farmers. At the same time, coexistence or symbiotic relationships also formed. Finally, a fusion type of relationship might have arisen between them after the end of their existence as hunters and farmers. This suggests that the relationships between the same groups could change over time based on circumstances.

In the example of the Osaka Plain, hunter–gatherers and farmers made contact in the sixth century BC, after which the two groups formed a coexistent relationship. Although we found a wooden farming tool at the farming site in the plain, which used Yayoi earthenware of the ‘Ongagawa’ type, remains of wood materials were to be found [24]. We surmise that the farmer would have taken the wooden farming tool from the hunter–gatherer site at the foot of the mountains. In the fifth century BC, they mingled increasingly. Subsequently, a group of people identifiable as Yayoi farmers emerged in the fourth century BC [25]. This sequence of events corresponds with the assimilation model. The transition from coexistence to assimilation evidently took approximately 200 years.

The farmers then spread to the eastern region of the main island (Honshu) of Japan by the fifth century BC. Indigenous hunter–gatherer groups gradually mingled with the farmers. The subsequent development varied among regions; it stopped at the fusion stage in some regions, while in other regions, hunter–gatherers assimilated with farmers. Paddy fields continued to spread to eastern Japan and the Tohoku region along the plain, including the Niigata region, except in the mountainous areas. The northernmost area is the Sunazawa ruins in the Tsugaru Plain of Aomori Prefecture. Paddy field farmers had long been unable to live in this area, a situation that may be explained using the coexistence model. In this habitat, survival was possible with only hunting and gathering. The Yayoi farming society was established throughout Honshu and Kyushu by the first century BC.

This context partly explains how hunter–gatherers became involved in farming. First, the mutual relationship between coexistence and symbiosis appeared during this period. Activities such as exchange, trade, intermarriage, and entrusting of labour, such as farming, presumably arose during this period. Recovering archaeological evidence of entrusted labour being practised in prehistory is difficult, although it might be inferred ethnographically. Another part of the context is the discovery of the responses of hunter–gatherers that are related to their foraging occupation while being influenced by farmers. Understanding the responses of these societies to the introduction of agriculture is especially important.

## 3. From Sedentarised Hunter-Gatherers to Early Farmers: Transition and Changes of Fusion Types C-1, C-2, and C-3

An examination of the transition from Jomon to Yayoi shows that the timing of the introduction of paddy fields varies considerably within the Japanese archipelago. Paddy villages developed during the Yayoi period in some areas such as the Fukuoka Plain, but paddy field farming did not begin on a full scale until the Edo period in the mountainous region near the Sea of Japan. Documents from the Early Edo period about paddy fields are available for research in that region. Although the habitat and socioeconomic contexts are different, certain characteristics about the onset of early paddy field farming can be examined using Edo-period reference information. Documents about rice and vegetable farming of the time are expected to have utility for framing factors that influenced Japan’s first farmers while taking into account the effects of the Tokugawa Japan domain called *han* in the Edo period (1603–1868).

The study area is a village upstream of the Miomote River in the northern region of Niigata Prefecture. This place is known for the Motoyashiki ruins from the latter half and final phase of the Jomon period, and 19 other sites of Jomon ruins sitting on river terraces (C-1). At the time, groups of hunter–gatherers maintained coexistence and symbiosis with each other. It remains unknown when and how upland farming and paddy farming were subsequently introduced into the area because no Yayoi ruins have been found. It is likely that farmers practising small paddy farming immigrated to Motoyashiki during the mediaeval or Early Edo periods. In other words, although the C-2 stage is assumed to have occurred, informative archaeological materials to verify this fact are lacking. This suggests that both dry-field farming and paddy field farming were being practised by the Early Edo period, which shows the C-3 phase. This shows the possibilities of the transition from the C-1 to the C-3 fusion types.

### *3.1. Combined Occupations of Sedentarised Hunter-Gatherers (C-1): Latter Half and Final Phase of the Jomon Period*

The 19 Jomon sites used in this study are located in three areas: Motoyashiki, along the Miomote River (Figure 2), Shimokubo, near the confluence of the Miomote and Suezawa Rivers, and Doromatasawa, along the Doromata River. Rock shelters are located in the mountains upstream of Iwaisawa, a tributary of the Miomote River [26]. Many pieces of earthenware, stone slabs for crushing nuts (hereafter, grinding stones), animal bones, charcoal, and other artifacts have been excavated from these 19 sites. By the Late Jomon period, the Shimokubo and Maeda sites from the Middle-Jomon period had been abandoned, although the rock shelters continued to be used. The Motoyashiki site, covering an area of 100 m east–west and 70 m north–south, replaced them. Artifacts such as stone spear points, monuments, stone plates, whetstones, clay figures, chipped stone axes, and ground stone axes have been excavated from Motoyashiki.

Plant remains representing 15 species were discovered at the Motoyashiki site. These included edible plants (nine types) and inedible plants (six types) [27]. Among the edible plants, horse chestnuts were excavated in the greatest quantities. They comprised approximately 28% of the total (3039 pieces) plant remains. Horse chestnuts were followed by beech, which comprised approximately 20% of the total amount (2212 pieces). Other plants discovered include Japanese walnuts, chestnuts, Japanese pepper, acorns, *Vitis* (grape) spp., Leguminae, and dogwood.

The following animal remains (calcined/whitened from high heat) were excavated at the Motoyashiki site: Japanese serow, Japanese deer, boars/Suidae (only one), badgers, Japanese raccoon dogs, Japanese red foxes, rabbits, flying squirrels, Japanese black bears, and other mammals [28]. Among the mammals, the relative weights of the excavated remains of Japanese serows and Japanese black bears were higher than that of Sika deer (Figure 4). Among the fish remains, Salmonidae and *Salvelinus* accounted for 44.4%. Fishing tools made of bones and horns were excavated as well. In addition, large amounts of frog remains were unearthed.

The Choja-Iwaya Rock Shelter Site is located approximately 8 km northeast of the Motoyashiki site. The small amount of grinding stones discovered at the site suggests that rock shelters are unlikely to have been used for long-term residence [26]. Although the grinding stones reflect a combination of types during the Jomon period, they are not time diagnostic. Analysis of animal teeth identified a large number of Japanese serows, along with Japanese black bears and Japanese macaques. In the case of the Japanese serows, the growth lines on the cementum of the lower jaws facilitated estimation of the animals' ages; estimation of the time of death indicated hunting activity from the end of winter to early spring. These findings indicate that this rock shelter was most likely a hunting camp.

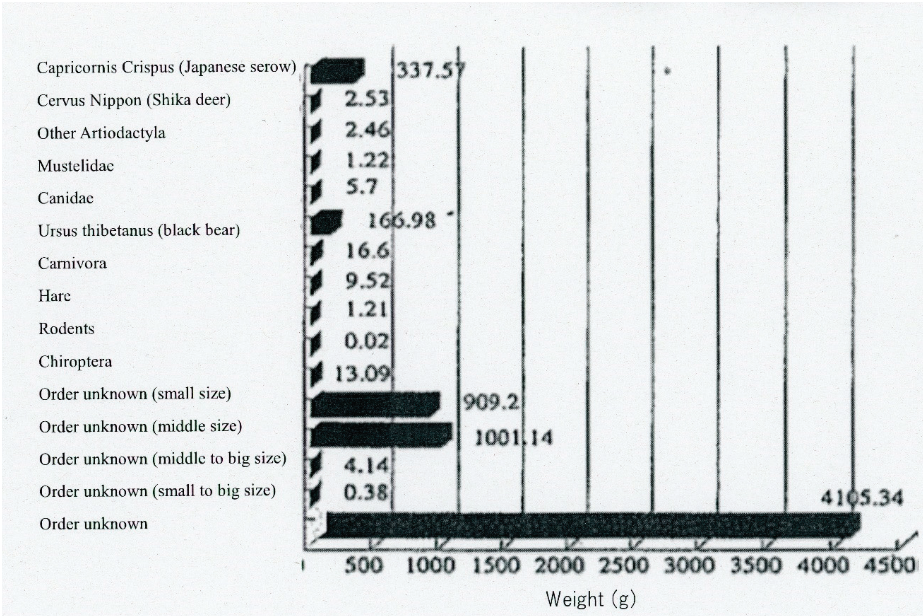



**Figure 4.** Weights of excavated animal remains [29].

Large quantities of chestnuts, walnuts, and horse chestnut endocarps were excavated at the Motoyashiki site, which was actively settled approximately 3000 years ago. The genetic diversity score obtained from DNA analyses of the excavated chestnut fruits was 1.517, which is similar to those of the Sannai-Maruyama Special Historical Site in Aomori Prefecture and the Sakuramachi site in Toyama Prefecture [30]. These results imply that the chestnut–people relationship termed "plant husbandry" or woodland management [31] had developed to a considerable degree. Although chestnuts are larger in western Japan and smaller in eastern Japan, those found at Motoyashiki were small. The excavated walnuts were identified from DNA analysis results as Japanese walnuts and heartnuts.

Artifacts brought from outside the local area have been discovered at the Motoyashiki site. An example is shark teeth; no vertebrae have been discovered. This suggests that people likely used the teeth as accessories and status symbols, rather than consuming shark meat as food [28]—although preservation issues might skew the findings regarding teeth. At the same time, the absence of the canine teeth of Asian black bears in the excavation implies that they were removed from this site. The discovery of a large number of unfinished ground stone axes suggests that the axes were being exported from this region and that there was a group specialising in their production (Sato et al. 2002). Furthermore, the percentage of excavated obsidian ore, which was used as material for various objects, was as follows: 20% (10 pieces) were produced in Itayama in the city of Shibata, 20% (10 pieces) were produced in Mt. Gassan in Yamagata prefecture, and 6% were produced in Mt. Kirigamine in Nagano Prefecture (Figure 5). This discovery implies that these were traded goods brought in from the outside. Additionally, appraisal of the gems excavated from the site indicates that the jade was light green to green in colour and was produced in the Oumi area of Itoigawa [32].

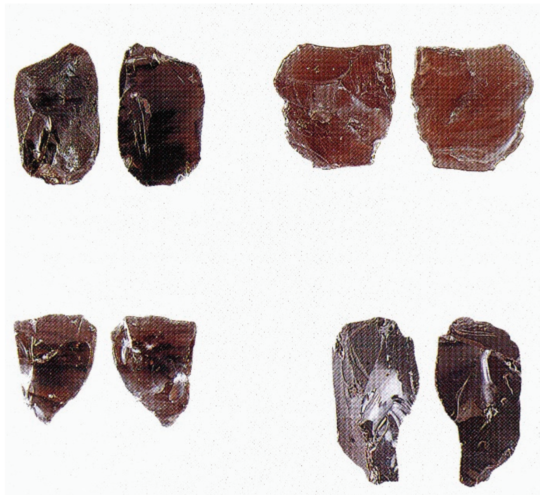


**Figure 5.** Obsidian from the Motoyashiki site [29].

Based on the discussion presented above, the following combination of occupations can be inferred from the archaeological resources of the Motoyashiki site (latter half and final phase of the Jomon period) (Table 1). The first is the addition of exchange and trade activities to hunting, fishing, and nut and fruit gathering. With regard to hunting, the animal bones found at the Choja-Iwaya Rock Shelter Site suggest that the favoured prey were Japanese serows, bears, and monkeys, rather than wild boars and deer, which had been commonly hunted during the Jomon period. As the furthest upstream area for salmon migration in the Miomote River did not reach the Motoyashiki site, people more likely fished for trout rather than salmon. It is unclear whether there is a relationship between the Choja-Iwaya site in the mountain and the Motoyashiki site near the river. It is assumed that there was a social network during the same period.

**Table 1.** Occupation calendar at the Motoyashiki site (latter half and final phase of the Jomon period).

| | **Month** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 |
| Hunting | | | | | | | | | | | | |
| bear | …… | | | | | | | | | | | |
| serow | | | | | | | | | | | ….. | |
| Gathering | | | | | | | | | | | | |
| royal fern (*zenmai*) | ……. | | | | | | | | | | | |
| bracken (*warabi*) | | ……. | | | | | | | | | | |
| horse chestnut (*tochi*) | | | | | | …… | | | | | | |
| walnuts | | | | | | …… | | | | | | |
| chestnuts | | | | | | ….….. | | | | | | |
| *maitake* mushroom | | | | | | ……….. | | | | | | |
| Fishing | | | | | | | | | | | | |
| trout | | | | …. | | | | | | | | |
| char | | | | …. | | | | | | | | |

Source: Information about the timing of hunting, gathering, and fishing was obtained from studies of animal and plant remains [26,28,30]. (Illustration by K. Ikeya).

*3.2. Combined Occupations among Early Farmers (C-3): Early Edo Period (1655)*

Archival information about the hunting, gathering, fishing, and trading conditions during the Edo period (1603–1868) is described below. People hunted commercially by hunting hibernating bears in early spring and trapping bears in the fall. The commercial value of bear gall bladders was high at the time. Notably, each household was assigned its own bear trapping area, according to documents from the Edo period [15]. Hunting of bears in early spring and serows in the coldest part of winter was conducted in groups. It was a ritual practice; hunters were required to use specific mountain words when in the mountains. The practice of serow hunting is evidenced by the fact that a villager by the name of Kanshichi presented serow fur as a year-end gift to the daimyo's councillor in charge of his master's castle. A man named Sagoemon from an area called Kiriba, who is mentioned in a cadastral register of the time, trapped bears.

Regarding gathering, the commercial gathering of sedge and chestnuts was conducted. Sedge was valued as a material for mats. Regarding chestnuts, people were granted certain rights to use shared chestnut forests. To explain further, the mountainous area on the opposite side of a river (termed foothills) consisted of chestnut forests. The area of forests shared by the village was approximately 10 ha [33]. Gathering activities were conducted based on village rules. During the fall harvesting season, the chief of the district would determine the gathering day and then notify each household of the date and time. The gathering period would be approximately two weeks, during which the gathering would be conducted six or seven times. On the morning of the specified day, one person from each household would collect all the chestnuts gathered by all the participants at the house of the district chief, who would then distribute them based on the number of household members.

Moving on to fishing, there was a productive salmon fishery. A skilled person could sometimes catch more than 10 salmon per day. Trout was the most important fish, and August through September was the best fishing season. There were two types of hunting methods: one was to dive and stab trout gathering in the depths using a double-headed spear, and the other was to place a fishing trap in the shallows.

The distribution of farmland during the Early Edo period can be estimated from a cadastral register of 1655. Figure 6 depicts the distribution of arable land for rice crops and shifting cultivation in the Early Edo period (1655). Rice fields were distributed near the Miomote settlement (Table 2 and Figure 6), with shifting cultivation fields in Motoyashiki (where a Jomon archaeological site is located). Incidentally, Kamimukai and Nakadouri in this region were used for shifting cultivation until the 1950s (Figure 6). This diagram shows that rice farming was concentrated in most of the area around the Miomote village, whereas both slash-and-burn farming and rice farming were conducted in the area around the Motoyashiki site. The two types of farming were also distributed in the area near the Suezawa River. As slash-and-burn farming continued into the 1950s, the following information about the condition of slash-and-burn farming is useful as a frame of reference.

Slash-and-burn farming, called *Kano*, was conducted on shared lands. Around 20 July, during the hottest part of summer, land users would go to a site together and assign households to farming areas by drawing lots. This farmland assignment was called *Kappatsuke*. Slash-and-burn farming was conducted by mowing grass in each person's assigned lot, leaving green grass only at the boundaries, drying the lot for three to five days, then burning the area. Swiddens were also visible on a steep hill with a 30° slope. As a crop, buckwheat (soba) was planted on a flat field in the first year. Buckwheat can grow in a cool climate, is unaffected by soil conditions, and can be grown easily without much labour. The growth period is short: seeds planted in summer mature in slightly over two months. During the second and third years, people would make ridges and plant soy, adzuki beans, and foxtail millet (awa). They would subsequently move the swidden field elsewhere on a rotating basis.

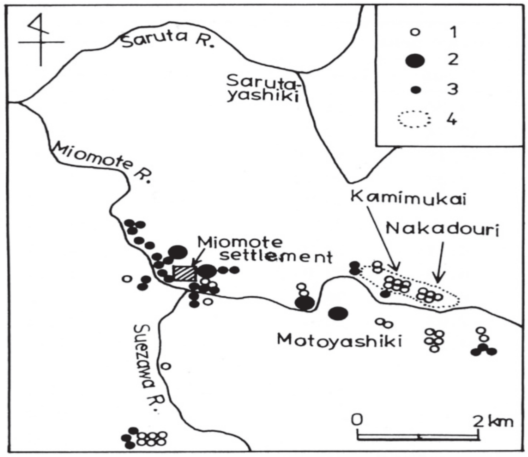



**Figure 6.** Distribution of shifting cultivation and rice fields in 1655: 1, one shifting cultivation field; 2, ten rice crop fields; 3, one rice crop field; 4, distribution of shifting cultivation later, in approximately 1955 [34].

**Table 2.** Occupation calendar of the Miomote settlement (Early Edo period).

| | **Month** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 |
| Hunting | | | | | | | | | | | | |
| bear | .... | | | | | | ...... | | | | | |
| Serow | | | | | | | | | | | | ...... |
| Gathering | | | | | | | | | | | | |
| royal fern (*zenmai*) | | ...... | | | | | | | | | | |
| bracken (*warabi*) | | ....... | | | | | | | | | | |
| horse chestnut (*tochi*) | | | | | | | ....... | | | | | |
| walnuts | | | | | | | ....... | | | | | |
| chestnuts | | | | | | | ....... | | | | | |
| *maitake* mushroom | | | | | | | .......... | | | | | |
| Fishing | | | | | | | | | | | | |
| trout | | | | | .... | | | | | | | |
| char | | | | | .... | | | | | | | |
| Farming | | | | | | | | | | | | |
| rice | | | ....... | | | | ....... | | | | | |
| Japanese millet | | | ....... | | | | ....... | | | | | |
| millet | | | | | | | | | | | | |
| *azuki* beans | | ..... | | | | ..... | | | | | | |
| Soybeans | | ..... | | | | ..... | | | | | | |
| buck wheat | | | | | ...... | | ...... | | | | | |

Source: Information about the timing of hunting, gathering, fishing, and farming was obtained from studies of animal and plant remains [33,35,36]. (Illustration by K. Ikeya).

Similarly, the following reference information is useful for paddy field farming. Tasks in a year would include, in order, ploughing in May, rice planting in June, paddy field management from July to September, and harvesting in October. Short-handled hoes were used for ploughing before the period of high economic growth. Rice planting was conducted through mutual assistance of a group, with the head family and branch families. Water management was necessary after rice planting. The water would be cold because of the mountainous location, and therefore, a method called *Nurume* was used to raise the water temperature. Long, winding irrigation channels were built to expose water to sunlight for long hours. Subsequently, the people would weed the fields. Harvesting was conducted through a mutual assistance relationship.

A registry of the registered rice paddies, new paddies, and wet and dry fields was established in the Miomote village by 1655. All 16 households owned paddy fields, permanent fields, and swiddens, despite some differences among households in terms of upper and middle paddy fields. The swidden areas of households ranged considerably, from 3 to 100 terraces, with an average of 42 ridges [34]. Disparities among paddy field areas of households were also evident. New rice fields had not been developed at the time.

Irrigation technology is particularly important for paddy field farming; Figure 7 depicts the distribution of irrigation channels in Miomote. The dates of construction for most of the channels are unknown, but they were clearly constructed in the Edo Era because they are listed in the land register ('Tochi-daicho') of the Early Meiji period. This canal network has four sources of water: mountain streams, springs, marsh and pond water, and rivers. The canals extended throughout the flatlands of the settlement.

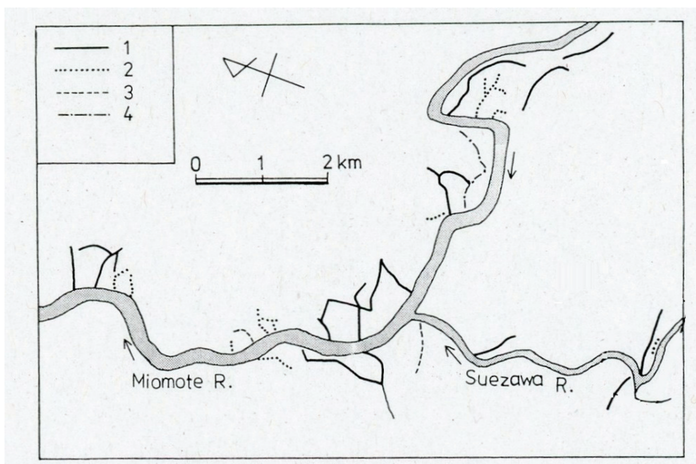



**Figure 7.** Distribution of irrigation channels: 1, mountain stream water; 2, spring water; 3, marsh and pond water; 4, river water [34].

This information suggests that the increase in rice yield, achieved during the Edo period, was accomplished by virtue of changes in irrigation technology. Irrigation using water drawn from a river, pond, or wetlands presumably existed before the Edo period (1655). During the Edo period, long-distance irrigation from the foot of mountains and using water drawn from rivers was likely developed. In the case of one canal for the mountain streams, water from the Tochidaira and Umahiki streams enters at the foot of the mountain and flows into the rice field along the Suezawa River. The canal length is more than one kilometre. The elders of the village say that the rice field was for common use. It is likely that the villagers originally dug the canal at the foot of the mountain.

The discussion presented above suggests that people of the Edo period combined their occupations, which included hunting, gathering, fishing, slash-and-burn farming, paddy field farming, and trade. The emphasis here, however, is on the position of farming in society. As the study region was mountainous, the amount of rice production was unstable, and no village had been developed. Products obtained from hunting and gathering were commercialised, and the villagers were thus actively engaged in hunting and gathering. Consequently, although the hunter–gatherers' valued practice of equally distributing shared resources was maintained strongly in hunting and gathering activities, disparities in terms of land ownership among households were evident in slash-and-burn farming and paddy field farming. In other words, the organisation of early farmers in this period entailed strong ideas of egalitarianism in the economies surrounding natural resources, partly because of the economic importance of hunting and gathering. This finding clearly reflects the characteristics of the fusion model.

## 4. Results and Discussion: Establishment of Farming by Sedentarised Hunter-Gatherers and Social Continuity

Based on current knowledge regarding the initial transition of sedentarised hunter–gatherers to farming between Japan's Jomon period and Yayoi period, this study has presented dynamic models of intergroup relationships between hunter–gatherers and farmers. Ethnoarchaeological reference data regarding the ways people combined farming and other occupations, and how they maintained and changed their occupations and society after introducing farming, were considered in terms of the dynamic fusion models, to refine expectations for modes of the transition. More specifically, the study specifically addressed the upstream mountainous area of the Miomote River area, a unique location where it is possible to assess detailed information about the archaeological site from the latter half and final phase of the Jomon period and ancient writings about slash-and-burn farming and paddy fields from the early Edo period at the same location in the Japanese archipelago. This study's results suggest the following three findings:

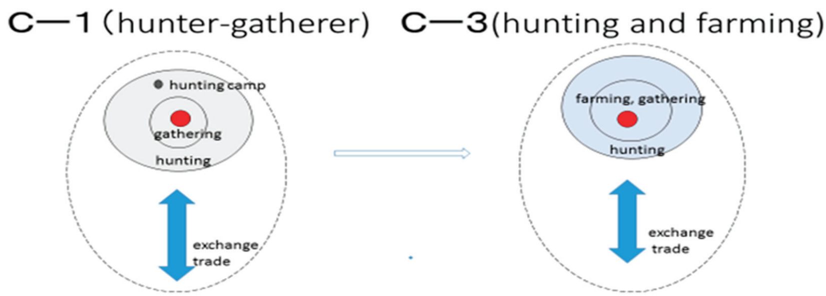
(1) A dynamic model of intergroup relationships between hunters and farmers.

Three relationship types are found in ethnohistorical resources for hunter–gatherers and farmers: coexistence and symbiosis, fusion, and assimilation. Coexistence and symbiosis are states in which the integrity of groups' lifeways is maintained after contact between the two groups. Fusion occurs in cases in which other factors are mixed in the contact between the groups. Assimilation occurs when the cultural factors and customs of one group disappear because of intergroup contact. Factors such as the population size of each group, the presence of intermarriage relationships, and the level of power to maintain a group culture are likely to be related to differences among these three relationships.

(2) How farming and other occupations were combined for the Jomon Period: Support for the fusion model.

Occupations in the latter half and final phase of the Jomon period included exchange and trade in addition to hunting, fishing, and gathering of nuts and fruits. These were combined depending on the season.

With regard to hunting, the animal bones found at the Choja-Iwaya Rock Shelter Site suggest that people primarily hunted Japanese serows, Asian black bears, and Japanese macaques rather than wild boars and deer, which were commonly hunted during the Jomon period [31,37]. Regarding gathering, large amounts of horse chestnuts and beech were found in excavations. Chestnuts were also used, and are distinguished by mechanisms of social control. Cereals have not been found. The spatial aspects of these activities indicate that gathering was conducted around the villages, and hunting was conducted around the gathering areas. In addition, the space for exchange and trade extended outside the hunting areas. This finding is presented as a three-layered concentric circle. People of the Edo period combined the occupations of hunting, gathering, fishing, slash-and-burn farming, paddy field farming, and trade. These activities also formed a three-layer structure consisting of farming and gathering around villages, hunting, and trade (Figure 8).




Type Period Subsistence Land use
C-1 late and final Jomon hunting, gathering, fishing, exchange commons
C-3 early Edo hunting, gathering, fishing, exchange commons
millet farming commons
paddy rice farming private land

**Figure 8.** Transition from hunter–gatherer (C-1) to early farmer (C-3) (C, fusion type). (Illustration by K. Ikeya).

Changes in combinations of occupations due to the introduction of farming are apparent in the comparison of the two periods. At the research site, the combination of farming activities, gathering edible wild plants in the spring, fishing in the summer, and gathering mushrooms and fruits in the fall would not cause an overlap of the periods of the various associated occupations (refer to Tables 1 and 2). In the Edo period, however, hunting methods and resource distribution for more concentrated use of resources had developed due to the commercialisation of forest products and social control methods of managing such activities. This particularly affected the trapping of bears and gathering chestnuts in the fall.

(3) Maintenance and changes in occupations and society after the introduction of farming: validation of the fusion model.

In this case, study, hunting, gathering, and fishing were maintained even after the introduction of farming. At the time, equal distribution of the shared resources of local residents, a method characteristic of hunter–gatherers, was practised during the hunting of bears and the gathering of sedge and chestnuts. Farmland, however, was divided into paddy fields, dry fields, and slash-and-burn farming. Disparities among households were evident in their areas of land for slash-and-burn farming and paddy field farming because irrigation systems and water management are fundamentally important for paddy fields. An ethos of land ownership had presumably developed by this time.

Therefore, hunter–gatherers most likely did not become rice farmers (assimilation type) despite the customs related to rice farming [35]. In other words, these findings suggest that although hunter–gatherers combined occupations and engaged in hunting as well as gathering and farming, the idea of egalitarian resource allocation that is characteristic of hunter–gatherers would be strong in the local community (characteristics of the fusion type). Paddy rice farming depended heavily on a high degree of social cooperation, community cohesion, and reciprocity, and thus resisted the development of social hierarchies [37].

A similar case is the San people, hunter–gatherers living in the southern region of Africa, who combined hunting and gathering with farming. A new combination of occupations was created by combining farming with hunting and gathering, even after small-scale agriculture was introduced [38,39]. Rather than becoming farmers, they maintained the values of the hunter–gatherer society. For instance, when certain households had harvested cultivated watermelons, the household that harvested a large amount temporarily stored the watermelons [39]. Subsequently, the watermelons harvested from the household's farm were distributed to other households.

In the Japanese archipelago, the modes of introduction for paddy field farming vary among regions. The common occupation in rice farming villages of the plains is the paddy field method. Although fishing in paddy fields was allegedly combined in some cases [40], the percentage of hunting and gathering was not large. This is a case of the assimilation type. In contrast, in mountainous regions such as the area studied here, it is expected that a lack of land suitable for paddy fields and the small volumes of rice production encouraged the combination of slash-and-burn farming and paddy field farming with hunting, gathering, and fishing to maintain subsistence. This case illustrates the fusion type.

As described in the examples presented above, agriculture can be combined with other pre-existing occupations by conducting it during different seasons. Moreover, cereal farming and paddy field farming (water management and land ownership) relate to the land very differently. The values of the hunter–gatherer society are maintained if the ratio of paddy field farming is low. If the ratio is high, then it is expected that the shift to the assimilation type would be based on how closely people are related to the land. There were not many social changes caused by the introduction of field farming; however, the introduction of paddy rice cultivation had different effects on society depending on the level of investment in channelling water from streams and springs and creating waterways. Based on these findings, regional diversity among the first farmers during the transition from the Jomon period to the Yayoi period can likely be explained by the types of mutual interaction between hunter–gatherers and farmers, the extent of investment in paddy field farming, and limiting characteristics of the habitat.

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*Article*

# Early Grain Cultivation and Starting Processes in the Japanese Archipelago

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**Abstract:** This paper presents a specific examination of the introduction of grain cultivation and the processes of development in the Japanese Archipelago. In fact, no definitive archaeological evidence has been found that Jomon hunter–gatherers cultivated grain in the Japanese Archipelago; the earliest potential evidence of grain is a stamp mark of rice on the surface of a final late-Jomon, in about 11th century BC, pottery found at the Itaya 3 site in Shimane Prefecture. Current evidence indicates that the first grain cultivation was started by Jomon people who adopted irrigated wet rice cultivation that had arrived from the Korean Peninsula to northern parts of Kyushu, and gradually spread eastward thereafter. This study specifically examines four regions, including northern Kyushu, Kinki, southern Kanto, and northern Tohoku, in order to investigate the processes of grain cultivation initiation and spread. First, the years during which wet rice cultivation started in each region are estimated based on carbon-14 dating of earthenware types used during that period. Secondly, the timing of the spread of wet rice cultivation has been estimated based on carbon-14 dating of earthenware. Subsequently, differences in the periods between the initiation and dissemination of wet rice cultivation were estimated. Results suggest that dissemination took place over approximately 250 years in northern Kyushu, where wet rice cultivation first started. The time required for adoption decreased gradually as the trend moved eastward. It was estimated to have taken approximately 150 years in Kinki and 20–30 years in southern Kanto, taking place at about the same time. A factor, significantly contributing to such differences in timing and development processes among regions, was likely the relationship between the first farmers who introduced wet rice farming and the indigenous hunter–gatherers who lived there.

**Keywords:** bronze age; hunter gatherers; interaction; irrigation system; Jomon people; Korean Peninsula; wet rice cultivation

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## 1. Introduction

Since the last glacial maximum, about 22,000 years ago, rising temperatures in the Japanese archipelago saw the emergence of pottery about 16,000 years ago. Earthenware appeared during the late glacial period [1]. In terms of Japanese archaeology, the Old Stone Age to the Jomon era is indicated by the appearance of earthenware [2].

The temperature rose only slightly during the Younger Dryas period of about 14,000 years ago, then warmed drastically from about 11,000 years ago [3]. This change marked the beginning of the post-glacial period in the Japanese archipelago. In this region, no edible wild grains grew during the post-glacial period. Major foods sought by Jomon people included nuts and other forest plants, forest animals, and seafood [4]. At the Sannai Maruyama site in Aomori Prefecture, a chestnut forest (*Castanea crenata*) existed that was as dense as today's chestnut gardens [5]. Stable sustenance using chestnuts as a staple food for subsistence is known to have continued for more than 500 years. Archaeological evidence suggests that Jomon people were able to grill and boil chestnuts.

Keiji Imamura defined the Neolithic culture of the Japanese archipelago as a "forest Neolithic culture" that used forest plants as a major food, in contrast to the "grassland Neolithic culture", which used grains and livestock as major foods in western Asia [6]. About 4200 years ago, the climate cooled suddenly and the Sannai Maruyama site was abandoned. Jomon people switched their subsistence emphasis from chestnuts to more cold-resistant horse chestnuts (*Aesculus turbinata*). Jomon people were compelled to go through complicated processes, such as heating and immersion, to make horse chestnuts edible [5]. Therefore, such water-exposed remains are being investigated continually at various locations.

In addition to gathering, the Jomon people might have conducted domestication of some plants. Soybeans and azuki beans (*Glycine soja* and *Vigna angularis*, respectively) are grown on Honshu Island and were collected by Jomon people as early as 10,000 years ago. Seiji Nakayama and Hiroki Obata confirmed from replica analysis that the wild bean size increased gradually over time, approaching the size of modern soybeans and adzuki beans (Figure 1). Nakayama and Obata designated these as Jomon beans, which are smaller than modern soybeans and adzuki beans, but suggest that they might constitute evidence of plant domestication by Jomon people [7].

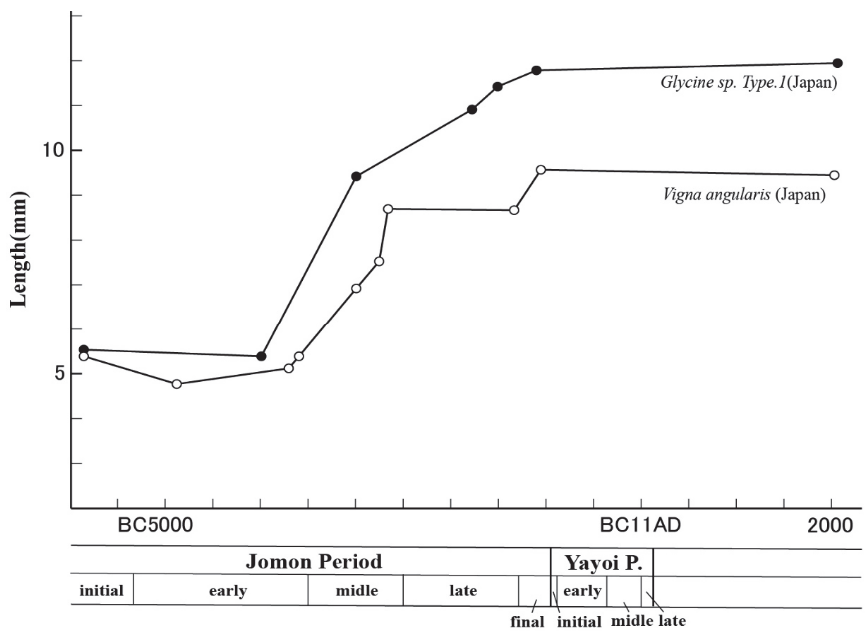


**Figure 1.** Changes in legume size during Japanese archipelago prehistory (Modified from Figure 101; referred from Hiroki Obata [7]).

From that experience with beans, Jomon people might have learned that managing plants would produce delicious and larger nuts or beans. Therefore, grain cultivation arrived at a time when the Jomon people had already accumulated selective cultivation knowledge and experience over thousands of years.

## 2. Who Brought Grain Cultivation to the Japanese Archipelago?

### *2.1. Diffusion from the Korean Peninsula to the Japanese Archipelago*

Grain cultivation was introduced to the Japanese Archipelago from outside cultures in the late 10th century BC. Ancient Korean people of Bronze-age culture brought wet rice cultivation to northern parts of Kyushu [8]. The wet rice cultivation technique, which incorporated irrigation systems, was accepted by hunter–gatherers from Honshu, Shikoku, and Kyushu over an approximately 700-year span (Figure 2).

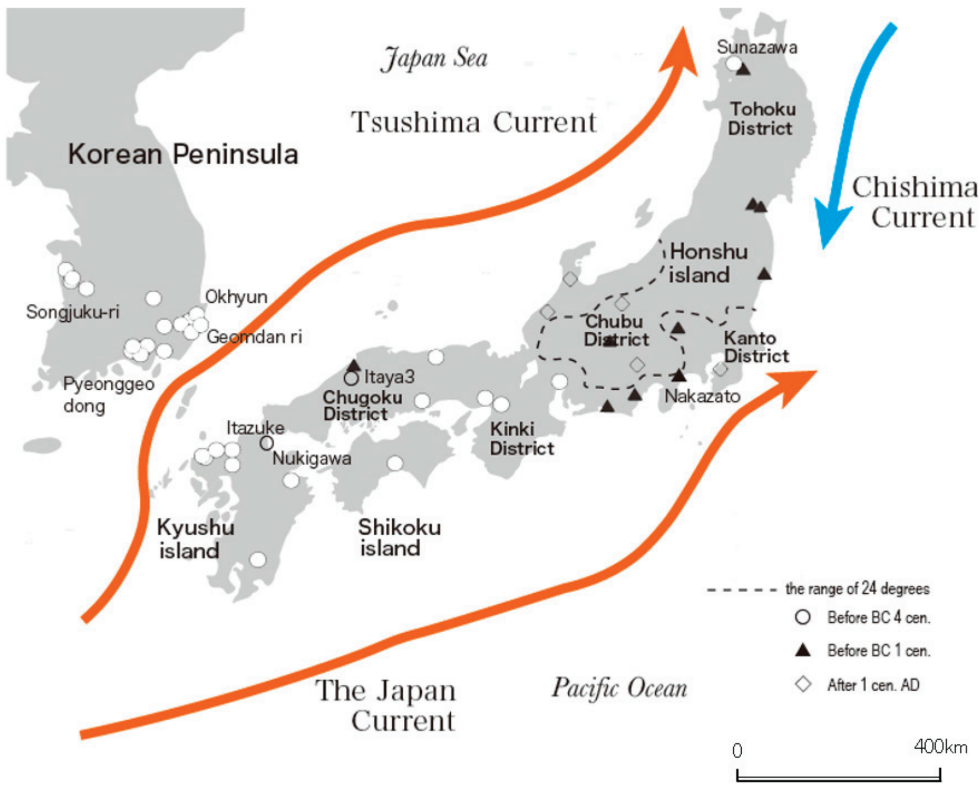


**Figure 2.** Geography, ocean currents, and prehistoric sites of the Korean Peninsula and the Japanese archipelago. (by Author).

The Tsushima warm current flows along the western Japanese archipelago; the Chishima cold current and the Japanese warm current flow along the eastern side. Therefore, during summer on the western Sea of Japan side, the Tohoku region is warm, but the eastern or Pacific side remains cold because of oceanic currents. The distribution of early rice farming sites is in areas with about 24 °C average temperature in August.

### 2.2. Introduction of Rice Cultivation

It seems that two occurrences supported the spread of grain cultivation to western Japan during the Jomon period (Figure 3). The first was the spread of rice and millet in the 11th century BC from the southeastern Korean Peninsula to eastern Kyushu and the Chugoku region [9]. The second was the spread of rice cultivation incorporating irrigation systems from the southern Korean Peninsula to northwestern Kyushu in the second half of the 10th century BC [10].

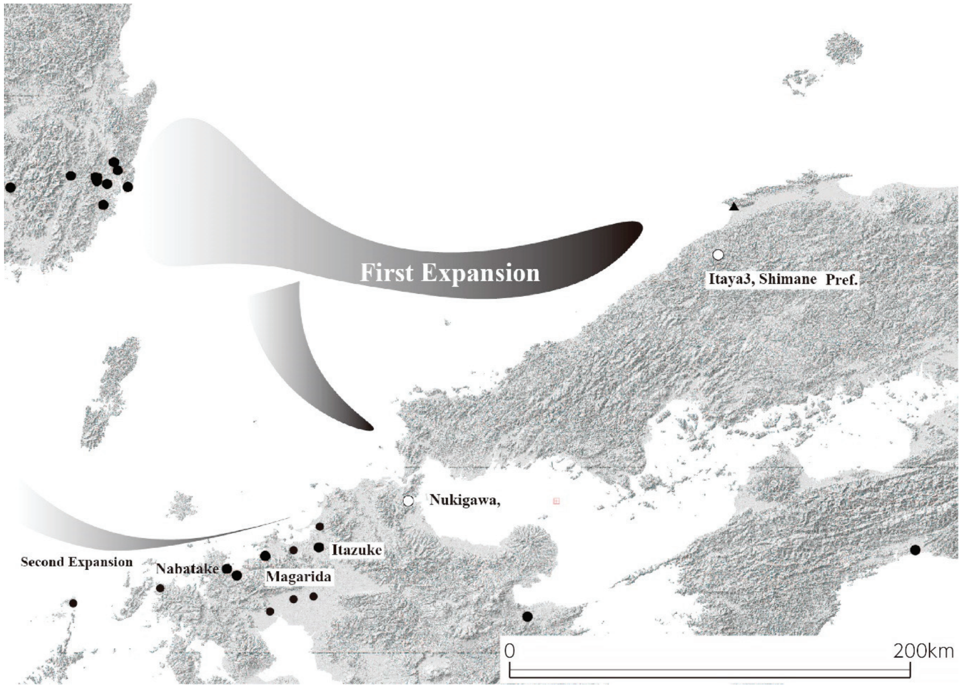


**Figure 3.** Two opportunities are apparent for grain cultivation to have spread from the Korean Peninsula to northern Kyushu and the Chugoku region. (by Author).

### *2.3. First Expansion*

Evidence for Japan's oldest rice is the impression of rice plants on pottery excavated from the Itaya III site in Shimane Prefecture (Figure 4) [11]. This evidence has been dated to the 11th century BC, at the end of the Jomon period. Contemporaneous harvesting tools (stone reaping knives) for gathering rice ears have also been found at the Nukigawa site in Kitakyushu-shi, Fukuoka Prefecture (Figure 5) [12]. This evidence indicates that rice was present, but it is not clear that rice was being cultivated. However, even if Jomon people grew rice, they did not subsist mainly on rice production. Since then, no evidence of the spread of rice cultivation has been found in this area. Rice cultivation in this area was not generalized until the early Yayoi period, about 400 years later.

The following archaeological evidence confirms that Kyushu's interaction with the Korean Peninsula took place approximately 7000 years ago. The first is that obsidian from Koshidake Mountain, Saga Prefecture was found in the southern part of the Korean Peninsula, and the joint fishing hooks and stone harpoons for catching large fishes are widely distributed in the area from the east coast of the Korean peninsula to the west coast of Kyushu. In particular, the presence of common fishing gear in both areas indicates the possibility that there were people engaged in fishing activities in both areas, and there is no doubt that exchanges of both areas were common. Takakura Hiroaki calls this type of exchange the "fishermen's exchange" [13]. The first expansions of the 11th century BC may have been brought about through such exchanges.

### *2.4. Second Expansion*

Paddy field cultivation began during the second half of the 10th century BC, in the initial Yayoi period, along the shores of the Genkai Nada in northwestern Kyushu. The paddy field excavated at the Itazuke site in Fukuoka Prefecture was full-scale, including irrigation facilities (Figure 6) [14]. Tools for rice cultivation were also present, such as stylized wooden farming tools, continental polished stoneware to make them, and stone reaping knives used for gathering rice ears.


**Figure 4.** Evidence of oldest rice in Japanese Archipelago revealed by the replica method provided by Tsuyoshi Ushino. The replica method investigates stamp marks by embedding a resin in a fine hole indented on the pottery surface, removal after hardening, and observation of the surface using an electron microscope.

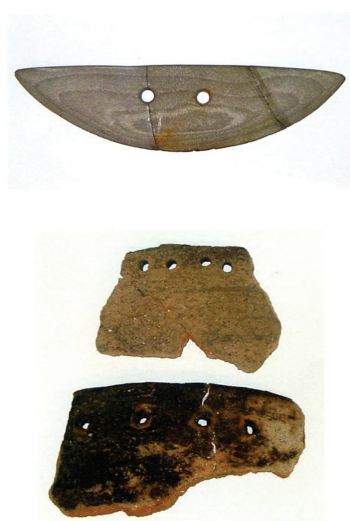

**Figure 5.** Stone reaping knives and a series of pottery items excavated from the Nukigawa site, Fukuoka Prefecture. Provided by Kitakyushu City Buried Cultural Property Research Office.

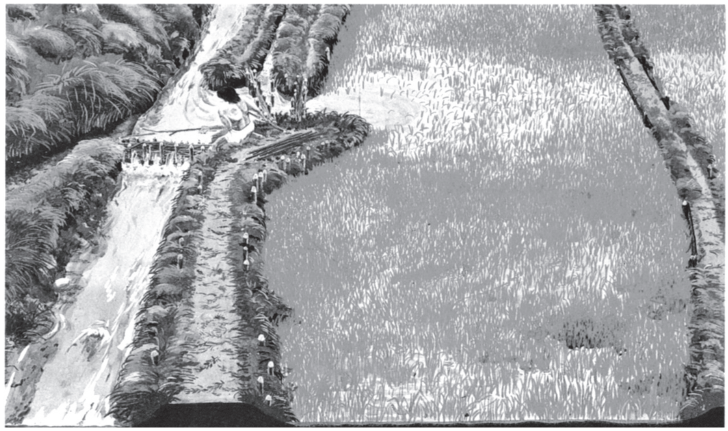

**Figure 6.** Reconstructed picture of paddy fields and wells and drainage channels during the latter 10th century BC excavated at Itazuke Site, Fukuoka Prefecture, provided by Fukuoka City Buried Cultural Property Center.

The paddy field found in the Itazuke site is a large-scale paddy field plot with a section of more than 300 square meters. Weirs installed at 50-m intervals in the main waterways supplied paddy fields with water.

*2.5. Each Homeland*

In the southern part of the Korean Peninsula, paddy field cultivation began during the 11th century BC. Small-plot paddy fields have been found at the Ulsan Okhyun site (Figure 7) [15]. The common pattern of pottery excavated at Itaya III Site indicates that the Yeungnam area might be its home region [9]. At that time, material culture of the southern Korean Peninsula in 11th century BC included bronze swords, which had not been used before the formation of agricultural society. The social situation was unstable. Moreover, the cultural elements of the southern Korean peninsula found in western Japan are fragmentary. Therefore, it is unlikely that rice was transmitted by large-scale movements of people from the southern Korean Peninsula.

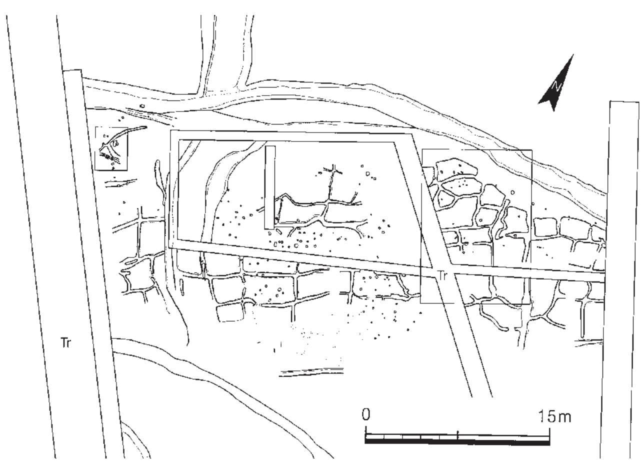


**Figure 7.** Oldest paddy field on the Korean Peninsula, Okhyun site, Ulsan, Korea. Provided by Busan University Museum.

During the 10th century BC, ditch-enclosed settlements began to appear in the Yeungnam area; an agricultural society had become established. Consequently, social contradictions became apparent. Some people who escaped from the society have been identified, who would have crossed the Korean strait to Kyushu [16].

One theory holds that, given the characteristics of small pots excavated from both areas, the origin of persons arriving from across the Korean strait was the homeland of the Nakdong River Basin. This second spread of paddy field cultivation occurred along with the spread of bronze age culture based on paddy rice cultivation, such as tools and techniques for paddy field cultivation, as well as a festival to pray for fertility. Such practices might have been imported along with the movement of large groups of people.

## 3. Interaction between Native Hunter–Gatherers and Newcomer Farmers

### *3.1. Introduction*

Jomon people from about 16,000 to 3000 years ago depended on gathering, fishing, hunting, and some farming for subsistence. They cultivated gourds, soybeans, and adzuki beans but not grains such as foxtail millet (awa, *Setaria italica*), or rice. Consequently, farming was only a component of Jomon subsistence. Farmers who came from the southern Korean Peninsula began wet rice cultivation with irrigation systems 3000 years ago in cooperation with original inhabitants of the Fukuoka Plain in northern Kyushu. Their interaction had just begun to resemble similar situations found in prehistoric Europe [17].

Research of the time period of interactions among these peoples has included AMS-$^{14}$C analyses of the Fukuoka Plain, Osaka Plain, Ashigara Plain, and Hirosaki Plain. Based on those results, the times of interaction are known to be shorter for east and north areas. The reason for this phenomenon must be discussed.

### *3.2. Analysis*

In Figure 8, the left panel portrays a set of pottery used by a farmer who began working on the Fukuoka Plain in the 10th century BC (Figure 8 left). The right panel depicts a set of pottery used by a farmer 200 years later in the 8th century BC (Figure 8 right). Cooking pots came to show a new form and style through cultural interaction. Moreover, one can ascertain the time of interaction and when such jars were used through $^{14}$C analysis of soot adhering to the cooking pot surface, as shown in the left and right panels of Figure 9.

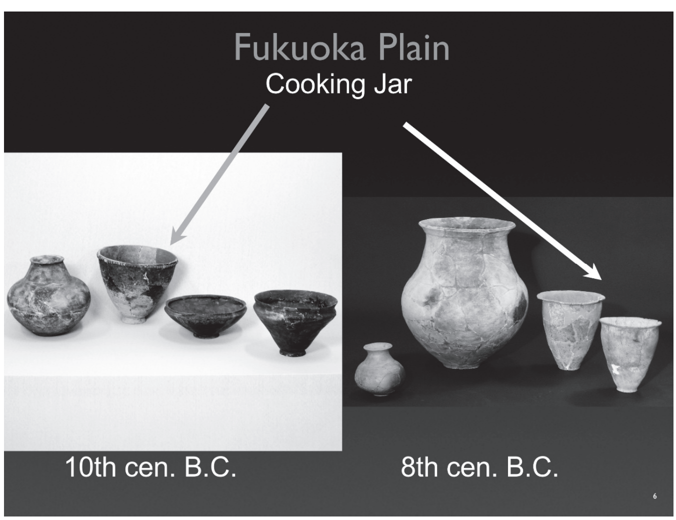


**Figure 8.** (**Left**), Set of pottery used by a farmer during earliest farming on the Fukuoka Plain in the 10th century BC; (**Right**), Set of pottery used by a farmer 200 years later during the 8th century BC. (photograph by Fujio).

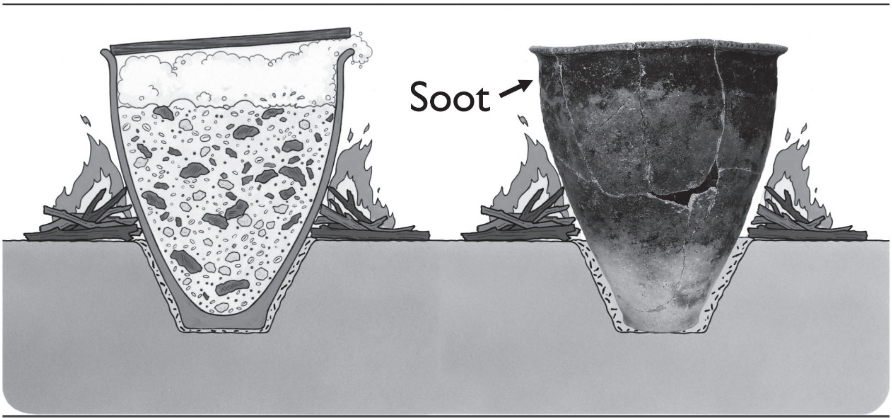


**Figure 9.** Schematic diagram of cooking in the early Yayoi period and the attachment of soot. (referred from Fujio) By carbon-14 dating of the soot which collected on the surface of the pottery during cooking, one can ascertain the age during which the pottery was used [18].

*3.3. Northern Kyushu*

Figure 10 portrays the distribution of sites on the Sawara Plain and Fukuoka Plain at the end of the final Jomon period in the 11th century BC [19]. Sites are rarely found in downstream basins on the plain. They are distributed in the middle and upper reaches of rivers. Native hunters and gatherers lived at sites in middle and upstream areas suitable for collecting nuts, fishing, and hunting, preferring these areas to the downstream basins.

Figure 11 presents the distribution of sites in the same region in the second half of the latter of 10th BC, when paddy field cultivation began [19]. The archaeological remains of paddy field farmers appeared in the downstream basin on the plain, where few archaeological sites had been identified to that time. For farmers, the downstream basin on the plains was a convenient place for paddy rice cultivation. *Sumiwake*, so-called habitat segregation, had begun.

In the Sawara Plain, numerous rice paddy farmers' settlements appear in the downstream region. Even in the Fukuoka Plain, numerous rice paddy farmers' settlements have appeared.

Circumstances leading to this situation are explained below [20].

The first farmers, as newcomers, developed paddy fields in downstream basins on the plains that had been used only slightly by the indigenous hunter–gatherers. Because the latter cultivated beans and other crops, collected nuts, and hunted in middle and upstream areas, the former settled there peacefully with few conflicts of interest. However, they did have mutual relations. Apparently, farmers were unable to cultivate wet rice independently. For example, without help from indigenous hunter–gatherers familiar with the land, they would have been unable to gain knowledge about rare raw materials: hard stone that might be processed for use as axes to cut down trees and hard oak trees with wood suitable for crafting wooden farming tools. The indigenous hunter–gatherers might have also been valuable for marriage and as laborers necessary to grow wet rice.

The farmers were also valuable for indigenous hunter–gatherers. Farmers offered food such as rice in exchange for information about local rare materials, as well as cultivation knowledge and social opportunities. These groups might therefore be regarded as interdependent. About 250 years passed from the start of farming to their interaction, which ended when hunter–gatherers themselves became farmers.

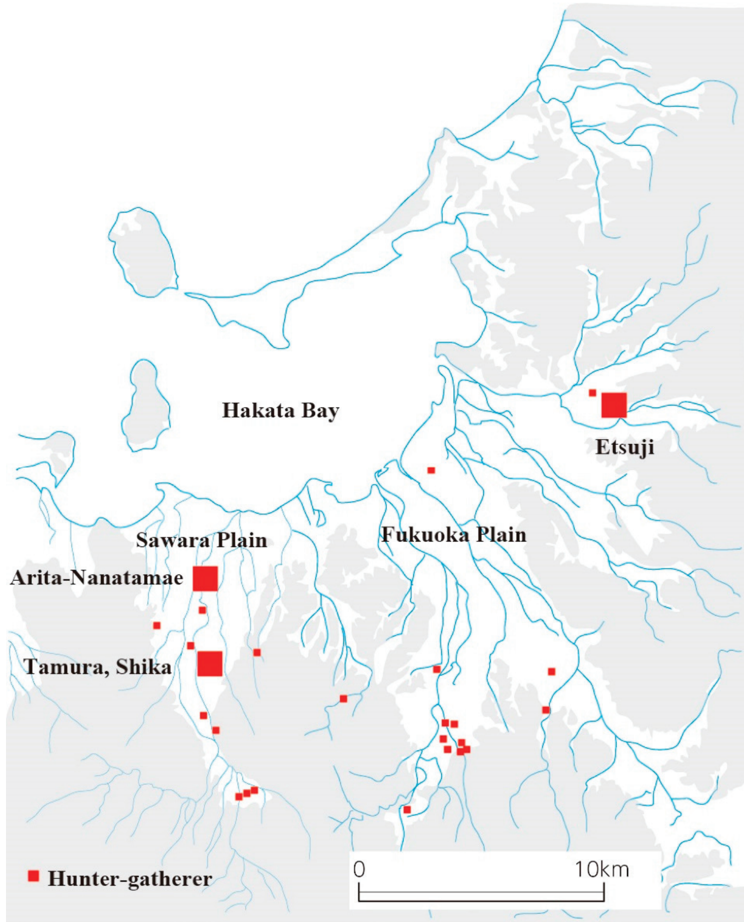


**Figure 10.** Distribution of sites at the end of final Jomon period in the Sawara Plain and Fukuoka Plain [19] (by Author). The Tamura and Shika sites are indigenous hunter–gatherer villages that have persisted since the late Jomon period. They are located in the middle reaches of the Sawara Plain. The Arita Nanatamae Site, which appears at the end of the final Jomon period, is located in the downstream area. It persisted in the initial Yayoi period. No site was found in the lower reaches of the Fukuoka Plain. The sites are located only in the upper and middle reaches.

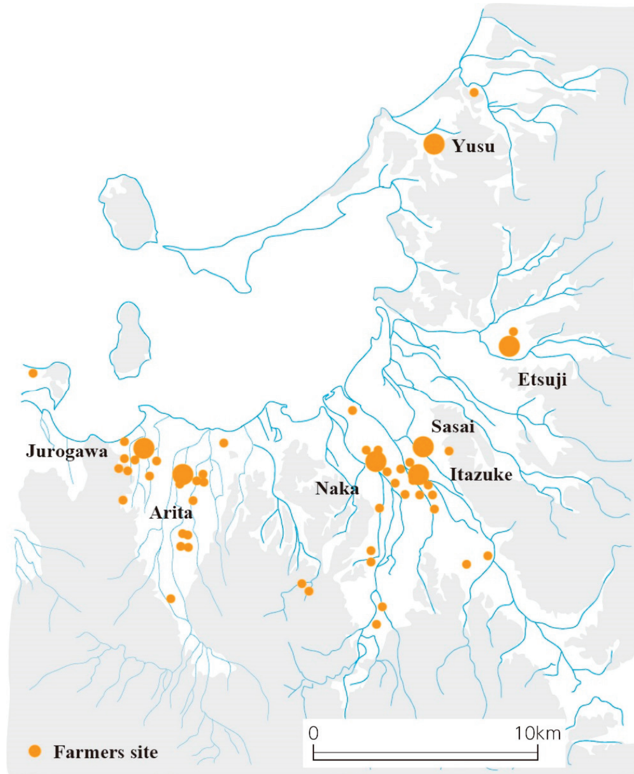


**Figure 11.** Distribution of initial Yayoi period sites in the Sawara Plain and Fukuoka Plain [19] (by Author).

### 3.4. Osaka Plain

On the Osaka Plain, farmer settlement occurred on the banks of Old Kawachi lagoon, whereas hunter–gatherer settlements were located on the upper and middle plains and hillsides in the 6th century BC to 5th century BC [21]. Their mutual interaction for 150 years has been ascertained from the character of pottery used by farmers and hunter–gatherers [22].

Reportedly, the Sanuki region in the northeastern part of Shikoku brought paddy field cultivation to coastal areas of Osaka Bay. Large amounts of Sanukite from the Sanuki region have been excavated from sites on the coast of Osaka Bay at the beginning of the Yayoi period [23].

### 3.5. Ashigara Plain in Kanagawa Prefecture, West of Kanto District

At Ashigara Plain in Kanagawa Prefecture, west of Kanto District, Jomon people had been cultivating foxtail millet, etc., in the upper and lower reaches of the river for about 500 years. Around 250 BC, paddy field cultivation suddenly began along the lower reaches of the river. Paddy field farmers set up paddy fields in the lower reaches of the plains, where no hunter–gatherers lived [19]. The farmers created ditch-enclosed settlements and built burial mounds surrounded by square moats (Figure 12). Because their pottery has been found in western Japan, it is believed that paddy field farmers immigrated from the west. Their interaction continued for 30–50 years [24]. The *Sumiwake* is shown between at the lower plain and hillside.


**Figure 12.** Ditch-enclosed settlement with a pit dwelling and a burial mound surrounded by a square moat excavated at the Nakazato site, which appeared during the third century BC. Provided by Tamagawa Cultural Property Research Institute.

### *3.6. Northern Tohoku District*

On the Tsugaru Plain in Aomori prefecture, in the northern part of Tohoku district, the northernmost paddy field, at 40° N latitude, was discovered at the Sunazawa site, Hirosaki-shi, Aomori Prefecture (Figure 13).

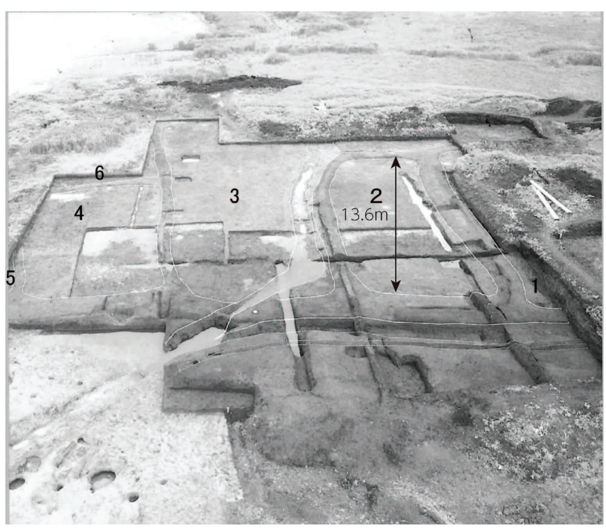


**Figure 13.** Oldest paddy field in the Tohoku region: Sunazawa site. Provided by the Hirosaki City Board of Education. There were seven large-scale paddy fields discovered at the Sunazawa site, which has no irrigation facility. The water flows naturally downward. The long axis of No. 2 paddy field is about 13.6 m.

Jomon people began wet rice cultivation with independently operated irrigation systems in the 4th century BC. Sunazawa people fundamentally used paddy field cultivation with traditional stone tools from the final Jomon period. They also continued traditional festivals using clay figurines, stone rods, and other materials. Paddy field farmers using these Jomon-origin festival tools resided only in Aomori prefecture.

Phytolith analysis results suggest that wet rice cultivation was conducted at the Sunazawa site for 12–13 years. Wet rice farming was practiced in this region for approximately 300 years thereafter. However, the paddy fields were eventually inundated and ruined because of the falling temperatures and flooding which occurred approximately in the 1st century BC [25]. Farmers subsequently returned to hunting and gathering without resuming wet rice cultivation. Not until ancient, but more recent, times did grain cultivation recommence in this region [19]. The Epi–Jomon culture would therefore continue without establishing agricultural society, let alone a transition to the Kofun period.

### *3.7. Discussion*

As described above for these four regions, the processes extending from the beginning of paddy field cultivation to the establishment of a fully agricultural society are readily apparent [23]. The duration of the transition was shorter in eastern regions. The analytical results also revealed that, likely as a result of climatic changes, some people resumed their original hunting and gathering life after ceasing the wet rice farming practices that they had used continuously for approximately 300 years. The models presented below illustrate the durations of interaction (Table 1) [24].

(A) 250 years, e.g., Fukuoka Plain.
(B) 150 years, e.g., Osaka Plain, probably western Japan.
(C) 20–50 years, e.g., Kanto Plain, probably eastern Japan.
(D) Native hunter–gatherers started wet rice cultivation independently without any new arrival of plant farmers. They passed down Jomon festivals. No mutual exchange occurred. They resumed hunting and gathering after approximately 300 years.

**Table 1.** Durations of interaction.

| Model | Duration of Interaction | Newcomers | Example |
|---|---|---|---|
| A | 250 years | Korean Peninsula | Northern Kyushu |
| B | 150 | e.g., Sanuki | Osaka Bay area |
| C | 30–50 | e.g., Harima, Mikawa | Eastern Japan |
| D | 0 | 0 | Northern Tohoku |

Carbon-14 dating of soot on the surface of cooking utensils found at the oldest paddy field site in the four regions supports the following hypothesis: Although immigrants spread from Kyushu to Honshu, excluding northern Tohoku, the period of interactions between natives and immigrants became shorter as they advanced to the east. Native hunter–gatherers came to dominate smaller areas as the introduction of wet rice farming moved eastward. People from the Korean Peninsula brought wet rice farming into northern Kyushu, not only as an occupation and method of sustenance, but as a cultural complex including social and ritual systems with wet rice cultivation as the productive base.

Establishment took 250 years presumably because of the considerable time necessary for adaptation of wet rice cultivation, which was the production base for the Bronze Age culture of the Korean Peninsula, to environmental conditions prevailing in northern Kyushu. In other words, most hunter–gatherers in northern Kyushu might have taken time to convert wet rice cultivation from the Korean Peninsula into the Yayoi rice farming appropriate for the ecosystems and daytime lengths of northern Kyushu. This adaptation represents the creation of the Yayoi wet rice farming.

Why, then, did the period of interaction decrease as the trend moved to the eastern regions? First, acceptance of the system based on wet rice cultivation, of which the conversion to the Yayoi system had been completed in northern Kyushu, was likely to have been easier for people of Osaka Bay coastal areas, where the natural environment, ecosystems, and culture resembled those of northern Kyushu. The reason for the shorter periods required by people in the regions other than northern Kyushu might have been that they had accepted the Japanese archipelago version of Yayoi farming that had been created in northern Kyushu [26].

The first people to bring wet rice cultivation into the Ashigara Plain in southern Kanto were purportedly wet rice farmers who had migrated from western Japan, as suggested by the introduction of cooking earthenware from the western region. In other words, wet rice cultivation was started by migrants from western Japan, rather than by indigenous hunter–gatherers. Moated settlements and square-moated burial precincts suggest rapid formation of agricultural society, which was achieved through the efforts of such migrants.

The last region is northern Tohoku. The local people resumed their original hunting and gathering life after relinquishing agriculture, which had served them for approximately 300 years from the start. That reversion occurred because they accepted wet-rice farming into their comprehensive work structure maintained since the Jomon period, but only as a part-time livelihood. If paddy fields were buried by severe flooding, such as that which occurred before the 1st century BC, then the people would not have had such severe difficulty in abandoning wet rice farming for alternative resources: it was merely one of several occupations on which they relied for subsistence. It was fortunate that they had adopted wet rice cultivation while maintaining labor organization and clay figure festivals and other rituals continuously since the Jomon period.

## 4. Conclusions: Early Grain Cultivation and the Starting Process

Two groups of farmers resided on Honshu, Shikoku, and Kyushu islands: those who started wet rice cultivation and those who started millet cultivation [19]. Hunter–gatherers of northern Kyushu and northern Tohoku first began wet rice cultivation (Figure 14). However, hunter–gatherers in other areas first began millet cultivation and subsequently switched to wet rice cultivation several hundred years later. Hunter–gatherers of the latter areas started paddy rice cultivation after cultivating foxtail millet and broomcorn millet (*Panicum* spp.) for about 300–500 years (Figure 14) as a means of subsistence that complemented wild foods.

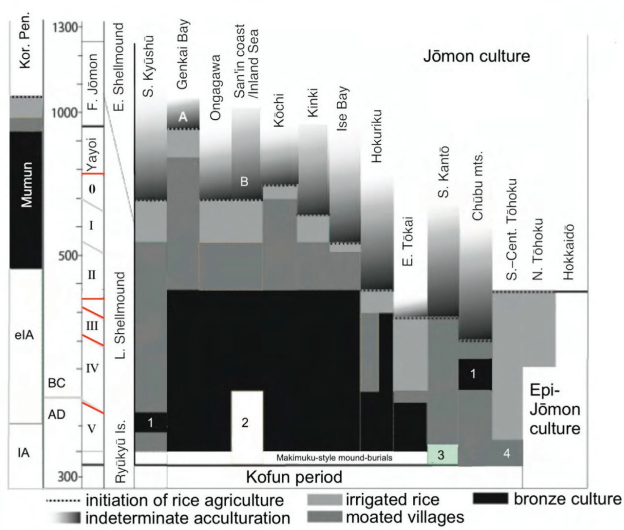


**Figure 14.** Regional distribution of the three elements of Yayoi culture: 1, bronze cache (Cache is designed to hold a bronze sword or a bronze bell-shaped vessel in soil until it is time to be spent next.); 2, withdrawal from bronze culture; 3, small bronze bell; and 4, burial mound surrounded by square moat. Japanese version provided by [19] (Fujio 2013: Figure 80) English version provided by Gina Barnes [27].

Komoto designated such a subsistence structure as comprehensive and regarded it as a generalized subsistence strategy of Jomon society [28]. However, paddy field farmers in northern Kyushu also collected, hunted, and fished, yet subsisted mainly on paddy field cultivation. Komoto designated this as a selective subsistence structure and regarded it as the representative subsistence structure of Yayoi society.

People who grew foxtail millet (awa) and broomcorn millet in the Jomon-like occupational structure crafted Jomon culture-specific festival tools such as clay figurines and stone rods. By contrast, paddy field farmers practicing selective subsistence had no clay figurines or stone rods. This important difference signifies that Jomon-like rituals are compatible with millet cultivation in the comprehensive occupation structure, but not with paddy field cultivation in the selective occupation structure. The rice prayer festival and the clay figurines and stone rod rituals might be completely different. Wet rice farmers in Aomori Prefecture used clay figurines probably because they used paddy field cultivation under a comprehensive subsistence structure.

The period from the start of millet cultivation to the start of irrigated paddy rice cultivation is designated as one of indeterminate acculturation. At this stage, neither Jomon nor Yayoi culture predominated. The transition period was short in areas where paddy field farmers might have migrated, as in northern Kyushu, and longer in areas where native hunter–gatherer and hunting people started with millet, as in western and eastern Japan. The length of the transition period increases with distance to the east, with that in Chubu and southern Kanto region lasting as long as 500 years. Figure 14 illustrates that the transitional period length varies among regions.

The next subject is the process that took place after adopting wet rice cultivation. There are four patterns that have been developed from the lengths of period between the introduction and dissemination of wet-rice farming in the regions. The analysis revealed that the period became shorter as the introduction of wet rice farming moved eastward, i.e., approximately 250 years in northern Kyushu, approximately 150 years in Kinki, and 20–30 years in southern Kanto. Only the hunter–gatherers in northern Tohoku resumed hunting and gathering after practicing wet rice farming for approximately 300 years. Thus, pre-existing conditions of subsistence structure are demonstrated to have a clear and predictable influence upon the adoption, retention, and intensification of wet paddy agriculture in the Japanese Archipelago.

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# Alternative Adaptation Strategy during the Paleolithic–Neolithic Transition: Potential Use of Aquatic Resources in the Western Middle Yangtze Valley, China

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**Abstract:** The middle Yangtze Valley is an important region for studying the origin of rice agriculture. Archaeological remains of rice have been found in sites such as Pengtoushan and Bashidang as early as 8000 years ago. However, we know little about the adaptive diversity in this region as research has mostly focused on rice cultivation. With the help of new discoveries, this paper explores another adaptation behavior pattern that emphasizes the utilization of aquatic resources in the western part of the Jianghan Plain during the Paleolithic–Neolithic transition. Although the sea level was continuously rising with the warming process of early Holocene, the lakes that later became widely distributed were still in formation, thus not available for human utilization in the middle Yangtze Valley. However, most notably, the amelioration of the environment was producing a sort of new niche: utilizing aquatic resources became possible at least in parts of this region. A case study from the Guanzhou Site, based on lithics, suggests there were increasing demands for the utilization of aquatic resources. The study proposes that at least two different adaptation strategy changes occurred in the western Jianghan Plain during the Paleolithic–Neolithic transition, i.e., rice agriculture or complex hunting–gathering. These strategies represent adaptations to the different ecological conditions at the crossroads of habitat types.

**Keywords:** complex hunting–gathering; Paleolithic–Neolithic transition; aquatic utilization; China

## 1. Introduction

About ten thousand years ago, the arrival of the Holocene was marked by a stable and mild climate after the last ice age terminated. Several dramatic changes in behaviors of prehistoric hunter-gatherers happened during the Paleolithic–Neolithic transition (PNT), such as the appearance of food production, complex social systems, complicated human behaviors, ideology and sedentism [1]. Meanwhile, in a general trajectory, the human adaptation based on hunting and gathering was replaced by reliance on food production, a process termed the origin of agriculture, also described by V. Gordon Childe as the "Neolithic Revolution" [2].The global impact of the agricultural revolution on humankind has given rise to "hot" topics including population growth, environmental degradation, the appearance of sedentism, social complexity, and other changes to adaptation strategies. Although the process was prolonged for several thousand years and there are various cultural responses aside from food production, the origin of agriculture has been a major research focus for decades [1,3–5], in other words, agriculture, as an important adaptation during the PNT have been explored much, especially in West Asia, which addresses the influence of environment and population growth [6–8]. However, in East Asia, further research is not only needed on the origin of agriculture, but also research relating to nonagricultural adaptations, which have received much less attention.

At present, evidence is fairly clear on the origin of agriculture in China, which includes two centers: North China (the east edge of the Loess Plateau) and South China (the plains of the middle and lower reaches of the Yangtze River). Yet the PNT of noncentral (noncenter regions: except the Loess Plateau and the plain of middle and lower reaches of the Yangtze River, the rest of the places around China are noncenter regions, such as Northeast China, South of the Five Ridges, Qinghai–Tibet Plateau, the mountain areas of the Yangtze reaches (Xijiang region) and so on) regions is still unclear. Since we have studied the question of the PNT for many years, in this paper we investigate the archaeological records in the Xiajiang area (Xiajiang area: the mountain and gorge area along the Yangtze River, including several important terrains, the Three Gorges, mountain area in Southwest China, the edge of Yunnan–Guizhou Plateau) and its adjacent regions, especially first-hand unearthed lithics from the Guanzhou site in Hubei Province. A special pattern of cultural adaptation can be recognized, which is characterized by a unique lithic technology: the "ridged hammer bipolar flaking" (RHBF) technique (see below), a representative technique in the Xiajiang area. Until now, very little research has focused on the question of the PNT process in this region, and only a few studies have been involved (e.g., [9,10]). Therefore, the present paper based on an analysis of lithic assemblages in this region can fill in gaps in the question to a certain extent and enrich our overall understanding the diversity about the PNT.

In general, the topography of China consists of three parts: the Tibetan Plateau, the floodplains and hills in the east, and the middle zone between these two parts. The region we discuss, the western part of middle Yangtze valley, is located in the eastern margin of the middle zone where rivers flow into floodplains. The power of rivers to carry sediment rapidly recedes with decreased flow rates, which leads to two consequences that could have impacted lives of prehistoric hunter-gatherers. First, the deposition of river boulders near the reach where a river enters floodplain. This zone can provide abundant raw material, for stone tool manufacturing, of adequate size. In contrast, in the lower reach, it is difficult to find lithic raw material of equivalent size. The other impact is the formation of wetlands in the floodplain, including lakes and seasonal wetlands. Effectively exploiting these special ecological zones would require more complicated technologies: for example, boat and paddle. Therefore, along a river there is an optimal zone for prehistoric hunter-gatherers, where they may find rich lithic raw materials, diverse food resources and a landscape suited for relatively easier mobility. The region discussed above is the transitional zone between the plateaus and hilly floodplains. Notably, the lithic source outcrops are located in more eastern areas, since the sea level in the Terminal Pleistocene did not reach the present level, and lakes along the middle Yangtze valley had not taken their current shape until about 6000 BP.

According to the latest archaeological evidence, the earliest sites with Neolithic features such as domestication, pottery, and sedentism are all located in the hilly flanks of the middle Yangtze valley. Carbonized rice remains suggesting domestication at the site of Xianrendong and Diaotonghuan in Wannian County of Jiangxi Province [11–14] and Yuchanyan in Dao County of Hunan Province, correspondingly [15,16]. The Yangtze valley in the subtropical zone is a marginal habitat for the growth of wild rice. Up to the Neolithic, there is a continuous sequence from the Shangshan Culture [17], the Kuahuqiao Culture [18–20] to the Hemudu Culture [21] in the lower Yangtze valley; a sequence similar to that from the Pengtoushan Culture [22,23] and the Chenbeixi Culture [24,25], the Lower Zaoshi Culture [26] to the Daxi Culture [27] in the middle Yangtze valley. It is noted that the PNT can be traced back to about 20,000 years ago, when pottery, polished stone tools and intensive utilization of wild rice appeared in several sites, and this process can be extended to around 8000 BP. This shows the process from the origin of agriculture to the formation of full-developed Neolithic societies is gradual. After the PNT, the Neolithic sites diffused from hilly flanks to floodplains. This tendency is attested by the site distribution from the Pengtoushan Culture to the Daxi Culture. At the same time, agriculture diffuses westward to mountainous zones, including the Sichuan Basin, in which the pottery assemblage of the Daxi Culture has been found. Agriculture in the other parts, confined by natural conditions, was adopted much later. For example, rice farming in Guizhou appeared in the second millennium BC.

The above is the overall situation that we have known up to this time, but the PNT is not clear for the marginal regions of agricultural origin. This transition, which happened worldwide, not only relates to environmental changes at the end of Pleistocene, but also more commonly implies the change in human adaptation—that is, origins of agriculture in various regions of the world. This change brought challenges and opportunities for the hunter-gatherers of noncentral regions in at least three aspects: (1) formation of a new niche with climate amelioration; (2) agriculture or food production as a new technology of cultural adaptation; (3) released constraints from ecological conditions and the inertia of the foraging lifeway inherited from their ancestors. It is generally assumed that hunter-gatherers in the marginal region were not influenced by the changes of the PNT including those from environmental and cultural backgrounds, but continuously kept foraging—their existing lifeways—and thus were forced to accept agriculture later during processes of immigration or other stressors. This assumption has been partially rejected by the results of recently analyzed archaeological records. In fact, foragers could have changed as early as in the central region for agricultural origins, but the form of change could have been different.

## 2. Background of the RHBF Technique

The ridged hammer bipolar flaking (RHBF) technique has been recognized in the eastern region of the upper reaches of the Yangtze River since the discovery and excavation of a series of sites from the Upper Paleolithic to the early Neolithic in recent years. These new archaeological records provide a precious opportunity to learn about the cultural diversity of this region.

The research relating to the RHBF technique began in the 1970s in China. At that time, RHBF flakes were first found at a prehistoric cave site in Guizhou Province [28]. Cao [28] did a preliminary study on these lithic artifacts, and then he named this technique after creating simple experiments. In the report, he described the process in detail: a flat and round boulder used for raw material was brought into contact with the anvil held at a slant, the experimenter firmly held the boulder with one hand and also grasped a hammer in other hand, and then smashed one end of the boulder with the sharp edge of the hammer. Generally, by hitting four or five times, a flake would fall off the boulder. Furthermore, in the following decades, the RHBF technique was reported in many other provinces (Figure 1).

Although the number of sites found in China is not small (Figure 1), due to insufficient understanding of RHBF technology and dating problems in previous studies, a systematic study on this lithic technology has not been conducted. Firstly, the definition is still not clear; the early definition was made based on flakes discovered in the cave site and the experiments we mentioned above. However, some following studies reported this type of technique or flakes as the Yangtze technique [9] or zero-platform flakes [29]. Secondly, although there are some experiments for the RHBF technique in previous studies, they almost all emphasize the special characteristics of the RHBF technique or other artifacts unearthed along with RHBF flakes [10]. However, the technical process and function of RHBF technology, particularly, the meaning of cultural adaptation, have not been deeply explored. Thirdly, chronology of the RHBF technique is still a puzzle. On the one hand, some typical sites located in the wilderness area of South China are difficult to get reliable absolute date, since it is impossible to correlate lithic findings to stratigraphy. On the other hand, some sites with RHBF flakes are rescue excavations, thus the dating obtained in Southwest China is speculative and unreliable.

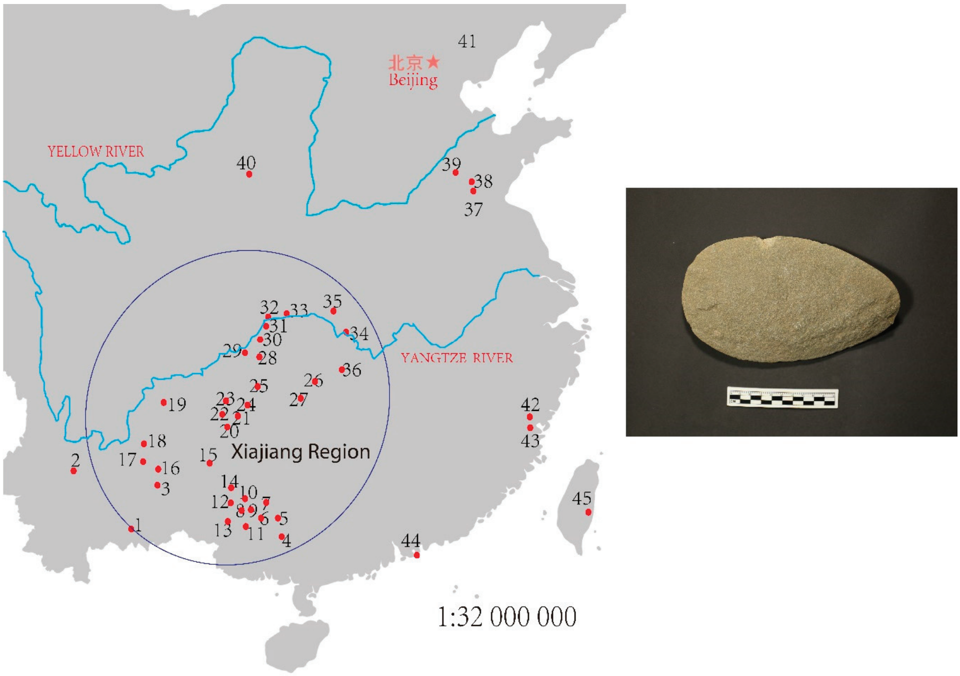


**Figure 1.** The distribution of Ridged-hammer Bipolar Flaking (RHBF) artifacts, China (1:32000000). 1. Ganlanba; 2. Tangzigou; 3. Laolongdong; 4. Baiwei; 5. Gexinqiao; 6. Banang; 7. Bailan; 8. Dongjian; 9. Nalao; 10. Balie; 11. Dingbang; 12. Weibo; 13. Donglong; 14. Yandongpo; 15. Yajiao; 16. FuyuanDahe; 17. Latuo; 18. QujingDahe; 19. Zhangkoudong; 20. Nayong Zhangkoudong; 21. Baiyanjiao; 22. Xiaohuidong; 23. Maomaodong; 24. Chuandong; 25. Ma'anshan; 26. Xinhuang Paleolithic site; 27. Xianrenqiao; 28. Yandunbao; 29. Chibaling; 30. Ranjialukou; 31. Zhongbazi; 32. Qiaojiayuanzi; 33. Ou'tang Neolithic site; 34. Honghuatao; 35. Zhujiatai; 36. Pengtoushan; 37. Xiaomaicheng; 38. Heilongtan; 39. Nanyangwucheng; 40. Zhaojiahuagougoukou; 41. Sifangdong; 42. Chuanfandong; 43. Lingfengdong; 44. Huangditong; 45. Changbin Culture.

The RHBF technique is long-standing in prehistory. The earliest existence of this technique could date back to the early Paleolithic, at a cave site called Wanshouyan in Fujian Province, Southeast China [30]. Additionally, sites in southwest China supposedly have evidence that the RHBF technique lasted until the Shang (c. 1570–1045 BC) and Zhou (c. 1045–256 BC) dynasties [31]. Archaeological sites associated with the RHBF technique are also widely distributed—Southeastern, Northern, and Southwestern China (Figure 1). However, we argue that this specific technique is mainly distributed in Southwest China, especially in the region from the Xiajiang region to the Yunnan–Guizhou Plateau (part of which extends into the territory of Guangxi) (Figure 1). The present paper argues that most sites in other regions of China cannot be classified into RHBF technique sites for three reasons:

(1) Some artifacts lack the important features of RHBF flakes, e.g., greater width than length, and a linearly notched striking point. For example, although the site in Southeast China, Wanshouyan [30] consists of some RHBF flakes, most of them are only in a similar shape of RHBF flakes and lack the diagnostic features of this technique.

(2) The sample size of RHBF artifacts is small, including only a few flakes discovered from sites of North China.

(3) Sporadic discoveries in Southeast and North China have not reported such technique in detail, which makes it difficult to figure out whether they are truly representative of the RHBF technique. Compared with sites in North and Southeast China, sites in the southwest that report RHBF techniques are numerous and mostly cluster in the Xiajiang region. Some of them are also much more clearly described in reports, which provides more compelling contextual evidence to prove the primary existence of RHBF techniques in Southwest China.

## 3. Materials and Methods

In this study, the Guanzhou site (Figure 2) was examined based on the observations of lithics and archaeological experiments conducted in 2018. The Guanzhou site, a typical RHBF site, was excavated by the Hubei Provincial Institute of Cultural Relics and Archaeology in 2016. The site is now located on an eyot or small island in the Yangtze River (Figure 2), which was once connected to the shore about the time before the Ming and Qing dynasties (Ming dynasty tombs were also found on the island, but no later tombs were found). This landform was then cut off from the right bank of the river by a flood and became an eyot. The 2016 excavation unearthed more than 8000 pieces of lithic, of which more than 2000 pieces were RHBF flakes. Among the most exciting and uncommon artifacts were hammers, anvils, and lithic cores—from the RHBF technique—were also discovered, which have provided us with valuable materials for reconstructing this unique lithic technology. Carbon-14 dating indicates this site could date back to around 8500 years ago [32], the early Neolithic. Similarly, sites with rich RHBF flakes are also known as the Cibingzhou site (the report of this site has not published yet, however, we have visited this site during summer, 2019 and observed the unearthed artifacts) and Maomaodong site in Guizhou [33,34], as well as the Tangzigou site in Yunnan [35]. During the PNT, the popularity of RHBF technology seems to reach its peak, and was widely distributed in China, especially in the Xiajiang region [36]. In 2019, we inspected the excavated materials at relevant sites in Guizhou, Yunnan, Guangxi, Hunan and other provinces, and confirmed the existence of RHBF techniques in these areas.


(**a**) (**b**)

**Figure 2.** The location of Guanzhou site. (**a**), 1:8,000,000; (**b**) 1:500,000.

The Paleolithic–Neolithic transition occurred worldwide, at least in Eurasia, but different regions do not share the common pattern as can be seen in representative local materials. The eastern region of the upper reaches of the Yangtze River in this study are represented by RHBF technology. In other words, the rise and fall of RHBF technology can better reflect the process of the PNT period in this area, and not only can this show changes in livelihoods, to some extent it, can also show changes in social organization. The method adopted in this article was used to combine the sample analysis and archaeological experiments with ethnoarchaeology to reconstruct the RHBF technology and the function of RHBF flakes, and on this basis, to further understand their meaning in terms of division of labor. Furthermore, we will also draw on the evidence of ethnoarchaeology to support our reasoning.

In the past ten years, we have carried out a series of experimental archaeological studies of stone tools [36–38], which helped us to analyze lithic production and form a set of effective methodologies. Our study can be divided into four levels as follows (Figure 3).

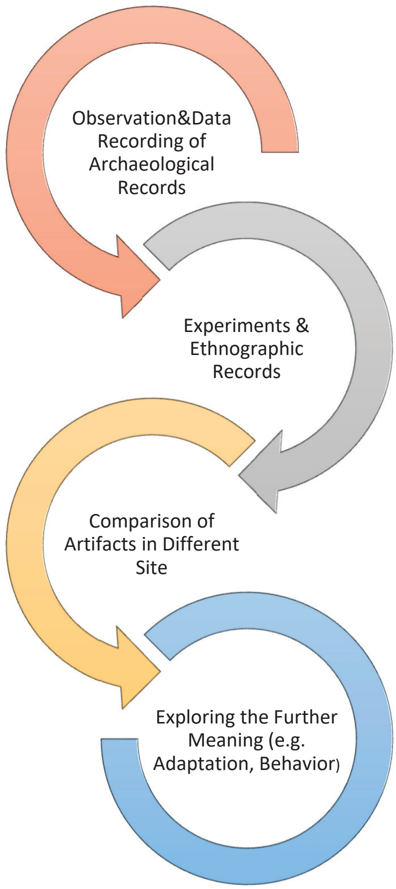


**Figure 3.** Four steps in lithic analysis.

Firstly, observations of the characteristics of the archaeological artifacts, including the classification and description of artifacts, the observation of the use-wear, the analysis of the technology process, and the preliminary assumption of the artifact's function. Secondly, experimental archaeology and looking for other reference information to support our assumption, such as ethnographic reportage. Thirdly, comparison of artifacts from different sites by considering the local ecology to further verify our judgment. Finally, further explore the meaning of cultural adaptation behind the artifacts or technique. This methodology has been used to analyze the relationship between the prehistoric stone industry in western Liaoning and primitive agriculture; since stone tools are usually the most complete archaeological materials, the analysis of lithics can provide an important reference to understand cultural as well as evolutionary significance in different periods. Therefore, the following section will use this methodology to explore the significance of RHBF technology during the PNT. In this study, the reasoning and analysis will be developed in the following steps:

(1) The observation and data recording of lithic artifacts (c. 8000 pieces) from the Guanzhou site, including length, width, height, weight, types of use-wear, position and level, breakage and so on.
(2) Replication experiments conducted on the bank of the Yangtze River adjacent to the Guanzhou site. Seven experimenters participate: 2 young male students, 2 young female students, 2 experienced males who have conducted lithic experiments for several years, and 1 less experienced male.
(3) Comparative experiments with other lithic techniques, such as throwing, anvil and hammer techniques.
(4) A functional experiment aimed to examine the usage of RHBF flakes.

Among the four steps, two key issues need to be addressed. On the one hand, the experimental location is important. Before the flood separated the Guanzhou site from the bank, the experiment location was connected to the site at about 250 m. The close distance between the experimental location and the site means that they share a similar ecological environment, both locales are covered with gravel, and the raw materials are the same as those found in the site so that equivalent ecology and raw material as the Guanzhou site could be easily accessible. On the other hand, comparative experimentation is significant because it is a way to figure out if other lithic techniques can produce the same flakes—although the RHBF technique is regarded as a throwing or anvil technique in previous studies. Since the comparative experiment is not closely related to topic of this study, the result of the comparative experiment will be not shown in the following section.

## 4. Result

### 4.1. Observation

Our investigation found that the most distinctive product of RHBF technology is the RHBF flake (Figure 4). From morphological observations, the ventral surface is very flat (Figure 5), with almost no bulb of percussion or striking platform, so it was also termed a zero-platform flake by Li [29]. The striking points are usually in a linearly concave shape, which is obviously different from the striking points of other techniques, which usually produce obvious bulbs of percussion. According to the measurement statistics of 2167 RHBF specimens unearthed from the Guanzhou site, such flakes often have a greater width than length (Figure 6), with an average length of 76.2 mm and a median of 73.2 mm, an average width of 96.2 mm as well as a median of 93.2 mm. The average thickness was 15.8 mm, and the median was 15.8 mm (Figure 6). If specimens with a thickness greater than 30mm are excluded, which are also extremely large specimens, then the thickness variation range of the stone pieces is very consistent [36]. In other words, RHBF flakes are the products of a highly consistent operation. Furthermore, by collecting data from 14 sites' reports, we found that the average length of RHBF flakes is 82.1 mm, the average width is 95.6 mm, and the average thickness is 19.1 mm, which is similar to what we get in Guanzhou site, although the amount of data from other sites is not large: only data from 22 pieces' flakes are accessible [36].

Based on these observations, some assumptions regarding the function of RHBF flakes can be developed. The edges of these flakes are thin, sharp and the design and the shape are very suitable for cutting activities, so we assume such flakes can be directly used as scrapers or knives. However, due to the obvious feature of thickness, RHBF flakes are not suitable for cutting large or tough items, such as thicker branches of trees. In addition, because larger RHBF flakes also have advantages in terms of weight, they can also be used directly for chopping activities—an alternative hypothesis relating to function. Additionally, the coexisting lithic tools found at the Guanzhou site may rationalize our assumptions. More than 400 scrapers and 200 chopping tools were found in the site. The majority of scrapers are made from RHBF flakes, the so-called repairing wear of which are mostly caused by use. Additionally, most scrapers have no obvious breakage: the edge is smooth, which also indicates the processing object should be not so hard or even soft. As to chopping tools, most of them are also made from RHBF flakes, but are much larger and heavier when compared with the RHBF flakes of scrapers. Furthermore, RHBF cores are important materials for making chopping tools.

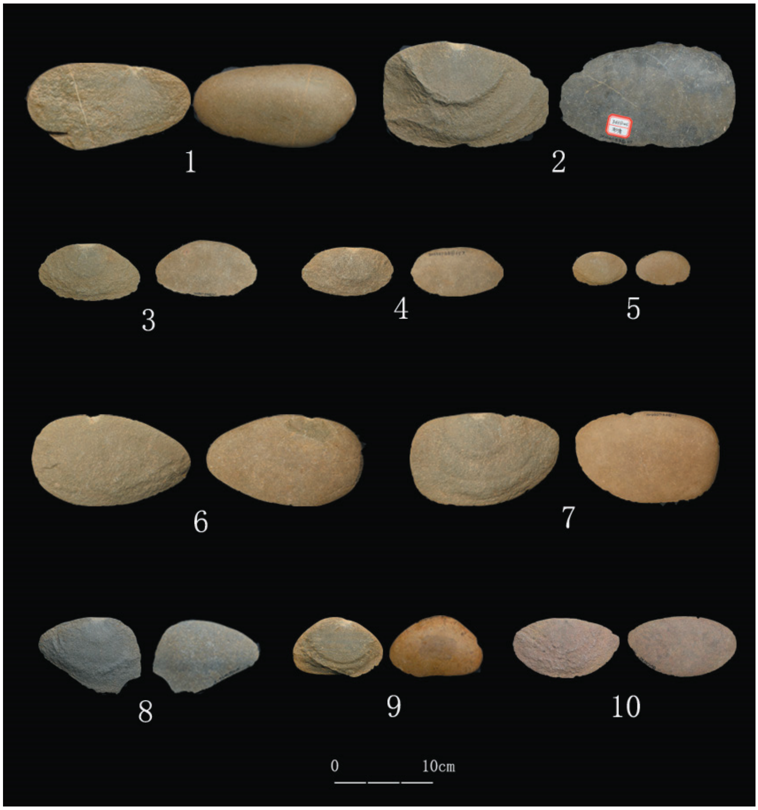


**Figure 4.** RHBF flakes in Guanzhou site. 1. 2016SGT1818⑤11; 2. 2016SGT1818⑥415; 3. 2016SGT1818⑥505 4. 2016SGT1818⑥657; 5. 2016SGT1818⑥751; 6. 2016SGT1819⑦82; 7. 2016SGT1919⑤7; 8. 2016SGT2019⑤5; 9. 2016SGT2019⑤11; 10. 2016SGT2119④60-1.

(**a**) (**b**)

**Figure 5.** RHBF flakes in Guanzhou site: (**a**) ventral side, (**b**) dorsal side.

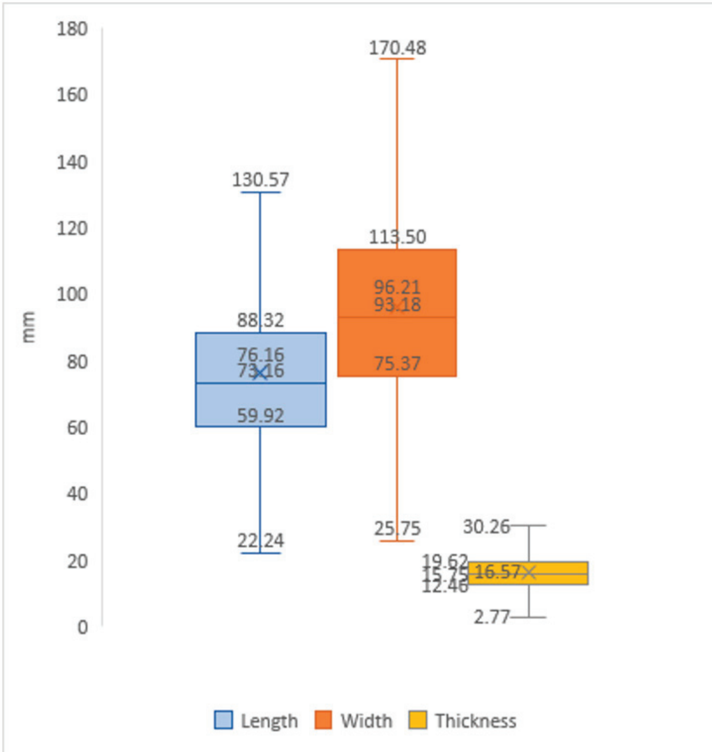


**Figure 6.** Length, width and thickness of RHBF flakes.

The observation of lithic artifacts in the Guanzhou site also sheds light on the process of the RHBF technique. For example, several hammers found with RHBF flakes and tools show significantly different features from hammers found in other archaeological sites. Hammers unearthed in Guanzhou site are cobbles in oval shape with a great size (c. 238 mm) and weight (c.1408 g) that cannot be easily held by one hand. In addition, striped collision marks are mainly concentrated in the middle of flat side (Figure 7) which is unique and different from the point-like use-wear of other hammer techniques. Because there is no use-wear at both ends of the hammer, we may assume the way to use it is holding it with both hands to produce flakes. Besides, the striped use-wear (Figure 7) in the middle of RHBF hammers also indicates that hammers struck an extremely narrow and linear platform, in other words, the raw material was once placed at an angle so that only the edge of the raw material could be struck with the hammer.

### *4.2. Replication Experiment*

In the replication experiment, the key was how to place the raw material securely. Several methods have been tried, including hand-held, stone-placement and mud-placement methods. The hand-held method is extremely dangerous and unlikely to be chosen because it is easy to get injured and holding a large hammer in one hand also makes it difficult to produce enough percussion power. Besides, it is also impossible to use other small stones to support the raw material, since the raw material cannot be steadily fixed in such a situation. Later, wet mud was considered for the location of the site, as this is easily accessible at the riverbank. The wet mud experiment is efficient in terms of supporting the raw material and tilting it slightly on the flat anvil (Figure 8).

**Figure 7.** RHBF hammer (2016SGT2019⑦109).


**Figure 8.** Wet mud fixing.

After exploring a method for setting up raw material, the replication process becomes much easier to figure out. Firstly, in order to reduce the counterforce from the anvil, the anvil is buried in the sand. Secondly, the operator lifts the stone hammer with both hands over his or her head (Figure 9), and then strikes the raw material with the help of gravitational potential energy. Generally, a flake can be produced after two or three times of striking. The characteristics of the experimental flakes are exactly the same as those in the site, suggesting the application of this method in the experiment might be the one employed by the person who produced the flakes during the Pleistocene. Experiments revealed two unique features of the RHBF technique. One shows that the RHBF technique is highly reliant on raw material. In the experiment, each boulder can usually only produce one flake, and the reason is because of a lack of a perfect flat form with regard to the boulder; in other words, once the core is split the position of the striking point becomes too thin to produce more flakes. Therefore, such technique is wasteful unless the raw materials are abundant, and such an uneconomical technique also indicates a local raw material source. The other feature of the RHBF technique concerns gender and labor division. In the experiment, female operators also participated and found that such technique is simple enough that even students who have no experience in lithic production can successfully produce RHBF flakes. Thus, we may assume that since such technique is not restricted to one gender, and so labor division could be further explored.

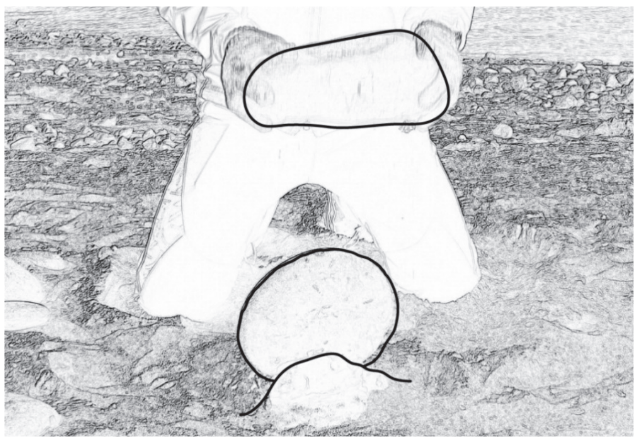

**Figure 9.** RHBF technique process.

*4.3. Functional Experiments*

Along with RHBF flakes and tools, a high number of fish bones were also discovered in the Guanzhou site. Taking the site location into consideration, an assumption relating to fish processing was examined in functional experiments. Experimental research shows that RHBF flakes are extremely effective for scaling (Figure 10). On the one hand, RHBF flakes are knife-like, and are thin enough to be scrapers. On the other hand, the edge of RHBF flakes is not sharp as knife, so when scaling, it cannot cut into the flesh. Furthermore, RHBF flakes are also efficient in cutting off parts of fish such as the belly, tail and head. We processed four grass carp of about 2000 g in total, which took an average of 10 min. After a period of practice, and with some supplemental tools with sharp points that could be used to pierce the belly, the processing time can be greatly reduced. Moreover, the site faunal remains show that fish caught here are mainly herring, with large individuals that can reach tens of kilograms. Thus, effective scrapers must be used to handle such large catches. The RHBF flakes are usually regular in shape (Figure 4), knife-like, and the sharpness of the blade edge is also appropriate for fish processing. Interestingly, in the Guanzhou site, fish bones are concentrated in the earlier stratum which contains a lower amount of RHBF flakes compared to the upper stratum. The inconsistency between the amount of fish bones and flakes in the strata suggests changes in fish processing that could be linked with mobility patterns: in the earlier period, people tended to conduct fishing, processing, and consumption on site; at the later stage, because of a greater need of food, people carried their catch to the settlement to process and consume, which may reflect logistical mobility, a possibly more specialized society, and labor division.


**Figure 10.** RHBF flake used for fish scaling.

## 5. Discussion

### *5.1. Aquatic Adaptation in East Asia and the RHBF Technique*

Although aquatic resources are abundant and relatively accessible, most models of human evolution have all but ignored the role of aquatic or maritime adaptations during the earlier stage of human history [39]. Besides farming, the use of aquatic resources is also an important adaptation during the PNT, especially in East Asia. By research on the organic residue of Neolithic pottery from Sakhalin Island in the Russian Far East, Gibbs [40] state that early pottery on Sakhalin was used for the processing of aquatic species, and that its adoption formed part of a wider Neolithic transition involving the reorientation of local lifeways towards the exploitation of marine resources, and other evidence in Russian far east also supports the aquatic use in hunter-gatherer groups [39]. In Japan and Korean, there is also evidence showing that people in the upper Paleolithic and PNT have access to the aquatic resources [41–43]. In China, sites in the PNT indicate there is a potential adaptation strategy relating to aquatic resources, and based on what we mentioned above, the RHBF technique has a potential in aquatic utilization.

The RHBF technique is mainly distributed in the Xiajiang region, where a mountain and gorge area are located in the middle reaches of the Yangtze River. Unlike the plains area of the Yangtze River, the Xiajiang region is not a center for agricultural origins. However, the rise of the RHBF technique may indicate there is an alternative pathway in the cultural evolution during the PNT. Cibingzhou, another site found recently in Guizhou Province, could also support our hypothesis of an alternative strategy in the PNT. Interestingly, the Cibingzhou site shares many similarities with the Guanzhou site. First, the artifacts found were from the same period, the PNT. Secondly, the Cibingzhou site is also located on an eyot that was originally connected to the shore. Additionally, the river was diverted recently, and erosion cut off the eyot. Finally, and most importantly, a large number of RHBF artifacts have been unearthed in the Cibingzhou site. Thus, judging from current records, sites with many RHBF flakes are mostly found near rivers or other water resources, and appeared around 8000 years ago. Because there is a possibility that the RHBF technique is suitable to process fish, based on the functional experiment, it is reasonable to assume that sites near water and containing RHBF artifacts may reflect dependence upon aquatic resources such as fishing. The use of aquatic resources could be an option for people living in areas that are marginal for agriculture. Moreover, fishing, as an adaptive way of enhanced utilization for hunter-gatherers in nonagricultural areas can relieve subsistence pressure on growing populations. Socially complex societies can potentially form if aquatic resources are rich enough, such as those known on the northwest coast of North America.

However, most results of aquatic utilization are based on pottery or the residue on pottery, and so a lithic analysis may not be the direct way to draw a conclusion on whether the RHBF technique is used for aquatic resources. Thus, three important things need to be addressed in future research. Firstly, a use-wear lithic analysis should be conducted to test if RHBF flakes are used to process fish. Secondly, pottery analysis and residue research should be taken into consideration. Thirdly, complete research on the fish bones discovered in the Guanzhou site should provide more information relating to aquatic utilization, which cannot be ignored.

*5.2. The Adaptation Patterns in Different Regions during the PNT Period*

During the PNT, there were several patterns in China for responding to the ecological and social changes: wheat agriculture in North China and rice agriculture that originated on the plains of the middle and lower reaches of the Yangtze River. In the region south of the Five Ridges, this change manifested as "low-level food production" [44], which is a mixture of rhizome planting, aquatic resource utilization, and hunting and gathering. In the northeast region, the end of the Pleistocene saw an increase in effective precipitation, and the use of aquatic resources began around 12,000 years ago. A series of sites appeared along rivers and lakes, forming the so-called "fishing and hunting of the Neolithic Age" [45]. The Yanshan Great Wall zone in North China is located in an ecologically interlaced zone, and local livelihood patterns throughout the Neolithic era fluctuated between hunting and gathering and agriculture along with climate change [46]. There has been a long-term lack of investigation regarding adaptation strategies in the grassland area in the PNT. However, recent investigations and excavations of a series of sites of Yumin culture (the materials and reports on the Yumin cuture have not been published, the information here is based on some of our investigation and observations of artifacts of Yumin culture) have explored the changing processes of the grassland area: an adaptive method that maintains obvious seasonal utilization, which can be distinguished between winter and summer. In the southwestern region, there is a partial overlap with the area discussed in this article: the continuous hunting and gathering and maintaining usage of stone tools, which is also called "post-Paleolithic era". However, what our studies have addressed here is the diversity of this post-Paleolithic era, since at least three adaptation strategies can be distinguished. With the advent of the Holocene, RHBF technology brought a significant differentiation of cultural adaptation. From the current materials, at least three different cultural adaptation methods include the following. The first occured in the upper and middle reaches of the Yangtze River transition zone where some population groups moved toward the center of the origin of agriculture, then these groups continued to spread into the plains and reclaim new farmland. Such spreading trends can be seen from the distribution features of the sites from the PNT to the late Neolithic period. Later agriculture dispersed from the edge of the basin to the hilly area in the early Neolithic period, and then entered the Jianghan Plain and Dongting Lake Plain in the middle and late stages. The second adaptation strategy was found in both the transition zone and some areas of in eastern upper reaches of the Yangtze River, where it is more convenient to use aquatic resources. During that time, hunter-gatherers began to emphasize the use of aquatic resources, a strategy which produces results similar to agricultural production in that it can also result in a higher population density and social complexity. The third adaptation strategy took place in areas that are neither suitable for early agriculture nor for the use of aquatic resources, where population groups continued their previous hunting and gathering living style. However, there is a possibility that other methods were used to control population growth, which could ensure that the population density was maintained at lower levels than the local carrying capacity if the population groups here only relied on hunting–gathering for living.

In the second strategy, groups took full advantage of the RHBF technique, which endured for a prolonged time and reached a peak in these areas; even as late as the Shang and Zhou dynasties, this technique could still be found. However, since the development of agriculture played the main role in the first strategy, RHBF technology was eventually replaced by the development of tools for processing crops, such as grinding tools. In the third strategy, RHBF technology was used to a certain extent, but not though a monopolistic technique, as other bipolar or percussion techniques still existed concurrently.

The PNT happened in Asia. For example, pottery has been discovered from 10,000 years ago in most Asian areas. Since pottery is a product of intensification [47], to some extent representing the changing trends of residency, we can be sure that the transition was a universal event, although the transition varied in time, space and strategies. Particularly, the adaptation in Southwest China, especially from the perspective of lithics, calls for further exploration since it shares some strategies with all of Asia. For example, lithic assemblages from southern Yunnan are similar to the Hoa Binh culture, an important archaeological assemblage found in Northern Vietnam [48–50]. This reflects a special adaption strategy that occurred in Southeast Asia.

### *5.3. The Possibility of Labor Division*

Similar lithic artifacts are found around the world, especially in North America. The Shoshone of western interior North America used similar tools called teshoa [11]. Such records provide a clue about the process of the RHBF manufacturing technique as well as tool function. A teshoa is kind of stone knife used by Shoshone women to process hide and meat. "When a woman needed a knife for butchering and skin dressing, she selected two quartzite cobblestones from the nearest stream; she then used one as an anvil to knock a large spall from the other. When the edge of the teshoa had done its job, it could be discarded, and a new one could quickly be made whenever it was needed" [51]. Such ethnology records show not only the process of teshoa manufacturing but are also consistent with our assumption regarding labor division. Among our experiments, results show that the RHBF technique is compatible with producing large amounts of flakes in a short time: students without much experience in lithic production can make RHBF flakes effectively because such techniques do not require percussion strength and experiences; thus people of all ages and genders can accomplish it easily.

However, the ethnographic records relating to labor division in China, especially the Xiajiang region, are still unclear, and thus, research on teshoa can only provide us with a possible hypothesis regarding labor division for the RHBF technique. In addition, based on our experiments, the results indicate that the female students and/or young people could conduct such a technique, and all were efficient in using flakes to process fish. Nevertheless, further research is needed to test such a hypothesis.

## 6. Conclusions and Further Suggestions

The RHBF technique is representative of the Xiajiang region during the PNT, which indicates a possible emphasis upon aquatic resources. This hypothesis is also supported by our experiments and ethnographic records. Additionally, the RHBF technique also shows diversity in the adaptation behaviors of the PNT in terms of not being restricted to agriculture—people living in marginal areas for agriculture adopted much more diverse and complex hunting and gathering strategies to support their subsistence. However, such an alternative adaptation and RHBF technique still need further exploration, since there is no systemic analysis of fish bones unearthed in the sites of the Xiajiang region. The lack of local ethnographic records calls for further consideration of the gendered division of labor. Furthermore, the compelling topic of complex hunter-gatherers also needs to be further addressed: is intensification through the use of aquatic resources a pathway to a complex society in China [52], and is division of labor a possible signal? More archaeological materials, especially evidence for sedentism, will be discovered and studied in marginal areas for agricultural origins, particularly in the Xiajiang region.

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# Modeling Incipient Use of Neolithic Cultigens by Taiwanese Foragers: Perspectives from Niche Variation Theory, the Prey Choice Model, and the Ideal Free Distribution

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**Abstract:** The earliest evidence for agriculture in Taiwan dates to about 6000 years BP and indicates that farmer-gardeners from Southeast China migrated across the Taiwan Strait. However, little is known about the adaptive interactions between Taiwanese foragers and Neolithic Chinese farmers during the transition. This paper considers theoretical expectations from human behavioral ecology based models and macroecological patterning from Binford's hunter-gatherer database to scope the range of responses of native populations to invasive dispersal. Niche variation theory and invasion theory predict that the foraging niche breadths will narrow for native populations and morphologically similar dispersing populations. The encounter contingent prey choice model indicates that groups under resource depression from depleted high-ranked resources will increasingly take low-ranked resources upon encounter. The ideal free distribution with Allee effects categorizes settlement into highly ranked habitats selected on the basis of encounter rates with preferred prey, with niche construction potentially contributing to an upswing in some highly ranked prey species. In coastal plain habitats preferred by farming immigrants, interactions and competition either reduced encounter rates with high ranked prey or were offset by benefits to habitat from the creation of a mosaic of succession ecozones by cultivation. Aquatic-focused foragers were eventually constrained to broaden subsistence by increasing the harvest of low ranked resources, then mobility-compatible Neolithic cultigens were added as a niche-broadening tactic. In locations less suitable for farming, fishing and hunting continued as primary foraging tactics for centuries after Neolithic arrivals. The paper concludes with a set of evidence-based archaeological expectations derived from these models.

**Keywords:** Paleolithic Taiwan; aquatic-focused foraging; Neolithic Taiwan; agricultural adoption; niche variation theory; invasion theory; prey choice model

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## 1. Introduction

> "... *these vast and largely uncharted [transitional] regions are not just uninhabited territory crossed on the way to an anticipated agricultural destination by evolutionary interstates without exits. They are, to the contrary, regions occupied by diverse, vibrant, and successful human societies that have developed stable, long-term economic solutions that combine low-level reliance on domesticates with continued use and management of wild species*" [1].

Research into the encounters, interactions, and knowledge transfer between hunting and gathering peoples and agriculturalists began with collection of field data in the 1960s and 70s. Hunting and gathering societies were observed using a range of interaction strategies from unilinear agricultural adoption to sustained symbiosis founded on forest product exchange [2]. Interaction studies continued with cultural history investigations and pattern recognition in the 1980s and 90s, and moved toward the synthesis of the ways that variability in relationships can lead to greater understanding of human social change [2,3]. This observed variability is germane to understanding evolutionary relationships, and framing archaeological expectations for major transitions such as the Neolithic.

The topic of agricultural adoptions by island hunter-gatherers offers perspectives on Neolithic onsets, particularly regarding the influences of aquatic resources, immigration, demographic pressure, constraints on mobility, and migrations [4,5]. Taiwan's biogeographic position at the east–west nexus between Southeast China and the islands of the Pacific Ocean and the north–south nexus of the Japanese archipelago and SE Asia places it at the intersection of diverse climates and ecosystems and the center of a cultural and adaptive interaction sphere rooted in the Paleolithic. As such, the island is an important case study with relevance for the Neolithicization of coastal and island Southeast Asia and eventual Austronesian expansions across Oceania [6–13]. The Neolithic onset of Taiwan is notable for its late date of circa (c.) 6000 BP compared to mainland China [10–14]. Neolithic cultures proceeded to expand, become regionally differentiated, and complex at a rapid rate: by 4500 BP, agriculture-based societies had radiated to most of the island, growing millet, rice, tubers, and tree crops; Middle Neolithic settlements are marked by social ranking, megaliths, production of prestige goods, and sizeable structures and features [15–17].

The nature of the initial interaction with Paleolithic groups, which established the foundations for the decline of foraging and replacement by agriculture, is not yet well understood, although most Taiwanese researchers agree that Neolithic cultures are not directly descended from Upper Paleolithic peoples [16]. Where might we find reference information about the adaptive responses of native Paleolithic foraging peoples to invasive dispersals of Neolithic immigrants? A promising area is the evolutionary study of various non-human species in order to better understand the process and its outcomes. With specific reference to subsistence changes associated with invasive dispersals, behavioral ecologists have investigated and described important parameters that influence the decision making of migrating individuals as well as the attendant costs and benefits to dispersers [18,19]. The adaptive response of native populations—who are 'dispersed upon'—is less well studied, but of particular evolutionary interest in the case of Neolithic transitions. The decision-making process for groups facing unfamiliar crop foods and cultivation techniques, their assessment of opportunity costs to mobility needed for food, technological materials, social networks, and other resources [2,20–22], and the ensuing societal and environmental feedback loops make up the localized and evolutionarily significant initial conditions of food producing societies.

In order to derive a working hypothesis about the adoption of agricultural practices by Paleolithic hunter-gatherers experiencing invasive migrations, this paper describes Taiwan's unique geographic position and biodiversity, summarizes current environmental and archaeological knowledge about the transitional Paleolithic to Neolithic transitional period, models Late Paleolithic foraging niche breadth using Lewis Binford's database of hunting and gathering peoples, and assesses the implications of niche variation theory, the prey choice model, and the ideal free distribution for mutually influential adaptive responses of Paleolithic Taiwanese foragers and arriving Neolithic Chinese farmer-fishers. Predicting variations in this process has important implications for settlement, the adoption of cultivation, and social integration by native foragers. The paper concludes with proposed lines of evidence for hypothesis testing with the archaeological record.

A note on spelling: for Chinese words, the Pinyin system of romanization is used except in the case where the Wade–Giles system is used for longstanding and familiar names. For Taiwanese indigenous words, Romanized versions that are commonly accepted in the scholarly literature are used. For site dates, BP or BC are used as presented in cited sources.

## 2. Human Behavioral Ecology and Subsistence Strategies of Invasive Dispersals

Human behavioral ecology (HBE) has developed an array of intellectual tools to explore the dynamic relationships between organisms and the environment using an evolutionary framework [23–28]. In comparison and complementary with macroecological models that explore broad patterns in extant data, concept models are derived from the principals of natural selection and general theory of behavior. These models seek to link behavior to expected material outcomes [28]. The development of testable hypotheses regarding the cumulative effects of decisions and broader patterns of evolutionary change aspire to bridge these two scales of analysis [26,29].

From early studies in optimal foraging, HBE is now exploring the socioecological contexts influencing why individuals modify their environments, move to new places, begin to produce food, and enter into cooperative or coercive social relations [26]. The ideal free distribution and its corollary, the ideal despotic variant [30] provide an explanatory framework to predict when individuals will disperse or migrate to a new habitat, based on density-dependent changes in the suitability of the habitats available to them [31]. This model ranks habitats by their quality, assessed by the fitness of the occupants. The Ideal Free Distribution (IFD) assumes that a dispersing organism will decide to settle in the preferred option of several habitats that differ in suitability (e.g., availability of resources, exposure to hazards, and other characteristics). Desirable habitats are occupied chronologically in rank order, presuming no competition from others. The ideal despotic variant (IDV) highlights immigration and differential access to resources, in which groups seeking to settle in already-occupied highly ranked habitats are deterred from entry by defense and are thereby forced to settle in lower-ranked locations. The habitat implications for this model can be provocative: the Allee effect [32] can result in positive feedback effects of population density in contrast to density dependent resource depression. Fruitful assessments of the Allee effect include North America and Australia, where certain prey types predicted by the Prey Choice Model (PCM) would be pursued on encounter and increase population size with increasing land use intensity [33–35]. The ideal free distribution has also been examined in island habitats, immigration, and settlement in Polynesia [31], California [36], and will be the focus of a future paper concerning Taiwan [37].

Returning to the impacts of dispersing farmers on foraging, the niche concept is foundational to both behavioral ecology and macroevolutionary approaches. Binford's [20] definition of niche is the dynamic articulation between the capabilities of a group of 'actors' and the organizational properties of their habitat: the types and quantities of resources as well as how, when, and why actors use them. A foraging niche is positioned along a continuum from specialized to generalized, in which generalized actors feed on a greater proportion of the species available in the habitat, and specialized actors feed on a smaller proportion [20,38]. Foraging niches are in a constant state of flux through adaptive responses to changes in prey or resource type, frequency, and distribution. Organizational properties of the habitat influence the distribution and frequency of prey. The process by which individual foragers take into account energetic costs and returns when encountering potential prey (including plants) is described in the encounter-contingent prey choice model (PCM) [39,40]. With a stipulated goal of maximizing net energy returns, the order of ranking for prey is determined by the evaluation of which items to take upon encounter [26,41–45]. The prey choice model predicts that, all other things being equal, high ranked resources will always be taken upon encounter, but lower ranked resources will only be taken if they will increase the overall return rate (expressed as energy/time). Under conditions of resource stress, the reduced encounter rate for highly ranked resources increases the likelihood that lower ranked resources will be taken. The implication is that scarcity of high ranked resources tends to encourage a broader dietary niche as energetic costs of the search eventually overwhelm the advantages of being selective.

During invasive dispersals of morphologically and functionally similar populations into occupied territories, the overlap between niches that results from similar prey choices increases competition, depresses prey, and in turn narrows the niche breadth of both dispersers and natives [46]. With regard to invasive immigrations, understanding the initial contexts and processes of competitive interactions provides an important benchmark for predicting the long-term consequences of invasion. Foraging niche breadth is one such factor: a broad or generalized foraging niche is considered to be key in determining the success of dispersers [46], but less is known about the effects upon pre-existing niche breadths of native species. Generalized native foraging niches would provide a wider range of prey options under competitive pressure; therefore identifying conditions for niche generalization versus specialization is helpful in characterizing niche breadth.

Niche variation theory describes the process of 'ecological release' by which foraging niche breadth broadens and diversifies when inter-species competition is reduced [18,47–50]. This mode of niche expansion increases foraging variation among individuals (or groups) rather than individual niche breadth. Subsequently, within-population variation is a key requirement for frequency-dependent interactions that may drive evolutionary diversification and influence the population dynamics and ecological interactions of species [18] (Figure 1).

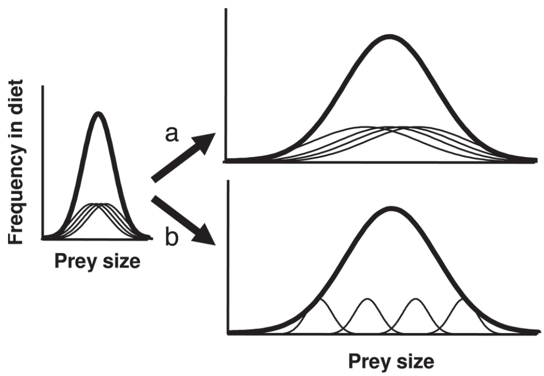


**Figure 1.** Two alternative patterns of population niche expansion. A population that uses a narrow range of prey sizes can increase its population niche breadth (bold lines) in two ways. (**a**) Inter-group niche breadths (thin lines) can expand, resulting in no increased niche variation among individuals. (**b**) Individual group niche breadths can remain limited, whereas groups diverge from each other to increase among-group variation (after [18], used by permission of lead author).

The obverse of ecological release—competitive pressure—is predicted by "classic invasion theory" (*sensu* [38]). A successful invading group may displace similar native species by overlapping their niche through direct competition for preferred prey. A generalist diet is a common trait of successful invaders, allowing them to exploit diverse resources in novel environments, competitively exclude native species, and breed successfully [51]. Under this theory, the decline of native species following an invasion may be a consequence of direct interspecific competition for prey e.g., [52,53]. If species occupy a larger niche in the absence of interspecific competition [50,54] under conditions of competition, both dispersing and native species are expected to occupy smaller niches than their allopatric equivalents [55]. In a potential variant, increased competition for resources could necessitate an increase in dietary niche breadth in order to maintain energy requirements [56] (also see below). Empirical evidence for different taxa indicates that interspecific competition can cause the niche widths of consumers to increase or decrease, depending on the context [57], with generalists having more capacity to increase dietary niche breadth. Niche breadths of both dispersing and native competitors is an important contextual factor in determining invasion success and predicting the impacts of invaders on biodiversity and foraging niche (e.g., [46,58]). The human foraging niche is highly flexible and may expand, contract, or shift; under some circumstances, the diets of different groups may functionally be as disparate as separate species. All other things being equal, in the early phases of invasion, native populations with a broad dietary niche are expected to have more adaptive options when facing competition.

Behavioral ecology applications have largely focused on in situ domestication or local adoptions of plant foods by landlocked human groups including intensified use of wild species and the domestication process for early cultigens [3,41–45,59]. Gremillion and Piperno [42] employed the prey choice concept to predict the manipulation of low-ranked plants that eventually became fully domesticated seed crops. In the case of invasive competition, the prey choice model predicts that dispersing competitors' appropriation of a higher proportion of available resources would incentivize natives to consider including unfamiliar, and (at least initially) low-ranked prey in the diet. Of course, there are limits to the expansion of niche by incorporating lower ranked prey items; eventually low ranked options are exhausted. The niche construction theory [59,60] employs Elton's [38] concept of an organism or population that modifies habitats to enhance energetic rates of return. With regard to plant domestication, there is room for debate regarding the onset of niche construction as a maximizing strategy during times of resource abundance (*sensu* [60,61]) or a Malthusian response to resource depression [59]. The latter approach is germane to resource depressions such as those we expect to follow invasive dispersals. A niche construction tactic like agriculture could initially offset direct competition for forager resources by providing an additional food source, but as foraging complements most traditional farming diets, it is expected that highly preferred wild resources would become depleted within a certain radius of sedentized farming communities. Therefore, a correlation to the working hypothesis for the Taiwanese Neolithic is that niche construction practices of immigrating farmers reduced mobility and limited foraging to the surrounding area. Preferred wild prey would rapidly become depleted in these areas, reducing encounter rates for native foragers. The harvest of lower ranked prey would broaden the subsistence niche for both the forager and farmer in these locations, and when the limits of low ranked prey are reached, foragers would be faced with two alternatives: adopt agricultural practices or migrate. This process is predicted for areas where farmers settled initially in direct overlap with forager territories.

A hypothesis may now be developed for the Neolithic transition of Taiwan: *If the assumptions of PCM hold*, with increasing land use intensification, high ranked wild prey should rapidly become depleted in areas of high suitability, reducing encounter rates for native foragers. The harvest of lower ranked prey should broaden the subsistence niche for both foragers and farmers in these locations, and when the limits of low ranked prey are reached, foragers would be faced with two alternatives: adopt agricultural practices or migrate. This process is predicted for areas where farmers directly overlapped with forager territories.

*If assumptions of an IFD with Allee effects hold*, we expect to see an initial increase in habitat suitability associated with habitat modification resulting from farming and/or intensified foraging, and associated increases in encounter rates for certain prey types that do better with heterogeneous vegetation and successional communities. In this modified expectation of niche variation theory, ecological release and niche variation resulted not from decreased population densities and resource demand, but manipulation of habitat characteristics that increase encounter rates.

The utility of model-based approaches for formulating explanations about evolutionary transitions of human subsistence is mediated by the scientists' ability to make testable inferences about the foraging niches of individuals and societies that we cannot observe directly. The archaeological remains of past dietary behaviors serve as the basis—albeit imperfectly preserved—for inferences regarding prey choice and variations in niche breadth (Figure 2; see also [26]).

Assembling reference knowledge about processes that are germane to, but independent of, past phenomena of interest can complement limited evidentiary data to help guide archaeological research questions [20,29,62–64]. Behavioral ecology concept models can be informative about the dynamics at the level of the individual, and assist in the development of hypotheses about systems that can be assessed with archaeological data. The case of the Taiwan Neolithic offers an opportunity to examine reference information about foraging niches from a mountainous island habitat.

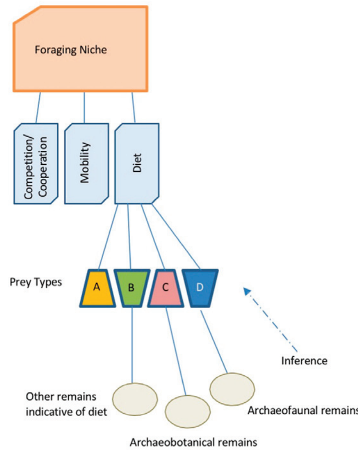


**Figure 2.** Relationship of niche to diet, prey types, and archaeological inference.

## 3. Materials and Methods

To scope a test for the effectiveness of the prey choice model versus the ideal free distribution with Allee effects, the paper first modeled Paleolithic foraging to create a ranking of wild prey types preferred by foragers. This is followed by a summary of the salient characteristics of Taiwan's first farmers to estimate the influence of farming combined with prey choice on habitat preferences.

### *3.1. Modelling Taiwan's Paleolithic Niche Breadth: Paleoenvironment and Subsistence*

The unique geographic position, climate, and landforms of Taiwan have had a profound influence on ecosystem characteristics and contexts since the Last Glacial Maximum. The island lies at the intersection of multiple climatic zones and ecosystems, conditioning for highly diverse habitats and access by boat from the west, north, and south. Along the eastern margin of the Asian continental shelf and the western edge of the Pacific Ocean and between longitude 120° E and 122° E and latitude 21° N and 25° N, Taiwan's geographic area is about 36,000 km$^2$, with a north–south distance of c. 394 km and east–west distance of about 140 km. Okinawa lies to the north, China lies c. 130 km to the west, Luzon Island about 250 km to the south, and the Pacific ocean to the east. Dozens of surrounding islands include the Penghu (Pescadores) group, Ludao (Green Island), and Lanyu (Orchid Island). The coastline is about 1566 km around the perimeter, and together with 129 sizeable rivers and more than 100 wetlands and estuaries, provides abundant aquatic habitats. Taiwan's western coastal plain is crossed by large meandering rivers, grading upward through dense deciduous forest in mountain footslopes to sub-tropical cypress and other evergreens at mid altitudes to an alpine oak scrub and steppe. Before urban development, estuaries and extensive low gradient wetlands lined the northern and western coasts, with a large lake basin where the Taipei metropolis now sits. On the east coast, most piedmonts are narrowly constricted and limited flat areas are mostly alluvial outflow deposits from steep mountain rivers.

Taiwan's landmass is more than 80% mountainous with tectonic activity manifested by volcanism, earthquakes, and frequent landslides. These steep mountains create diverse microhabitats and influence the mobility and foraging patterns of game species. The central mountain range forms the spine of the island, with more than 100 peaks higher than 3000 m above sea level, although the island is only c. 144 km at its widest point. The smaller coastal mountain range to the east is about 140 km long with peaks of about 1000–1500 m. A long, narrow inland valley runs north–south between the central and coastal mountain ranges, and three major lake basins are located in the north, west, and west-center (as Figure 3).

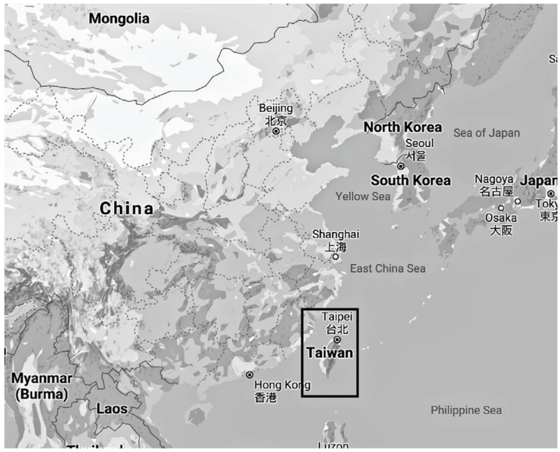


**Figure 3.** Location map of Taiwan.

Currently, the Tropic of Cancer runs through Taiwan, creating a sub-tropical climate merging into tropical conditions in the south. Sea breezes, typhoons, and monsoons keep modern temperatures warm, with annual averages between 21.5 and 24.5 Centigrade. Annual humidity is high with average rainfall between 1820 and 2720 mm. High seasonal variability in rainfall comes from the rainshadow effect and seasonal variation in wind direction; the central west coast is driest and the northeast coast, the wettest.

The wild vegetation of Taiwan is adapted to the temperature and moisture gradient [65], and the two main forest ecoregions currently include subtropical evergreen forests across most of the island and tropical monsoon rainforests on the southern tip. Temperate and sub-alpine communities exist in high mountain settings. During the middle Holocene optimum, pollen records indicate that during the time period around 6100 BP, warm climates allowed tropical evergreen forests to grow across most of the island [66]. Overall, climates have undergone major fluctuations in the past 12,000 years, and during the Tainan Paleoenvironmental Period (early to middle Holocene, 10–5 kyr BP), temperatures were warmer overall. A variety of geological indicators show that melting glaciers and local tectonics led to a rise in regional sea levels, reaching a maximum at around 6500 BP [67] and inundating the margins of Taiwan's western coastal plain, the Penghu Islands and others [68], and the Southeast Chinese coast across the strait [69]. Environmental fluctuations during the subsequent Nankuanli Geological Period (c. 5000–3000 BP) included actively fluctuating sea levels [67,70]. Marine transgressions and retreats created a dynamic estuarine and littoral environment, particularly in the low relief western and southern plains of Taiwan and the SE China coast. Chen et al. [68] noted localized major marine transgressions at c. 4700 BP, and at the same time, uplifts in the southwest central mountains caused aggradation and drainage formation and movements. Estuarine and marshland resources were abundant, albeit shifting, during this period of environmental upheaval on both sides of the Taiwan Strait.

These warmer climates likely created wind patterns, rainfall, seasonal variance, and ecosystems that are different from today's. Rising sea levels would have altered land availability, and vegetation communities would have resembled those currently on the southern tip of the island. However, ecosystems likely varied according to elevation, slope, and aspect, much like today.

Largely isolated from mainland influences since the late Pleistocene, Taiwan's highly diverse flora and fauna include unique island forms such as the Taiwanese cypress (*Taiwania cryptomerioides*), bay tree (*Machilus kusanoi*), Formosan bear (*Ursus thibetanus formosanus),* clouded leopard (*Neofelis nebulosa brachyura*), boar (*Sus scrofa taivanus*), Sika deer (*Cervus nippon taioanensis*), sambar (*Rusa unicolor swinhoei*), serow (*Capricornis swinhoei*), muntjac (*Muntiacus reevesi*), pangolin (*Manis pentadactyla pentadactyla),* rock macaque (*Macaca cyclopis*), and giant flying squirrel (*Petaurista alborufus*). Many large bodied species now limited to forested upland reserved areas were broadly distributed in the piedmont and forested interface with the coastal plain [71]. The island is home to a wide variety of endemic and migratory birds, and the marine fishery includes diverse and abundant shellfish, crab, and shallow water fish populations on the west and south coasts. A productive pelagic fishery lies off the east coast, and edible kelp and algae are common. The pre-20th century freshwater fishery was also diverse including shellfish, crayfish, and catadromous (sea-spawning migratory) and landlocked species including Formosan salmon (*Oncorhynchus masou formosanus*).

### *3.2. Paleolithic Environment and Cultural Adaptations*

Archaeological preservation of the Paleolithic to Neolithic transitional period is complicated by marine transgressions, mountain building, and sediment aggradation during the significant period between 14,000 and 6000 BP [5,67]. Currently, Taiwan's earlier Paleolithic cultural sites, termed Changbinian, have been found primarily in caves along the rugged east coast and date to c. 20,000–6000 BP [72–77]. The type site of Baxiandong (Pah-Hsien-Tung) is made up of a beach caves located in rugged terrain that was somewhat inland during the early period of occupation (Figure 4). The lithic assemblage of Baxiandong lower levels includes unifacially flaked choppers and cobble flake tools (c. 20,000–25,000 BP) [75] made of sandstone pebbles sourced from nearby beaches [77] that were knapped on-site based on refit data [72]. Changbin core/flake pebble technological systems show affinities with the Paleolithic cultures of the Ryuku Islands and the Philippines [77]. Faunal remains mostly represent fish, shellfish, and cervids [75,77].

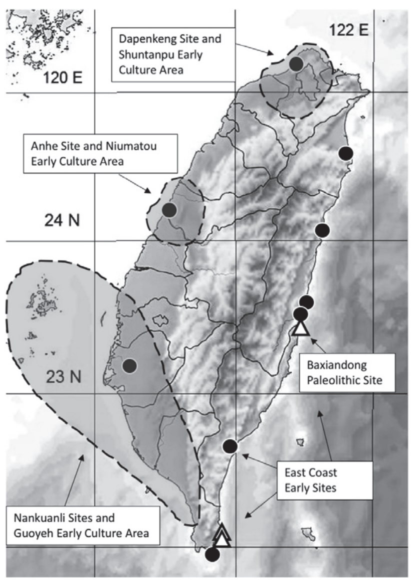


**Figure 4.** Map of Taiwan's Paleolithic and early Neolithic culture areas and sites (Adapted from [78]).

From Changbinian origins, regional foraging variants emerged at about 15,000–5000 BP. These cultures are termed as the Persistent Upper Paleolithic because they retain Paleolithic technological systems and lack ceramics [79]. The upper Paleolithic levels of Baxiandong include mostly unretouched flakes, but some pieces show evidence of faceted striking platforms. Tool types include side scrapers, points, knives, and notched scrapers made of higher quality raw material such as quartzite and chert [72]. Hearth-like ash lenses have also been found [72,77]. Other Persistent Upper Paleolithic sites are located in the northwest near Taipei [73,74,80] including the northwest Wangxing culture, which terminates at c. 6000 BP and is described as an adaptation particular to this region [81,82].

Persistent Upper Paleolithic sites are also found the central west near Miaoli and Taichung [80–83], in the southwest near Tainan [74], on the southern tip at O-luan-pi, Xiaoma, and Longkeng [84], the southeast near Pingtung [85,86] and southeast near Taitung [87]. In particular, the time period of 6500–5000 BP is well-represented in the south. Organic preservation is rare at most Paleolithic sites, mostly consisting of fragmented animal and fish bone as well as shell [ibid], which suggests a mixed subsistence strategy. The presence of horn implements and needles from large body size game at Baxiandong indicates that deer and other large prey were taken regularly [75–77]. Overall, archaeological evidence indicates that Taiwan's Paleolithic cultures were evolutionarily dynamic and adapted to diverse habitats, with some emphasis on aquatic resources. From Asian cobble technologies after the Pleistocene to Holocene transition, Persistent Upper Paleolithic cultures shifted to smaller lithics of higher quality raw materials, retouch techniques, and an increase in bone tools as well as regional variation in subsistence, technology, and settlement.

### *3.3. Reference Information about Foraging from the Binford Hunter-Gatherer Database*

Lewis R. Binford's database of hunting and gathering peoples [20,88] includes environmental data for climate, topography, soils, and primary (plant) and secondary (animal) biomass from individual weather stations around the globe. Johnson [29] demonstrates that habitat data can be used to project hunter-gatherer subsistence, social organization, and demography where foraging societies no longer reside, based on regressions of variables of climate data and living hunter-gatherer societies. The Binford database is used to calculate projections for foraging behaviors based on a global sample of data from 339 ethnographically documented hunting and gathering societies that is geo-referenced to climatic and environmental parameters. This allows for informed estimates of foraging behaviors where detailed ethnographic information is not available such as Taiwan. The projection for Taiwan's anticipated foraging niche breadth is based on modeled foraging subsistence diversity and climate and environmental data from 27 Taiwanese weather stations (Figure 5).

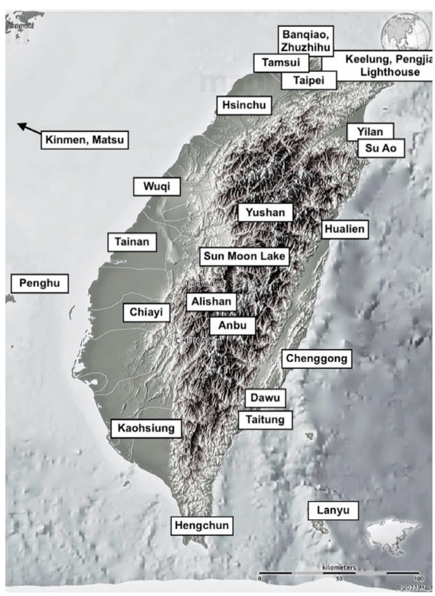


**Figure 5.** Taiwanese weather stations where temperature, rainfall, soil, and vegetation data were used to derive environmental and ethnographic projections [20,88].

Environmental calculations were derived from average temperature and rainfall data from the early 2000s as well as soil type, vegetation, modeled ungulate biomass, elevation, and proximity to the coast. Thus, the Binford projections for Taiwan do not represent accurate environmental conditions of the middle Holocene. Rather, this information offers a frame of reference for foraging lifeways that are plausible for a warm, mountainous island setting and can be assessed using more direct lines of evidence such as paleoclimatic records and archaeological information. This paper selected the following subsistence related variables from the Binford database [88].

a. WHUNTP/WGATHP/WFISHP: Expected percentage of hunting, gathering, and fishing/aquatic resources derived from ethnographically known hunter-gatherer groups who reside in habitats with similar environmental characteristics.
b. SUBSPE: Ordinal classification of projected foraging subsistence specialty. 1 = primarily hunting or dependence on terrestrial animals; 2 = gathering or dependence on terrestrial plants; 3 = primarily fishing or dependence on aquatic prey.
c. SUBDIV: An index of foraging diversity or 'evenness' that is calculated using Simpson's diversity index (see below for details of calculation). Expressed as a decimal value between 0 and 1 in which values approaching 1 indicate less evenness or more specialization.

## 4. Results

### *4.1. Foraging Subsistence Projections and Preferred Wild Prey in Taiwan*

To estimate foraging subsistence focus, SUBSPE, an ordinal variable is calculated for predominant expected dependence upon foraging modes available in the habitat. Options include terrestrial animal focus (1 = hunting), terrestrial plants (2 = gathering), and aquatic species (3 = fishing/shellfish). For example, the SUBSPE for the weather station located near the Tamsui estuary in the north estimated more than 50% dependence on aquatic food resources. Therefore, SUBSPE was designated as "3" for Tamsui. Overall, the Binford projections for Taiwan foraging subsistence indicate that, if Paleolithic hunter gatherers were behaving as they did in similar habitats during the ethnographic present, most groups would be focused on fishing/aquatic resources (Figure 6). The only exceptions are in the central or coastal mountains, which are predicted to rely mostly on hunting.

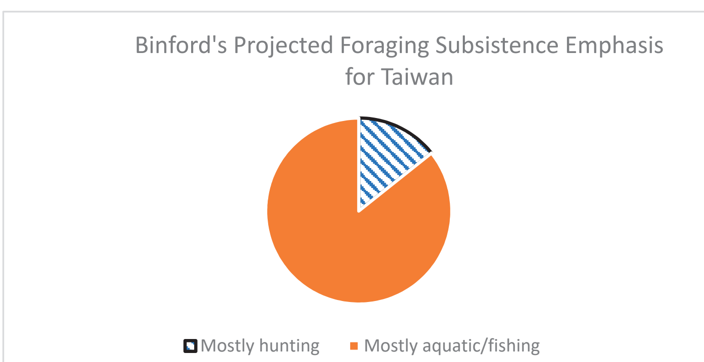


**Figure 6.** Binford's expected subsistence emphasis (SUBSPE) for 27 Taiwanese weather stations.

In his worldwide analysis of hunter gatherer subsistence patterns, Binford [20] noted several interesting generalizations about aquatic-focused foraging. Usually, early stage niche broadening is accomplished by including more terrestrial plant foods (often those requiring additional processing). Binford notes that the majority of aquatically focused hunter-gatherer groups worldwide are situated in forest plant communities that generally offer little accessible plant food for hunter-gatherers [20]:

"...*Human dependence upon aquatic resources occurs either as a supplement to a plant-based strategy or as the primary strategy in environments that prohibit plant-based subsistence options. The shift to a highly aquatic focus happens only in cases where edible plants are rare*". The low frequency of edible endemic Taiwanese forest species [89] and corresponding predominance of non-native plant food species in traditional diets of Taiwan's indigenous Amis and Paiwan peoples [90,91] are consistent with Binford's generalization: specialization in aquatic foraging occurred early in Taiwan due to the lack of terrestrial plant food species. Most edible plant foods endemic to the island that are known today include ferns, fungi, fruit, and algae or kelp.

Binford's projections for Taiwan's foraging subsistence focus by percentage (Figure 7) indicate that the distance to the coast is a predictor of aquatic specialization, with mountain sites such as Alishan, Sun Moon Lake, and Yushan comprising the highest terrestrial hunting focus. The outlier Chiayi is distant from the coast, but the high aquatic focus could be influenced by a local river. Notably, no Taiwanese site was modeled to have greater than 37% dependence on terrestrial plant foods.

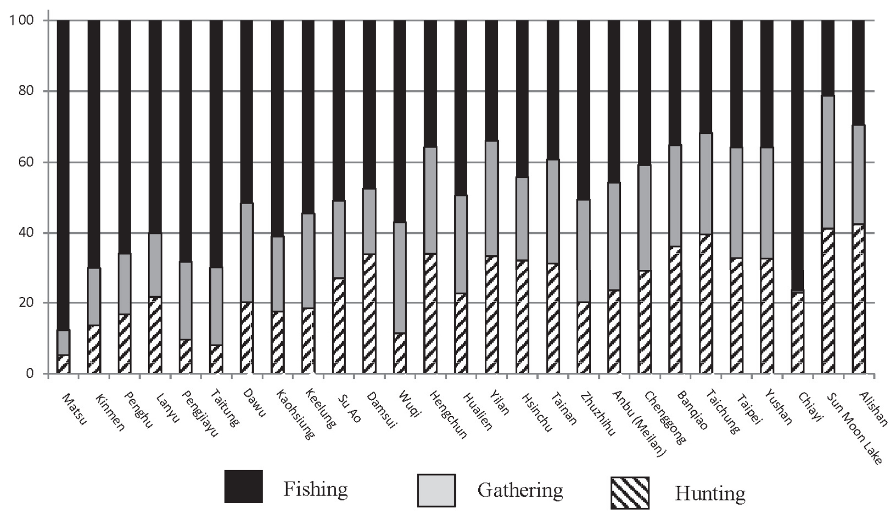


**Figure 7.** Binford's estimated percent contribution to foraging subsistence by distance to coast.

Foraging niche breadth can be characterized as the degree of evenness between relative reliance on terrestrial animals, plants, and aquatic foods: more evenness indicates a generalized and broad niche. To make an estimate for Taiwan foraging, Simpson's diversity index [92] (originally calculated for biodiversity) is used to measure evenness, defined as the relative degree of reliance of hunting, gathering, and aquatic subsistence for each location. This calculation is made using variables that reflect 'packed' population conditions that are referable to those of the ethnographic present, >9.1 persons/km$^2$ (Binford's WHUNTP, WGATHP, and WFISHP variables) [20,88]. The diversity index is expressed as $D = \Sigma[n/N]^2$ in which n = the total number of organisms of a particular species and N = the total number of organisms of all species. The equation used in this calculation is: Foraging diversity [D] = $(\text{WHUNTP} + \text{WGATHP} + \text{WFISHP})^2/10{,}000$. The value D ranges between 0 and 1, where 0 represents infinite diversity and 1, no diversity. Thus a value closer to 1 indicates un-evenness and a high degree of specialization. Thus, the percentage dependence on either hunting, gathering, or fishing is substituted for the number of organisms in the diet, and the result is divided by 10,000 for ease of viewing.

Figure 8 indicates that foraging is specialized upon fish/aquatics near the coast, then shifts inland to mountain-oriented hunting. Again, the outlier is Chiayi, possibly influenced by a large freshwater river with migratory catadromous fish. Overall, the Taiwan foraging diversity projection reflects Binford's expectation that niche specialization may occur in groups that are primarily dependent upon aquatic resources under nonpacked conditions, where there are few or no wealth or rank differentials [20]. Furthermore, Paleolithic population densities are likely to have increased over time as a consequence of the predictability of aquatic resources: Binford's database of known foragers indicates that aquatic-dependent groups have higher population densities (17.9 persons per 100 square kilometers) than plant gatherers (10.5 persons) or hunters (3.4 persons) [20].

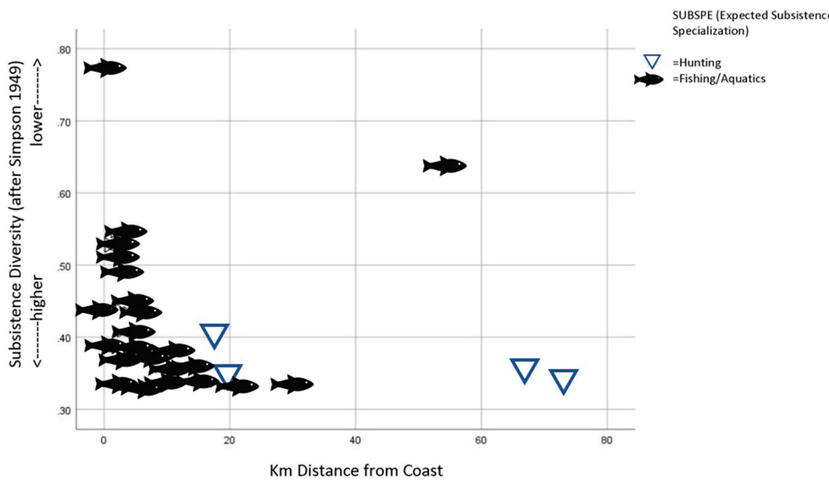


**Figure 8.** Binford's [20,88] estimated diversity of foraging subsistence for Taiwan, assessed by distance from the coast, calculated using Simpson's diversity index [92].

Binford's projections from global hunting and gathering data have interesting implications for the evolutionary pathway of foraging in Paleolithic Taiwan. During the early period of c. 20–10,000 BP, foraging groups moving to the island, most likely over land, added aquatic resources as a niche broadening tactic. With the onset of Holocene conditions and population infilling from c. 10,000–6000 BP, foragers became specialized in aquatic foods. Shellfish and other nearshore/wetland species required little effort to harvest and could be taken by children and the elderly. Through specialized technology (boats, nets, spears, harpoons), large bodied offshore species could be pursued. With growing population densities and competition for coastal resources, the aquatic focused niche became filled and foraging shifted inland toward montane terrestrial resources, with ungulates preferred. Taiwan's rugged mountain uplands typically require arduous foot travel from the coast, which would likely necessitate a near full-time commitment to hunting.

Projections from reference information are consistent with post-ecological release described by the niche variation hypothesis: early Paleolithic human migration to the island allowed for niche-broadening over time and increasing among-group variation toward either mountain hunting or coastal fishing. These niches eventually became specialized to form the regionally diverse Persistent Upper Paleolithic foraging adaptation of Taiwan. These projections allow us to estimate rank order of the foragers' preferred wild prey as follows.

If the prey rankings in Table 1 are correct, then high ranked habitats for foragers were coastal, lake, and wetland, followed by coastal plain, piedmont, and forested uplands. The last habitats to be occupied were predicted as high mountain regions that are sub-alpine today and likely forested during the warmer mid-Holocene. Projections from reference information are consistent with post-ecological release described by the niche variation hypothesis: early Paleolithic human migration to the island allowed for niche-broadening over time and increasing among-group variation toward either mountain hunting or coastal fishing. These niches eventually became specialized to form the regionally diverse Persistent Upper Paleolithic foraging adaptation of Taiwan.

**Table 1.** Estimated ranking of preferred prey and habitat, Upper Paleolithic foragers.

| Prey Type Rank Order | Habitat Type |
|---|---|
| 1. Shellfish, nearshore fish including migratory catadromous species, waterfowl | Littoral/estuary/delta wetland/lake basin |
| 2. artiodactyls (deer, sambar, muntjac, serow), perissodactyls (boar) | Coastal plain, forested mountains, valleys |
| 3. Deep water fish, turtles, marine mammals | Pelagic/offshore, islets |
| 4. Arboreal and burrowing prey (macaque, pangolin, flying squirrel, and birds) | Forested valleys, piedmont and uplands |
| 5. Resident river fish, catadromous species, turtles | Riverine/inland |
| 6. Wild plants (geophytes, ferns, fungus, fruit, algae) | Forested valleys, piedmont and uplands |

### *4.2. Transitional Neolithic Paleoenvironments and Archaeology*

Against this heterogeneous and dynamic environmental and cultural backdrop, the first evidence of sedentized agriculture appears in Taiwan between 6000 and 5000 BP during what is termed the Dapenkeng (previously Tap'enkeng) period [4,10,11,15–17,67,78,93]. Saltwater inundation and the loss of low lying arable lands and productive wetlands on China's southeast margin could have created conditions favoring sea-faring over further investment in local agriculture, leading to migrations across the Taiwan Strait [5]. Regional Neolithic variants emerged early (see Figure 4, above), as evidenced by the Shuntanpu Early Culture in the north, Niumatou Early Culture in the central region, and Guoye in the south. At the time of writing, the influence of Paleolithic regionalization on early Neolithic cultures is not known.

Dapenkeng period sites are mostly distributed on the southern, northern, and eastern coasts around the island [16]. Hung and Carson [4] noted that today's alluvial plains accumulated mostly after 3000 BC, especially along the western coastline. Thus, most early Dapenkeng communities overlooked swampy nearshore environments, which have since became in-filled with alluvium [4,67]. Archaeological materials from the Dapenkeng type site (c. 5600 BP) near Tamsui in northern Taiwan include cord-marked pottery, polished stone adzes and harvesting knives, drilled slate projectile points, and baked clay spindle whorls [10–12]. Pottery is thick walled, sand-tempered and cord marked; stone adzes are quadrangular in cross-section and usually polished. Pecked pebbles were possibly used as net sinkers, and distinctive bark-cloth beaters were used to create raw material for clothing and other purposes [93]. Other cultural traits of Shuntanpu Early Culture include site placement on coastal and stream terraces, and planned semisedentary communities with extensive ditch and well construction and ash pits [4,10,11,93–95]. Faunal remains from the Dapenkeng type site include fish, shellfish, and mammal remains [10,89]. Macrobotanical evidence of millet and rice has also been found at multiple Shuntanpu sites, along with irrigation features [78,93].

Niumatou Early Culture sites (c. 5600–4200 BP) in the Taichung Basin of central Taiwan include the large Anhe site. Niumatou culture is remarkable for extensive cemeteries that indicate a wide range of ages and sexes, and tooth extraction practices [96]. Well-crafted burial objects include sandy paste ceramics (both red and occasionally black wares) such as *dou* double and triple cups, tapa bark beaters, and nephrite adzes and jewelry [ibid]. The ceramics have strong affinities to Southeast Chinese wares across the strait, indicating continued cultural interchange [78]. Sika deer, muntjac, small fish, shark, and shellfish remains indicate a mix of terrestrial and aquatic foods, along with macrobotanical evidence for rice [78,96].

In the south, recent excavations near Tainan have revealed a major Neolithic site complex at Nan-kuan-li and Nan-kuan-li East. The Dapenkeng period/Guoye phase dates to between 5000 and 4300 BP [16,67,97]. Site placement was preferentially on plains, terraces, and low hills facing wetlands [67,78]. Material evidence includes a robust assemblage of soft pottery of red and brown ware, rounded bottoms and feet, and decorations from cord-marking or comb-incised or shell-impression [67,97]. The toolkit is dominated by wood working and farming implements such as polished stone hoes, axes, adzes, and chisels. A small number of hoes are fashioned of thick shell. Drilled stone knives, stone projectile points, fishnet sinkers, and tapa bark beaters are common [67,97]. The consistent presence of olivine basalt from Penghu off the southwest coast indicates a strong trade connection with people of that island complex throughout the Guoye period [67]. Bone, tooth, and shell were used for drills, needles, jewelry, and cutting implements [ibid]. Faunal remains were well preserved, with shellfish predominant as well as a variety of sharks and other cartilaginous fish like stingray as well as bony fish from estuarine and pelagic habitats [16,97]. Reptiles include tortoise, soft shell turtle, and snake, and wild mammals include rat, sika deer, muntjac, Formosan badger, Formosan wild boar, and a small species of wild cat. Domesticated dog bones are found in midden settings as well as buried intentionally [67]. Plant remains include diverse wild species, dominated by chinaberry tree [Melia azedarach] as well as nigaki shrub (*Picrasma quassioides*) and hackberry tree (*Celtis sinensis*) [16]. Seeds and fruits may have been used for food, similar to Donghulin and other transitional Neolithic sites in China [98–100]. Both carbonized rice and millet remains have been found, with millet somewhat earlier in the sequence [67]. The local landrace of rice may have been domesticated locally based on seed morphology [67], whereas foxtail millet (*Setaria* spp.) likely arrived from China.

On the east coast, Dapenkeng period sites are smaller, consisting of either nephrite quarries or concentrations of cord-marked soft pottery below later Neolithic settlements. No settlements of the size and complexity of the western and southern regions have yet to be discovered [78], thus subsistence evidence is not sufficient for detailed discussion yet.

Overall, archaeological evidence suggests that the subsistence niche during the transitional Neolithic was broadly based. Evidence for fishing and shellfish collection predominates over farming, hunting, and collecting [67]. Taiwan's first farmers employed diverse cultivation techniques for two crop types: dryland (millet) and wet paddy (rice), which suggests influences both from the northern and eastern regions of mainland China [67,100]. Other crops such as geophytes and tree crops also may have been cultivated. Sizeable communities, burial grounds, and irrigation features along with distinctive vessel shapes and tapa bark beaters and genetic affinities of millet and rice suggest ongoing influences and interchanges with the cultures of what are now the Fujian coast and Guangdong/Pearl River delta regions in southeast China [78].

These data suggest that rats, mustelids, reptiles, and cats were part of the earliest Neolithic diet. Although differences in the preservational environment could allow for better species identification in Neolithic depositional contexts, this listing is broader than the Paleolithic and includes more genera and smaller body size prey. This, in combination with crop cultivation, allows us to estimate the rank order of the farmer-fisher's preferred prey as follows (the term 'prey' is used generally here, including cultigens).

If the prey rankings in Table 2 are correct, then high ranked habitats for Taiwan's first farmers were initially coastal, lake, and wetland adjacent to coastal plains. These habitats required to practice cultivation and access wild aquatic prey are distributed on the northwestern, west, and southern areas of the island. Piedmont, forested uplands, and the steep east coast would have been occupied after preferred habitats became infilled. The least desirable habitats to be used consistently by early farmers have been predicted as high mountain regions that are sub-alpine today and likely forested during the warmer mid-Holocene.

**Table 2.** Estimated ranking of preferred prey and habitat, Incipient Neolithic farmer-fishers.

| Prey Type Rank Order | Habitat Type |
|---|---|
| 1. Shellfish, nearshore fish including migratory catadromous species, waterfowl | Littoral/estuary/delta wetland/lake basin |
| 2. artiodactyls (deer, sambar, muntjac, serow), perissodactyls (boar) | Coastal plain, forested mountains, valleys |
| 3. Cultigens and edible weeds | Coastal plain, valleys |
| 4. Arboreal and burrowing prey (macaque, pangolin, flying squirrel, and birds) | Forested valleys, piedmont and uplands |
| 5. Resident river fish, catadromous species, turtles | Riverine/inland |
| 6. Deep water fish, turtles, marine mammals | Pelagic/offshore, islets |
| 7. Wild plants (geophytes, ferns, fungus, fruit, algae) | Forested valleys, piedmont and uplands |

## 5. Discussion

The estimated prey rankings indicate that the overlap in habitat preference of foragers and farmer-fishers includes coastal plains, lakes, and other flat wetland areas with easy access to the coast or major bodies of water. These are located in the northwest, west, and south. More mobile foragers would have had an edge when exploiting the rugged east coast or the mountain uplands. The working hypothesis prediction regarding the earliest Neolithic in Taiwan can now be refined as follows.

If the assumptions of the PCM hold, high ranked aquatic prey (e.g., large shellfish and other nearshore species) and ungulates should rapidly become depleted in highly ranked habitats. The harvest of lower ranked prey such as small body size mammals and reptiles, and wild plants, should become more common. This process would end when foragers decide to adopt agricultural practices, or migrate to the east coast or mountain habitats.

If assumptions of an IFD with Allee effects hold, the flatlands of the northwest, west, and south adjacent to the coast should see increases in encounter rates for sika deer, pigs, and muntjac, which do well with more heterogeneous vegetation and successional communities associated with farming [71]. It is less clear if farming and/or intensified foraging would improve encounter rates with near shore aquatic prey, although in upland lake habitats, indigenous Taiwanese create fish islands of bamboo and thatching to improve the survival of young fry. The antiquity of this practice is not known, but it is reasonable. Given the scarcity of edible wild plant options in Taiwan, the adoption of crops would have provided a niche construction tactic to increase energetic returns per area. Edible commensal weeds that volunteer in the fields likely provided a dietary complement [90].

This process has important implications for predicting the ways that feedbacks in the consequences of resource/land use may shape interactions in diverse subsistence strategies, settlement, and social interactions. If, as modeled by Binford's database, the Persistent Upper Paleolithic foraging niche was specialized in either coastal or mountain resources, foragers of agriculturally desirable regions such as the northwestern, western, and southern coastal floodplains, flat, well-drained areas near river confluences, and terraces would have been affected the earliest by immigrating farmers. Competition for wild resources needed by foragers would have been direct, continuous, and increasing as farmers settled and expanded. The prey choice model predicts immediate and unidirectional drops in preferred prey, which would result in a 'push' for foragers in these regions to move, or adopt unfamiliar crops and cultivation techniques. The IFD with Allee effects predicts an initial increase in encounters with preferred prey due to beneficial niche construction activities, which might delay—though not for long—the thresholds for foragers to cultivate or move. Another consideration is the 'pull' associated with forager-farmer social interactions that rapidly reduced language barriers and other obstacles to knowledge exchange.

A more nuanced process is expected for areas not initially settled by early Neolithic agriculturalists in the mountain uplands, islets, and rugged east coast. Here, processes predicted by the PCM and the IFD with Allee effects were delayed. Competitive pressure on wild resources needed by foragers would initially have been indirect, gradual, and sporadic, most likely driven by the movements of foragers in response to immigrating farmers rather than by the farmers themselves. The 'pull' to expand niche breadth by adopting crops and cultivation knowledge would be weaker, with crop types adopted in ascending order of cost and risk to existing foraging lifeways (Yu, in press). Figure 9 shows areas preferred by farmers for settlement and variability in expected modes of competitive pressure on wild resources needed by foragers.

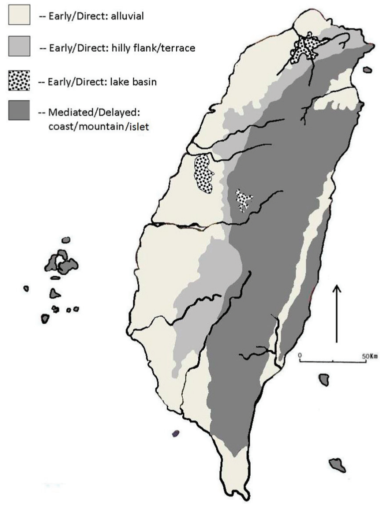


**Figure 9.** Geographic representation of Taiwan's modes of variable invasive pressure on wild resources associated with Neolithic onset, based on Binford's subsistence projections [37] used by permission.

In sum, niche variation theory, the prey choice model, and the IFD with Allee characteristics are useful heuristic tools for the latest Paleolithic and earliest Neolithic of Taiwan when combined with macroecological reference information about late-stage foraging. However, is an important difference in extrapolating theoretical predictions derived from non-humans for human groups: our flexible and constructible niche. Neolithic immigrants initially enhanced vegetative diversity through cultivation, potentially increasing encounter rates with high ranking prey. Farmers also brought along novel food species such as seed and possibly tuber crops, thus foragers under resource pressure could offset narrowing niche options by adopting crops that they deemed the least costly to mobility needed for acquiring preferred wild resources [37]. A working chronological reconstruction of Taiwan's Neolithic transition follows:

1. Early Paleolithic foragers migrated to Taiwan from the mainland c. 20,000 years ago, moving into new territory under conditions of ecological release.
2. Niche variation theory predicts an expansion of foraging niche breadth, increasing among-group variation within the niche. By the Persistent Upper Paleolithic, foraging niches divided into two specialized modes: either aquatic resources or mountain hunting.
3. The arrival and first dispersal of Neolithic Chinese farmers caused farmer-forager competition for wild resources, especially aquatic, in flat areas near coasts and wetlands. The prey choice model predicts that the niche overlap would lead to reductions in preferred prey and resource depression, whereas the IFD with Allee effects predicts that niche constriction could have increased encounter rates with preferred prey, at least in the beginning.
4. Foragers choosing to remain in colonized areas responded adaptively by taking low-ranked prey, then including low-ranked, low-cost cultigens in the diet, expanding the foraging niche temporarily (Figure 10). The PCM predicts this would have occurred rapidly; the IFD predicts a delay due to the beneficial effects of niche construction.
5. This phenomenon occurred early and rapidly in coastal areas and neighboring flat regions that were favorable to arriving farmers, then dispersed into more distant mountain uplands and the east coast as demographic packing continued.
6. The transition was more gradual in the central mountains and east coast. Foragers who opted to move away from farmer interactions may have encountered forager-forager competition and

resource depression in those areas, and demographic growth fueled a cycle that ultimately ended full-time hunting and gathering across Taiwan.

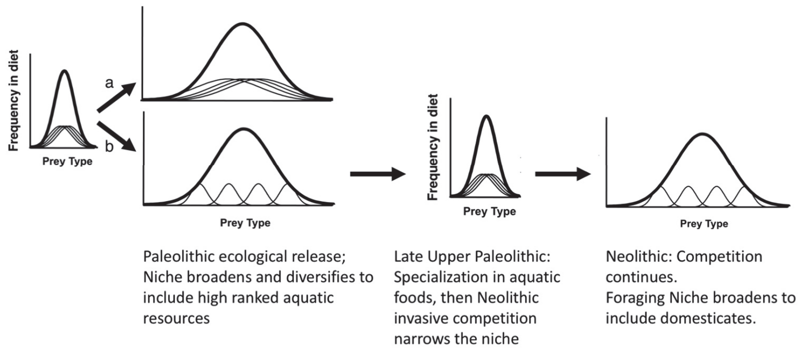


**Figure 10.** Schematic of the Niche Variation Theory applied to Neolithic impacts on foraging niche (adapted from [18], used by permission). (**a**) Inter-group niche breadths expand, resulting in no increased niche variation among individuals. (**b**) Individual group niche breadths remain limited, then groups diverge to increase among-group variation.

This qualitative assessment of the PCM and IFD has utility for making predictive statements about timing and intensity of the Taiwan Neolithic transition, particularly from the foraging perspective. In fact, this finding explains why foraging persisted in the mountains and along the east coast, even into the Middle Neolithic. The eventual demise of the Paleolithic lifeway can be predicted once the foraging niche could no longer be expanded through the addition of low cost options, or prolonged through niche construction [37]. Even after the full commitment to cultivation was made, selective forces actively favored a prolonged stage of mixed economies that included wild prey, commensal species, and vegeculture resources alongside cereal cultigens. This moderate risk/moderate yield mixed strategy with Neolithic roots is seen in Japan, Southeast China, and other areas worldwide, and played a role in oceanic migrations. The mixed strategy maintains diverse and nutritious diets, sustains crop diversity and wild resource viability, reduces travel and processing costs, and hedges against risk and loss [1].

The limitations of testing this approach for the Taiwan Neolithic transition include the imperfect preservation of material evidence for foraging subsistence behaviors, and therefore small sample sizes and lack of a basis for strong inferential arguments. However, as the rate of discovery of well-dated early sites increases, the likelihood of new Persistent Upper Paleolithic and Dapenkeng sites—and therefore the sample size—is increasing. The PCM and IFD working scenarios could be assessed using various classes of archaeological evidence as new data become available (Table 3).

**Table 3.** Potential lines of evidence to assess Prey Choice Model and Ideal Free Distribution expectations.

| Model/Prediction | Categories of Evidence (Incipient NEOLITHIC, c. 6000–5000 BP) |
|---|---|
| 1. Prey Choice Model/Resource Depression | Subsistence: Decreases in frequency, diversity, age, and size of high ranked prey species relative to lower ranked prey.<br>Technology: Increased processing tools and features such as ovens and graters.<br>Settlement: Temporal and geographic overlap between Paleolithic and Neolithic sites in flatlands near the coast.<br>Low frequency of earliest Neolithic sites in mountain uplands, islets, and east coast. |
| 2. IFD/Allee Effects/Niche Construction and Resource Benefits | Subsistence: Initially, increases in frequency, diversity, age, and size of highly ranked prey types relative to lower ranked prey. Could decrease over time after population rises.<br>Technology: Few processing tools and features such as ovens and graters; more procurement tools (e.g., fishing and hunting equipment).<br>Settlement: Temporal and geographic overlap between Paleolithic and Neolithic sites in flatlands near the coast; initial increase in Paleolithic sites close to Neolithic settlements, then replacement by agricultural sites.<br>Low frequency of earliest Neolithic sites in mountain uplands, islets, and east coast. |

## 6. Conclusions

A major challenge in assessing hypotheses for this time period in Taiwan is the lack of means to distinguish early Neolithic sites from sites in which Paleolithic foragers were experimenting with cultivation. Although the presence of ceramics is one indicator of farming, some of Taiwan's 'last foragers' may have been able to obtain ceramics or ceramic manufacturing techniques while maintaining a mostly foraging lifestyle. Across the strait in SE China, a prolonged Neolithic transition included coastally-adapted hunter-gatherers who used ceramics, lived in semi-sedentary villages, and created cemeteries as late as 3000 BP [17,101–103].

Nevertheless, predictions derived from the niche variation theory, the prey choice model, and the IFD with Allee effects allow us to explore alternative processes for the incipient Neolithic. Taiwan's geographic position and diverse habitats and foraging opportunities ensured that the transition to farming was neither simple nor linear, but may be predicted. With the increase in chronometrically dated sites from this time period, archeofauna and other lines of evidence can be used to determine alternative explanations for the ways that Taiwan's Upper Paleolithic foragers and Chinese Neolithic farmer-fishers evaluated the costs and benefits and made strategic adjustments to their subsistence niche as they encountered new food types and each other to create a mosaic of potential habitat choices. If the PCM is supported, the ability to adjust prey choice and niche breadth ensured that the Persistent Upper Paleolithic endured in areas remote from farmers as late as 5000 BP, and likely even later. The IFD with Allee effects also accommodates prolonged foraging in areas where increased diversity of habitat succession and plant communities arose from the mosaic created by cultivation.

On the Neolithic side, farmers continued to include wild and semi-domesticated species alongside crops, with aquatic resources as a major, if not the most important dietary staple. The role of prey choice, niche, and habitat preferences in invasive dispersal and native adaptations is central to understanding variability in crop adoption by foragers, helping to frame the process in an evolutionary framework that places the foraging legacy in a key position for influencing evolutionary transitions to agriculture and later pathways to complexity.

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Article

# The Climate Fluctuation of the 8.2 ka BP Cooling Event and the Transition into Neolithic Lifeways in North China

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**Abstract:** Early Neolithic lifeways in North China, which are marked by a low-level food production economy, population aggregation, and sedentism, thrived just after the period of a climatic cooling event at 8.2 ka. Instead of simply regarding this climate fluctuation as a cause for the significant socio-economic transition, this paper attempts to explore the interplay between people's choices of coping strategies with climate change as a perspective to learn how people respond to this climate fluctuation and how such responses generated the interlocked socio-economic transitions. This analysis indicates that pre-existing changes in human adaptive behaviors prior to the cooling events were sufficient to enable people in certain areas to apply the intensification of food procurement in circumscribed territories as a strategy to cope with the climate fluctuations of the 8.2 ka BP cooling event. The application of such a coping strategy facilitated the economic and sociopolitical transition into Neolithic lifeways and led to the flourishing development of Neolithic cultures after 8 ka BP in North China.

**Keywords:** climate fluctuation; 8.2 ka BP cooling event; transitional sites; Early Neolithic; adaptive strategy; North China

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## 1. Introduction

The development of Neolithic culture occurred right after the eighth millennium BP in North China, which is marked as one of the most dramatic economic, social, and cultural changes in Chinese history. For hundreds of thousands of years in North China, human beings lived in mobile hunting–gathering lifeways in simple and small groups. Then, during the early Holocene (approx.: 12–7 ka BP), significant changes happened and facilitated the multi-faceted transformations of people's lifeways in terms of economic practice, sociopolitical organization, and cultural identity. By contrast with Paleolithic lifeways, people in the Neolithic period were integrated into larger social communities, lived in sedentary or semi-sedentary villages, developed new types of art forms and beliefs, and carefully treated the dead to increase inter-personal social and cultural connections [1]. Rather than seasonally exploiting food resources in a large range of territories, people began to intensively use the local resources in the circumscribed environment, firstly by the combined reliance on intensified hunting–gathering and low-level primitive farming and then by further developed agriculture [2,3]. Such lifeways stimulated the booming of the population and fundamentally changed the pattern of interactions between humans and the environment [4].

It is widely assumed the Holocene climatic optimum facilitated the prevalence of Neolithic lifeways since it provided an affluent environment of food resources and provided suitable climate conditions for farming [5]. However, a finer-scale examination of the climatic change suggests that there are multiple rounds of climate fluctuations in post-glacial periods, reflected as the oscillations between the warmer–wetter and colder–drier periods [6–8]. The 8.2 ka BP cooling event is such a climate fluctuation and was expressed as a drop in temperature during the general trend towards the warmer and wetter climate in Early Holocene. This cooling event occurred at around 8.2 ka BP and lasted for two to four centuries (some records detected that the decrease in temperature was initiated as early as 8.4 ka BP) [9,10]. The archaeological records in North China indicate a dramatic increase in site numbers and the thriving development of Neolithic culture after 8–7.8 ka BP, implying that the all-round and widespread transformation into Neolithic lifeways in North China happened soon after the 8.2 ka BP cooling event. Such a temporal correlation implies that the 8.2 ka BP cooling event might have played an important role in stimulating the significant cultural transition. However, rather than simply regarding this climate fluctuation as a cause of the cultural transition, I present how the interplay between humans and the environment across the 8.2 ka BP cooling event drove the cultural change.

Accumulative cultural preparation is an important focus of this study, since how people respond to climate change deeply relies upon their knowledge derived from long-term experience. One aspect of such cultural preparation is a suite of technological packages used to intensively exploit resources and massively store them for delayed consumption since sedentary lifeways and large group aggregation require sufficient food supplies in a confined area [11–13]. Another aspect of cultural preparation is organizational innovation, since the need to maintain large group aggregation and strengthen the sense of territoriality required more sophisticated sociopolitical organization and intensified social connections than ever before [14–16]. Such cultural preparations were formed and developed along with human coping strategies to deal with environmental changes. Some traits of such cultural preparations sporadically occurred as early as the Late Paleolithic but were significantly developed and deeply converged with other traits in the Early Neolithic period. Therefore, learning how people are technically and sociopolitically organized either to cope with challenges or take advantage of the favorable conditions of the environment over a long time span would be an insightful approach to explore how the human–environment interaction during the 8.2 ka BP cooling event generated the profound social and economic transition into the Neolithic lifeways.

## 2. Materials and Methods

### *2.1. The Study Area and the Research Approach*

North China (about 33°–43° N, 100°–125° E) is a vast geographic region in East Asia that features a temperate semi-humid monsoon climate. It is separated from Central and South China by the Qinling mountains and Huai River to the south, bordered by the Mongolian Plateau and the Yinshan and Yanshan Mountains to the north, and bounded by the Yellow Sea and Bohai Sea to the east and the neighboring Gobi Desert region in the west. The Yanshan and Taihang Mountains divide North China into two regions. The area to the west and north is the Loess Plateau, which is comprised by loess-covered highland, mountains, hills, and basins. The area to the east is the North China plain, a flat landscape with large water bodies and sporadically distributed hills and low mountains. Influenced by the alternations of summer and winter monsoon, North China has hot and wet summers and cold dry winters. As for the intra-environmental variations across the sub-regions, the weather becomes drier moving from the southeast to the north and west, where the strength of the summer monsoon declines gradually. The climate becomes colder moving from lower elevation plains to the mountains and highlands [17].

North China is one of a few centers in the world where complex agricultural systems emerged independently. The most widely consumed staple grains in the Neolithic period of North China were two types of millet, namely foxtail millet (*Setaria* spp.) and broomcorn millet (*Panicum* spp.) (foxtail and broomcorn, *Setaria* and *Panicum* spp., respectively) [3], while people in the southern and eastern parts of North China also consumed domesticated rice (*Oryza* spp.) as a supplemental food resource [18]. The onset of flourishing Neolithic cultures in North China was once thought as the outcome of fully fledged millet agriculture [19]. However, recent studies have revealed that multiple factors of Neolithic lifeways, such as sedentism, large group aggregation, and cultural and technological sophistication, all came before the full establishment of the agricultural economy [5,20]. Thus, early Neolithic cultures were based upon a low-level food production economy characterized by the broad-spectrum use of wild resources and the incorporation of domesticates as auxiliary resources [2].

North China is an ideal area to investigate how the 8.2 ka BP cooling event impacted the patterns of human–environment interactions and facilitated the significant cultural transitions. This climatic event is well evident in the paleoclimate records of China. Furthermore, the growing body of archaeological discoveries provides sufficient evidence to learn how people respond culturally during climate fluctuation. In the following section, the manifestation of the 8.2 ka BP cooling event in China is presented under the general paleoclimate background during the Paleolithic–Neolithic transition in North China. It provides a better understanding of the nature of this climate fluctuation at the suitable regional scale focused on by this paper. Then, the range of the sites used for the studies are mapped out in a sequential chronological frame, and the charts of the sum probability of their radiocarbon dating results are compared with the charts of the paleoclimatic proxies to show the concurrence pattern between the climate fluctuation and the significant cultural transition. Finally, the possible modes of coping strategies under climate fluctuation are summarized according the previous anthropological studies and how they are reflected by archaeological evidence is discussed, shedding light on the range of evidence I collected and discuss in the following sections to learn what specific coping strategies people have applied, how their application was based on the previous cultural preparation, and how the application of such strategies impacted the subsequent cultural development.

### *2.2. Paleoclimate Fluctuation and the Paleolithic–Neolithic Transition in North China*

The early and mid-Holocene are the key periods of significant social transformation into Neolithic lifeways. On average, increased humidity and temperature distinguish the early-mid Holocene "Anathermal" from the preceding Younger Dryas. At the peak of the wet/warm period, the average temperature was 2~3 °C higher than today's standard and the annual precipitation was 50~300 mm more than it is currently in North China [21,22]. However, the wet and warm periods were not consistent, but punctuated by periodical aridity and temperature decreases [23]. The 8.2 ka cooling event is an example of one period with noteworthy magnitude [24].

The 8.2 ka BP event is apparent in many climate records, particularly from the Northern Hemisphere. The event itself was most likely caused by meltwater escaping from Lake Agassiz-Ojibway into the Atlantic Ocean via the Hudson Bay, which altered thermohaline circulation [9,25,26]. The evidence of such a climate anomaly around 8.2 ka BP is clearly shown in ice cores from Greenland, where air temperatures dropped by 3 to 6 ± 2 °C [27]. The reinforced Northern Hemisphere cooling would have increased the temperature gradient between high and low latitudes, which caused the migration of the inter-tropical convergence zone southward. Such an effect would have led to the weakening of the East Asian monsoons and increased aridity [28].

The high resolution, well-dated paleoclimate proxies from East Asia can reflect the impact of this cooling event. The pollen records from Bigeum Island near the Korean Peninsula revealed a rapid drop in arboreal pollen frequency and a corresponding increase in fern spores, which implies that an abrupt dry and/or cold event significantly impacted the distribution of vegetation on the island [29]. The changing $\delta^{18}O$ values of the Guliya ice core in the Tibetan Plateau and stalagmites from Lianhua Cave in the Loess Plateau of North China, Heshang Cave in Central China, and Dongge Cave in South China all reflect an interval of weakening Asian monsoons during a certain period between 8.4 and 8.0 ka BP, coinciding within error with the 8.2 ka BP event reflected by the Greenland ice cores [30–33]. Furthermore, a 10-year moving average annual rainfall record in southwest China during the 8.2 ka BP event was reconstructed based on a central-scale model and the comparison of two high-resolution stalagmite $\delta^{18}O$ records from Dongge Cave and Heshang Cave. This reconstructed record reveals that the mean annual precipitation in southwest China during the central 8.2 ka BP event was less than that of the present (1950–1990) by ~200 mm and decreased by ~350 mm in ~70 years [34]. The stalagmite records of Shihua Cave and Nuanhe Cave in Northeast China indicate that the summer monsoon-dominated $\delta^{18}O$ record only weakly express the 8.2 ka event. Nonetheless, the variations of the winter-dominated proxies of $\delta^{13}C$ and Ba/Ca reflect a colder and drier climate initiated at 8.42 ka BP and centered at ~8.2 ka BP [35]. A clear drop in $\delta^{13}C$ at 8.6–8.1 ka BP can also be detected from the peat bog record of Hongyuan in the eastern Tibetan Plateau, indicating an obvious dry/cold period with decreased humidification [36].

A sharp increase in precipitation and temperature can also be detected by these paleoclimatic proxies after the 8.2 ka BP cooling event, which marks the onset of the mid-Holocene climatic optimum. The stalagmite record of Lianhua Cave shows a 2.5‰ $\delta^{18}O$ isotope depletion at 8.1 ka [33]. Such a magnitude of change is roughly similar to the transition from the Younger Dryas to the Early Holocene at 11.5 ka [5].

The cultural development and site distributions throughout the period from 11,500 to 7000 BP are presented in Figure 1. The comparison of climate fluctuation and cultural development (particularly referring to the occupation intensity of different types of sites) throughout this period is presented in Figure 2 (Supplementary Table S1). These two figures reflect the patterns of concurrence between climate and cultural changes, suggesting that the transitional sites occurred along with climate change into warmer and wetter conditions initiated from the beginning of Holocene (after 12 ka BP). These sites still share many features in common with the Upper Paleolithic sites in North China (45–12 ka BP) but, meanwhile, have shown the buds of the Neolithic cultural traits. During or even preceding the 8.2 ka BP cooling event, the Early Neolithic sites, characterized by settled inhabitation, large group aggregation, and intensive site use, emerged but were very rare and distributed only in limited areas of North China. With the onset of the climax of the Holocene climatic optimum (7.8–7 ka BP), the numbers of Early Neolithic sites soared and they were widely distributed across North China with sharply increased occupation intensity. In the following sections, the specific interplay between humans and the environment will be analyzed and discussed to learn the underlying mechanisms of this significant social change under climate fluctuations.

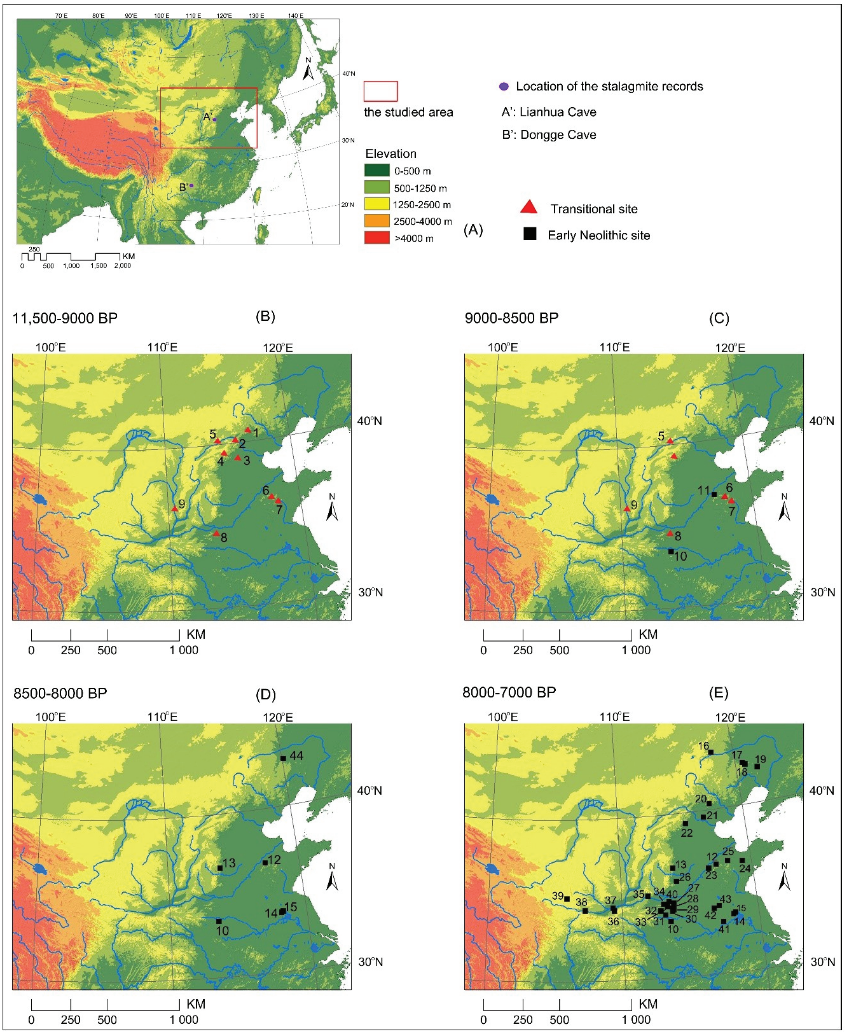


**Figure 1.** The distributions of the archaeological sites from 11,500 to 7000 cal BP. (**A**). Studied area; (**B**). The distributions of the archaeological sites from 11,500 to 9000 cal BP; (**C**). The distributions of the archaeological sites from 9000 to 8500 cal BP; (**D**). The distributions of the archaeological sites from 8500 to 8000 cal BP; (**E**). The distributions of the archaeological sites from 8000 to 7000 cal BP (The name of the sites: 1: Zhuannian [37]; 2: Donghulin [38]; 3: Nanzhuangtou [39]; 4: Ximiao [40]; 5: Yujiagou [41]; 6: Huangya [42]; 7: Bianbiandong [43]; 8: Lijiagou [44]; 9: Shizitan S9 and 12G [45,46]; 10: Jiahu [47]; 11: Zhangmatun [48]; 12: Xihe [49]; 13: Cishan [50]; 14: Shunshanji [51]; 15: Hanjing [52]; 16: Baiyinchanghan [53]; 17: Xinglonggou [54]; 18: Xinglongwa [55]; 19: Chahai [56]; 20: Shangzhai [57]; 21: Beiwang [58]; 22: Beifudi [59]; 23: Yuezhuang [60]; 24: Qianbuxia [61]; 25: Houli [61]; 26: Huawo [62]; 27: Shawoli [63]; 28: Peiligang [64]; 29: Tanghu [65]; 30: Shigu [66]; 31: Shuiquan [67]; 32: Zhongshanzhai [68]; 33: Egou [69]; 34: Tieshenggou [70]; 35: Bancun [71]; 36: Beiliu [72]; 37: Baijia [73]; 38: Beishouling [74]; 39: Dadiwan [75]; 40: Maliangou [76]; 41: Shuangdun [77]; 42: Shishanzi [78]; 43: Xiaoshankou [79]; 44: Xiaohexi [80]).

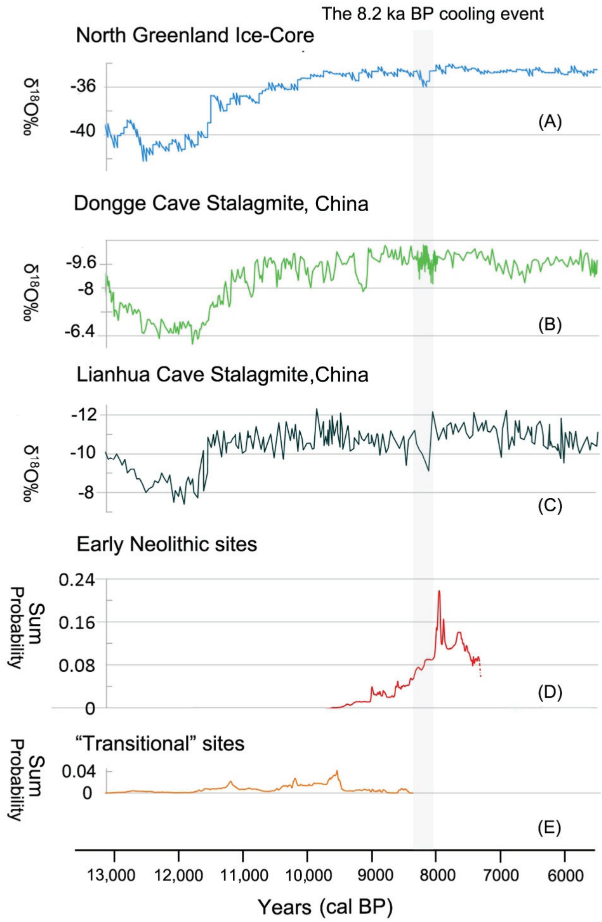


**Figure 2.** Graphic comparison of human occupation intensity and climate fluctuation. The shaded gray bar shows the time span of the 8.2 ka BP cooling event. The curve (**A**) represents hemispheric changes in precipitation and temperature recorded in the North Greenland ice core [81]. Higher $\delta^{18}O$ values indicate warmer temperatures and higher humidity. The curve (**B**) represents a proxy for monsoon intensity in South China from the Dongge Cave stalagmite records [31]. Higher $\delta^{18}O$ values indicate strong winter monsoons (cold/dry) and lower $\delta^{18}O$ values indicate stronger summer monsoons (warm/wet). The curve (**C**) represents a proxy for monsoon intensity in North China from the Lianhua Cave stalagmite records [33,82]. Higher $\delta^{18}O$ values indicate strong winter monsoons (cold/dry) and lower $\delta^{18}O$ values indicate stronger summer monsoons (warm/wet). The curves in (**D**,**E**) respectively indicate the relative occupation intensity of the Early Neolithic and the transitional sites across North China based on the sum probability of radiocarbon age estimates. The basic information of the radiocarbon dates (including the dataset of the radiocarbon dating and the explanation of how the sum probability distribution model was built) is presented in the supplementary data.

### *2.3. Human Responses to the Impacts of Climatic Change*

How climate change impacts on the development of human society has long been a hot topic attracting broad academic attention. Nowadays, environmental determinism is already obsolete and few scholars would regard environmental change as the decisive force leading to social changes.

The influences of climate change on human society are now evaluated under the complex patterns of the interplay between humans and the environment since we realized that human beings are able to flexibly handle the situations caused by environmental changes in various ways [83]. Facing similar natural challenges caused by environmental deterioration, different human communities might come up with varied coping strategies to deal with them. Such divergent strategies would have different impacts on the trajectory of local social and cultural development [84–86]. The choice of coping strategy is usually the result of previously held beliefs, social–political organization, technological bases, and historical interaction with neighboring societies [87,88]. Moreover, the potential advantageous conditions due to climatic amelioration may only benefit people and stimulate cultural fluorescence when people are fully prepared in cultural and social dimensions to sufficiently make use of such conditions [11,89].

The change into a colder and drier climate in historic and present day North China is often considered as climate deterioration because: (1) it would lead to the reduction of total biomass and therefore cause a decrease in resource affluency and the sizes of rich resource patches [90]; (2) it will also shorten the growing season, leading to the extension of the lean season for food resources [91,92]; (3) it will lead to unfavorable conditions for farming activity, at least in some parts of North China, due to the threat of disasters like drought and frost [93,94]. The sharp climatic change from a warm/wet period into a cold/dry period could also increase the risks of subsistence practice and force people to adjust their coping strategies, since the past experience of subsistence strategy might no longer fit well with the changing environment situation [95].

Based on an anthropological view, the ancient foragers might have had several options to handle the situation of such climate deterioration, as listed below:

(1) To increase mobility: This can be achieved as either expanding the foray distance or increasing the frequency of movement, or both [96]. Such a coping strategy could have enabled foragers to use a larger range of territory to procure resources and make up the deficiency of food resources in any confined areas, or reduce the resource pressures of any circumscribed regions [90,96].

(2) To actively intensify the yields of food resources in the circumscribed area where the resources are relatively abundant or have a suitable environment for food production [87]: The surplus of the food resources usually went into storage and could be consumed later in lean seasons [97,98]. A substantial amount of effort and/or prerequisites are required to fulfill such a strategy, such as technological improvements, new inventions, part-time cultivation, and improved methods and investments for resource management [13,99,100]. Such requirements call for intensified investment in the circumscribed area and therefore people must have settled down and developed effective ways to defend the resources within their immediate territory [14].

(3) To make long-distance migrations: Since environmental deterioration exerts impacts to varying degrees in different places, some areas might be less severely affected by climate change and might serve as destinations for migration [101]. Differing from the two strategies mentioned above, the migration strategy might have not necessarily required people to modify their adaption strategies since people could have still relied on past coping strategy by moving into the places where their past experience of subsistence strategy still fulfilled their needs [102]. However, since these destinations are usually not "empty", the long-distance migration might have caused changes in social and cultural interaction, either reflected by inter-group conflict or amalgamation [103].

(4) To develop social alliances and increase the intensity of social exchanges: This can increase reciprocal ties and buffer against subsistence risks [104]. This strategy is especially suitable in more heterogenous environments where the neighboring people may have relied on different subsistence bases and could have mutually complemented each other's strategies through exchange [11].

Different coping strategies can be reflected by a range of archaeological evidence listed in Table 1. In the following section, the multiple lines of evidence from the sites will be analyzed to learn the specific coping strategies people relied on to deal with the climate fluctuation in North China. The sites include both the ones during the time span of the 8.2 ka BP cooling event and prior to this climate fluctuation. Since the choice of coping strategy is closely based on the cultural preparedness that evolved from prior subsistence practices, the incorporation of the earlier sites strategies provides us an important cultural context to evaluate how and why people chose certain strategies to cope with the climate fluctuation of the 8.2 ka BP cooling event.

**Table 1.** Different coping strategies under climatic deterioration and their corresponding material implications reflected by archaeological evidence.

| Coping strategy under climatic deterioration | Archaeological manifestation |
|---|---|
| Increase mobility | Scarcity of the sites; lack of the permanent site structure; thin cultural deposits; portable toolkits. |
| Intensify the resource exploitation of the circumscribed affluent area | Toolkits used for intensive resource extraction; traces of intensified site occupation (thick cultural layer, permanent site structure, etc.); faunal and floral evidence showing the intensified resource use; traces of increased social integration (enlargement of the site, non-utilitarian goods); traces of territoriality (cemetery, defense structure). |
| Long-distance migration | Evidence of cultural transmission; the sharp decline in site numbers contrasted by the dramatic increase in site numbers in another area. |
| Alliance and trans-regional exchange | The presence of exotic goods, mutual cultural influences; stylish cultural markers showing the presence of reciprocal ties. |

## 3. Results

### 3.1. The "Transitional Remains" of the Early Holocene (11.5–8.5 ka BP)

In China, "Paleolithic" and "Neolithic" are short-hand terms for Pleistocene foragers and primitive Holocene farmers [4]. The differences between the two temporal/cultural entities are so pronounced that their shared heritage and genealogy are largely unexplored [4]. In past studies, some scholars have drawn attention to the lack of information connecting terminal Pleistocene foragers to the Early Neolithic farmers (or low-level food producers) and cited a "gap" in the archaeological record of North China from about 11,500 to 9000 BP [105,106]. However, although the evidence is still scarce, transitional sites that emerged in the Early Holocene prior to the full appearance of "Neolithic packages" have been found in different regions of North China. The names of the distributions of these sites are listed in maps "B" and "C" in Figure 1.

People were probably not sedentary and were organized as relatively small groups in this period. This inference is made from the evidence that: (1) no permanent dwelling structures have ever been found across the sites; (2) the site size is usually smaller than that of village-like settlements, except for the Nanzhuangtou site (which is estimated to be as large as 2 ha, but the precision of the estimation is still debated) [39]. The open-air site Donghulin is as large as 0.3 ha, smaller than most of the Neolithic sites found in a later period [38]. The Bianbiandong and Huangya sites are rock shelter sites, with only narrow spaces for daily activities [42]. The Lijiagou and Shizitan Locality 9/Locality12 G sites are deeply buried under the earth, so it is hard to make a reliable estimation of the site area. However, according to the exposure of the lithic remains on the profile, the site areas are probably not large [45,46,107].

Nonetheless, other lines of evidence suggest that people might have put more investment in site construction than in earlier periods. Burned earthen surfaces have been found in both Donghulin and Bianbiandong sites [38,43]. These are in an irregular oval shape and are harder than the surrounding depositions, which is inferred as living floors [38,43]. Decayed wooden poles have been found in the Nanzhuangtou site, which are suggested to have been used for constructing simple dwellings [39]. The hearths identified in the Donghulin site are in a more complex structure than the ones found in the Upper Paleolithic period (45–12 ka BP). The lower level of the hearths was arranged neatly by placing rocks in a circle. They are about 0.5–1 m in diameter and 0.2–0.3 m in depth, which is thicker than most of those found in the earlier period, showing the more intensive and perhaps persistent use of them [38]. Piles of rocks in semi-circular shapes have been found in the Lijiagou site. Such rock crescents might be correlated with dwelling construction and indicate more labor investment for inhabitation [107].

The occurrence of secondary burial in the Donghulin and Bianbiandong sites also implies that people had relatively permanent settlements at this time, to which the dead were brought back for ritual burials [108].

The faunal and floral remains found during this period indicate that people relied on a wide range of wild resources for their subsistence base. Some r-selected species (referring to the ones that quickly and massively produce short-lived "cheap" offspring), which are abundant in nature and hard to deplete in a short time, were intensively exploited, such as acorns in the mountainous regions and water caltrop in wetland environments [109]. Meanwhile, the earliest evidence of millet domestication was identified from the flotation results of the Donghulin site and starch analysis from the Zhuannian and Nanzhuangtou sites. The morphological studies of these millet remains show a combination of both wild and domesticated features, indicating that millet was still undergoing domestication [110,111]. Even though flotation results show that the broomcorn and foxtail millet make up only a tiny proportion of the charred seeds, morphological changes from the wild versions suggest that people had begun to carry out intensive intervention and management of the growth and reproduction of millet [111].

Corresponding technologies related to resource intensification are widely found in this period. Except for Shizitan Loc 9/Loc 12 G, pottery sherds have been discovered in all other sites [112]. Pottery provided people with innovative cooking techniques, which facilitated a more thorough intake of nutrients from food resources, like the grease from animal bones and hard-to-digest plant resources such as millet [92,113]. However, pottery is breakable and not suited transport over long distances, therefore it does not fit well in highly mobile lifeways [114]. The pottery found in this period is simple in form, crude, coarse-grained, and fired at low temperatures. The quantities are small in comparison with later period sites [115]. Such evidence indicates that even though the pottery and accompanying new cooking methods were widely adopted by foragers, vessels were not as intensively used as by the subsequent Neolithic farmers. The mobile lifeways and the limited levels of resource intensification might have confined the extent of people's reliance on pottery use [113].

Like pottery, grinding stone tools are also used for the intensive exploitation of food resources. They can process a wide range of foods, like nuts, tubers, bulbs, roots, and grass seeds, grinding them into powders that facilitate storage and consumption [116]. The grinding stones can be found in all of the abovementioned sites, except for Shizitan S12G [112]. However, most of the grinding stones found in this period are less regular in shape, with narrower grinding surfaces in comparison with those found in Early Neolithic sites after 8 ka BP [117] (the grinding slabs shown in Figure 3 and Figure 5 can provide an intuitive comparison). Moreover, grinding slabs make up only a small proportion of the lithic tool assemblage in each site except Nanzhuangtou, where only very limited number of lithic remains have been found [39]. In the Donghulin site, the grinding tools only comprise 11.05% of the tool assemblage [118]. In the Lijiagou site, they are only 13% of the tool assemblage in its upper cultural layer (approx. ~10.5–10 ka BP) [44]. Chipped stone tools still dominate the lithic assemblages in these sites. Such a pattern indicates that, even though grinding stones were widely adopted by people as auxiliary tools for food processing, they were not yet expected to play an important role in massively processing food resources at the unprecedented levels seen in the Early Neolithic period (about 8.5–7 ka BP).

To sum up, the features of the transitional sites, on the one hand, more closely resemble the preceding Upper Paleolithic sites in terms of the lack of permanent dwelling structures, small site size, chipped stone-dominated tool assemblage, and thin cultural depositional layers. Such similarities indicate that people in the Early Holocene at least partially inherited the socio-economic organization and land-use strategies from terminal Pleistocene foragers. However, the techniques necessary for the intensive exploitation of resources that were prevalent in the subsequent Neolithic period had already appeared and were widely adopted during this period [112]. The presence of domesticated millet also indicates that the knowledge of intensive resource management for certain species, and even cultivation, was developed in this period [111].

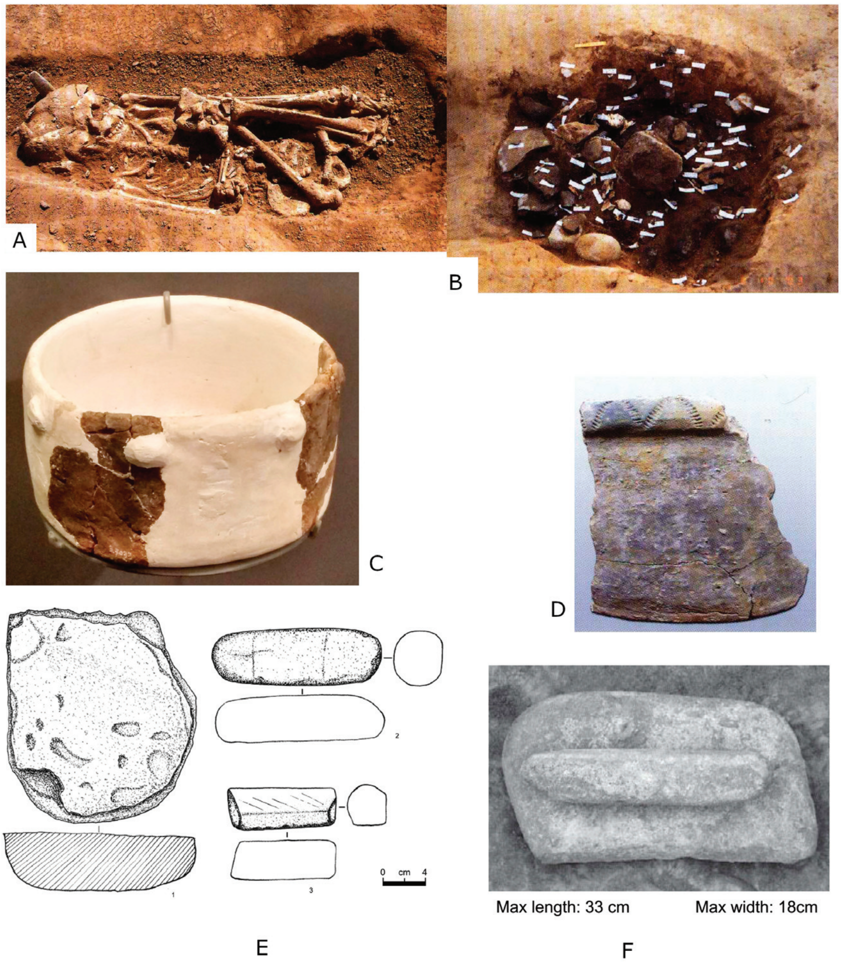


**Figure 3.** Features and artifacts found from transitional sites (11.5–8.5 ka BP) which show the innovative cultural traits that herald the "Neolithic package" and differ from typical Paleolithic remains ((**A**): sedentary burial, Donghulin site (2 in Figure 1); (**B**): stone-lined hearth, Donghulin site (2 in Figure 1); (**C**): Pottery bowl, Zhuannian site (1 in Figure 1); (**D**): pottery sherd with decorations on the rim, Donghulin site (2 in Figure 1); (**E**): stone slab and rollers Bianbiandong site (7 in Figure 1); (**F**): stone slab and roller, Donghulin site (2 in Figure 1), the maximum length and width are marked in the graph, after [37,38,43]).

Though these techniques and knowledge were still in their primary stage of development and had not yet became prevalent, they did stimulate subtle behavioral modifications and provided cultural preparedness for further social and economic transformation. For instance, such techniques and knowledge enabled people to fully exploit certain kinds of food resources that thrived due to climate amelioration at the beginning of Early Holocene, such as acorns and water caltrop. The paleoclimate data indicate that the beginning of the Early Holocene (which started at around 12 ka BP) was a warmer and wetter period in comparison with the Terminate Pleistocene period [31,82]. The warm and wet climate facilitated the recovery of forests in the mountainous region of North China and may have increased the distribution of nut-bearing trees, like oaks. The wet climate also expanded wetland areas and facilitated the growth of highly productive wetland food resources [109]. Even though sedentary lifeways had not yet been formed, the enhanced food resource supplies or the need to intensively exploit food resources in certain areas might have led people to stay for longer durations, making more intensive and regular use of certain sites within their land-use system.

### *3.2. Pioneering Changes in Coping Strategies Across the 8.2 ka BP Cooling Event in North China*

Dating results for the transitional sites in the Early Holocene reveal that most of them are concentrated between 11.5 and 8.5 ka BP, suggesting that the main occupational phase of these sites is before the 8.2 ka BP cooling event. There are large "empty" areas where no archaeological sites have been discovered during the 8.2 ka BP cooling event except for a few "pioneering" sites found in specific regions which provided rich and diversified food resources. These sites show similar features to those thriving Early Neolithic settlements that appeared after 8 ka BP. This pattern implies significant modifications to human coping strategies in the period of the 8.2 ka BP cooling event.

The appearance of the "pioneering sites", characterized by larger-scale population amalgamation, sedentary lifeways, intensive site use, and rich material remains, suggests that people in some areas adopted the strategy of staying put in resource-rich areas and investing in ways to increase the local food supply as a means to adapt to climatic deterioration. Several sites have reflected the adoption of such a strategy, as discussed below.

#### 3.2.1. The Jiahu Site

The Jiahu site (shown as 10 on maps "D" and "E" in Figure 1), is located in the Huai River Valley on the southeast edge of the Huanghuai alluvial plain in Wuyang County, Henan Province. Based on radiocarbon dates and cultural features, the Jiahu site was occupied from 9000 to 7600 BP, and can be divided into three phases: (1) 9000–8500 BP; (2) 8500–8000 BP; (3) 8000–7600 BP [119]. The total area of the site is about 5.5 ha and more than 2900 $m^2$ have been excavated over eight seasons of excavation from 1983 to 2013 [120,121]. Phase 1 of the Jiahu site was before the appearance of the 8.2 ka BP cooling event and was contemporary with some "transitional remains", such as the upper layer of the Lijiagou site and the lower layer of Shizitan Locality 9. Certain features of cultural remains in Jiahu Phase 1 differ pronouncedly from the "transitional remains" for various aspects. One crucial difference is the complexity of the site structures. Fifteen houses have been discovered, which are widely distributed from the west to east zone of the site and can be divided into five clusters. Fifty-one burials are laid close to the pit houses. In addition, two kilns and numerous pit structures have been found within the excavation zone. The pit structures were used as storage facilities or midden deposits [47]. Such complexity of site structure implies that people were sociopolitically organized in different ways and occupied the sites with more stable residency. The clustered distribution of houses probably reveals the amalgamation of different groups (which might have family ties) rather than the natural growth of a small band [122]. More investment for dwelling construction, storage facilities, and garbage disposal indicate a pattern of relatively stable habitation rather than ephemeral site use [123]. Moreover, pottery was used far more frequently in the Jiahu site [47]. The forms of pottery were more diversified than those found in the transitional sites, and they were made in more regularized shapes and fired at higher temperatures. The grinding stones were also made in more regular shapes [124].

Phase 2 of Jiahu had temporal overlap with the 8.2 ka BP cooling event. In this period, the settlement was further developed and became prosperous. The increasing number of artifacts, as well as houses, burials, and pit structures, indicates that people made more intensified use of the site during this period [47]. The houses were still distributed in clusters (the Jiahu report divides them into six clusters). The increase in burial numbers from 51 to 348 between Phase 1 and Phase 2 suggests a sharp increase in population size [119,121]. Unlike Phase 1, when burials and houses were mixed together, concentrated cemetery zones appeared. The distributional pattern indicates that, while they were spatially separated from the houses, each of the cemetery zones roughly corresponded with one house cluster. Analysis of the strontium isotopes of human bones from the cemetery indicates that, beginning in Phase 2, a few people from other regions migrated into the Jiahu site [125]. Some special items, such as turtle shells with gravel, a bone flute, and other carved bone "folk-shaped" items, have been found in a few of the burials [47]. Such items (seen as Figure 4) probably served as ritual paraphernalia and the appearance of them implies the elaboration of ritual activity during this period.


**Figure 4.** The items possibly used as ritual paraphernalia in the Jiahu site ((**A**) turtle shell with gravel, found in burial M363; (**B**) bone folk-shaped item; **1**: found in burial M395, **2**: found in burial M363. (**C**) bone flute; **1**: found in burial M57, **2**: found in burial M68; after [47]).

How could the Jiahu community have become prosperous during the general background of climatic deterioration? This could well be closely related to people's strategical exploitation of rich resource patches during the period of climate deterioration. The Jiahu site is located on the low-lying alluvial plain and near the confluence area of the ancient Hui and Sha rivers. Based on the study of geomorphology and sedimentology, Jiahu is situated on a hillock slightly higher than the surrounding area and faces large marshes and waterbodies to the east. Such a location offered easy access to different ecozones for procuring food resources within a circumscribed area. The marsh to the east of the site provides highly productive wetland food resources and is an ideal place for rice cultivation. To the east, a zone with rich aquatic resources provides habitat for freshwater fishes and shellfish. To the west of the site is a vast plain with terrestrial resources like deer, tree nuts, and fruit [47]. The Jiahu tool assemblages (seen as Figure 5) indicate that, through all three occupational phases, people were equipped with complex techniques to procure various resources from different ecozones: specially designed bone harpoons in varying sizes were used for gathering fish, and bone arrowheads were used for hunting. The grinding tools were enlarged and produced in more formal shapes, making up higher proportions within the lithic tool assemblages (30% of the lithic tools in Jiahu Phase 2) in comparison with those of "transitional remains" [125]. Such changes reflect that specialized technologies were used intensively for the bulk processing of plant resources. The stone hoes and sickles may have been used as tilling and harvesting tools relevant to farming activity [124]. The flotation results and faunal remains also indicate that people extracted a broad spectrum of wild plant and animal species from different ecozones and incorporated domesticated rice and pigs as supplemental food resources [126,127].

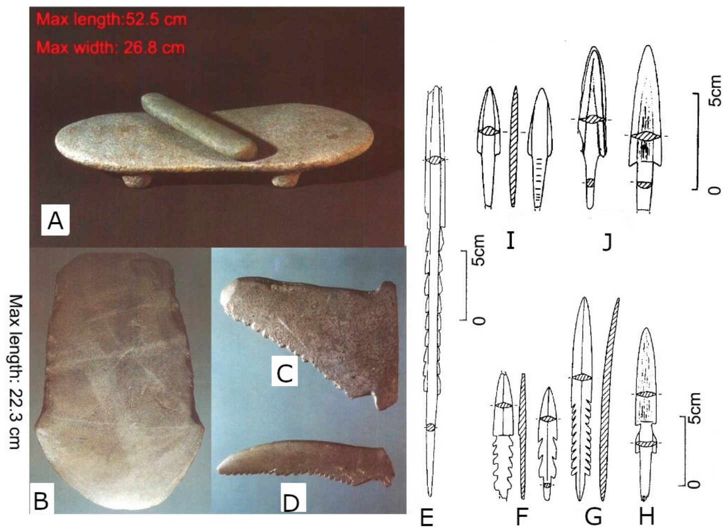


**Figure 5.** Toolkits of the Jiahu site which show the intensity of the techniques of food acquisition ((**A**): stone slab and roller, the size of the stone slab is marked in the figure; (**B**): stone hoe; (**C**,**D**): stone sickle; (**E**–**H**): bone harpoon; (**I**,**J**): arrowhead, after [47]).

The climatic deterioration and sophistication of the techniques for resource acquisition increased the value of specific rich resource patches, like the area around the Jiahu site. For one thing, climate deterioration resulted in a "patchy" distribution of freshwater resources that effectively constrained the distribution of the plants and animals that depended on them. This would concentrate the distributions of rich resource patches into smaller areas and increase the inter-patch distance [90]. Additionally, food resources in such rich patches could be fully exploited by human beings with the assistance of complex techniques. Under such circumstances, people would likely be tethered to such constrained areas instead of making a long-distance movement. This would facilitate the growth of local populations and even attract people from less affluent areas. The enlargement of the community size required more food supplies and therefore stimulated further resource intensification. Besides, increasing population density would have led to scalar stress among community members and might even have cause social conflict, which called for innovative sociopolitical solutions to cope [128]. The elaboration of ritual activities, the division and management of cemeteries, and perhaps even the construction of ditches at the boundary of the settlement at Phase 2 were likely used as a cultural means for the Jiahu community to enhance social integration. The intensification of ritual activities, as ethnographic evidence indicates, could also potentially have been used as a means to deal with subsistence stresses and risks, which often appear when factors like population growth, social interaction, environmental change, and climate fluctuation have broken up the pre-existing balance between humans and the environment [86,129].

### 3.2.2. Shunshanji and Hanjing

Shunshanji and Hanjing are two adjacent sites located in the low-lying hills of the lower Huai River drainage area in the eastern part of Huanghuai Plain, which is the transitional zone between North and Central China (respectively shown as 14 and 15 in maps "D" and "E" of Figure 1).

The cultural remains of Shunshanji can be divided into three phases. Radiocarbon dates indicate that Phase 1 and Phase 2 lasted from 8.5–8 ka BP (the boundary between Phases 1 and 2 is estimated to be at 8.3~8.2 ka BP), while Phase 3 is estimated as the period of 8–7 ka BP. The size of Shunshanji is 17.5 ha, which is the largest ever found before 8 ka BP in North China. An area of 2750 $m^2$ has been excavated in total over three field seasons. The settlement has a ditch that encircles an area of nearly 7.5 ha. The cultural remains were found both within and outside of the ditch, including houses, pit structures, and burials [51].

Phytoliths from the ditch profile reflect the impact of the 8.2 ka BP cooling event at the beginning of Phase 2, with types indicating the cold climate significantly increasing during this period [130]. Yet like the Jiahu site, the Shunshanji cultural remains suggest that the settlement became prosperous during Phase 2. During this period, the ditch was constructed and a cemetery appeared to the northwest of the ditch. The distribution of cultural remains expanded and a richer amount of artifacts and relics was deposited [51]. Such a pattern indicates more intensified occupation of the site. According to the presence of a large quantity of deer, boar, fish, and turtle bones and the features of lithic types [51,131], the subsistence base of the settlement was still based on the intensive exploitation of wild resources. Rice phytoliths have also been found, and interestingly, the amount of them in Phase 2 is higher than those from both Phases 1 and 3, which may suggest that people intensified the cultivation of rice to some extent during the cooling period and decreased the level of intensification when the climate returned to a warmer and wetter pattern [130]. Whether or not people applied institutionalized rituals to enhance social integration at Shunshanji is still not clear. But the placement of small animal- or human-shaped pottery figurines in the ditch might be correlated with specific rituals or sacrifices [132].

The Hanjing site is 4 km west of Shuishanji and radiocarbon dates indicate that the main occupational phase was contemporaneous with Shuishanji [52]. The Hanjing site is about 5 ha and a 3 ha area of the site was encircled by a ditch. The ditch was infilled with numerous types of garbage, like broken ceramics and animal bones. The evidence shows that the ditch was filled and the roads and activity zones were formed on top of it during the late occupational phase, suggesting the expansion of the site [52]. Besides the ditches, houses, and pit structure, a section of paddy field has been found, directly indicating intentional rice cultivation [131].

### 3.2.3. Zhangmatun and Xihe

Zhangmatun and Xihe are two adjacent sites (slightly more than 20 km apart) located in the transitional zone between the hills/low mountains of the Taiyi Mountain range and the North China alluvial plain in Shandong Province in eastern North China (respectively shown as 11 and 12 on maps "C", "D", and "E" of Figure 1). The Zhangmatun site is estimated to be as large as 0.7 ha, and 600 $m^2$ have been excavated. One pit house and one pit structure have been identified, along with a rich amount of faunal and floral remains. Dating results show that this site was occupied from 9 to 8.5 ka BP [48]. Although the limited excavation area does not allow us to explore the site's layout features, the appearance of a pit house and associated rich food remains resemble the site features of Jiahu Phase 1. Though the site size is smaller than Jiahu, it is larger than most of the sites classified as "transitional remains". Such evidence suggests that the transition into Neolithic lifeways, as indicated by growing residential stability, increasing levels of resource intensification, and the enlargement of group size, appeared prior to the 8.2 ka BP cooling event in this region.

The Xihe site dates to between 8.4 and 7.7 ka BP. The early occupational period of the site was contemporary with the 8.2 ka BP cooling event. More than 2400 $m^2$ of the site have been excavated, revealing over 30 houses and numerous surrounding pit structures. Houses were more densely distributed than in the Zhangmatun site. The largest house is more than 70 $m^2$ and most are as large as 25~50 $m^2$ [49]. The living floors and walls are more elaborately treated than the house found in Zhangmatun. The density of pottery in Xihe is also higher than in Zhangmatun, indicating that people used pottery far more frequently [133]. All these lines of evidence suggest that during the period of the cooling event, people were more stably settled in the circumscribed area, perhaps with a larger population aggregation and more intensified social integration (evidenced by the more compact distribution of houses and pit structures). However, the Xihe site is devoid of the elaborate expressions of ritual and symbolic affairs seen in the Jiahu site, indicating a less complex sociopolitical integration than at the Jiahu site.

The faunal and floral remains of Zhangmatun and Xihe indicate that people relied heavily on a wide range of wild resources and also incorporated domesticated crops and pigs as supplemental foods [20,134]. The domesticated crops in Zhangmatun were two types of millet (broomcorn and foxtail) [135]. The crops in Xihe were rice and foxtail millet [136]. The practice of rice cultivation, as well as a large amount of fish and bird bones found in both the Zhangmatun and Xihe sites, suggest that in addition to the exploitation of terrestrial resources, wetland and freshwater resources were intensively used [20].

#### 3.2.4. Cishan

The Cishan site is located in the transitional zone between the Taihang Mountains and the North China plain (shown as 13 on maps "D" and "E" of Figure 1). Cishan has been dated between 8.4 and 7.6 ka BP. Three pit houses and 889 pit structures have been found within the 5519 $m^2$ excavation zone [137]. The site sits on a loess platform near a large river, and is not far from the forested piedmont zone. Such a location provides good opportunities for people to get resources from different environmental zones near the site [138].

The nature of the site is highly disputed. Given the facts that (1) millet and hackberry (*Celtis sinensis*) seeds have been found in some of the pit structures and (2) the majority of the remains are identified as pit structures instead of houses, some scholars have considered that the Cishan site was used as a specific place to store food resources and even hold sacrifice activities based on stored foods [139,140]. However, some scholars still insist that the Cishan was a residential site since it was excavated during the early period when the archaeologists still lacked the experience to distinguish large pit structures and small and simply built pit houses without interior hearths [141–143]. I agree with the inference that the Cishan site was a residential settlement for the following reasons: (1) some simply constructed houses could be mis-identified as large pit structures (i.e., middens or storage pits) and (2) the diversity of tools suggests that people were engaged in various activities besides the storage behaviors at Cishan, like woodworking, food processing, hunting, fishing, and cultivation [50]. The highly diversified faunal remains, such as migratory birds and deer with both dropped and undropped antlers, suggest multi-seasonal hunting [144]. Therefore, the Cishan community also shows a coping strategy of intensively using resources around the site and massively storing the food for delayed consumption in lean seasons. The large site area (estimated as roughly 10 ha) probably implies a large group aggregation as well.

However, the in situ distribution of about 140 suites of tool compounds reflects the behavior of intentionally preparing and leaving the tools for later use. This implies that people might have left the site temporarily and anticipated a later return [123]. Such combined evidence suggests that, on one the hand, Cishan communities stayed for a longer period of time in the site and repetitively used it based on a broad range of resources exploited from the surrounding environment. For another thing, the characteristics indicating sedentism were not yet stable.

#### 3.2.5. Xiaohexi Remains

Prior to the flourishing development of Xinglongwa culture around 8~7.2 ka BP, a couple of newly discovered sites have been attributed to "Xiaohexi culture" in the west Liao River Valley in the northeast part of North China [145] (the type site, Xiaohexi, is marked as 16 on the maps "D" and

"E" of Figure 1). The Xiaohexi sites are usually located on slopes or high loess platforms along river valleys [146]. The age of these remains is mainly inferred from the stratigraphic evidence. The previous excavation of the Baiyinchanghan site revealed that a pit house of Xiaohexi culture was stratigraphically overlain by a pit house of early Xinglongwa culture [147], suggesting that at least part of the Xiaohexi remains might be even earlier than Xinglongwa culture, potentially with a time overlap with the 8.2 ka BP cooling event.

The Xiohexi sites are organized as hamlets or small villages. The appearance of pit houses and diversified toolkits indicates more settled lifeways with the intensive use of a wide range of surrounding resources near the site [80]. However, the Xiaohexi pottery is crude and simple in form [148]. The cultural deposits are thin and there are no complex overlaps of houses and pit structures built at different times, as seen in the Jiahu site [145]. Such patterns indicate that the degree of residential stability was lower than that of Jiahu.

#### 3.2.6. Nucleated Sedentism and Resource Intensification: An Innovative Coping Strategy Occurred in Multiple Sites but in Different Expressions

All the sites I discussed above in this section (Section 3.2) point to increasing sedentism and resource intensification as a way to cope with environmental change—But expressed to varying degrees. The sedentism of the Jiahu site seems more stable since there is a complex pattern in which later houses or pit structures overlaid those built in earlier times. Corresponding sociopolitical practices to support the operation of the large and sedentary community of Jiahu were also more elaborate. The Shuishanji site is the largest site in this period, probably indicating the largest scale of population aggregation. The appearance of the cemetery and possible evidence of ritual or sacrifice activities also indicate intensified social integration. The fine-scale evaluation of the residential stability of Shuishanji is difficult since an only a very limited number of houses has been excavated. Yet according to the period of site occupation and relatively thick cultural deposition, we can at least infer that people inhabited and used this settlement with high levels of intensity.

As for the other sites, although they show tendencies of technological organization that are similar to Jiahu or Shunshanji/Hanjing, such as the increasing use of pottery and more sophisticated lithic and bone tool assemblages, they were less developed both in terms of the stability of sedentism or group aggregation and the elaboration of sociopolitical integration like those of Jiahu or Shuishanji. Such a pattern suggests that, even though people have attempted to rely on the increase in residential stability and resource intensification as a way to deal with environmental changes, the extent to which such a strategy can be fulfilled is still heavily influenced by the constraints of the local environment. The scale of the intensive use of wetland and aquatic resources in Jiahu, Shunshanji, and Hanjing seems larger than that of other sites mentioned above, indicating the importance of the exploitation of waterfront environments for the thriving development of Neolithic communities during the period of the 8.2 ka BP cooling event.

#### 3.2.7. The Scarcity of the Archaeological Remains across North China and Its Implications

The distribution of the above-mentioned sites across multiple regions of North China suggest that the new coping strategy, applied to deal with the 8.2 ka BP cooling event, was not an occasionally occurring phenomenon confined to any specific region. Nonetheless, the site numbers are still scarce compared to those after 8 ka BP. There are vast gap areas distributed "in between" these sites which are devoid of any detachable sites. Though the absence of archaeological remains in these gap areas does not necessarily mean that people migrated out of such regions and left large portions of North China unoccupied, it is highly possible that people increased their mobility and left few visible remains for archaeologists since, as discussed in Section 2.3 of this article, increasing mobility could be an efficient coping strategy when used in an area with few or less rich resources to alleviate resource pressure and expand the area for resource exploitation [90]. Hence, the limited number of intensively occupied sites accompanied by vast "in between" areas devoid of any visible archaeological remains likely indicates that people might have adopted divergent ways to cope with environmental changes (nucleated sedentism, intensified resource exploitation vs. increase in mobility) across the area with varying degrees of resource affluency.

## 4. Discussion

### *4.1. Preexisting Cultural Preparations and the Path to the Neolithic Lifeway*

The transitional remains of the Paleolithic to Neolithic disappeared during the period of the 8.2 ka BP cooling event. Such a change indicates that the land-use pattern, as reflected by the transitional sites, did not work well as an adaptive strategy for this climate fluctuation. People were either forced to return to more mobile lifeways to buffer against subsistence risks caused by the cooling event, or develop new forms of socioeconomic coping solutions.

The scarcity of archaeological remains probably indicates that people increased residential mobility in many regions of North China. However, a few sites, discussed in Section 3.2, like Jiahu, Shunshanji, Hanjing, Zhangmatun, Xihe, Cishan, and Xiaohexi, are quite distinctive since they show evidence for the initial formation of a "Neolithic package", indicating that people were economically and sociopolitically organized in new ways to pursue subsistence needs and interact with the environment. These groups were aggregated in larger communities and settled down in confined places based on the intensive resource exploitation of the surrounding area, combined with intensified hunting–gathering, part-time farming, and even small-scale animal husbandry. The locations of such settlements are usually in rich resource patches like the transitional zone between mountainous areas and plains, or between dryland and marshes and large water bodies. For one thing, some of these ecozones have certain types of highly productive food resources. For another, easy access to different ecozones provided people with diversified ranges of plant and animal resources to use [149].

People were able to fully exploit such "rich areas" partly based on the cultural preparations developed prior to the 8.2 ka BP cooling event. The onset of climate amelioration in the Early Holocene (12–8.5 ka BP) changed the resource distributional pattern and provided opportunities for people to experiment with new ways of resource exploitation and to modify their previous subsistence practices. Grinding stones and pottery became more widely adopted as part of the resource intensification techniques. Domesticated millet was incorporated for the first time into the diet, implying accumulated knowledge about plant domestication and cultivation. Such changes provided important technical and knowledge support for the further development of resource intensification. Accompanied by the modifications of subsistence practices, people began to stay for longer periods at certain sites and their mobility gradually decreased. Some even attempted to settle down in a few resource-rich areas with larger group sizes during 9~8.5 ka BP, as reflected by Jiahu Phase 1 and the Zhangmatun site.

Therefore, before the coming of the 8.2 ka BP cooling event, people in some regions of North China were fully prepared to intensify resource exploitation and increase sedentism as coping strategies to deal with climatic deterioration. However, since people's capabilities for food production were still low, and their subsistence basis was still heavily dependent on wild resources, the application of such a coping strategy only happened in the areas with rich resource patches, where people could take full advantage of extracting highly productive natural resources.

### *4.2. The Impact of Climate Change Coping Strategies on the Thriving Development of Neolithic Culture*

Before the period of the 8.2 ka BP cooling event, sedentary settlements were only found sparsely in a few resource-affluent areas in North China. However, after the end of the 8.2 ka BP cooling event, sedentary settlements that embody distinctive Neolithic features thrived and became widely spread across different regions of North China (shown in Figure 1). Such a pattern indicates that the period around the 8.2 ka BP cooling event was a key time for the formation of Neolithic lifeways.

The specific interactive pattern between environmental change and the practice of coping strategies accounts for such significant social and cultural transitions. The drier and colder climate of the 8.2 ka BP cooling event reduced general resource affluence in North China and pushed the population in certain regions to aggregate in the constrained resource patches of relatively richer resource distributions than the surrounding areas. Under the general background of climatic deterioration, the values of such resource patches would have increased, which facilitated people to maintain long-term access to these places through more stable residency to ensure more persistent occupation and exclusive exploitation of such "sweet spots". As a result, the land-use pattern became transformed from relatively extensive resource acquisition across broad regions into intensive resource exploitation in a circumscribed environment. Such a change created favorable conditions, as well as the stimulus, for the development and prevalence of techniques relevant to intensive resource exploitation, which contributed to the subsequent thriving development of Neolithic lifeways in two main aspects: first, it increased the levels of resource intensification and enabled people to acquire wild resources effectively and in substantial quantity in the circumscribed region during affluent seasons and store them for use during the lean season. On the other hand, as an important part of the resource intensification technique, the knowledge and skills of farming became further developed and people were able to use the benefits of the climatic amelioration after the end of the 8.2 ka BP cooling event to expand farming activity and increase the importance of domesticates as supplement food resources.

Besides consolidated economic bases, the maintenance of large group aggregation in the settled area also required sociopolitical innovations; otherwise, the population was inclined to split away and disperse when faced with increasing scalar stresses resulting from local population increases and densities [128]. Cemeteries, symbolic items, and ritual activities could have been effectively used to strengthen group identity and increase social integration [150,151]. The need to apply such sociopolitical innovations might at first have arisen in large aggregated communities that appeared around 8.5–8 ka BP, since the increased population was inclined to nucleate rather than split away under conditions when the environment outside the resource patches was less productive and there was a need for people to stay put in larger community sizes to facilitate perimeter defense. Among the sites found from around 8.5–8 ka BP, Jiahu, Shunshanji, and Hanjing show relatively large population aggregation and the most stable form of sedentism. The appearance of a cemetery in Jiahu and Shuishanji, as well as the emergence of ritual paraphernalia in Jiahu Phase 2, are ahead of the prevalent applications of such sociopolitical innovations during the prosperity of Neolithic culture after 8 ka BP [152]. Such a leading development of sociopolitical innovations might have provided the basis for future wide adoption by later societies.

Therefore, the application of resource intensification and increasing sedentism to deal with the climate fluctuation caused by the 8.2 ka BP cooling event provided favorable conditions for the convergence of the multiple "Neolithic traits" together, such as the sophistication of resource intensification techniques, sedentary inhabitation, the enlargement of group size, and the elaboration of social interaction. This combination generated new full-fledged forms of socioeconomic solutions to meet subsistence needs. Due to the environmental constraints around 8.2 ka BP, the appliance of such socioeconomic solutions was only possible in a few rich resource patches and was developed at different levels of prosperity in different regions. Nonetheless, after the 8.2 ka BP cooling event, the climate began to ameliorate and the warmer/wetter climate increased general resource affluence, creating more rich resource patches and decreasing the risks to food production. As a result, the practice of such new socioeconomic lifeways was less confined by environment constraints and was more widely adopted by people in different regions of North China.

## 5. Conclusions

As indicated by the material implications of the archaeological remains, certain types of "Neolithic traits" budded from the terminal Pleistocene to the early Holocene, accompanied by and partly as a consequence of climate amelioration. However, the dispersal of fully-fledged Neolithic lifeways across different regions of North China did not appear until the onset of the Holocene climate after 8–7.8 ka BP. The climate fluctuation caused by the 8.2 ka BP cooling event, which happened just before the coming of the climate optimum, exerted a significant impact on the development of the Neolithization process.

The occurrence of "pioneering" sites, with comprehensive Neolithic features during the period of 8.5–8 ka BP, suggests that changing environmental conditions required people to settle in relatively rich resource patches and form intensive interpersonal relationships, as well as between humans and resources. Such an intensive relationship required people to provide sufficient food supplies in the confined environment and develop more sophisticated socioeconomic mechanisms to reconcile social conflict and enhance the cohesion of the community. Therefore, as indicated by archaeological evidence, intensified techniques for resource acquisition were further developed based on the previous cultural accumulations. The innovative sociopolitical ways used to meet the social demand of nucleated sedentary societies also emerged during this period. The interplay of these two ever-evolving factors has fundamentally changed humans' land-use strategies and formed a new full-fledged sociopolitical practice for people to integrate their societies and interact with the environment. Taking favorable opportunities brought by climate amelioration after the period of the 8.2 ka BP cooling event, this Neolithic lifeway was widely adopted by people, it expanded into broader regions and was further developed, which was reflected in the thriving development of Early Neolithic cultures in North China.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2571-550X/3/3/23/s1, Table S1: The radiocarbon dates of the sites used for constructing the cumulative probability model of Figure 2 in the paper.

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# Microblade–Based Societies in North China at the End of the Ice Age

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**Abstract:** One of the most prominent cultural changes during the end of Ice Age in northeastern Asia was the adoption of microblade technology by prehistoric hunter–gatherers to deal with the challenge brought by the climate deterioration and oscillation during and post the Last Glacial Maximum (LGM). The Pleistocene to Holocene transition in North China witnessed the rise of broader spectrum subsistence alongside a series of cultural changes, including adoption of food production, highly mobile lifeways being replaced by sedentism, and the formation of new social organization based on their agricultural land–use patterns. From the perspective of technological change, this project aims to build a socio–ecological framework to examine the cultural change of prehistoric microblade–based societies. In contrast to previous studies, the present research employs a macroecological approach based on Binford's *Constructing Frames of Reference* (2001) to reconstruct the behaviors and demography of prehistoric foraging groups, under both modern and LGM climate conditions. Three case studies are conducted to show cultural and technological changes among microblade–based societies in North China during the Pleistocene–Holocene transition.

**Keywords:** microblade technology; broad spectrum revolution; Pleistocene to Holocene transition; origin of food production; hunter–gatherers; macroecology; *Constructing Frames of Reference*

## 1. Introduction

During the Pleistocene to Holocene transition, northern China not only witnessed a broad spectrum revolution, intensification, and food production, but also saw the increasing use of durable stone tools linked to a terrestrial plant–dependent economy and the fading of microblade technology linked to highly mobile hunting–dominated lifeways. This process is generalized by Chen and Yu [1,2] as the Paleolithic to Neolithic Transition (PNT) (ca. 15,000–8500 Carbon 14 [C14] BP) in the period after the Late Upper Paleolithic (LUP) (ca. 24,000–15,000 C14 BP). Archaeological records suggest that the early Neolithic sites and sites with cultivation dated to the terminal Pleistocene are both located in relatively small habitats in basins, valleys and foothills of forest–steppe ecotones in the zone between the terrestrial plant threshold and the storage threshold in Lewis Binford's system (effective temperature [ET] = 12.75 − 15.25 °C) [3]. Agriculture appeared on the North China Plain after humans achieved sophisticated food production technologies during the Middle Holocene. Chen also attributes food production to collectors who practiced logistical strategies in Binford's forager–collector system [4,5]. Microblade–based societies cannot securely be classified as either foragers or collectors, but according to Chen's proposition, it seems that the foragers in northern China (if there were such) may have changed their subsistence–settlement system to collecting during the terminal Pleistocene. Current archaeological records are inadequate to fully test this hypothesis, but they can be investigated from a macroecological and analogical viewpoint. Recent research indicates that in northern China during the transition from the unpacked to the packed population condition, hunting-dominated subsistence is expected to become gathering-dominated subsistence in the west (the Loess Plateau), and fishing–dominated subsistence in the east (North China Plain) in which lakes and marshes formed at the end of the Last Ice Age [6]. Most early sites associated with cultivation, ground stone tools, and microblade assemblages are located along the boundary of the gathering–fishing–dominated subsistence line, suggesting that prehistoric foraging societies might have been practicing a mixed economy.

This project only focuses on the relationship between the rise of food production and the decline of microblade–based societies, within the time range from the Last Glacial Maximum to early Holocene. The decline of microblade–based societies cannot be explained as humans migrating out to the frontiers, since the archaeological record in Northern China tends to support an explanation of cultural transition rather than replacement [7]. In the following three sub–topics concerning Northern China, I apply the macroecological approach to study the development and decline of microblade–based societies under the background of the PNT, with the time range from the LGM to the early Holocene.

## 2. Methodology

The present project employs an analogical research strategy from the anthropological side to evaluate ideas generalized from the archaeological side in the previous studies which mainly followed a cultural–historical paradigm. The main methodology adopted here is macroecology, developed from the late Lewis Binford's book *Constructing Frames of Reference* [3], which has been fully standardized by his colleague Amber Johnson as a calculation program EnvCalc 2.1 [8]. This program makes possible the reconstruction of prehistoric hunter–gatherers' foraging strategies possible on a global scale [9] and the regional scale [7,10,11]. More than 300 variables derived from the program can be grouped as four datasets: (1) Climate, biomes, and habitat; (2) Minimalist terrestrial model; (3) Modelling density-dependent change in hunter-gatherer subsistence; and (4) Growth rate model and density–controlled subsistence (the variables referring to the present research are listed in Table 1). These variables provide an irreplaceable referential framework to help anthropologists predict/project hunter–gatherers' foraging strategies in a specific region even the foraging populations no longer exist due to cultural transformation or resettlement. For example, several variables, including duration of growing season (GROWC), net aboveground productivity (NAGP), and terrestrial model value for population density (TERMD2), are used to test the hypotheses of the transition from hunter–gathering to farming in the Near East by Binford [3] (pp. 434–464).

**Table 1.** Key variables used in this research project.

| Topics and Models | Hunter-Gatherers | Variable | Definition [1] |
|---|---|---|---|
| **Climate, Biomes, and Habitat** | Climate | GROWC | Length of growing season: Length of growing season. Number of months with mean temperatures greater than 8 degrees Celsius |
| | | ET | Effective temperature: a measure designed to examine biological implications of ambient warmth |
| | Biomes and habitat | NAGP | Net above–ground productivity |
| | | BIO5 | Primary biomass |
| | | EXPREY | Expected moderate body-size ungulate biomass (kg/km$^2$) |

**Table 1.** *Cont.*

| Topics and Models | Hunter-Gatherers | Variable | Definition [1] |
|---|---|---|---|
| **Minimalist Terrestrial Model** | Population density | TERMH2 | Number of persons per 100 $km^2$ unit who could be supported by the ungulate resources alone |
| | | TERMG2 | Number of persons per 100 $km^2$ unit who could be supported by the plant resources alone |
| | | TERMD2 | Population density expected at a particular location, expressed in terms of persons per 100 $km^2$ |
| | Subsistence specialty | SUBSPX2 | Terrestrial model expected subsistence bias for use with ethnographic cases h = hunting, g = gathering, m = mixed, u = uninhabited |
| **Modelling Density–Dependent Change in Hunter–Gatherer Subsistence** | Subsistence | SUBSPE | Ordinal classification of projected hunter–gatherer subsistence specialty 1 = hunting, 2 = gathering, 3 = fishing |
| | Population density | WDEN | Projected hunter-gatherer density |
| | Group size | EXGRP1 | Projected mean size of smallest residential group, segmented by group pattern and subsistence specialization bias |
| | | EXGRP2 | Projected mean size of largest residential seasonal camps, segmented by group pattern and subsistence specialization bias |
| | | EXGRP3 | Projected mean size of periodic regional camps, segmented by group pattern and subsistence specialization bias |
| | Mobility | EXDMOV1 | Projected total distance moved, scaled for subsistence type, for groups with year round camp to camp mobility pattern |
| | | EXDMOV2 | Projected total distance moved, scaled for subsistence type, for groups who move into and out of a central location or who are primarily sedentary |
| **Growth Rate Model and Density–Controlled Subsistence** | Subsistence specialty against the unpacked background | UPSUBSPE | Ordinal classification of projected unpacked HG subsistence specialty (packing multiplier = 0.5) 1 = hunting, 2 = gathering, 3 = fishing |
| | Subsistence specialty against the packed background | D1PSUBSPE | Ordinal classification of projected packed HG subsistence specialty (packing multiplier = 1) 1 = hunting, 2 = gathering, 3 = fishing |

Note: [1] from "variables used or calculated in EnvCalc2.1 program (except UPSUBSPE and D1PSUBSPE) [8].

The author's dissertation combines macroecological approach of hunter–gatherers, modern and simulated LGM climatic data, and prehistoric technological organization associated with microblade technology to investigate the role of microblade technology in the development of human adaptations in NE Asia, especially northern China, during the closing millennia of the Upper Pleistocene and across the Pleistocene–Holocene transition [6]. Microblade–based societies as a new concept provides a fresh perspective to characterize a socio-technologically adaptive convergence and radiation of human groups before and after the Last Glacial Maximum (LGM) across NE Asia, in which people adopted microblade technology as the basis for the lithic elements of composite tools/weapons to help organize their lives in their territories, depending, of course, on the availability and quality of local lithic resources.

## 3. Archaeological Sites Associated with Microblade Technology in North China

North China, in the narrow sense, refers two subregions: the Loess Plateau in the west and the North China Plain in the east. According to archaeological record recovered, the southern limit of distribution of microblade technology during the late Pleistocene is northern side of the Qinling Mountain and the Huaihe River, which is also the north–south division of modern Chinese geography. The northern line of North China is along the Great Wall, which is also the steppe–forest ecotone during the early Holocene.

Since this paper mainly focuses on the period of origin of food production, using Shizitan site as an example to discuss the possibility of plant-intensified exploitation behaviors during the LGM, and at the end, using the Donghulin site to talk about the demise of microblade–based societies, data collected for this project are associated with those sites dated to the Pleistocene–Holocene transition (Table 2). They are mainly Accelerator Mass Spectrometry Carbon 14 (AMS C14) dates, as well as latitudes and longitudes of the sites. To further discuss issues of the broad spectrum revolution, archaeological data are categorized into artifact assemblage, site organization, and biological remains are also shown in Table 3.

**Table 2.** Chronometric dates of the sites in the Paleolithic to Neolithic Transition (PNT) group.

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| Nanzhuangtou | layer 5–6 | wood | AMS C14 | BK86120 | 9875 ± 160 | 10,028–9112 (87.2%)<br>9083–9041 (1.1%)<br>9026–8838 (7.1%) | Yuan et al. [12] |
| | | wood | AMS C14 | Bk86121 | 9690 ± 95 | 9298–8799 (95.4%) | Yuan et al. [12] |
| | | wood | AMS C14 | BK87093 | 9810 ± 100 | 9669–9116 (86.1%)<br>9076–9055 (0.6%)<br>9016–8843 (8.7%) | Yuan et al. [12] |
| | | wood | AMS C14 | BK89064 | 9850 ± 90 | 9752–9722 (1%)<br>9692–9146 (94.4%) | Yuan et al. [12] |
| | Layer 6 | charcoal | AMS C14 | BK87075 | 10,510 ± 100 | 10,731–10,149 (95.4%) | Yuan et al. [12] |
| | Layer 5 | silt | AMS C14 | BK87086 | 9980 ± 100 | 9983–9941 (1.6%)<br>9877–9266 (93.8%) | Yuan et al. [12] |
| | | silt | AMS C14 | BK87088 | 10,815 ± 140 | 11,096–10,576 (94%)<br>10,518–10,485 (1.4%) | Yuan et al. [12] |
| Zhuannian | | | AMS C14 | | 9200 ± 100 | 8701–8676 (1.4%)<br>8646–8250 (94%) | Ren and Wu [13] |
| | | | AMS C14 | | c.9800 | | Yu [14] |
| Donghulin | M1 (Burial 1) | human bone | AMS C14 | | 9570 ± 70 | 9216–8755 (95.4%) | Cui [15] |
| | Layer 8, T3 | charcoal | AMS C14 | | 9180 ± 80 | 8608–8273 (95.4%) | Cui [15] |
| | Layer 7, T3 | charcoal | AMS C14 | | 9155 ± 40 | 8528–8521 (0.8%)<br>8473–8282 (94.6%) | Cui [15] |
| | Layer 4, T3 | charcoal | AMS C14 | | 8780 ± 90 | 8205–8035 (20.6%)<br>8016–7606 (74.8%) | Cui [15] |
| | Layer 4, T9 | charcoal | AMS C14 | | 8805 ± 50 | 8204–8102 (13.8%)<br>8096–8036 (5.6%)<br>8015–7711 (75.6%)<br>7692–7685 (0.4%) | Cui [15] |

**Table 2.** *Cont.*

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| Donghulin | Layer 3, T9 | charcoal | AMS C14 | | 8772 ± 40 | 8165–8138 (1.5%)<br>7973–7647 (93.9%) | Cui [15] |
| | Layer 2, T9 | Pineapple | AMS C14 | | 8885 ± 55 | 8240–7825 (95.4%) | Cui [15] |
| Lijiagou (north area) | Layer 6 | charcoal | AMS C14 | BA091494 | 8950 ± 40 | 8272–8166 (44.3%)<br>8131–7970 (51.1%) | He et al. [16] |
| | Layer 5 | charcoal | AMS C14 | BA091417 | 8015 ± 35 | 7064–6814 (95.4%) | He et al. [16] |
| | Layer 4 | charcoal | AMS C14 | BA091416 | 7740 ± 40 | 6642–6483 (95.4%) | He et al. [16] |
| Lijiagou (south area) | Layer 4 | charcoal (3 samples) | AMS C14 | 10300–10500 cal. BP | | | Zhao et al. [17] |
| Bianbiandong | | Human skull | AMS C14 | BA04308 | 8675 ± 40 | 7786–7768 (2%)<br>7759–7592 (93.4%) | Sun et al. [18] |
| | | Human skull | AMS C14 | BA04309 | 8670 ± 30 | 7738–7597 (95.4%) | Sun et al. [18] |
| | | Animal skull | AMS C14 | BA04310 | 10,030 ± 40 | 9800–9786 (1.2%)<br>9773–9381 (94.2%) | Sun et al. [18] |
| | | Human skull | AMS C14 | BA04317 | 8730 ± 50 | 7941–7605 (95.4%) | Sun et al. [18] |
| | Area I Layer 3A | Animal bone | AMS C14 | BA07226 | 8505 ± 45 | 7596–7507 (95.4%) | Sun et al. [18] |
| | Area I Layer 3B | Animal bone | AMS C14 | BA07227 | 8585 ± 40 | 7704–7700 (0.5%)<br>7681–7541 (94.9%) | Sun et al. [18] |
| | Area I Layer 4 | Animal bone | AMS C14 | BA07228 | 8180 ± 45 | 7321–7067 (95.4%) | Sun et al. [18] |
| | Layer 2 | Animal bone | AMS C14 | BA07229 | 6120 ± 45 | 5211–4944 (95.4%) | Sun et al. [18] |
| | Collected | Animal bone | AMS C14 | BA07230 | 6305 ± 40 | 5364–5214 (95.4%) | Sun et al. [18] |
| Kengnan | Layer 2, 3 | | C14 | ~10,000–9000 BP (calibrated?) | | | Li, Song [19] |
| Yujiagou | | | OSL | | 18 ka–14 ka | | Mei [20] |
| Ma'anshan [1] | | | | | – | | |

**Table 2.** *Cont.*

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| Hutouliang | Terrace II | bone | Conv. C14 | PV–0156 | 10,690 ± 120 | 10,879–10,428 (93.3%)<br>10,391–10,352 (0.8%)<br>10,335–10,287 (1.2%) | IA–CASS [21] |
| | Layer 6 (upper) | polymineral | OSL | | 9.2 ± 1.4 ka | | Nagatomo et al. [22] |
| | | polymineral | OSL | | 9.0 ± 1.3ka | | Nagatomo et al. [22] |
| Mengjiaquan | | | | | – | | |
| Jijitan [1] | | | | | – | | |
| Xueguan | | charcoal | Conv.C14 | BK81016 | 13,170 ± 150 | 14,274–13,371 (95.4%) | IA–CASS [21] |
| Lingjing | Layer 5 | charred material | AMS C14 | IAAA–92123 | 11,360 ± 50 | 11,350–11,145 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material | AMS C14 | IAAA–92124 | 11,490 ± 50 | 11,502–11,285 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material | AMS C14 | IAAA–92125 | 11,930 ± 50 | 12,009–11,930 (8.6%)<br>11,915–11,625 (86.8%) | Li et al. [23] |
| | Layer 5 | charcoal | AMS C14 | IAAA–100080 | 28,610 ± 120 | 31,223–30,139 (95.4%) | Li et al. [23] |
| | Layer 5 | burnt bone | AMS C14 | IAAA–100082 | 11,520 ± 40 | 11,499–11,331 (95.4%) | Li et al. [23] |
| | Layer 5 | burnt bone | AMS C14 | IAAA–102634 | 11,400 ± 50 | 11,406–11,168 (95.4%) | Li et al. [23] |
| | Layer 5 | charcoal | AMS C14 | IAAA–102635 | 11,600 ± 50 | 11,601–11,365 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material on sherd | AMS C14 | IAAA–102636 | 8610 ± 40 | 7723–7576 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material (charcoal?) | AMS C14 | IAAA–102638 | 10,180 ± 40 | 10,106–9757 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material (charcoal?) | AMS C14 | IAAA–102639 | 11,710 ± 50 | 11,763–11,721 (3.2%)<br>11,681–11,483 (92.2%) | Li et al. [23] |
| | Layer 5 | charred material (charcoal?) | AMS C14 | IAAA–102640 | 11,860 ± 50 | 11,822–11,613 (95.4%) | Li et al. [23] |
| | Layer 5 | burnt bone | AMS C14 | IAAA–102641 | 11,290 ± 50 | 11,307–11,115 (95.4%) | Li et al. [23] |

**Table 2.** *Cont.*

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| Lingjing | Layer 5 | charred material (charcoal?) | AMS C14 | IAAA–102642 | 10,970 ± 50 | 11,032–10,772 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material (burnt bone?) | AMS C14 | IAAA–102643 | 11,280 ± 50 | 11,302–11,109 (94.4%) | Li et al. [23] |
| | Layer 5 | Charcoal (?) | AMS C14 | IAAA–102644 | 11,550 ± 50 | 11,525–11,335 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material (?) | AMS C14 | IAAA–102645 | 11,470 ± 50 | 11,489–11,251 (95.4%) | Li et al. [23] |
| | Layer 5 | charcoal | AMS C14 | IAAA–102647 | 11,220 ± 50 | 11,242–11,046 (95.4%) | Li et al. [23] |
| | Layer 5 | charcoal | AMS C14 | IAAA–102648 | 11,520 ± 50 | 11,511–11,321 (95.4%) | Li et al. [23] |
| | Layer 5 | charred material (burnt bone?) | AMS C14 | IAAA–102649 | 11,800 ± 50 | 11,801–11,587 (89%)<br>11,576–11,532 (6.4%) | Li et al. [23] |
| | Layer 5 | charred material (charcoal?) | AMS C14 | IAAA–102650 | 11,860 ± 50 | 11,822–11,613 (95.4%) | Li et al. [23] |
| Shizitan, Locality S29 | Layer 1 | bone | AMS C14 | BA10129 | 11,175 ± 60 | 11,203–10,903 (95.4%) | Song [24] |
| | Layer 2 (203 cm deep) | Bone | AMS C14 | BA101414 | 14,650 ± 70 | 16,077–15,674 (95.4%) | Song and Shi [25] |
| | Layer 2 (200–206 cm deep) | Bone | AMS C14 | BA10132 | 15,725 ± 80 | 17,238–16,844 (95.4%) | Song and Shi [25] |
| | Layer 2 (248 cm deep) | Charcoal | AMS C14 | BA10131 | 16,760 ± 65 | 18,494–18,058 (95.4%) | Song and Shi [25] |
| | Layer 2 (276 cm deep) | Bone | AMS C14 | BA101416 | 15,390 ± 70 | 16,862–16,553 (95.4%) | Song and Shi [25] |
| | Layer 3 (282 cm deep) | Bone | AMS C14 | BA101419 | 17,200 ± 50 | 18,987–18,615 (95.4%) | Song and Shi [25] |
| | Layer 3 (303 cm deep) | Bone | AMS C14 | BA10133 | 17,360 ± 60 | 19,232–18,762 (95.4%) | Song and Shi [25] |
| | Layer 4 (465 cm deep) | Bone | AMS C14 | BA101420 | 17,500 ± 70 | 19,449–18,936 (95.4%) | Song and Shi [25] |

**Table 2.** *Cont.*

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| Shizitan, Locality S29 | Layer 4 (469 cm deep) | Bone | AMS C14 | BA10134 | 16,170 ± 50 | 17,754–17,367 (95.4%) | Song and Shi [25] |
| | Layer 4 (605 cm deep) | Bone | AMS C14 | BA10135 | 16,930 ± 50 | 18,649–18,268 (95.4%) | Song and Shi [25] |
| | Layer 4 (620 cm deep) | Bone | AMS C14 | BA101422 | 16,750 ± 80 | 18,511–18,030 (95.4%) | Song and Shi [25] |
| | Layer 4 (622 cm deep) | Bone | AMS C14 | BA101421 | 18,570 ± 60 | 20,638–20,363 (95.4%) | Song and Shi [25] |
| | Layer 4 (624 cm deep) | Bone | AMS C14 | BA101423 | 19,210 ± 80 | 21,495–20,943 (95.4%) | Song and Shi [25] |
| | Layer 4 (640 cm deep) | Tooth | AMS C14 | BA10136 | 17,040 ± 60 | 18,804–18,391 (95.4%) | Song and Shi [25] |
| | Layer 5 (772 cm deep) | Bone | AMS C14 | BA10137 | 18,360 ± 70 | 20,477–20,025 (95.4%) | Song and Shi [25] |
| | Layer 5 (787 cm deep) | Charcoal | AMS C14 | BA10485 | 20,420 ± 80 | 22,973–22,319 (95.4%) | Song and Shi [25] |
| | Layer 5 (750.5 cm deep) | Bone | AMS C14 | BA101426 | 19,650 ± 100 | 22,028–21,432 (95.4%) | Song and Shi [25] |
| | Layer 5 (751.5 cm deep) | Charcoal | AMS C14 | BA101427 | 19,510 ± 70 | 21,815–21,244 (95.4%) | Song and Shi [25] |
| | Layer 5 (750.5 cm deep) | Charcoal | AMS C14 | BA101428 | 19,940 ± 70 | 22,284–21,811 (95.4%) | Song and Shi [25] |
| | Layer 5 (804 cm deep) | Charcoal | AMS C14 | BA101429 | 19,710 ± 80 | 22,050–21,535 (95.4%) | Song and Shi [25] |
| | Layer 5 (801.8 cm deep) | Charcoal | AMS C14 | BA101430 | 19,860 ± 70 | 22,185–21,707 (95.4%) | Song and Shi [25] |
| | Layer 6 (968 cm deep) | Bone | AMS C14 | BA101431 | 18,140 ± 80 | 20,326–19,812 (95.4%) | Song and Shi [25] |

**Table 2.** *Cont.*

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| Shizitan, Locality S29 | Layer 6 (964 cm deep) | Charcoal | AMS C14 | BA101433 | 20,410 ± 80 | 22,961–22,306 (95.4%) | Song and Shi [25] |
| | Layer 6 (964 cm deep) | Bone | AMS C14 | BA101434 | 19,850 ± 80 | 22,190–21,680 (95.4%) | Song and Shi [25] |
| | Layer 6 (961.5 cm deep) | Tooth | AMS C14 | BA121954 | 20,155 ± 45 | 22,471–22,067 (95.4%) | Song and Shi [25] |
| | Layer 6 (1004 cm deep) | Charcoal | AMS C14 | BA10487 | 20,500 ± 100 | 23,117–22,388 (95.4%) | Song and Shi [25] |
| | Layer 6 (1004 cm deep) | Bone | AMS C14 | BA10488 | 18,090 ± 70 | 20,242–19,733 (95.4%) | Song and Shi [25] |
| | Layer 6 (1004 cm deep) | Bone | AMS C14 | BA121951 | 18,280 ± 45 | 20,393–19,978 (95.4%) | Song and Shi [25] |
| | Layer 6 (1026 cm deep) | Charcoal | AMS C14 | BA101438 | 20,350 ± 90 | 22,886–22,201 (95.4%) | Song and Shi [25] |
| | Layer 7 (1160 cm deep) | Bone | AMS C14 | BA121960 | 21,690 ± 80 | 24,151–23,840 (95.4%) | Song and Shi [25] |
| | Layer 7 (1160 cm deep) | Bone | AMS C14 | BA101439 | 19,650 ± 80 | 21,996–21,465 (95.4%) | Song and Shi [25] |
| | Layer 7 (1160 cm deep) | Charcoal | AMS C14 | BA101442 | 20,010 ± 70 | 22,353–21,901 (95.4%) | Song and Shi [25] |
| | Layer 7–8 boundary (1355 cm deep) | Bone | AMS C14 | BA101445 | 20,510 ± 90 | 23,107–22,414 (95.4%) | Song and Shi [25] |
| | Layer 8 (1425 cm deep) | Charcoal | AMS C14 | BA101444 | 24,185 ± 90 | 26,575–25,976 (95.4%) | Song and Shi [25] |
| Shizitan, Locality S5 | Layer 1 | bone | AMS C14 | BA101404 | 9220 ± 50 | 8565–8299 (95.4%) | Song and Shi [26] |

**Table 2.** *Cont.*

| Site | Layer | Material | Method | Lab. No. | Dates | Cal. BC (2–sigma) | Reference |
|---|---|---|---|---|---|---|---|
| **Some other sites dated to PNT time range, but not related to origin of food production (data shown below, recorded as others in the maps)** | | | | | | | |
| Shuidonggou Locality 12 | Layer 11 | charcoal | AMS C14 | LUG06–54 | 9797 ± 91 | 9654–9580(2.5%)<br>9548–9478 (2.3%)<br>9465–9117 (80.9%)<br>9074–9056 (0.5%)<br>9013–8911 (7%)<br>8905–8845 (2.2%) | Liu et al. [27] |
| | Layer 11 | quartz | OSL | IEE1110 | 11.6 ± 0.6 ka | | Nagatomo et al. [22] |
| | L1–L5 | cultural layers formed between 11,000 and 12,000 years ago, starting at the middle of the Younger Dryas | | | | | Yi [28] |
| Gezishan 53S/0W | Stratum E | – | | Beta 97241 | 10,230 ± 50 | 10,189–9810 (95.4%) | Elston et al. [29] |
| | Stratum E/F | – | | Beta 86731 | 11,620 ± 70 | 11,626–11,353 (95.4%) | Elston et al. [29] |
| | Stratum G2 | – | | Beta 97242 | 12,710 ± 70 | 13,398–12,857 (95.4%) | Elston et al. [29] |
| Gezishan 3N/3W | Stratum D | – | | Beta 86732 | 10,020 ± 60 | 9818–9318 (95.4%) | Elston et al. [29] |
| | Stratum D | – | | Beta 97346 | 10,130 ± 70 | 10,086–9452 (95.4%) | Elston et al. [29] |
| PY–04 | | charcoal | AMS C14 | CAMS94202 | 10,670 ± 40 | 10,759–10,618 (95.4%) | Barton et al. [30] |

Note: [1] no absolute date available.

**Table 3.** Presence of markers of the PNT in North China, by site [3] Table 2 modified from [2]. These sites are mapped in Figure 1.

| Site | Type | Artifact Assemblage | | | | | | | | Site Organization | | | | | | | Biological Remains | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** | **P** | **Q** | **R** | **S** |
| Nanzhuangtou | PNT | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0.5 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 |
| Zhuannian | PNT | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Donghulin [1] | PNT | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.5 | 0 | 0 |
| Lijiagou | PNT | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0.5 | 1 | 0.5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bianbiandong | PNT | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0.5 | 0.5 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| Kengnan | PNT | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Yujiagou | PNT | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ma'anshan | PNT | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hutouliang | PNT | 1 | 0.5 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mengjiaquan | PNT | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Jijitan | PNT | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Xueguan | PNT | 1 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lingjing [1] | PNT | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shizitan [2] | LUP | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Xiachuan | LUP | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Longwangchan | LUP | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0.5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 = present | | | 0.5 = possibly present | | | | | | | | | | 0 = not discovered yet. | | | | | | | |

Notes: The rows: A = microblade, B = pottery, C = mortar (millstone), D = pestle (millstick), E = adze, F = stone container, G = polished tool, H = diversity of artifact types, I = hearth, J = diversity of site types, K = structure, L = grave, M = central camp, N = ditch, O = pit, P = foxtail millet, Q = broomcorn millet, R = dog, S = wild pig (boar). The columns: Other sites without data except microblades: Xishi (Late Upper Paleolithic, LUP); Shuidonggou Loc. 12; Dadiwan (Component 4); Gezishan (Pigeon Mountain); PY–04, all classified as "other" (see maps of Northern Chinanorthern China). [1] updated information according to Cui [15]; [2] new site added according to Li et al. [23]; [3] updated information of Locality 29 according to Liu et al. [31].

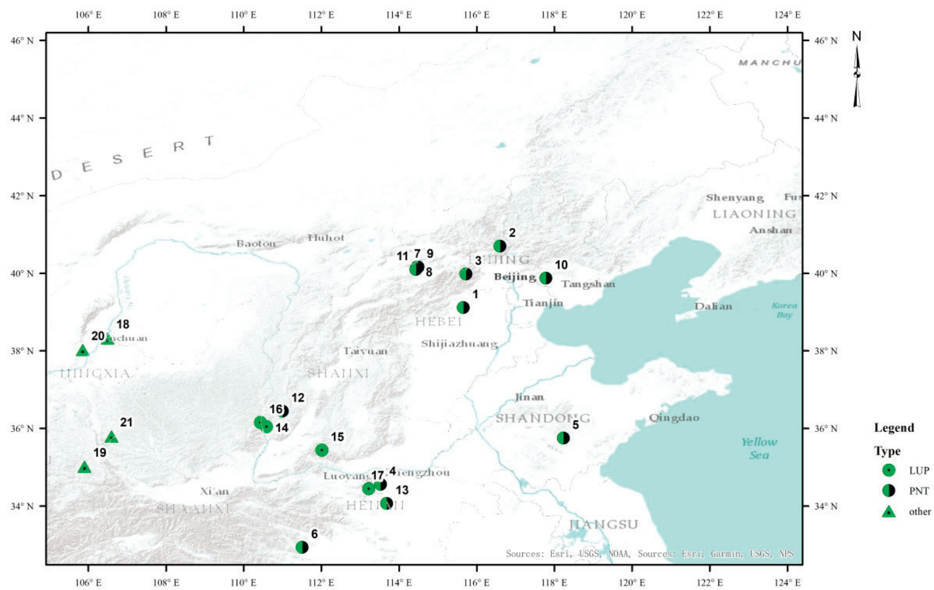


**Figure 1.** Archaeological sites dated to Pleistocene-Holocene transition in Northern China. PNT sites: 1 Nanzhuangtou; 2 Zhuannian; 3 Donghulin; 4 Lijiagou; 5 Bianbiandong; 6 Kengnan; 7 Yujiagou; 8 Ma'anshan; 9 Hutouliang; 10 Mengjiaquan; 11 Jijitan; 12 Xueguan; 13 Lingjing LUP sites: 14 Shizitan; 15 Xiachuan; 16 Longwangchan Other sites: 17 Xishi; 18 Shuidonggou Locality 12; 19 Dadiwan, Component 4; 20 Gezishan; 21 PY-04.

## 4. Microblade–Based Societies during the Last Glacial Maximum

Among archaeological sites in north China associated with microblade assemblages, the Shizitan site is best studied, especially in the terms of interdisciplinary approach focusing on human behaviors at a specific site. Shizitan is located at the Jixian County, SW Shanxi Province. Several localities are distributed along the Qingshuihe River, a tributary of the Yellow River. In recent years, Li Liu, in collaboration with local archaeologists, has been conducting a research project on plant use at this site, based on use–wear and residue analyses, suggesting that prehistoric plant use in northern China can be traced back to the immediately pre–LGM period, about 28 ky cal. BP [31–34]. The plant use, including harvesting and processing using stone tools, can be divided into 6 phases (Table 4). This work suggests near–continuous exploitation of various plants in the Middle Yellow River Valley (both the Xiachuan site and the Longwangchan site share many material features with the Shizitan site, including microblades, grinding stones, and hematite processing) [31]. Their investigation provides substantial evidence of an early broad–spectrum subsistence strategy in the Upper Paleolithic northern China.

**Table 4.** Phases of plant use at the Shizitan (SZT) site (data collected from [31]).

| Phase | Site and Stratum | Material | Function for Plants | Plant Use |
|---|---|---|---|---|
| Phase I (pre-Last Glacial Maximum (LGM)) | Stratum 8, SZT 29 | 2 FL<br>2 SL | FL: cutting, scraping<br>SL: processing | Starchy plants, including Panicoideae (possibly Job's tears), Triticeae and yam<br>No clear evidence for wild millet collection |
| Phase II (the early part of LGM) | Stratum 7, SZT 29 | 7 MB<br>3 FL<br>4 SL<br>1HS | MB: cutting<br>FL: plant cutting<br>SL: processing *<br>HS: processing | Wild cereals (e.g., Triticeae, Job's tears and wild millets), tubers and other plants |
| Phase III (the late part of LGM) | Strata 6, 5, and 4, SZT 29 | 1 MB<br>7 FL<br>3 SL | MB: cutting<br>FL: cutting<br>SL: processing | Wild cereals, and especially Panicoideae |
| Phase IV (the terminal LGM) | Strata 3 and 2, SZT 29 | 4 FL<br>4 SL | FL: cutting<br>SL: processing | Grasses, including Panicoideae and Triticeae. Tubers are much less well represented |
| Phase V (warmer conditions) | Stratum 1, SZT 29 | 2 FL | FL: cutting | Unknown, only one non–specific phytolith was recovered. |
| Phase VI (Early Holocene) | Stratum 1, SZT 5 | 2 FL | FL: cutting | Unknown, only starch |

Notes: FL: flake, MB: microblade, SL: slab or slab fragment, HS: handstone. * Both slab fragments and handstones are used for processing plant food and minerals.

Liu et al. [33] propose the viewpoint, "The trajectory from intensified collection of a wide range of wild plants to domestication of a small number of species was a very long process in north China", and suggest that it "parallels the transition from the 'broad spectrum revolution' to agriculture in the Near East" (pp. 3524). Although they did not use the term "intensification" to generalize this process, plant processing could be seen as a means of food resource intensification, since people need to invest much labor to extract energy from plants, including tubers and seeds. Plant use might suggest a local population packing effect during the LGM in the Middle Yellow River Valley, possibly caused by southward movement of prehistoric peoples from the north or the west, which can be tested as a hypothesis.

The effective temperature (ET) value of the Shizitan site under LGM climatic conditions was below the terrestrial plant threshold, suggesting that the prehistoric foraging societies needed to depend on terrestrial animal resources during the LGM. However, a relatively longer growing season than that of Siberia provides this location higher net above–ground productivity and primary biomass. The Shizitan site is also located in the belt of high secondary biomass, making it a place that possessed plenty of both terrestrial plants and animals. The Qingshuihe River, a small tributary of the Yellow River, also provided people with enough water and aquatic resources for survival, although archaeologists have not found substantial evidence of fishing. The maps in Figures 2–6 support the following characterization of the environment and resource use at the Shizitan site:

> "*Around 23,000–18,000 years ago during the LGM, the Qingshui River valley appears to have been an area with a wide range of faunal and floral resources, which attracted small hunting-gathering groups. In addition to hunting, people collected and processed many types of plants, including grass seeds of Triticeae and Paniceae,* Vigna *beans,* D. opposita *yam, and* T. kirilowii *snakegourd roots, among others*". [32] (p. 5384)

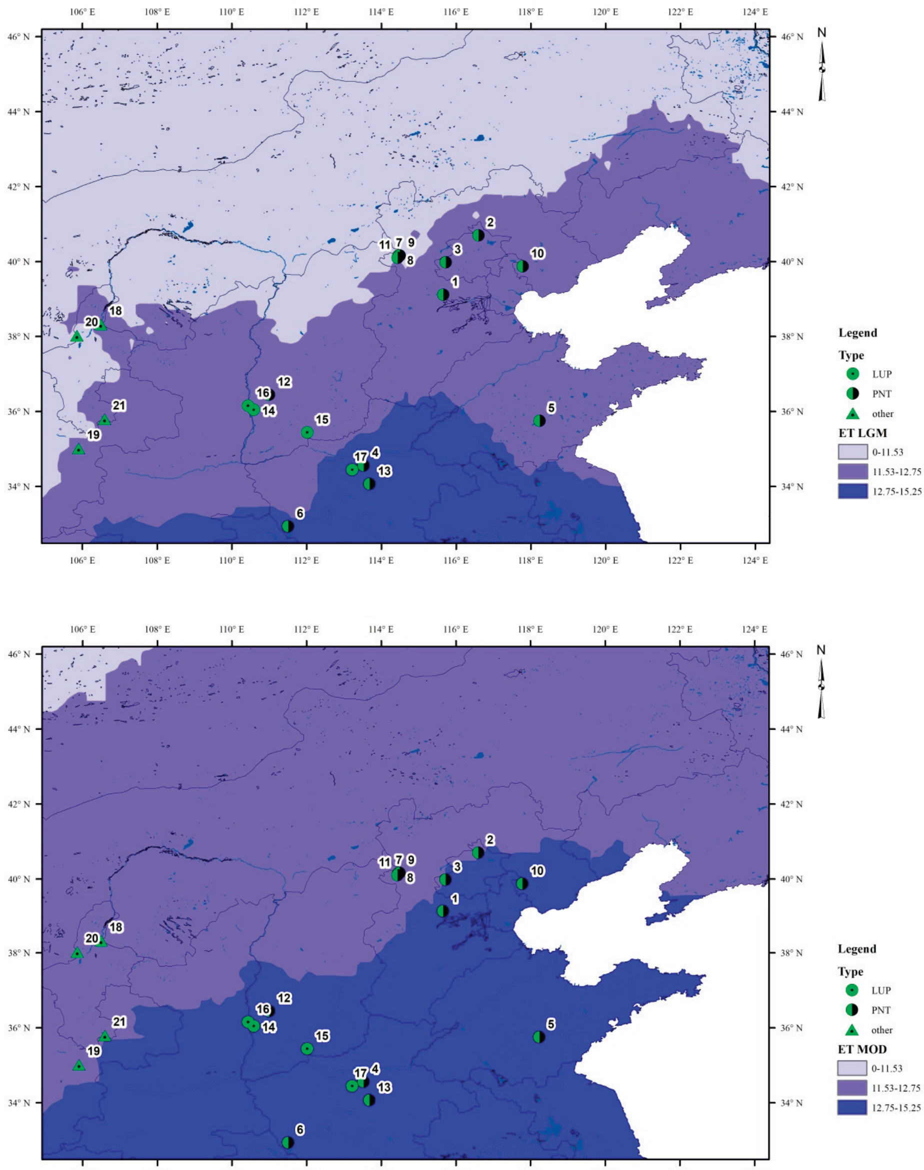


**Figure 2.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of effective temperature (ET) in Northern China under LGM and modern climatic conditions.

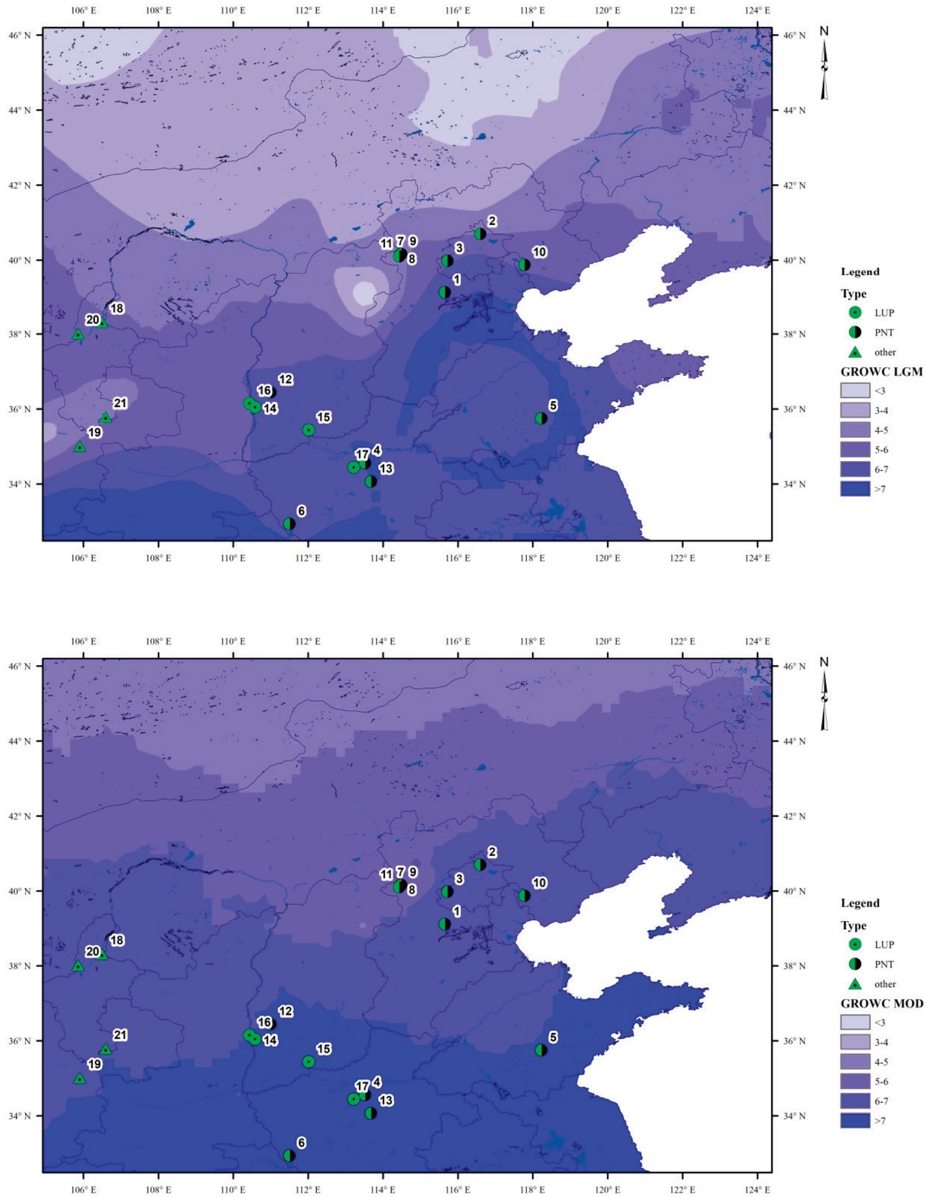


**Figure 3.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of growing season (GROWC) of Northern China under LGM and modern climatic conditions.

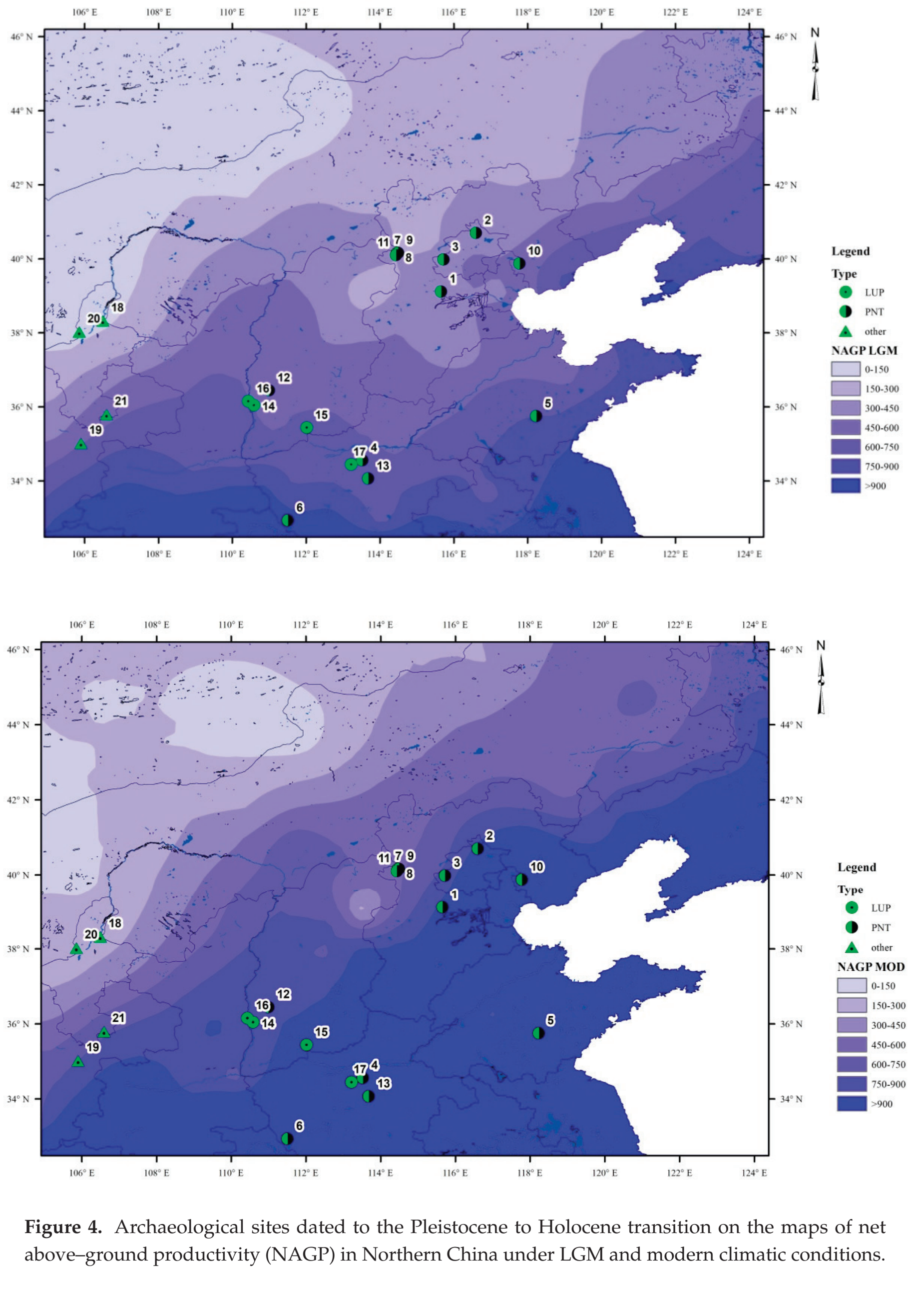


**Figure 4.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of net above–ground productivity (NAGP) in Northern China under LGM and modern climatic conditions.

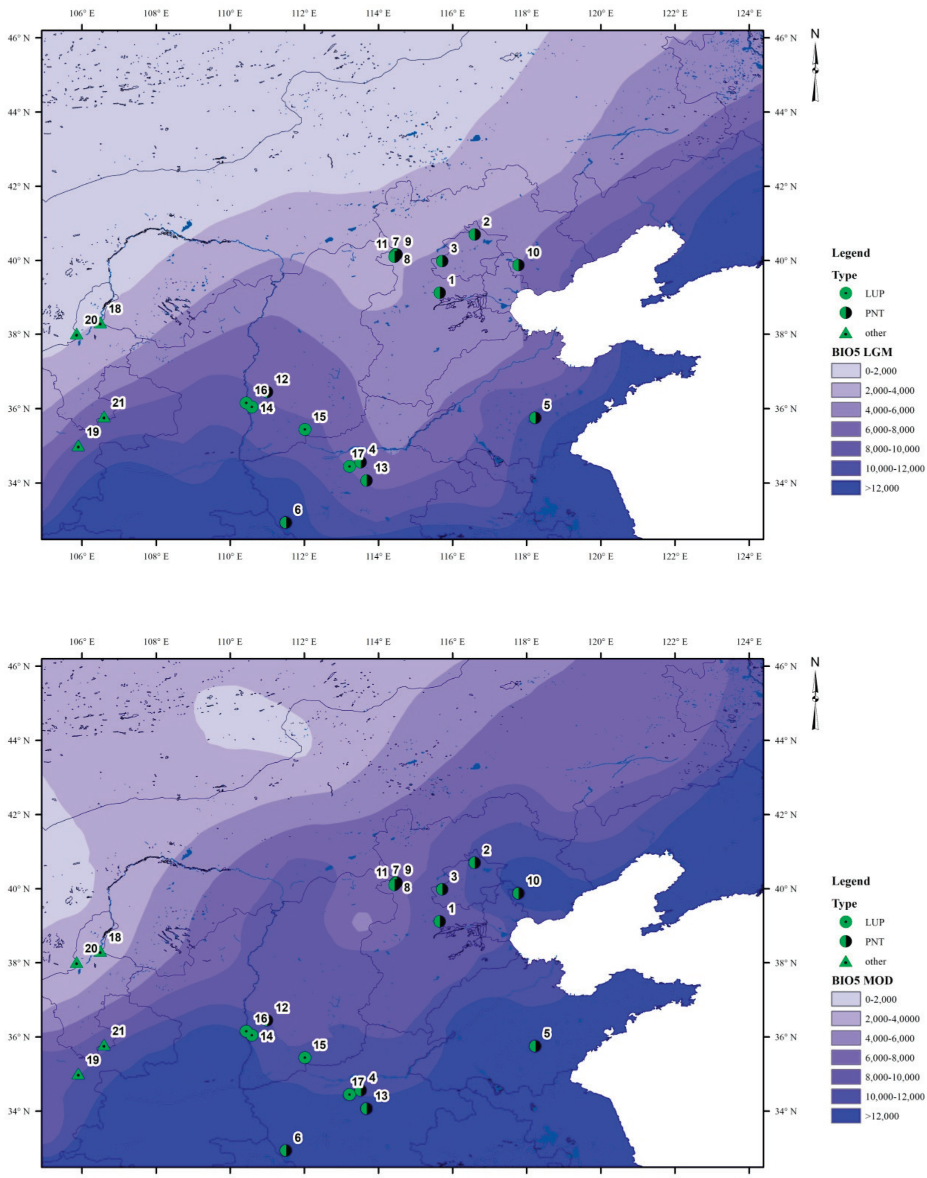


**Figure 5.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of primary biomass (BIO5) of Northern China under LGM and modern climatic conditions.

Thus, there is no question that prehistoric hunter–gatherers in this region adopted a mixed economy to satisfy their subsistence requirements, which might have been a general strategy adopted by the peoples during the LGM. The peoples in the lower latitudes or above the subpolar bottleneck (ET = 11.53 °C) have significantly more terrestrial plant resources to utilize.

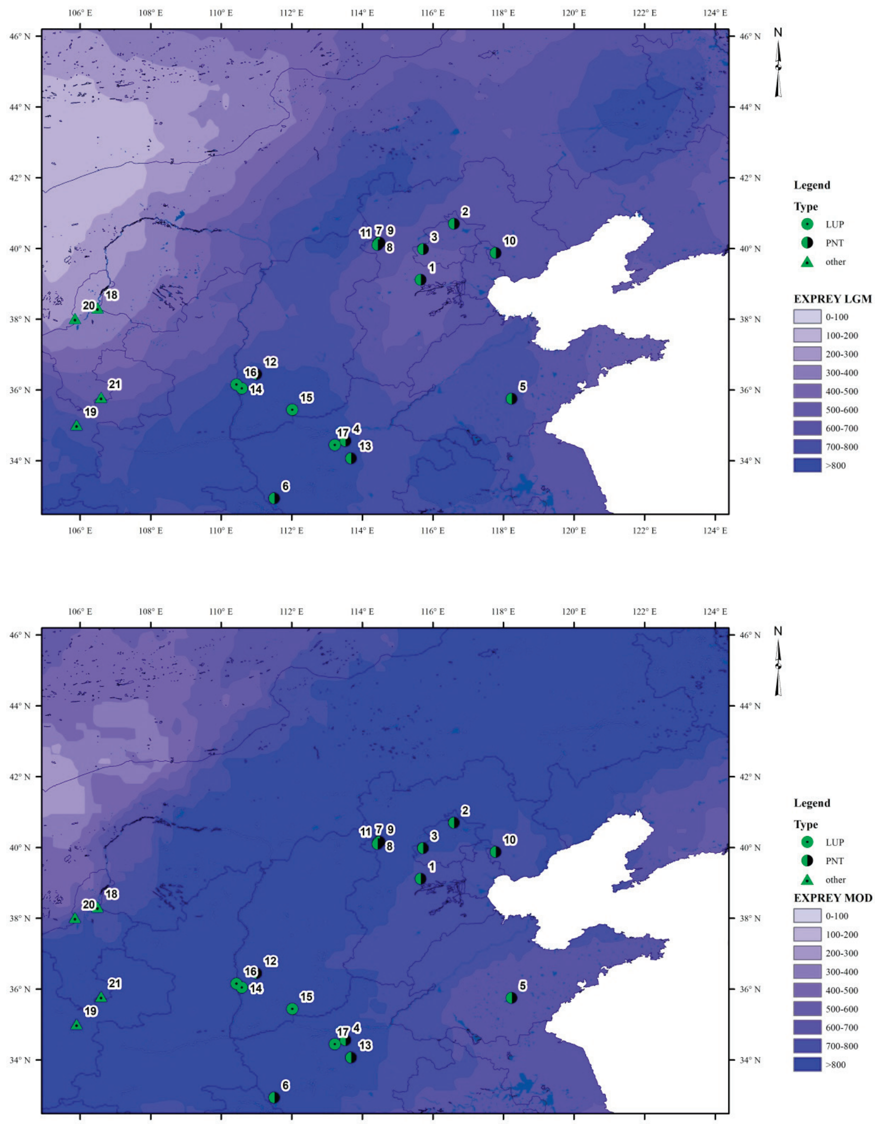


**Figure 6.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of secondary biomass (expected moderate body–size ungulate biomass, EXPREY) of northern China under LGM and modern climatic conditions.

The question is whether resource intensification on terrestrial plants was practiced during the LGM. According to the maps produced under the growth rate model, unpacked/packed maps show that the location of the Shizitan site is expected to have favored a gathering-dominated economy if population became packed, while it would have favored a hunting–dominated economy if population was unpacked (Figure 7). The ethnographic projected population density map under LGM climatic conditions (Figure 8) suggests that local resource cannot support a high population density in the region where the Shizitan site is located (2–3.033 persons per 100 km$^2$). The patterns resulting from these projections can only be used if hunter–gatherers in this location were organized like recent hunter–gatherers in similar contexts, rather than used to say what the archaeological record actually was. In addition, the packing threshold was developed using data for mobile plant-dependent hunter–gatherers who used no long–term storage—the density threshold at which highly mobile hunters might need to intensify would be lower. In other words, the occupants at the Shizitan site during the LGM might have intensified plant resources especially for storage. But more archaeological evidence is needed to support this hypothesis.

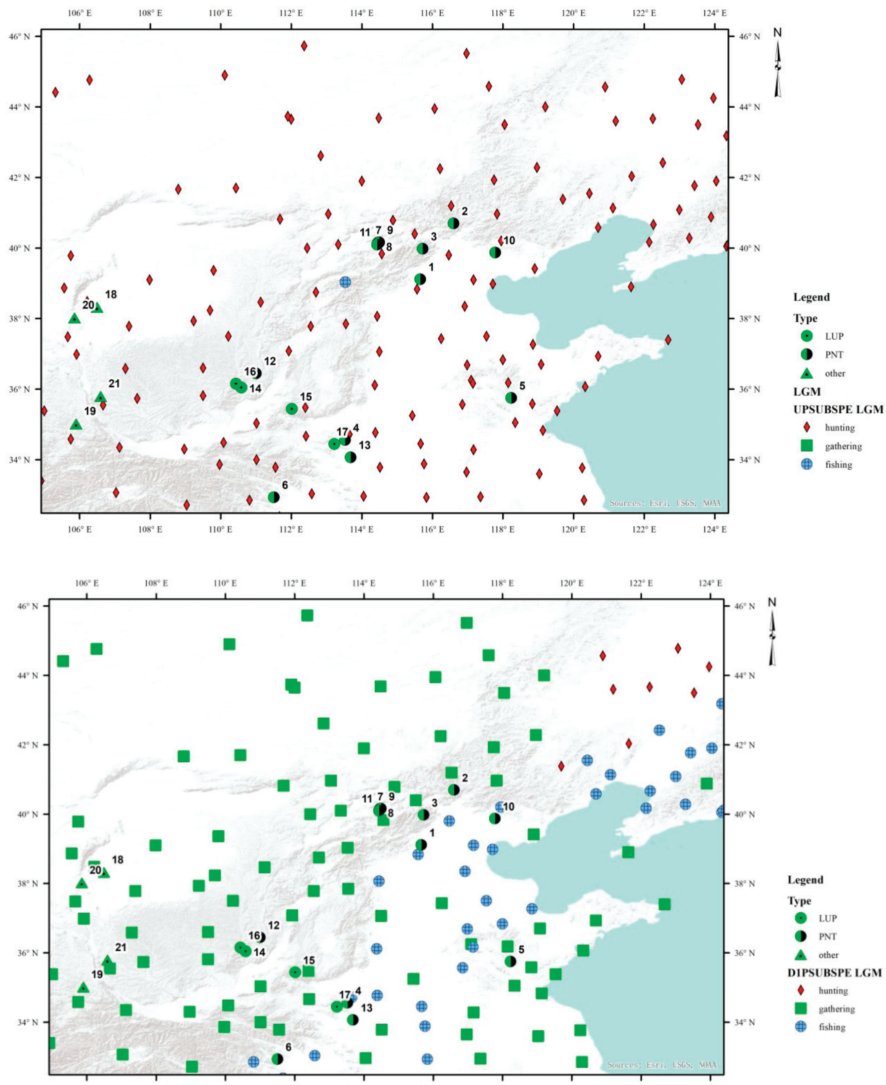


**Figure 7.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of projected unpacked and packed HG subsistence specialty (UPSUBSPE and D1PSUBSPE) in northern China under LGM climatic conditions.

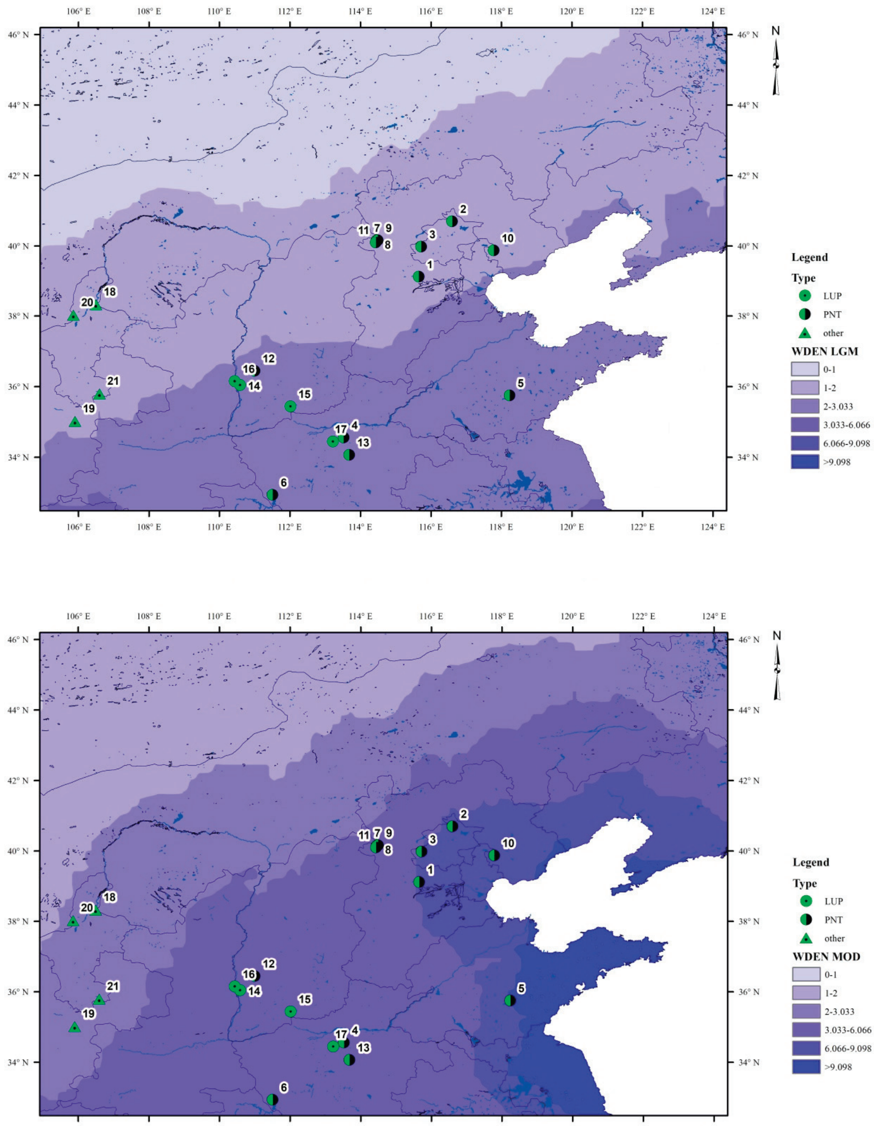


**Figure 8.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of projected HG population density (WDEN) of northern China under LGM and modern climatic conditions.

Is there any other possible explanation for the existence of intensive plant use at the Shizitan site? The map of EXDMOV1 (projected total distance moved, scaled for subsistence type, for groups with year round camp to camp mobility pattern) shows that foraging societies in northern China during the LGM had to adopt highly mobile lifeways (comparing with the values of EXDMOV1 under current climatic conditions) (Figure 9). Widespread microblade technology provided them with effective and light composite weaponry to hunt animals; some microblades were used as reaping knife inserts to harvest and process plant resources. Microblade–based societies successfully adapted to the deteriorated environment with relatively lower primary and secondary biomass. The region surrounding the Shizitan has a relatively lower value in terms of expected distance of residential movement (250–300 miles) than its neighboring regions to the east and northwest, which suggests that the occupational duration in one location might be longer and occasional sedentism might have happened during the LGM (Figure 9). Maps of population group size in the subsistence-settlement system (Figure 10) suggest that under LGM climatic conditions, prehistoric foraging societies near the Shizitan site, as well as the Longwangchan and Xiachuan sites, harbored 20–25 persons in the most dispersed settlement phase, 90–120 persons in the most aggregated phase, both less than its eastern neighboring regions. However, the site is located in the zone with high GROUP3 values (400–500 persons), representing a high probability of annual or every several year's aggregation. Although it is located at the edge of GROUP3 isoline (400 persons), the Qingshuihe–Yellow River system and valley environment offer an advantage with regard to supporting populations, especially aggregations. The Shizitan site and Longwangchan site Locality 1 share almost the same archaeological record, suggesting that prehistoric foragers could easily have crossed the Yellow River in winter on ice under very low temperatures during the LGM and post-LGM Pleistocene (personal communication with Y.-H. Song). The combination of high GROUP3 size in this region and its river valley topography might have made the Shizitan site an ideal place for multi-group aggregations (annually or every few years). This hypothesis is consistent with the archaeological record associated with 285 hearths at Locality S29 (Table 5). Microblade assemblages imply the existence of organized hunting activities, and plant remains studied in Li Liu's project might prove the association between plant-use behaviors and the activities surrounding the hearths in localities S14 and S29 in further research [31–33]. At least, this hypothesis has been partly supported by the recent analysis of Locality S29 [25], but detailed discussion of human aggregation at the Shizitan site is needed.

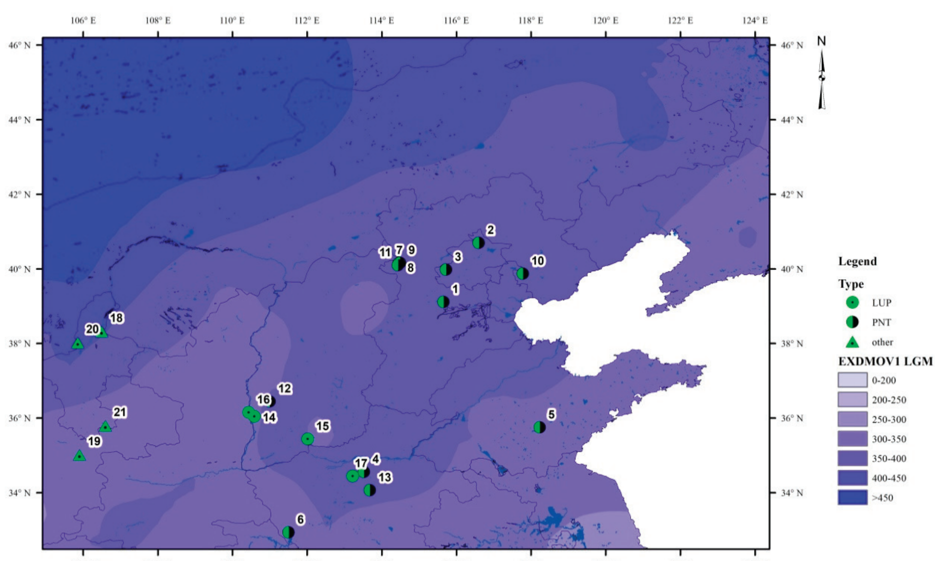


**Figure 9.** *Cont.*

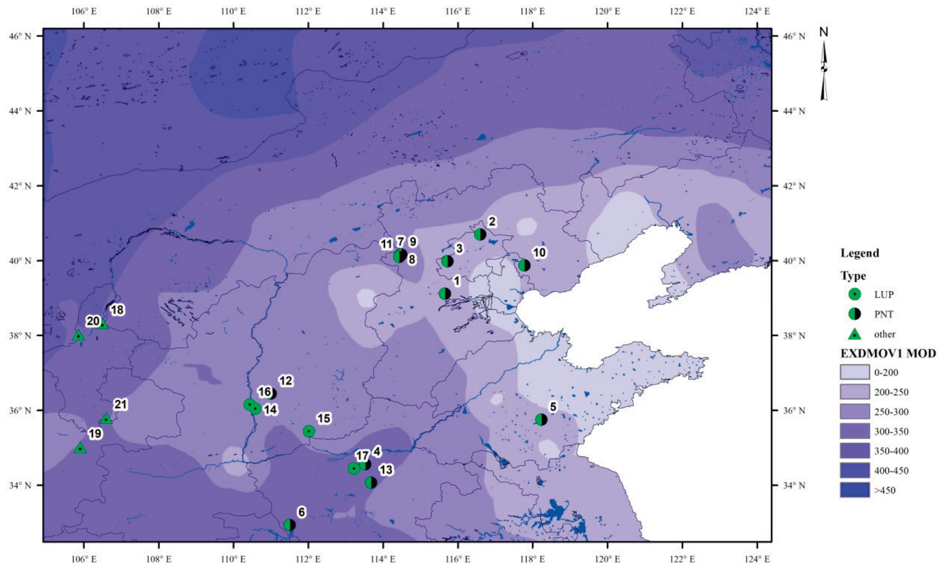


**Figure 9.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of expected distance of residential movement per year of hunter–gatherers (EXDMOV1) in northern China under LGM and modern climatic conditions.

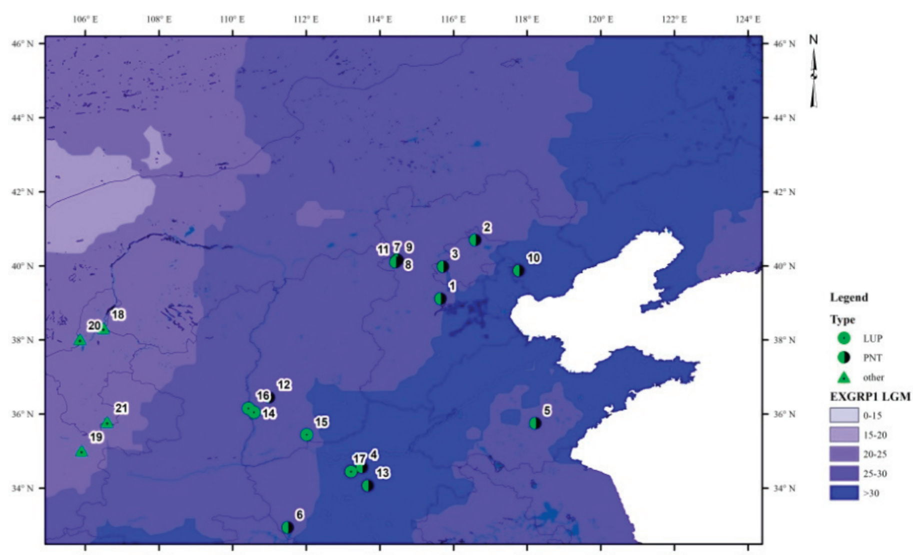


**Figure 10.** *Cont.*

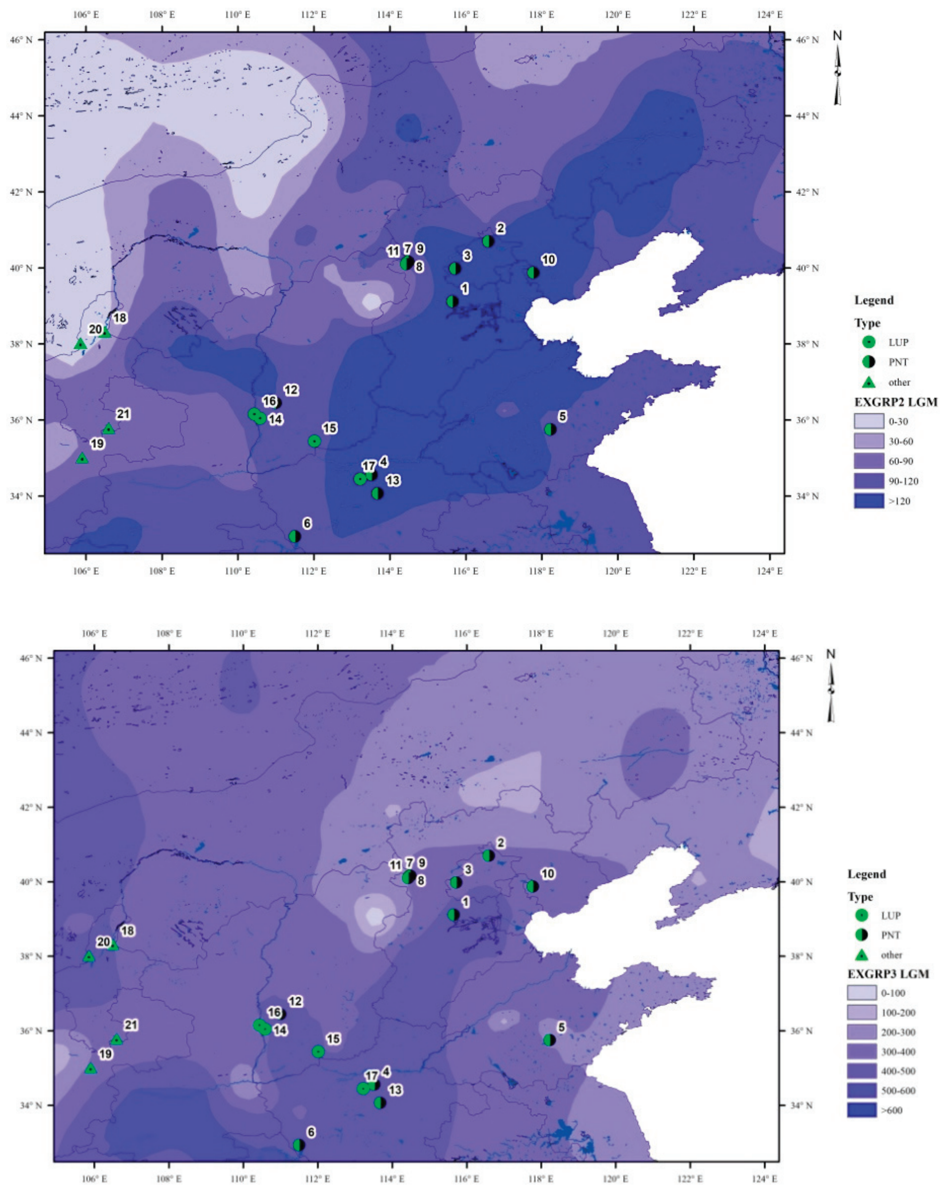


**Figure 10.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of expected hunter–gatherer group size in northern China under LGM climatic conditions.

**Table 5.** Hearths in the Shizitan site, Locality S29 [25].

| Type of Hearth | Number | Percentage |
|---|---|---|
| Above–ground hearth | 265 | 92.98% |
| Above–ground hearth with sandstone rocks | 13 | 4.56% |
| Round–pit hearth | 5 | 1.76% |
| Hearth with stone–floored pit | 2 | 0.7% |
| Total | 285 | 100% |

To sum up, the macroecological approach suggests that intensification might not have existed at the Shizitan site during the LGM. The archaeological record of plant resource exploitation at the Shizitan site indicates that increasing population densities might have made intensification important. However, plants may have been used as supplementary food resources (tubers and wild millet) in daily life. Just as the maps suggested, the plant foods also might have been used to satisfy the regional band requirements of periodic aggregations at the Shizitan site (e.g., Localities S29 and Loc. 14). Unfortunately, because of a lack of lithic refitting research, the hypothesis proposed here remains speculative, although the limited available evidence is suggestive. Limited by the preliminarily published data, testing this hypothesis will require more evidence and question-oriented studies in the future. Plant use at the Shizitan site lasted until the early Holocene, when it was totally abandoned. This is a key site for archaeologists to investigate the process of a potential broad spectrum revolution in the Upper Paleolithic of the Middle Yellow River Basin, and/or to study subsistence-settlement systems and technological organization of microblade-based societies in northern China, since it possesses a complete record from Phase I to Phase III (and some in Phase IV).

## 5. Broad Spectrum Revolution and Intensification during the Pleistocene–Holocene Transition

The Late Pleistocene and Early Holocene in northern China witnessed the transformation from societies composed of mobile hunter-gatherers equipped with microblade technology to societies equipped with ground stone tools, pottery, food production, and durable dwellings. There have been many studies on these aspects of the transition. Although their appearances can be dated to different specific times in different regions, the formation of agricultural societies can be seen as an emergent event, rather than as the simple overlap of historical events. Chen and Yu [1,2] have termed this period the Paleolithic to Neolithic transition (PNT). They "synthesize a broad range of diagnostic artifacts, settlements, site structure, and biological remains to develop a working hypothesis that agriculture was differentially developed or adopted according to 'initial conditions' of habitat, resource structure, and cultural organization" [2]. The authors noted multiple and divergent evolutionary pathways, including northern China (divided at the Taihangshan Mts. into the North China Plain and Loess Plateau). Published data on the chronology and archaeological record of northern China linked to the PNT are presented, clearly showing basic information on diagnostic artifacts, settlements, and site structure associated with social organization, and potential species for domestication Tables 1 and 2 in ref [2], with updated information from recently published results. The two papers by Chen and Yu [1,2] clearly and successfully illustrate cultural change during the PNT of Northern and Southern China, but the authors did not fully apply a macroecological approach in their study.

Since I have shown a series of maps of Northern China for the Shizitan case under LGM conditions, I now only show the corresponding maps under modern climatic conditions, representing the early Holocene. Readers can compare the maps under the two sets of climatic conditions.

The Pleistocene–Holocene transition witnessed a dramatic change from glacial to interglacial, especially after the Younger Dryas. The Terminal Pleistocene after the LGM (starting at 15 ky uncalibrated BP), experienced several climatic phases of relatively warm and cold periods. The Younger Dryas is seen as a stimulus for food production in Northern China and the Near East [7]. In this project, the maps of LGM climatic conditions can be read similarly to those under Younger Dryas conditions, since paleoclimate data suggests that the Younger Dryas was associated with marine isotopic values as low as those of the LGM, but during a much shorter time (about 1300 years, 12.9–11.6 ky cal. BP, or about 600 years, 10.8–10.2 ky uncalibrated BP) [34,35].

Effective temperature dramatically increased and the isoline of the terrestrial plant threshold (ET = 12.75 °C) moved northward. Several sites with the best evidence of food production are located around this isoline (Nanzhuangtou, Zhuannian, and Donghulin) (Figure 2). In contrast to the more localized and fragmentary distribution of growing season isolines under LGM climatic conditions, the length of the growing season dramatically increased, causing more gradual change along latitudes (34° N–40° N) under interglacial conditions (Figure 3), which could help in the formation of belts favorable for stable plant growth and provide a good initial condition for cultivation. The increases of ET and length of growing season resulted in an increase of net above–ground productivity and primary biomass (Figures 4 and 5). Secondary biomass also increased and the central region moved northwest to the modern forest–steppe ecotone along the southwest–northeast China line Figures 5 and 7 in ref [6]. Under modern climatic conditions (early Holocene), the three sites—Nanzhuangtou, Zhuannian, and Donghulin—are all located at the edge of the zones with high values of both primary and secondary biomass, i.e., the transition zone (Figure 6). This phenomenon matches the basic hypothesis advanced by Binford [36,37], that early food production would appear in zones adjacent to areas with the most resources, as a cultural adaptation after mobility declined or ceased to be effective to solve the problems of population growth.

The growth rate model also shows the replacement of terrestrial hunting by gathering and aquatic resource use. Different from the maps under LGM climatic conditions, the subsistence replacement indeed happened during the Pleistocene to Holocene transition—Chen and Yu's Paleolithic to Neolithic Transition. For northern China (above 30° N), hunting in some places was replaced by the gathering of terrestrial plants (e.g., the Gezishan site in Upper Yellow River Basin), by aquatic resource use (some sites in NE China, such as the Houtaomuga and Shuangta sites), or food production (i.e., Nanzhuangtou, Zhuannian, Donghulin, and other PNT sites, as well as the early Neolithic sites) (Figure 11). The hunters north to the Yanshan Mts. (north to the area of Beijing) retained their hunting–dominated lifeways in a mixed economy with the aid of advanced microblade technology (pencil–shaped microcores) during the early and middle Holocene, perhaps as specialized hunters who exchanged wild meat with neighboring agriculturists, who were in turn finally replaced by pastoralism (about 1000 BC) [38]. The sites of Nanzhuangtou, Zhuannian, and Donghulin are all located in the boundary regions of combined hunting, gathering and fishing under the packed population condition, suggesting that they needed to manage a pluralistic subsistence style. This is supported by the coexistence of microblade–equipped hunting weaponry, pottery, mortars and pestles, and polished tools at the Zhuannian and Donghulin sites. The lack of any microblade assemblage at the Nanzhuangtou site perhaps resulted from the sampling representation of the excavated area (300 out of 2000 $m^2$), or a higher level of food production with a very low level of hunting activities. In addition, evidence of hunting activity calls for further research focus, since some sites are located near water systems and people are expected to have exploited some aquatic resources.

The increase of sedentary life can also be investigated from the viewpoint of a macroecological approach, in terms of projected population density and expected distance of residential movement per year. The Nanzhuangtou, Zhuannian, and Donghulin sites are located at the position of 2/3 packing threshold, and the Bianbiandong cave site is at the packing threshold (Figure 8). Thus, the people at Bianbiandong should have experienced population pressure, while the occupants at sites Nanzhuangtou, Zhuannian, and Donghulin might have experienced population packing if they emphasized hunting during the early Holocene. If they were mobile hunter–gatherers, their mobility should have dramatically decreased from 250/300–350 miles travelled per year during the Younger Dryas (see the EXDMOV1 under LGM climatic conditions), to 200–250 miles per year during the early Holocene (Figure 9). However, if they were sedentary hunter-gatherers their mobility only needed to be 20–40 miles per year during early Holocene (Figure 12). For people who practiced cultivation, the decrease in mobility could focus on a habitat where they could use low-energy food resources through dietary expansion and/or intensification. Therefore, zones with relatively lower primary and secondary biomass compared to neighboring regions associated with optimal resource distribution could serve as new locations in which 'daughter' groups could practice food production [37,38]. The lifeways built on sedentism (decreased mobility) favored durable ground/polished and expedient stone tools, rather than highly curated and formal chipped stone tools designed for mobile hunting, because the most important part of the economy became plant resource–use and even cultivation [39,40]. This may explain the disappearance of microblade assemblages in early Neolithic sites in northern China.

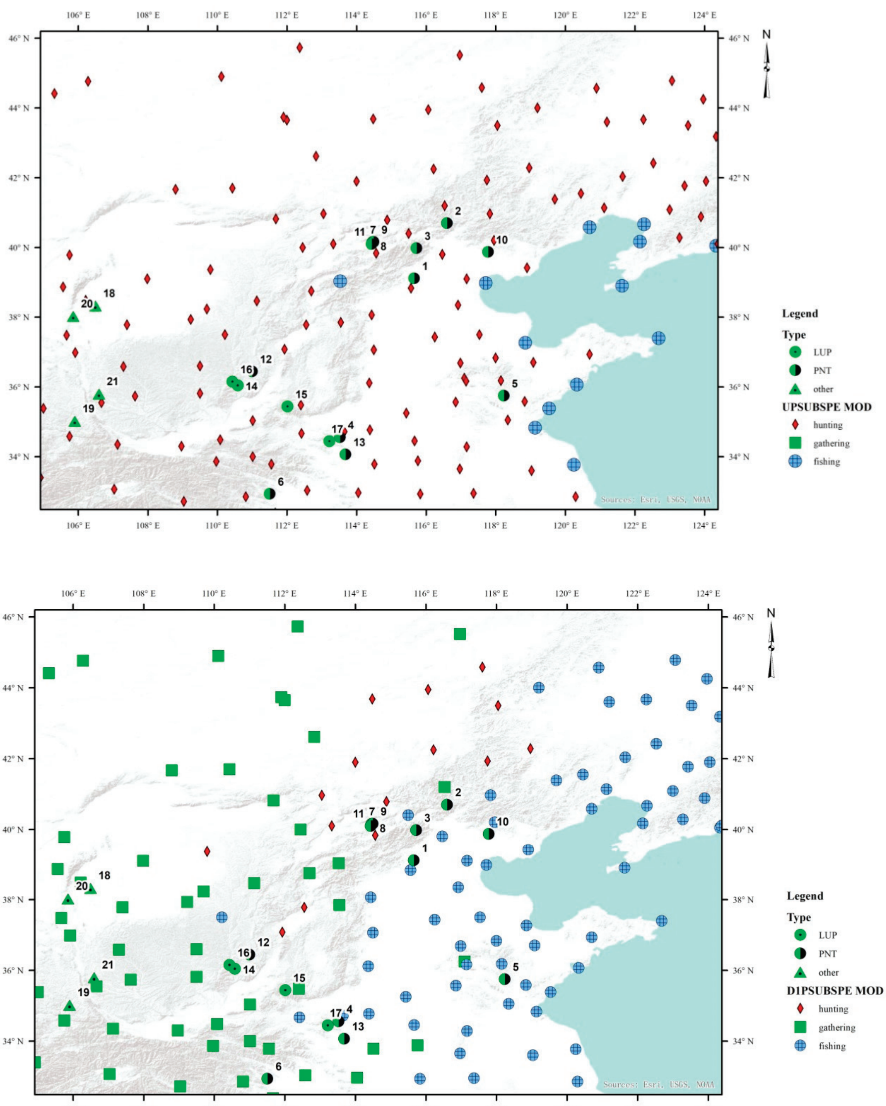


**Figure 11.** Archaeological sites dated to the Pleistocene to Holocene transition on the maps of projected unpacked and packed hunter–gatherer subsistence specialty (UPSUBSPE and D1PSUBSPE) in northern China under modern climatic conditions.

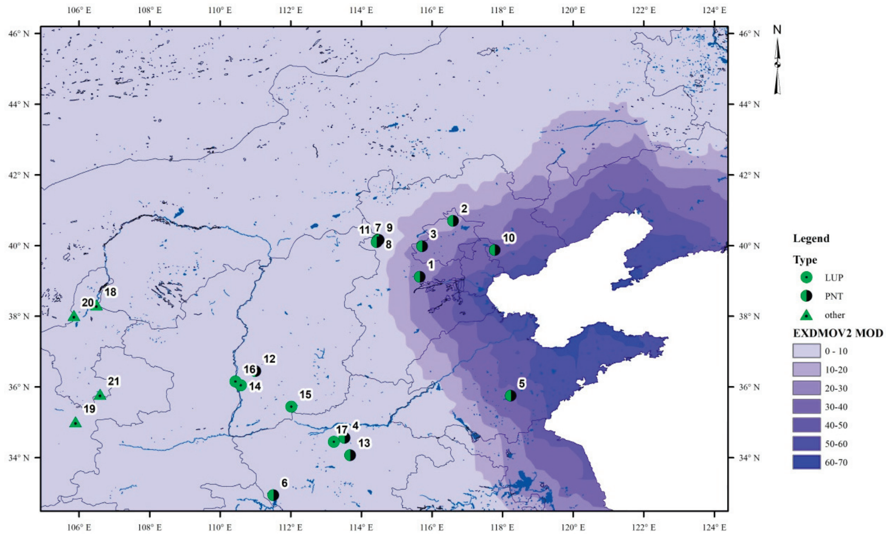


**Figure 12.** Archaeological sites dated to the Pleistocene–Holocene transition on the map of EXDMOV2 (expected distance of residential movement per year of hunter–gatherers with central location or who are primarily sedentary) in northern China under modern climatic conditions.

## 6. The Demise of Microblade–Based Societies

The Early Holocene witnessed the disappearance of microblade technologies in North China and the demise of microblade-based societies, although there were a few later sites associated with some of these technologies. However, investigating this cultural process is tough, since those specializing in Neolithic archaeology rarely report those data in the early stages. There are few published data on microblades or microcores in the Neolithic sites (8500–2000 BP) of the northern China cultural region. Although this can be explained as a reporting bias of Neolithic archaeologists, in fact there may be a real absence or very few microblades in the sites. In contrast, Holocene microblade assemblages have been reported in some sites of the Inner Mongolia Steppe, in NE and NW China, on the Tibetan Plateau, and in SW China, all of which are frontier regions of China. Details of the disappearance of microblade technology are little known, let alone the process of the decline and disappearance of microblade–based societies. Among the sites dated to the late PNT after the Younger Dryas event, only the Donghulin site has been researched in detail in Tian-Xing Cui's [15] dissertation. Microblade assemblages at this site co-exist with ground stone and other percussion tools. By contrast with the classic microblade technology at sites dated to terminal Pleistocene, such as Hutouliang [41], Lingjing [42], Yujiagou [20], and Shuidonggou Locality 12 [28,43], the microcores at the Donghulin site show great variety with unstandardized production methods (Cui used many subtypes to classify them), and some tools show expedient characteristics. The degeneration of microblade production methods might be a result of the transition to a patchy environment composed of forest and grassland. Forest animals dominate the fauna of the Donghulin site (Figure 13), which might impede the use of weaponry equipped with microblades, since open landscape was being replaced by forest and marshes that favor alternative hunting technologies. Paleoethnobotanical research suggests that the occupants at the Donghulin site intensified the use of plant products. Macrobotanical remains including Gramineae, Leguminosae, and *Celtis sinensis*, and microbotanical remains (starch) on mortars and pestles including Triticeae and wild foxtail millet (*Setaria italica*), imply a broad–spectrum economy and intensification. Sedentism had already been adopted by the late PNT occupants, which also reduced the use of microblade technology designed for highly mobile lifeways.

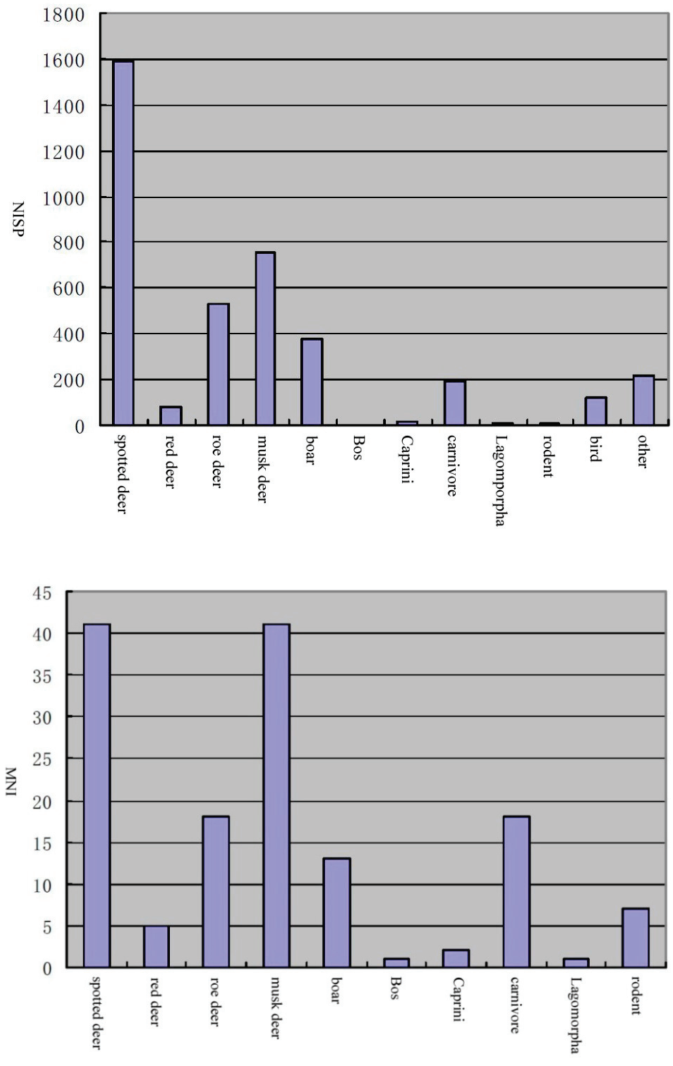


**Figure 13.** Number of identified specimens (NISPs) and minimal number of individuals (MNIs) of fauna at the Donghulin site (permission from Dr. Tian–Xing Cui).

To sum up, the current published archaeological record is inadequate to explain the cultural process of microblade technology disappearance in northern China. However, the correlation between the decline of microblade–based societies and the rise of agriculture is certain, and we need further detailed studies to build the links.

## 7. Conclusions

This paper does not aim to provide a synthesis of archaeological sites associated with microblade technology, but rather to explore the mechanisms of cultural change for prehistoric hunter–gatherers equipped with microblade products during and after the Last Glacial Maximum. Three sequential stages of microblade–based societies are addressed in this paper, and the conclusion can be summarized as follows:

(1) Based on the calculated results in the EnvCalc2.1 program under LGM climatic conditions, especially the variables BIO5 (primary biomass), WDEN (projected density) and EXGRP3 (annual or several-year aggregation size), the plant use at the Shizitan site might not be linked with resource intensification, but rather with social group aggregation in a region with relatively high productivity of plant resources. However, the equifinality in the archaeological explanation needs to be further studied to evaluate alternative hypotheses, including the scale and seasonality of human aggregation and the possibility of resource intensification.

(2) The sites dated to the Pleistocene–Holocene transition experienced Paleolithic to Neolithic technological and economic transitions, marked by use of pottery, appearance of permanent settlements, and widespread adoption of ground stone tools. The broad spectrum revolution and subsistence intensification can be explained within the framework of the macroecological approach; the replacement of the hunting-dominated economy by a gathering-and/or-fishing-dominated economy is linked with population growth during the interglacial or interstadial periods, matching the maps under the packed condition of regional population. Decreased mobility also provided the occupants an opportunity to use low-energy food resources through dietary expansion and/or intensification. Against this background, microblade-based weaponry became less significant in daily life due to the previously open landscape becoming more closed, leading to a decrease in the density of large herd ungulates, and durable ground/polished and expedient stone tools were favored.

(3) The disappearance of microblade technology accompanies the end of microblade-based societies in North China. At present, there are very few publications on this period but the microblade assemblages at the Donghulin site show much less standardization in microblade production. This might be linked with the full adaptation of sedentary lifeways and significant decreases of wild ungulates during the Neolithic.

The present research provides a case study using the macroecological approach for exploring the technological change of prehistoric foraging societies equipped with microblade technology in North China, facing dramatic climatic oscillation during the end of the Ice Age. Although a research framework has been built in this project, more substantial archaeological research is needed using systematic observation of interassemblage variability, a well–controlled chronological database, detailed studies on the function of targeted tools with the aid of use–wear analysis, and interdisciplinary projects on land–use patterns and resource exploitation to test hypotheses proposed here on the cultural dynamics of the microblade-based societies.

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**Conflicts of Interest:** The author declares no conflict of interest.

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# Rethinking the Disappearance of Microblade Technology in the Terminal Pleistocene of Hokkaido, Northern Japan: Looking at Archaeological and Palaeoenvironmental Evidence

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**Abstract:** Archaeological research, for several decades, has shown that various microblade technologies using obsidian and hard shale appeared and developed from the Last Glacial Maximum to the terminal Pleistocene (Bølling–Allerød–Younger Dryas) in Hokkaido, Northern Japan. It is well accepted that microblade technology was closely related to the high mobility of foragers to adapt to harsh environments. Recent archaeological and palaeoenvironmental evidence from Hokkaido demonstrates that the disappearance of microblade technology occurred during the terminal Pleistocene, influenced by a wide range of factors, including changes in landscape, climate, subsistence and human populations. The goal of this paper is to provide an overview of the current state of research on the process and background of the disappearance of microblade technology and to discuss prospects for future research. This paper will (1) review palaeoenvironmental research in Hokkaido on changes in climate and biological composition from the terminal Pleistocene to the initial Holocene; (2) survey changes in the technological adaptations and resource use of humans based on the archaeological evidence; and (3) discuss how the abrupt fluctuations of climate that occurred in the terminal Pleistocene affected human behaviour and demographics in Hokkaido.

**Keywords:** microblade technology; palaeoenvironment; Hokkaido; terminal Pleistocene; initial Holocene

## 1. Introduction

The accumulation of Upper Palaeolithic studies in Hokkaido, for several decades, has revealed that there are numerous lithic assemblages characterised by various microblade technologies using raw materials such as obsidian and hard shale [1–3]. Detailed lithic technological analyses and chronological reconstructions in Hokkaido have made it clear that the various microblade technologies that appeared and developed were closely related to the behavioural strategies of mobile hunter-gatherers adapted to living in harsh environments from the Last Glacial Maximum (LGM; 26,500–19,500 years ago) [4] to the terminal Pleistocene (Bølling–Allerød–Younger Dryas) [1–3]. In this paper, 'microblade' refers to parallel-sided small artefacts possessing one or more ridges running parallel to their long axes, generally 15–60 mm long, 4–10 mm wide, and 1–2 mm thick [5–9]. Systematic observation of the techno-typological characteristics of microblade cores and lithic refitted pieces has demonstrated that highly standardised microblades were produced through complicated lithic reduction sequences from lithic raw materials [2,10,11]. Microblade technology enables the production and maintenance of compact and lightweight stone tools that can be used as part of composite tools. For humans adapted to a cold and dry environment in the Upper Palaeolithic, the manufacturing and use of microblades can be considered an important technological choice for behavioural adaptation in terms of efficiently using and transporting lithic raw materials collected during foraging [3,12,13].

It is widely known that microblade technology was distributed across regions of northeast Asia, such as North China, the Korean peninsula, the Russian Far East, Mongolia and Siberia [13–22]. Many researchers have made advances with comparing the techno-typological features of microblade assemblages and accumulating radiocarbon dates. As a result, we are currently in the process of getting a better understanding of the spatiotemporal patterns of microblade technology in northeast Asia. Understanding when and how microblade technology appeared and disappeared in each region has been a topic of debate in northeast Asian Upper Palaeolithic research. Although several hypotheses on the origin(s) of microblade technology in northeast Asia have been presented and debated until recently [6,13,15,16,22,23], the disappearance of microblade technology in each region has received less attention.

According to records from ice cores from Greenland, drastic and abrupt environmental changes occurred repeatedly from the terminal Pleistocene to the initial Holocene [24]. A warming period occurred from 14,700 years ago until 12,900 years ago called the Bølling–Allerød, followed by a cooling period called the Younger Dryas. The Younger Dryas is designated as lasting until 11,650 years ago. After the end of the Pleistocene, a period of global warming began. The Preboreal is designated as lasting from 11,650 years ago until 8500 years ago. Quaternary scientists have long demonstrated that episodes of glacial readvance and retreat, shifts in precipitation and forest destruction and re-growth occurred during the transition from the terminal Pleistocene to the initial Holocene [25].

Techno-typological comparisons and some radiocarbon dates show that microblade technology disappeared in Hokkaido during the terminal Pleistocene [2–4,26,27]. To explain the background of the disappearance of microblade technology in terms of relationship to palaeoenvironment change would offer valuable insights into the nature of the technological and behavioural characteristics of microblade technology in Hokkaido, as would identifying the differences with regions such as Siberia, Mongolia and North China, where microblade technology continued after the onset of the Holocene [8,21]. Furthermore, recent archaeological research in eastern Hokkaido shows that different techno-complexes, including not microblades but various bifacial points and burins associated with potteries, emerged during the terminal Pleistocene [27–29]. Did the appearance of these techno-complexes play a role in the end of microblade technology in Hokkaido? Or should we expect a significant overlap for some time? The archaeological sequence of Hokkaido in the transition from the terminal Pleistocene to the initial Holocene and its implication for the process of how the palaeoenvironment related to the changes in human adaptive systems are rarely a subject of major agreement among scholars working in the region [27,29]. Understanding the relationship between them will be beneficial to any final interpretation of past human adaptations. This will provide insights into the process through which hunter-gatherers who had adapted to the warming of the natural environment after the Preboreal adopted sedentary lifestyles and highly diversified subsistence, making use of marine-based and other stable food sources [28,30,31].

Recently, there have been some important archaeological achievements that suggest how hunter-gatherers in Hokkaido accomplished technological adaptations and resource use during the transitional period from the terminal Pleistocene to the initial Holocene. Based on these studies, this paper will survey the process through which microblade technology disappeared in Hokkaido and the background behind this process, influenced by a wide range of factors, including changes in landscape, climate, subsistence and human populations. This paper will (1) review research on the palaeoenvironment carried out in Hokkaido regarding changes in climate and biogeography from the terminal Pleistocene to the initial Holocene; (2) assess changes in the technological adaptations and resource use of humans by focusing on lithic production technology and patterns of land use; and (3) discuss the ways in which sudden cooling affected human behaviour and demographics, particularly during the Younger Dryas.

## 2. Palaeoenvironment

Hokkaido is a large island located in the northern tip of the Japanese archipelago (Figure 1). During the LGM, lower sea levels caused by a cooler climate meant that Hokkaido was connected to the island of Sakhalin via the Soya land bridge and to Siberia via the Tatar land bridge. Humans and the faunal community were able to disperse from the Eurasian continent to Hokkaido without any straits to interrupt their migration. The resulting palaeoenvironment of Hokkaido during the LGM was somewhat more continental in character than it is at present. On the contrary, there was no land bridge across the Tsugaru Strait dividing Hokkaido and Honshu, thus, creating a barrier for humans and the faunal community [32]. This brought about disparity between Hokkaido and Honshu in terms of various cultural features and the composition of the faunal community during the Upper Palaeolithic [33–35]. Some researchers suggest that by the onset of the Bølling–Allerød interstadial the bridge between Sakhalin and Hokkaido had disappeared and Hokkaido was surrounded by ocean [26].

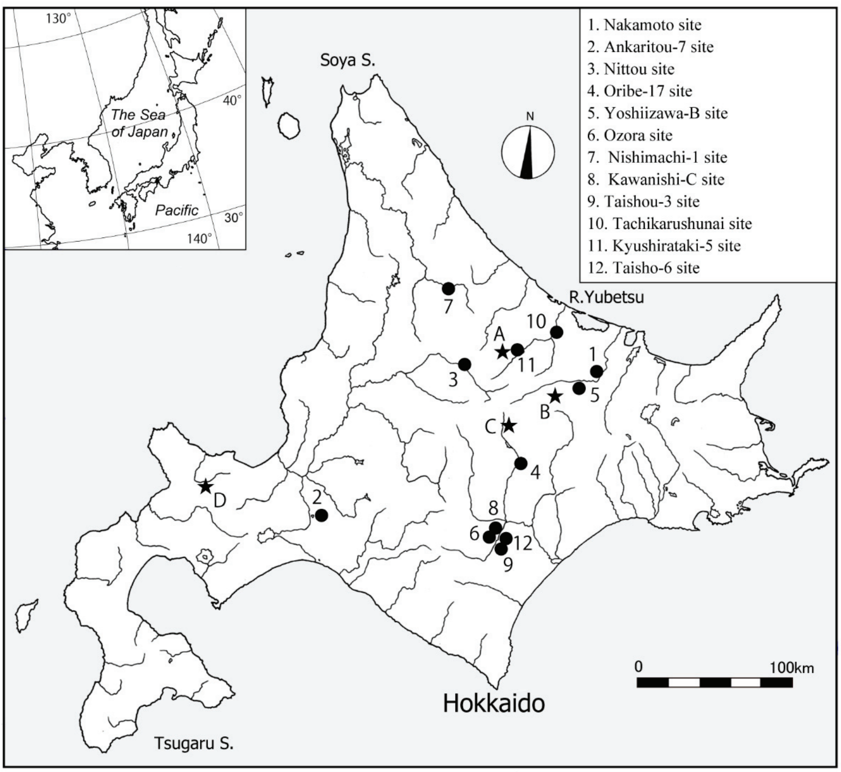


**Figure 1.** Locations of the sites referenced in this text. Major obsidian sources: (**A**) Shirataki; (**B**) Oketo; (**C**) Tokachi-Mitsumata; (**D**) Akaigawa.

The analysis of oxygen isotope ratios and dust in varved sediment has led to highly detailed explanations of climate changes from the Last Glacial, which experienced drastic fluctuations in temperature, to the Holocene. The analysis of varved sediment in Lake Tougetsu and Lake Suigetsu in western Japan shows that a cooling event occurred corresponding with the Younger Dryas [36–38]. The palaeoenvironment changes occurring on Hokkaido have been approached by many fields, including geology, topography, palaeopedology, palaeoecology and microfossils. In particular, there has seen plentiful research focusing on the changes in vegetation via pollen analysis since the 1960s [39,40].

The analysis of pollen deposits at Kenbuchi, northern Hokkaido, shows that during the latter stage of the Marine Isotope Stage (MIS) 3, about 30,000 years ago, *Picea jezoensis* and/or *Picea glehnii* were predominant and boreal forests mixed with *Pinus pumila* were widespread. Starting from around 25,000 years ago, cooling led to the spread of steppes, where *Pinus pumila* was mixed with *Larix gmelinii*. Beginning around 21,000 years ago, *Pinus pumila* suddenly decreased, while *Picea jezoensis* and/or *Picea glehnii* increased. From around 17,000 years ago, there was another cooling period, and the appearance of *Pinus pumila* and *Microcachrys tetragona* increased. Beginning around 14,000 years ago, the ratio of *Pinus pumila* pollen in the record suddenly declined; however, a temporary recovery has also been observed. This period is thought to be the Younger Dryas. The prevalence of the *Quercus* subgenus increased around 10,000 years ago [41–43]. Pollen analyses conducted at Nakafurano in central Hokkaido show that although *Pinus pumila* and *Microcachrys tetragona* declined when *Picea jezoensis* and/or *Picea glehnii* increased between 14,000 and 12,000 years ago, there was a temporary period of cooling from 12,000 to 11,500 years ago, during which *Pinus pumila* increased. After this, conifer forests declined, and *Betula* forests expanded. Around 10,000 years ago, they were joined by *Juglans*, and around 9000 years ago, temperate, broad-leaf, mostly *Quercus* forests were formed [41]. Thus, it was only from around 10,000 years ago that humans in Hokkaido could begin to make intensive use of nuts as a stable food source.

According to pollen analysis, a significant expansion of subarctic conifer forests occurred in the mountainous areas of northern Honshu and in Hokkaido during the Younger Dryas. However, we know significantly less about the mammals that humans hunted relative to our knowledge of contemporaneous flora, due to the lack of palaeontological and zooarchaeological records describing the faunal community of the terminal Pleistocene. Palaeontological records from Hokkaido show that mammoths and bison existed there during the LGM, around 25,000 to 17,000 years ago [33,34,44]. However, the woolly rhinoceros and other species of large ungulates, such as the *Equus* and *Gazella* genera, common to the steppe and frequently observed during the Last Glacial in northeast China, are not attested at all in Hokkaido and neither are the *Hyaena*. Hokkaido is, thus, thought to have been less cold and dry than the northeastern part of the Eurasian continent, placing it near the edge of the distribution area for mammoths, which were distributed mainly across the mammoth steppe [34,44]. It is not known exactly when mammoths, bison, and other large mammals disappeared from Hokkaido. Taking into account the abovementioned changes in vegetation, it seems that climate warming gradually shifted their habitat north after the end of the LGM [45,46]. Therefore, we can estimate that at the time of the terminal Pleistocene, after large fauna such as mammoths and bison declined and were no longer a stable and dependable source of human food, the faunal community was composed mainly of mammals that were small, or of medium size, such as deer [47]. This, then, was the faunal community that would continue into the Holocene and that Jomon hunter-gatherers would rely on for diet [26,48].

Regardless of when the large fauna disappeared from Hokkaido, it appears that there were major changes in the faunal communities targeted by hunter-gatherers with microblades before the onset of the terminal Pleistocene. Interestingly, recent zooarchaeological analysis at the Yujiagou site (Layer 4 and Layer 3b), part of the Hutouliang Site Complex in North China, shows that the terminal Pleistocene hunters with microblades preferred juvenile gazelles and horses and used bone marrow as a significant source of energy [49]. Therefore, this analysis highlights that there were differences between the animal resources available in Hokkaido and North China during the terminal Pleistocene, although human foraging behaviours using microblade technology were dispersed in both regions. It is necessary to note that the terminal Pleistocene hunter-gatherers with microblades in Hokkaido had to adapt differently to changing environments.

## 3. Microblade Technology in the Terminal Pleistocene

From the LGM to the terminal Pleistocene, microblade assemblages, including microblades and various types of microblade cores mainly made from obsidian and hard shale, continued to exist in Hokkaido. Researchers have long focused their attention on the construction of a chronological framework and a techno-typological classification system for microblade technology [10,50,51]. In the study of microblade technology in northeast Asia, the Yubetsu method is most commonly seen in which a microblade was produced from a bifacial core blank with symmetrical cross sections and forming platforms by removing spalls [52,53]. Moreover, the Rankoshi, Tougeshita, Pirika, Oshorroko, Hirosato, Horoka and Momijiyama methods are also defined in Hokkaido and relate to differences in the manufacturing processes of microblade core blanks [10]. These microblade reduction methods are used as indices to locate lithic assemblages chronologically. The Rankoshi, Tougeshita and Pirika methods appeared around 25,000 to 24,000 years ago during the LGM [1,2].

There are few reliable radiocarbon dates available to determine the period to which microblade assemblage continued, which was at some point in the terminal Pleistocene [54]. Lithic assemblages associated with the Hirosato method (the Hirosato techno-complex) (Figure 2) obtained from the Nakamoto site indicate radiocarbon dates of around 15,200 to 13,700 years ago [1]. These dates were obtained from charcoal associated with hearths. This definitively shows that the lithic assemblage associated with the Hirosato method continued until the period of warming known as Bølling–Allerød in the terminal Pleistocene. The Hirosato techno-complex is confirmed in the Ankaritou-7 site [55], the Nakamoto site [1], the Nittou site [56], etc. Lithic artefacts, such as bifacial stemmed points, bifacial points and stone axes, associated with the Hirosato method have been found to show commonalities with artefacts associated with the Oshorroko method (Figure 3). As a result, lithic assemblages associated with the Oshorroko method (the Oshorroko techno-complex) have also been chronologically located during the same warm period (the Bølling–Allerød) [1,3,47,57]. The Oshorroko techno-complex has been confirmed in the Oribe-17 site [58], the Yoshiizawa-B site [57,59,60], the Ozora site [61], etc. Furthermore, lithic assemblages with small boat-shaped tools (the boat-shaped tool techno-complex) (Figure 4) have also been chronologically located during the terminal Pleistocene [47]. The boat-shaped tool techno-complex has been confirmed in the Nishimachi-1 site [62], the lithic concentration No.17 at the Kawanishi-C site [63], etc. Microblade technology is not seen in the lithic assemblages with the boat-shaped tools. However, the techno-typological features of burins, end-scrapers, bifacial points and bifacial stemmed points included in the lithic assemblage, as well as the technical features of the reduction sequence of the blades that serve as their materials, have recognised some commonalities with both the Hirosato and Oshorroko techno-complexes. Thus, the assertion that they should be placed at the same chronological stage is convincing [64].

Researchers have come to no agreement regarding the chronological relationship of these different techno-complexes [54]. Recently, it has been proposed that they appeared together and co-existed for some time. Some researchers have focused on the presence of newly invented tools, such as bifacial stemmed points and stone axes, that have been recognised in these techno-complexes [1,47,65]. A further accumulation of reliable radiocarbon dates showing clear relationships with lithic assemblages is urgently needed to resolve this issue of chronology. However, such additional research is hampered by the lack of any features, such as hearths, and complex post-depositional disturbances that are characteristic of the terminal Pleistocene sites in Hokkaido.

It is possible to identify flaking techniques from the assessment of crack velocity through the analysis of fracture wings observed on flaking surfaces [66]. In a large proportion of cases in Hokkaido, microblades were systematically detached by pressure flaking, with the exception of some cases [67–71]. The results of use-wear analyses based on materials from the Yubetsu method dated to around 18,000 to 17,000 years ago illustrate that standard and formal microblades were used as hunting implements, with many of them generally hafted on the side of bone/antler tools, according to the parallel striations identified along the sides of the microblades [72,73]. Low discovery rates and weak development of the use-wear observed on the microblades can be interpreted as indicating that they were not used as processing tools, such as burins and end-scrapers [73]. It allows us to infer that the microblades from the terminal Pleistocene sites were probably used as weapon insets, although further functional research will be needed.


**Figure 2.** Stone artefacts in the Hirosato techno-complex. Examples from the Ankaritou-7 site in central Hokkaido: (**A–E**) microblades; (**F**,**G**) Hirosato-type microblade cores; (**H–K**) burins; (**L**,**M**) drills; (**N**) bifacial tool; (**O**) broken edge-ground stone axe. Reproduced from [55].

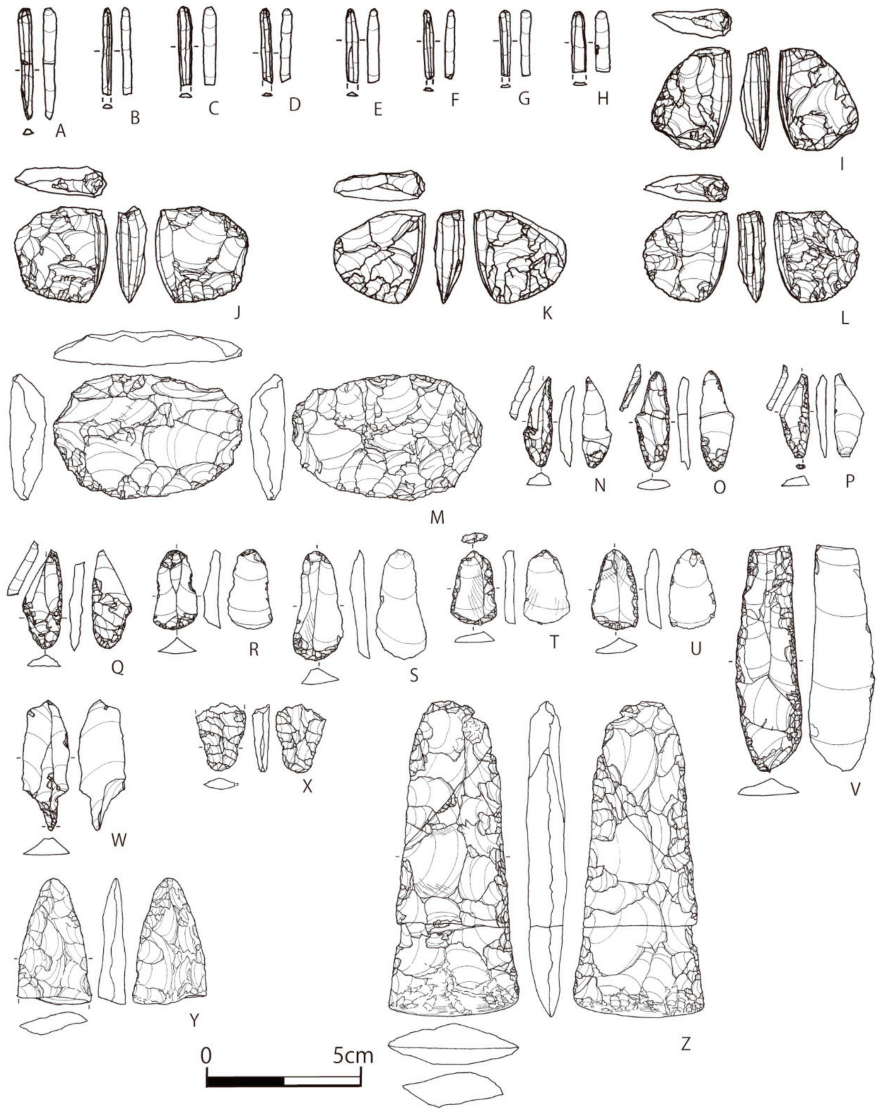


**Figure 3.** Stone artefacts in the Oshorroko techno-complex. Examples from the Oribe-17 site in eastern Hokkaido: (**A–H**) microblades; (**I–L**) Oshorroko-type microblade cores; (**M**) bifacial blank; (**N–Q**) burins; (**R–U**) end-scrapers; (**V**) side-scraper; (**W**) drill; (**X**) broken bifacial stemmed point; (**Y**) broken bifacial point; (**Z**) edge-ground stone axe. Reproduced from [58].


**Figure 4.** Stone artefacts in the boat-shaped tool techno-complex. Examples from the Nishimachi-1 site in northern Hokkaido: (**A–E**) boat-shaped tools; (**F–I**) burins; (**J**,**K**) end-scrapers; (**L**) side-scraper; (**M**) drill; (**N**,**Q**) broken bifacial points; (**O**,**P**) bifacial stemmed points. Reproduced from [62].

Microblade assemblages in the terminal Pleistocene are frequently accompanied by standard and abundant burins and end-scrapers made of blades. High proportions of formally shaped tools indicate the preparation of curated tool kits. The use-wear analysis of these burins shows that use-related traces are mainly located on burin facet edges and that they were often used in the manufacture and maintenance of bone/antler tools [65,74]. Burins have often been observed in lithic assemblages before the appearance of microblade assemblages in Hokkaido. However, use-wear analysis has not detected any signs of the manufacture and maintenance of bone/antler tools from these assemblages [75]. Accordingly, the beginning of intensive manufacture and the use of bone/antler tools is thought to be closely related to the emergence of microblade assemblages [76,77].

The use-wear analysis of end-scrapers from the microblade assemblages in the terminal Pleistocene suggests that they were intensively used in hide processing [65]. In addition, the traces of intensive rejuvenations of edges on end-scrapers can often be observed in these microblade assemblages [78,79]. Such evidence enables us to infer that foragers using microblade technology in the terminal Pleistocene conducted the production and maintenance of a diversified set of relatively specialised tools, reflecting the occurrence of task-specific occupation. It seems that this behavioural strategy brought about the inter- and intra-site variability of stone toolkits among the microblade assemblages in the terminal Pleistocene of Hokkaido [1,47,65,80].

It is widely known that many obsidian artefacts have been recovered from the Upper Palaeolithic sites in Hokkaido. There are twenty-one obsidian sources on Hokkaido [81]. In particular, four major sources, namely Shirataki, Oketo, Tokachi-Mitsumata and Akaigawa (Figure 1), had been mainly exploited for acquiring lithic raw materials throughout the Upper Palaeolithic. The provenance studies of Shirataki obsidian, including the results from the Sokol site in Sakhalin, show that the extra-regional transportations associated with the Yubetsu method extended throughout the Hokkaido and Sakhalin islands [82–88]. The long-distance transport of complete toolkits made from a single obsidian source can inform us of the long-distance movements (about 400 km) that the hunter-gatherers with microblade technology accomplished before the onset of the terminal Pleistocene. Several authors have attempted to discuss the diachronic change of the obsidian usage pattern during the Upper Palaeolithic based on the compiled data from which obsidian provenance studies have been carried out thus far [82,86–88]. The results of analyses from the Oshorroko and the boat-shaped tool techno-complexes demonstrate that these were dominated by obsidian from the nearest and various major sources, typically procured within 100 km. Debitage analyses and studies of technological activities among these techno-complexes indicate that preforms and finished tools were often transported a relatively limited distance, and secondary reduction and tool refurbishing were the most common activities observed in a number of sites [57,60,64,78,79]. In contrast, the results of analyses from the Hirosato techno-complex show that obsidian and/or artefacts from Oketo were frequently transported and used for producing various stone tools including large blades (up to 30 cm long) [87]. Extra-regional raw materials in the terminal Pleistocene microblade assemblages occur primarily as finished points and/or other tools that most likely moved through social networks. These trends of obsidian usage may be consistent with changes in the faunal community and subsistence during the terminal Pleistocene.

## 4. Techno-Complex with Potteries in the Terminal Pleistocene

In recent years, it has been shown that there were hunter-gatherers in Hokkaido during the Bølling–Allerød who produced and used potteries but did not use microblades [27,89,90]. From the excavation at the Taisho-3 site in eastern Hokkaido, a lithic assemblage composed mainly of small obsidian bifacial points associated with potteries has been discovered (Figure 5). Based on such techno-typological features, the Taisho-3 techno-complex can be defined. There are no lithic tools made from blades in the Taisho-3 techno-complex. This clearly differs technically and typologically from the microblade assemblages described earlier, showing that two distinct cultural groups existed. Although this may be somewhat influenced by the marine reservoir effect, we know from radiocarbon dating of charred residues from potteries at the Taisho-3 site that the Taisho-3 techno-complex dates between 15,000 and 13,700 years ago (Table 1).

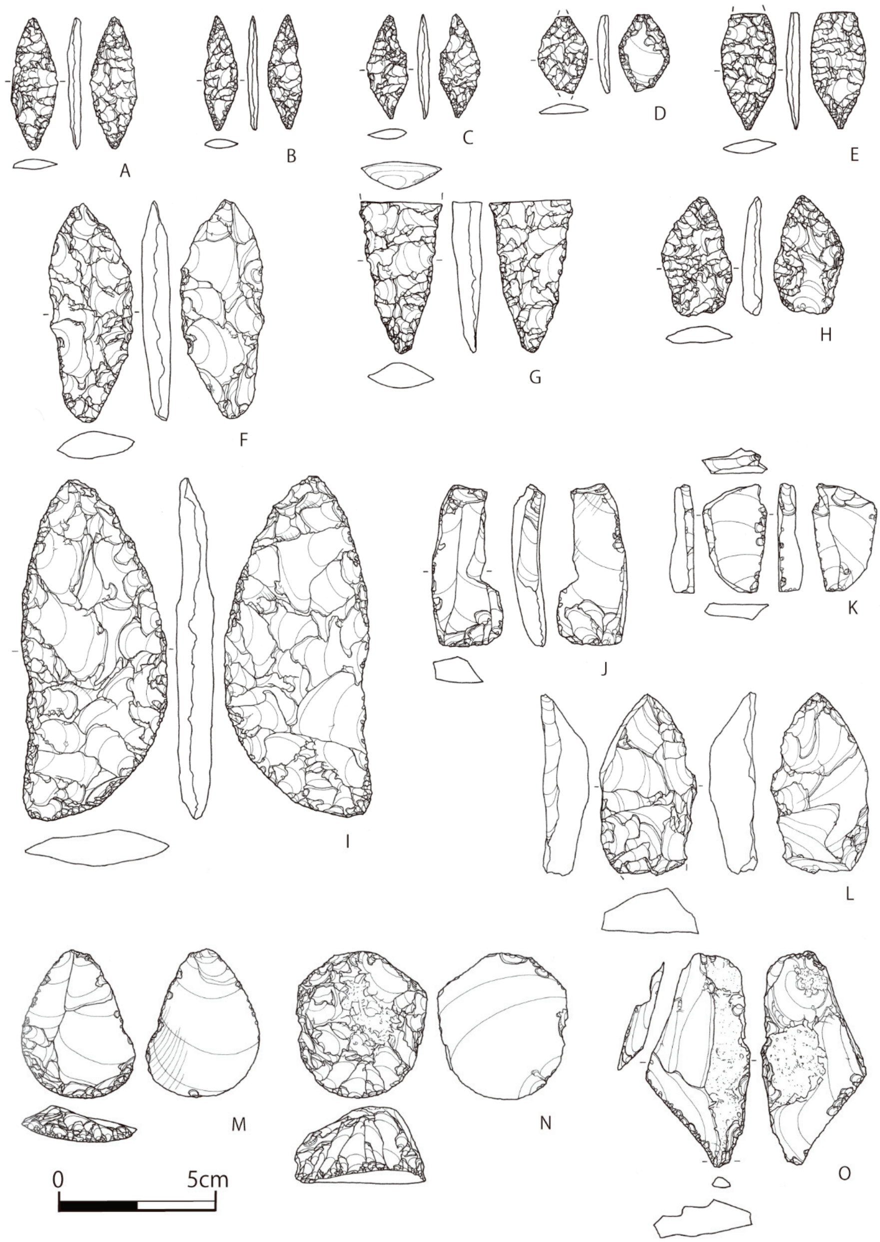


**Figure 5.** Stone artefacts in the Taisho-3 techno-complex. Examples from the Taisho-3 site in eastern Hokkaido: (**A**–**D**,**F**) bifacial points; (**E**,**G**) broken bifacial points; (**H**,**I**) bifacial tools; (**J**–**L**) burins; (**M**,**N**) end-scrapers; (**O**) drill. Reproduced from [90].

**Table 1.** AMS radiocarbon dates from the Taisho-3 site (calibrated using IntCal 13).

| Lab Number | Material | 14C BP | 1σ | δ13C | Calibrated date, cal BP (2σ) upper | Calibrated Date, cal BP (2σ) Lower | References |
|---|---|---|---|---|---|---|---|
| Beta-194626 | Charred remains inside pottery | 12,400 | 40 | −23.5 | 14,780 | 14,170 | [90] |
| Beta-194627 | Charred remains inside pottery | 12,220 | 40 | −24.0 | 14,260 | 13,980 | [90] |
| Beta-194628 | Charred remains inside pottery | 12,350 | 40 | −23.7 | 14,675 | 14,120 | [90] |
| Beta-194629 | Charred remains inside pottery | 12,460 | 40 | −22.6 | 14,960 | 14,265 | [90] |
| Beta-194630 | Charred remains inside pottery | 12,210 | 40 | −23.4 | 14,240 | 13,970 | [90] |
| Beta-194631 | Charred remains inside pottery | 12,130 | 40 | −23.3 | 14,140 | 13,830 | [90] |
| IAAA-41603 | Charred remains inside pottery | 12,290 | 60 | −21.6 | 14,630 | 14,025 | [90] |
| IAAA-41604 | Charred remains inside pottery | 12,330 | 70 | −23.2 | 14,745 | 14,060 | [90] |
| IAAA-41605 | Charred remains inside pottery | 12,120 | 60 | −22.1 | 14,145 | 13,780 | [90] |
| IAAA-41606 | Charred remains inside pottery | 12,470 | 60 | −21.7 | 15,025 | 14,250 | [90] |
| IAAA-41607 | Charred remains inside pottery | 12,160 | 60 | −22.5 | 14,210 | 13,815 | [90] |

The Taisho-3 site is located on a slightly elevated terrace that forms a natural embankment adjacent to a river (Figure 6). Just below the stratum containing the cultural horizon during the terminal Pleistocene is a gravel layer that was formed by river flooding; thus, human activity was conducted in a riverbed-like environment [90]. Unlike the Taisho-3 site, almost all other sites where microblade assemblages have been discovered are located on river terraces at a distance from rivers. The environmental setting of the Taisho-3 site demonstrates that aquatic resources were important for the daily activities of the hunter-gatherers who lived there. Stable carbon and nitrogen isotope analysis and gas chromatography–mass spectrometry analysis using charred residues from the potteries at the Taisho-3 site have shown that fish and other aquatic resources were exploited by the terminal Pleistocene hunter-gatherers [28,91]. These results are consistent with the patterns of land use inferred from the location of the Taisho-3 site.

In recent years, the Taisho-3 techno-complex has also been discovered from the excavation at the location M–I of the Tachikarushunai site, located in the Yubetsu River basin [92]. Nevertheless, it is apparent that sites with a Taisho-3 techno-complex are extremely rare compared to those with microblade assemblages in the terminal Pleistocene, although a taphonomic bias cannot be excluded for this record. The potteries discovered at the Taisho-3 site include the so-called nail-impressed wares (Figure 7). This pottery type has been found in several terminal Pleistocene sites in Honshu [93]. Some researchers argue that the technological characteristics of bifacial points have also been found to show commonalities with lithic artefacts among the Incipient Jomon from Honshu [94]. Accordingly, there is a strong possibility that the archaeological materials from the Taisho-3 site and the location M–I of the Tachikarushunai site indicate the results of small-scaled migrations from Honshu and adaptations to Hokkaido [27,29,89,94].

Lithic assemblages, composed mainly of leaf-shaped, foliate denticulate bifacial points (the Kyushirataki-5 techno-complex), have also recently been discovered [54,95]. Techno-typological comparisons of bifacial points have shown that they have significant commonalities with lithic assemblages from the first half of the terminal Pleistocene in Honshu [29,95]. However, there has been no radiocarbon dating of samples that clearly correspond to the Kyushirataki-5 techno-complex. In addition, it is necessary to note that there are also very few sites confirmed to be of this techno-complex. This can be explained by the reflection that group migration from Honshu most likely occurred on a small scale. It is apparent that we need to obtain reliable radiocarbon dates from future excavations to determine the chronological position of this techno-complex.

**Figure 6.** Distant view of excavation at the Taisho-3 site. Reproduced from [90], with the permission of the Obihiro Centennial City Museum.

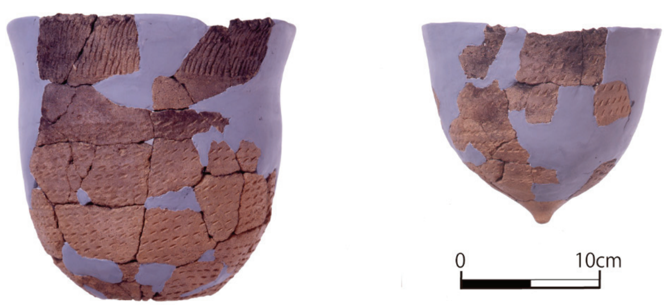


**Figure 7.** Potteries from the Taisho-3 site. These are the so-called nail-impressed wares. Reproduced from [90], with the permission of the Obihiro Centennial City Museum.

Based on radiocarbon dates obtained from the Taisho-3 techno-complex and those from the microblade assemblages in the terminal Pleistocene, it is difficult to assume that there was a temporal gap between the two. However, there are contrary views that they were not parallel in time [96]. As mentioned, if we are to consider the disparity in the patterns of land use, it is quite possible that they coexisted in Hokkaido during the same period of time [29,89]. Migratory communities new to the area might have developed a niche that had not been used among the hunter-gatherers in the area, who had until then, relied upon microblade technology. In other words, the investigation of the Taisho-3 site suggests that these communities migrated into eastern Hokkaido and made use of the aquatic resources they found there. The small size of the community, in addition to the fact that they explored new resources for their subsistence, could explain their ability to coexist with indigenous groups in the same region who produced and used microblades. It is noteworthy that Hokkaido provided a setting for multiple groups, with different cultural lineages developing different niches, to coexist during the warming phase in the terminal Pleistocene.

## 5. Disappearance of Microblade Technology

We have no reliable radiocarbon dates from archaeological sites to fill the gaps beginning from around 13,700 years ago in Hokkaido to the time when the Holocene began [26,54,97,98]. Using techno-typology, some argue that the lithic assemblages accompanying the small boat-shaped tools can be chronologically located to the period from around 13,700 years ago to 11,650 years ago [54]. At the present stage of knowledge, this possibility cannot be completely excluded. Regardless of its validation, there are apparently very few sites where lithic assemblages have been discovered that support this hypothesis [54]. Remarkable differences clearly exist in comparison to the number of sites, until the warming phase in the terminal Pleistocene.

Based on these trends, we can conclude that there was most likely a large change in the population of humans residing in Hokkaido during the Younger Dryas. The intense cooling of the Younger Dryas made adaptation to the environments in Hokkaido difficult for groups that had survived throughout the long period of the Last Glacial using microblade technology. As suggested above, it seems that mammoths and other large fauna declined or no longer existed in Hokkaido during this period. The large animal resources that the hunter-gatherers using microblade technology had stably exploited became scarce before the onset of the terminal Pleistocene. It seems that the re-cooling of the Younger Dryas period brought about the abrupt decrease of resources, such as small- or medium-sized mammals, including deer, that the hunter-gatherers maintaining microblade technology during the Bølling–Allerød had adapted to. This may have been the trigger for the end of microblade technology in Hokkaido. As suggested from the palaeoenvironment and archaeological evidence, the exploitations of large mammals and long-distance foraging could be maintained during the Younger Dryas in North China and Siberia [21,49,99], but not in Hokkaido.

Here, it is interesting to note that the clear failure of the traditions that were brought by the groups that migrated from Honshu reflects the Taisho-3 and Kyushirataki-5 techno-complexes during the terminal Pleistocene. Beyond one temporal gap, archaeological sites with potteries did not appear in eastern Hokkaido until the Holocene [98]. After the second half of the Preboreal, the number of sites suddenly increased in Hokkaido [27,89,100,101]. It is presumed that the abrupt cooling of the Younger Dryas period in Hokkaido made resource use difficult for human adaptations, regardless of whether human groups could use aquatic resources for subsistence or not. Therefore, this means that the migration from Honshu with the non-microblade tradition did not play a significant role in the disappearance of microblade technology.

Reliable evidence of human activity in eastern Hokkaido in the initial Holocene has been found through excavations at the Taisho-6 site [102]. This site includes lithic assemblages composed of stone arrowheads, burins, side-scrapers and polished stone axes associated with flat-bottom potteries, defined as the Tenneru-Akatsuki type [27,89,100–102]. Radiocarbon dating of the charred materials from potteries shows that human activities at the Taisho-6 site began around 11,000 years ago. Many pit dwellings have also been discovered in sites in eastern Hokkaido, where the Tenneru-Akatsuki-type pottery was found, so we can assume that a more sedentary way of life followed in the second half of the Preboreal. A more intensive use of aquatic resources and nuts has been shown at the stage where the Tenneru-Akatsuki-type pottery appears and spreads [27,101,103].

Despite a few claims to the contrary [27,89], many argue that the appearance of Tenneru-Akatsuki-type pottery in eastern Hokkaido reflects the migration of groups from Honshu and their adaptation to Hokkaido [101,104]. At present, it is unreasonable to expect that the various cultural features observed in potteries and stone tools in the initial Holocene sites of Hokkaido originated in the Younger Dryas period. Though, archaeological sites chronologically located during the Younger Dryas may be discovered in the future. However, even if such discoveries become possible, it would not change the conclusion that a sudden decrease in the number of sites occurred during the Younger Dryas compared to other periods. In Honshu, there are some fluctuations in the number of sites, but human activities continued across all periods of the terminal Pleistocene without interruption [94,105]. No definite break in the archaeological record can be seen, distinguishing it from the trends seen in Hokkaido.

## 6. Conclusions

Advancements in the investigation of archaeological sites across northeast Asia have revealed changes in human adaptations from the terminal Pleistocene to the initial Holocene. Radiocarbon dating has allowed a highly precise chronological framework to be constructed. Moreover, the analysis of nitrogen and carbon isotope ratios in charred materials from potteries has provided important information on the emergence of new subsistence activities. A systematic discussion of the disappearance and continuation of microblade technology and its various developments, as well as the background to these events following the LGM, is now becoming possible, based on archaeological studies of stone tools and potteries as well as the accumulation of evidence from bioarchaeology and palaeoenvironmental studies.

This paper has discussed the period during which microblade technology in Hokkaido disappeared, as well as the background to this. Microblade technology, seen until the Bølling–Allerød in the terminal Pleistocene, disappeared during the Younger Dryas. It may be that continued habitation in Hokkaido was made difficult due to the significant re-cooling of the climate, which caused a striking decline or extinction of the resources that humans had relied upon for food. Despite some drastic changes caused by the Younger Dryas, long-lasting developments in human behaviour such as high mobility and the hunting of large mammals in North China and Siberia, indicating open forest and grassland zones, seemed to have been unaffected by the impact of this event. In contrast, discontinuity rather than continuity in human behaviour and populations during the Younger Dryas has been observed in the archaeological records from Hokkaido. It is apparent that this process occurred during the terminal Pleistocene and was influenced by a wide range of factors, including changes in landscape, climate, faunal community, subsistence and human populations.

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*Commentary*

# New Discoveries and Theoretical Implications for the Last Foraging and First Farming in East Asia

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**Abstract:** A brief summation of the issue's articles is presented. This leads to a discussion of thematic issues of concepts, methods, and theory that crosscut the articles. These include use of the EnvCalc2.1 program, some issues of terminology, the theoretical approaches of niche construction as opposed to human behavioral ecology (HBE), and the linkage between technology and subsistence change, notably the difference between biface and microblade production.

**Keywords:** East Asia; origins of agriculture; paleolithic to Neolithic transition

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## 1. Introduction

Let me first make clear that I am an expert on neither Asian archaeology nor the origins of agriculture. I cannot comment on the specifics of particular Asian archaeological sites or on the botanical histories of the various plants involved in the transition from foraging to agriculture in Asia. I do know something about hunter-gatherers, and about how archaeologists have been thinking about the origins of agriculture in North America, where, as in these Asian cases, we have both domesticated indigenous plants (in the eastern US, e.g., Chenopodium) and already-domesticated imports (maize, from southern Mexico/Central America). My comments here, therefore, result from taking a step back from the specifics of the papers to look more at methods, data, and theoretical constructs. However, first I make some observations on the individual contributions.

## 2. The Case in Asia

The precise pathways taken toward agriculture in any given prehistoric case—the woodlands of the eastern US, Taiwan, Japan, or mainland China—depend on numerous factors of geography, climate, plant genetics and habitat, other subsistence options, human population growth, and others. However, what I see in these papers is a story that has occurred repeatedly in various places in the world over the past 15,000 years. Human population grew to the point where diet had to be supplemented, first, with lower return-rate-resources, which in many cases included plants that produce small seeds (or below-ground storage vessels, such as tubers). These resources responded to their human use and manipulation by becoming more productive in density and/or seed size; eventually, for better or for worse (a steady diet of maize or rice, e.g., is not good for long-term health), they became the focus of diet—and the plants that support the modern world's 7.8 billion people.

This collection of papers, however, does show that this general, global process has variations produced by local environmental, historical, botanical, and prior cultural conditions. Investigation of this variation helps us understand variety in the specific pathways to agriculture, and consequently which variables are important under what conditions.

There are different theoretical tools at our disposal to understand this variation. Agriculture was imported from Southeast China to Taiwan about 6000 years BP, and, using the combined perspectives of human behavioral ecology (HBE) and niche variation theory (NVT), Yu [1] argues those Neolithic agriculturalists met a population divided into two basic adaptations: one focused on coastal fishing and the other on mountain hunting. The arrival of agriculturalists almost certainly increased the island's population density. The result was most likely increased competition, and niche contraction. HBE would predict increased diet breadth under these conditions, and that appears to be what happened, as previous hunter-gatherers incorporated low-ranked/low-cost cultigens into diet. I will add that the ideal free distribution (IFD) model might be a useful next step, as it would predict the order in which different regions should witness the transition to agriculture. Right now, that appears to be western coastal areas, the mountains, and then the east coast.

Fujio [2] also looks at an instance where agriculture (and, later, irrigation technology) was imported, in this case, to Japan from the Korean peninsula before about 3000 years ago. This seems to have been driven by population packing and competition for land on the Korean peninsula. It is often said that hunter-gatherers solve problems by moving; agriculturalists do, too, but not as a matter of course (hunter-gatherers expect to move, agriculturalists do not), and not after exhausting other possibilities. A hunter-gatherer can live in many places; suitable places for agriculture might be few and far between. In Japan, the Jomon population appears to have grown in size, especially after 5500 years ago, when large pithouse villages formed, and then declined, with movement to dispersed groups about 4900 years ago. This process may reflect a "rigidity trap" one based on more focused use of labor-intensive resources such as horse chestnuts [3]. If so, it might signal that the Jomon population ~3000 years ago was in need of a new food source, and rice agriculture from Korea provided it; the same might have happened in the eastern US woodlands, with the appearance of full-time maize horticultural systems ~1100 years ago (maize appears ~2000 years ago but was not consequential for a long time), after which eastern US societies made rapid changes in social and political organization (the "Mississippian culture"). Fujio [2] is able to examine the timing of settlement of different regions of Japan in some detail, and, again, this offers the potential to test whether this process can be described by the IFD. For both Japan and Taiwan, if the IFD fails, then it is probably pointing to some other factor—such as the presence of foragers—that affected agriculturalists' choice of where to settle.

Likewise, in Japan, Ikeya [4] is concerned with the process whereby Yayoi agriculturalists replaced or subsumed the existing Jomon hunter-gatherers. Across the globe, agriculturalists gradually replaced hunter-gatherers. In fact, this process is not complete, and is still on-going, with very few populations left who live even partially by hunting and gathering (virtually no population today lives entirely by foraging). Again, the IFD model could help explain the spread of agriculture (keeping in mind the "starting" point, where Korean migrants landed may not have been the "best" place to start on the islands of Japan). Nevertheless, Ikeya [4] is more interested in what governs whether the indigenous (Jomon) people of Japan, simply became Yayoi agriculturalists or remained hunter-gatherers to one extent or another. That is a complicated question, and no doubt has to do with the returns from rice agriculture versus the returns from foraging in different parts of Japan. Determining those returns will require further ethnographic and/or experimental work with foraged foods versus cultigens.

Takakura [5] looks at the archaeology of Hokkaido, Japan's northern island. Here he finds, as others have, that microblade technology disappears during the Younger Dryas (YD) cooling, perhaps, quite possibly, because the human population itself disappears at this time (although the ages of the boat-shaped tool assemblages are not well dated and may fall within the YD). When people returned to the island after the YD (or when their numbers rebounded), they used bifacial technology, without microblades, and ceramics. The Taisho-3 site assemblage shows that the shift away from microblade technology (and accompanied by ceramics) had happened even before the YD, but after the demise of large Pleistocene fauna on the island. At Tasiho-3 there is evidence for the use of aquatic resources, a subsistence shift that in other places (according to the accompanying papers) was a precursor to an agricultural economy.

In North China, Paleolithic foragers shifted to a more Neolithic-like adaptation, including sedentism in large aggregated settlements, large-scale food storage, and so on, before full agriculture (millet) appears. In this regard, North China is similar to the Near

East; and also portions of the eastern US, where the "Hopewell culture" (much later in time) had a predominantly foraging adaptation, with some low-level use of indigenous cultigens. Hopewell people lived in large, sedentary villages that show evidence of social and political "complexity" in the form of elaborate log-tomb burials beneath mounds, and large, sophisticated earthen enclosures, many in geometric forms. Zhao [6] shows that the transition to a fully Neolithic lifeway with millet agriculture (rice in some portions of North China) appears after the 8.2 k climatic cooling event (that increased aridity in northern latitudes). I suspect the adaptive system was moving in the direction of a fully-agricultural lifeway due simply to population pressure and resulting competition. Population pressure, of course, results from an increase in population and/or a decline in resource abundance. I suspect Zhao [6] is right: the 8.2 k event was a severe "trigger" that sped the Neolithization process up by decreasing food availability in North China. Obviously, what is needed are tighter chronological studies to sort assemblages into pre-8.2 k, 8.2 k, and post-8.2 k intervals, e.g., [3].

Liu and her colleagues [7] show that the Paleolithic-to-Neolithic transition was not a simple phenomenon, especially in those zones that are somewhat marginal for agriculture (marginal without considerable labor investment). They see a geographic mosaic of at least three adaptations in the Middle Yangtze region: rice agriculture, hunting and gathering (a continuation of Paleolithic lifeways), and low-level horticulture coupled with hunting, gathering, and fishing, the last indicated by the appearance of a simple, but consistent and apparently efficient flake tool technology incorporating "ridged-hammer bipolar flaking." It is regions of such adaptive mosaics that, in the future, can provide some of the best tests of hypotheses, given that they allow us to see the effect of different combinations of environment, geography, and population density.

Zhang [8] employs Binford's [9] macroecological approach to help reconstruct changes in diet, mobility and group size in northern China at the last glacial maximum (LGM), YD, and afterwards. He finds that the evidence matches Binford's now >40-year-old hypothesis that agriculture should appear in the areas adjacent to those with the greatest density of the wild ancestors of domesticated plants. Binford was thinking specifically of the Near East, and the domestication of wheat and barley. However, the best evidence now suggests that domestication in the Near East began in those areas with high densities of the wild ancestors of domesticated plants, not in the adjacent areas. The North China case, therefore, might be another place to test Binford's hypothesis rigorously.

Yu [1], Liu and colleagues [7], and Zhang [8] all see an interplay between aquatic resources (riverine in one case, marine in the others) and the incorporation of agriculture into the diet. Cross-cultural studies do suggest that aquatic resources are used in lieu of storable gathered foods, but also in lieu of hunted foods [9,10]. In both cases, an increasing population density would restrict access to food, probably first to large game and then to storable plant foods (but this could depend on specific resource distributions). In any case, Asia offers the potential to examine the trade-offs between the plant, animal, and aquatic components of diet in understanding why some people added agriculture to the mix when they did.

### 3. EnvCalc2.1 Program

Two papers (Yu [1] and Zhang [8]) make use of the EnvCalc2.1 program [11,12], based on Binford's [9] exhaustive set of ethnographic and environmental data. With this program one can hypothesize the nature of prehistoric foraging societies by using modern climate data at specific locations to reconstruct past climates, such as the LGM, and then, based on correlations between environmental variables and ethnographic data on foraging societies, predict a number of aspects of prehistoric hunting and gathering societies. It is potentially remarkable, but I have three concerns with the use of this approach.

First, and briefly, the program is not designed to serve in place of reconstructions of the past based on archaeological data. Yu [1] and Zhang [8] are both aware of this, and they instead offer the approach as a way to frame hypotheses about how we expect prehistoric hunter-gatherers to have behaved, hypotheses that can then be tested against archaeological data. I make this comment only to reiterate and hence avoid any misunderstanding of Binford's goal: to create a way to use the prehistoric record to improve our understanding of why hunter-gatherers acted the way they did and consequently to understand why prehistory took the particular path it did in a particular region. Yu [1], for example, uses Binford's approach combined with HBE and NVT to provide some testable ideas of what happened in Taiwan's prehistory; Zhang [8] uses the approach to suggest when LGM hunter-gatherers might have increased exploitation of storable food resources, such as seeds, again a testable idea.

Second, a shortcoming of Binford's "macroecological" approach is that no explicit theory stands behind it. Instead, it is empirical generalizations, correlations between environmental and human behavioral variables. Make no mistake: these are enormously useful and, to use one of Binford's favorite terms, provocative. The idea that stands behind much of Binford's approach is cultural ecology, or, its updated version, HBE. Although, inexplicably, in my opinion, Binford always rejected HBE, and thus he rejected the most obvious theory to account for the many patterns he demonstrated.

Third, I have concerns about the ethnographic data that stand behind EnvCalc's predictive capacity. I have only checked one of Binford's datasets [9], the mobility data presented in his Table 8.04 (I am indebted to Brigid Grund for her dogged assistance in this task). There are 303 cases listed in this table. Of these, 26 (8.5%) are presented as "LRB estimates," and another 13 (4.3%) are based on personal communications from a relevant ethnographer; the remainder list published references.

I have found no one who knows what "LRB estimate" refers to; they are obviously not based on Binford's own fieldwork or the field notes of others. In some of those cases it is clear that the group had ceased being nomadic long before any ethnographer could have been on the scene. I have also searched Binford's archives at Truman State University, but I could find no personal letters from ethnographers in the folders. Although, to be precise, all of Binford's materials were not yet archived when I made my visit, so they may yet be discovered.

Of the 264 cases with references listed we could verify the exact data in only 3 (1.1%) cases. We found mobility data in 85 (32%) cases but came up with (sometimes only slightly) different estimates; and in some cases, Binford presents data as miles, but they are actually kilometers. However, some of the cases are ones where I am certain there are no mobility data. For example, the Toedökadö (Cattail-Eater) Paiute in western Nevada, is listed as having 5 residential moves/yr and a total annual movement of 90 miles/yr, and the reference is Fowler's [13] compilation of Willard Park's 1930s fieldnotes. There are no mobility data in that compilation; indeed, there cannot be, for the Paiute no longer lived a nomadic lifeway in the 1930s. Perhaps Binford made a mistake and listed the wrong reference. That is possible, and I cannot cast the first stone here as there is at least one such mistake in my own mobility data compilation [10] (for the Netsilik). However, I did my dissertation fieldwork in Toedökadö territory, and consequently I am very familiar with the literature, and there are no mobility data in any of the region's ethnographic or ethnohistoric references. I do not know where Binford's Toedökadö data came from.

Binford's data were gathered over many years, and most likely from the efforts of many students. No doubt some errors have crept in as happens with all large compilations of data. Whether they are enough to negate EnvCalc is something that ought to be investigated. I sincerely hope the answer is no.

## 4. Terminology: Intensification, Complexity, Climate Amelioration/Deterioration

Archaeology uses terms whose meanings are often thought to be clear, but, upon reflection, are not. Morgan [14] makes clear that one such term is intensification. Part of the problem is that "intensification" is not a substantive thing, but a concept. Concepts are good to think with, but not if they mean substantially different things to different researchers. Intensification can refer to increased productivity, increased efficiency, or increased productivity with increased efficiency. It almost always implies a process or trend over time, as in "increasing intensification."

Since the *concept* of intensification is not a *definition*, it is not always clear what evidence will prove or disprove an argument for intensification. I have long preferred the language of HBE, whose hypotheses entail expectations such as an increase or decrease in diet breadth, which can be measured by relative changes in the range of food resources evidenced in archaeological assemblages; whether it entails a decline in efficiency (it usually does) and/or an increase in productivity (it can, but usually at an increase in time input). In such cases an increase in diet breadth can be defined as "intensification" but what matters is that the hypothesis permits its testing. Agriculture is a special case because it begins with an increase in diet breadth (including, e.g., small, initially low-return-rate seeds in the diet) that implies a decline in efficiency and a consequent increase in workload [10] (pp. 50,51)). However, these small seeds respond to human use and ingenuity by an increase in productivity (through selection of larger seeds to generate next season's crop, or productivity-enhancing behaviors such as irrigation or terracing—all of which require increased labor input). Being part of a package, a plant with an enhanced return rate due to genetics, and to human behavior aimed at exploiting those genetics can leapfrog other resources, especially when imported in their fully domesticated form to a new region (e.g., rice to Japan, or maize to the US eastern woodlands). What is needed, then, is knowledge of how plants of different potential (genetic) productivities coupled with different human behaviors aimed at exploiting those potentials (e.g., simple floodplain farming, irrigation, fertilizing, etc.) affect the return-rates of different horticultural systems. Barlow [15] does this for indigenous maize farming systems in the American southwest.

Other terms have similar difficulties: climate amelioration/deterioration should be made more specific in terms of precipitation and temperature and, when discussing subsistence, their linkages to food availability (or seasonality, etc.) be made clear. Likewise, "complexity" has long bothered me. On the one hand, it implies that the behavior of nomadic hunter-gatherers was simple, which simply is not true (even an hour's reading on indigenous Australians' social organization or Dreamtime theology will leave the reader's mind spinning); even what appears to be "simple" technology and subsistence is predicated on detailed knowledge of natural history and physics. More to the point, "complexity" masks the actual behaviors at work in producing the artifacts that lead archaeologists to label a case of prehistoric hunter-gatherers (or anyone) as "complex" for these are usually artifacts pointing to the importance of formalized social relations between individuals or groups, or to social, political, and/or economic inequality. A concern with terms is not trivial because imprecise terms lead to imprecise explanations.

## 5. Niche Construction versus Human Behavioral Ecology

Long before maize appeared in the eastern US, inhabitants in the mid-continent cultivated indigenous plants, including squash (*Cucurbita pepo*), sunflower (*Helianthus annuus*), marshelder (*Iva annua*), and chenopod (*Chenopodium berlandieri*). Other possible cultigens (of lesser importance if they were cultivated) are giant ragweed (*Ambrosia trifida*), little barley (*Hordeum pusillum*), maygrass (*Phalaris caroliniana*), and knotweed (*Polygonum erectum*). The process of cultivation was underway sometime between 5800 and 3200 cal BP, but was not significant until well after 3200 cal BP. By ~1100 cal BP, maize supplanted these cultivated indigenous plants and long-time horticulturalists/foragers in the eastern US became agriculturalists.

In recent years, some researchers have used niche construction theory (NCT) to explain the origin of agriculture in the eastern US [16]. This approach is not used heavily in these papers (see Yu [1]), but I am certain my Asian colleagues are reading this literature, especially those interested in the origins of agriculture.

Briefly, NCT focuses on how behaviors emerge from the effects that interactions among organisms have on one another. Exploitation of a plant leads to a change in the plant's productivity, which leads to a change in human use of the plant, which further affects the plant's productivity, which further changes how humans use it. Such a process may entail both intentional and unintentional behaviors. Many of the early cultigens of the eastern US grew in the floodplains of rivers, and especially in disturbed habitats. Human occupation of those floodplains, and the removal of trees, e.g., for house construction, or burning to enhance forage for wild game, would have increased the abundance/density of these weeds, possibly increasing their return rate, making them a more attractive food choice. Human foragers might realize that they could enhance this process, and horticulture/domestication would be underway.

An alternative to NCT is HBE. HBE sees subsistence change as driven largely by changes in the availability of high-return-rate resources, changes produced by climate—linked environmental change and/or human population growth that results in a food's over—exploitation and consequent decline in abundance, a situation described as "resource depression." Changes in the abundance of low-return-rate resources (such as small seeds), changes that do not increase a resource's return rate, are not anticipated to have an effect on diet composition.

Although proponents present NCT as an alternative to HBE, it is not. In fact, the predictions of NCT fall quite comfortably within the models used by HBE [17,18], although HBE has admittedly focused on resource depression and not on how human use of resources might have the opposite effect—increasing their return rate by increasing their abundance and/or by technological innovations. (Note, however, that increasing abundance does not automatically increase a food's return rate. However, under some conditions, an increase in density can increase a resource's return rate by making the resource more amenable to mass collection methods that raise its return rate by raising the efficiency of collection. A new technology is usually involved: Imagine the return rate from scattered seed-bearing plants, harvested plant by plant as opposed to that of a dense field of the same plant, harvested with a wicker paddle and basket. This process can be enhanced by humans through selective breeding, e.g., for larger seed size.)

The difference between NCT and HBE matters because NCT proponents argue that human population growth was not responsible for the origins of agriculture. Zeanah [17] argues there is good reason to expect that small seeds such as chenopod, even with a density enhanced by human activity, would not be incorporated into the diet until high- return-rate foods were diminished in abundance. He shows that the archaeologically- documented patterns of use in the eastern woodlands—heavy use of hickory, with the later addition of walnut over small seeds, and then diminished use of walnut in favor of the enhanced returns from cultivated small seed plants—fits with an HBE model that predicts cultivation as a response to declines in the abundance of higher-return-rate resources. Miller [19] shows that intensive use of lower-return-rate seeds and cultivation of indigenous plants appears in the eastern US after evidence appears of both population growth and the reduced use of high-return-rate resources.

In other words, the origins of agriculture in the eastern US seems to be completely consistent with a model of changing subsistence driven by population growth, reduction of high-return-rate food resources, coupled with the effects of human activity on the abundance of weedy, small-seed-producing indigenous plants. NCT is an important addition to our understanding of the origins of agriculture, in both primary and secondary settings, but its legitimate concern with the effects of human behavior on the environment and their subsequent effects on subsistence choices falls comfortably within HBE, which provides a sounder foundation in evolutionary theory.

## 6. Population

Several papers rely implicitly or explicitly on the relationship agriculture had to population growth. It has long been logically assumed that agriculture leads to population growth, what is known as the Neolithic Demographic Transition, and recent studies demonstrate this fact from the data of prehistory [20–22]. At the same time, studies show that the long-term rate of growth of hunter-gatherer and agriculturalists is the same,

~0.04% [23], but with a difference: agricultural populations can grow at high rates over short periods of time but are more susceptible to periodic population crashes [23,24]. Future research should give specific attention to measures of population growth/density to test demographic hypotheses about the relationships among agriculture, social and political organization, warfare, and agriculturalists' foraging neighbors. Asia offers an excellent laboratory for this project.

## 7. Technology

The stone component of the technology that immediately precedes agriculture in eastern Asia entails microblades. To an archaeologist of the continental US, microblades are quite foreign and I am not qualified to discuss their various methods of production or use. However, let me make two comments that might be useful in understanding why microblade technology disappears. First, Takakura [5] and Zhang [8] associate the decline in microblade technology with the demise of the large Pleistocene fauna of Hokkaido—and that association indeed appears to be true. Although in the US, large fauna, including mammoths and mastodons were hunted with Clovis spearpoints, large bifacial points, a technology that, invented by a population that migrated to North America from Asia about 15,000 years ago, almost certainly came out of a microblade tradition. Microblade technology is certainly not *necessary* for the hunting of large game. In fact, I have long thought that microblades and bifaces are two different ways to accomplish the same goal of ensuring maintainability, the former relying on modularization-with-replacement and the latter on resharpening.

Second, my sense, and it is only a sense, is that microblade technology is more difficult and time-consuming to learn than bifacial technology. The best candidate in my opinion for the precursor to Clovis technology is the Yubetsu microblade method, which first requires production of a biface, one edge of which is then removed (with one or more "ski spalls") to create a platform for the removal of standard-sized microblades. That is, the Yubetsu method requires biface technology *and* creation of a core to produce pressure-flaked, standard-sized microblades. The simple fact that there is a second production stage tells us the microblade method will be more difficult to master. (Clovis retained some of this difficulty with the production of flutes, and, in some places, macroblades from cores, but the fluting technique was dropped, after it was used most prominently in the slightly later-in-time Folsom spearpoints. Macroblade production also disappears.)

What these two facts suggest is that microblade-using populations replaced one technology, microblades, with another, bifaces and flake tools, that (probably) turned out to work just as well for hunting and yet allowed time for children to be enculturated in other tasks that had become necessary, and thus more important than microblade "education," due to environmentally-induced changes in food resources and/or an increased population, e.g., ceramics, plant gathering, and the hunting of a wider range of animals with all their various behaviors (I will note that the lack of blade standardization at Donghulin may point to less enculturation in proper production methods). Thus, the key to the decline in microblades may lie in a shift in the importance of tasks that children had to learn to be successful adults in a post-Pleistocene world.

## 8. Conclusions

From an outsider's perspective, the Near East has dominated our understanding of the origins and development of agricultural and of early agricultural society. Clearly Asia, as an independent center of agricultural origins, and one that contains plants of quite different needs (millet and wet-farming of rice) offers the possibility of testing hypotheses generated by research in the Near East and elsewhere. To do so will require: (1) a better understanding of how climate affects the distribution and abundance of the local, non-domesticated food resources over the past 18,000 years; (2) the collection of data (such as radiocarbon dates, but also measures of site frequency and artifact densities over time) that will permit testing hypotheses relating agriculture's inception and development to population growth; (3)

better understanding, generated by ethnographic, ethnohistoric, and experimental work on the productivity, constraints and possibilities of different agricultural plants and systems; and (4) better understanding of technologies, their constraints and possibilities. Although NCT certainly points to the importance of understanding how one generation's behavior alters the environment to which the next generation must adapt, I think that HBE is a productive theoretical approach within which to understand the material possibilities and consequences of such a process. I, for one, look forward to this research in Asia with enthusiasm.

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