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Tempo and Mode of Neolithic Crop Adoption by Palaeolithic Hunter-gatherers of Taiwan: Ethno-archaeological and Behavioural Ecology Perspectives

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ABSTRACT

Archaeological evidence from the Early Taiwan Neolithic facilitates the development and assessment of predictive statements about habitat-related variance in the initial adoption of agriculture. This paper summarises archaeological research about Taiwan's terminal Palaeolithic and early Neolithic periods, and derives working expectations from human behavioural ecology models of diet breadth, opportunity cost, and future discounting, as well as ethno-archaeological research. Expectations are evaluated using Lewis Binford's hunter-gatherer database. Results allow for the prediction that selective forces during the Neolithic transition of Taiwan favoured mixed economies that varied according to the properties of the local habitat, the social and subsistence organisation of hunter-gatherer groups, and the degree and timing of exposure to immigrating farmers: 1. Coastal plains of the west and the lacustrine basins of the north were ideal zones for initial colonisation by Neolithic Southeastern Chinese farmers. Land pressure and resource competition from immigrants would decrease the costs of crop adoption from the hunter-gatherers' perspective, and personal encounters and transfer of cultivation knowledge were direct and continuous. 2. Wild resources maintained higher values on the east coast, where hunter-gatherer populations were supported by aquatic resources, and the mountainous interior where mobile hunting predominated. Flatlands suitable for farming are scarce in these zones. Future discounting, opportunity costs, and marginal value models predict that hunter-gatherers of the east coast and mountains delayed the full adoption of cultivation practices. This result may be tested using archaeological data and is relevant for other sub-tropical island agricultural adoption.

A note on spelling. For Chinese words, the Pinyin system of romanisation is used, except where the Wade-Giles system is used for longstanding and familiar names. For Taiwan indigenous words, Romanised versions that are commonly accepted in the scholarly literature are employed. For site dates, BP or BC are used as in published sources.

INTRODUCTION AND BACKGROUND

The Neolithic transition for the island of Taiwan is remarkable for its late date and nuanced archaeological record (Chang 1969, 1989; Chang and Goodenough 1996; Tsang 2005; Hung and Carson 2014), important as a case study of agricultural adoption by hunter-gatherers in an island setting, and relevant to the Neolithicisation of Southeast Asia and the eventual Austronesian expansion across Oceania (Pawley 2002; Bulbeck 2008; Bellwood 2009; Blust 2009). A growing body of archaeological evidence provides an excellent opportunity to test predictive statements using multiple frames of reference for the tempo and mode of the adoption and spread of agriculture. In this paper, I summarise the current state of archaeological research about Taiwan's terminal Palaeolithic and early Neolithic periods, derive working expectations from human behavioural ecology and ethno-archaeological research, and refine those expectations using Lewis Binford's (2001; Binford and Johnson 2014) database of environmental and ethnographic data.

Physiography, Climate, and Environment

The island of Taiwan is located on the eastern edge of the Asian continental shelf and the western rim of the Pacific Ocean between longitude 120E and 122 E and latitude 21N and 25N. The area of the island is about 36,000 km^2, with a north-south distance of about 394 km and an east-west distance of about 140 km. Okinawa lies to the north, China lies about 130 km to the west, Luzon about 250 km to the south, and the Pacific Ocean to the east. The surrounding islands include the Penghu (Pescadores) group of islands, Green Island, Orchid Island, and Hsiao Liuchiu. The Tropic of Cancer runs through Taiwan, and the climate is mostly sub-tropical, with tropical conditions in the south. Sea breezes, typhoons, and monsoons keep temperatures warm, with annual averages between 21.5 and 24.5 C. Humidity is high year round, with average rainfall between 1,820 and 2,720 mm. High variability in average annual rainfall comes from the rainshadow effect and seasonal variation in wind direction and moisture delivery; the central west coast is the driest and the northeast coast the wettest.

Palaeoclimates of the terminal Pleistocene were cooler and dryer than today, and a land bridge connected Taiwan to Southeast China during glacial maxima. In the middle to early late Holocene, temperatures fluctuated widely and were significantly warmer than today. Seasonal wind and rainfall patterns likely differed as well: It is not clear if the winter monsoon/summer typhoon cycle existed. However, the island's position and physiography likely had a similar influence on relative temperature and humidity to today.

Taiwan's landmass is more than 80% mountainous and characterised by volcanism, earthquakes, and constant landslides. Taiwan's coastline is about 1,566 km around the perimeter, and dozens of rivers flow out of the mountains in all directions. The central mountain range forms the spine of the island, with more than 100 peaks higher than 3,000 m above sea level, although the island is only c.

144 km at its widest point. The coastal mountain range to the east is smaller, about 140 km long, with peaks of about 1,000 m to 1,500 m. A long, narrow inland valley runs north-south between the central and coastal mountain ranges. Three major lake basins are found in the north, west, and west-centre of the island.

Taiwan's ecosystems are highly bio-diverse. Before urban development, the western coastal plain was crossed by large meandering rivers, grading upwards through dense deciduous forest to sub-tropical cypress and other evergreens to alpine oak scrub. On the east coast there is very little flat land; most piedmonts are narrow, and the largest flat areas are localised alluvial outflow deposits from steep mountain rivers. The southern tip of Taiwan is tropical in climate and vegetation. The island's flora and fauna include island forms such as the Taiwanese cypress (*Taiwania cryptomerioides*), the Formosan bear (*Ursus thibetanus formosanus*), clouded leopard (*Neofelis nebulosa brachyura*), boar (*Sus scrofa*), Sika deer (*Cervus nippon taioanensis*), sambar (*Rusa unicolor swinhoei*), serow (*Capricornis swinhoei*), muntjac (*Muntiacus reevesi*), pangolin (*Manis pentadactyla pentadactyla*), macaque (*Macaca cyclopis*), giant flying squirrel (*Petaurista alborufus*), and a wide variety of endemic and migratory birds.

Backdrop to the Neolithic: Taiwan's Palaeolithic Foraging Adaptations

The evolutionary backdrop or initial conditions (*sensu* Binford 2001) for the earliest East Asian agriculture are foraging adaptations. These include subsistence, settlement and land use, and social organisation (Chen and Yu 2017). Hominin occupation of the island dates back to the late and possibly Middle Pleistocene (Shikama et al. 1976; Liu 2009; Tsang et al. 2009), with the earliest evidence being a mandibular fragment of archaic *Homo*, recovered from the Penghu Trench off the west coast (Chang et al. 2015). The island was periodically connected to the mainland during glacial maxima, but for c. 10,000 years Taiwan has been separated from China by a strait. Anatomically modern *H. sapiens* likely immigrated to Taiwan on foot during times of lowered sea levels, or potentially by boat.

Foraging cultures of the Taiwanese Palaeolithic are termed Changbinian, and archaeological evidence dates to c. 20,000–6,000 B.P. (Figure 1) (Sung 1969, 1980; Tsang et al. 2009, 2011; Lien 2015). The site of Baxiandong is a multi-cave complex located on rugged terrain along what is now the east coast. During glacial maxima, the caves were likely a short walk from the ocean. The lithic assemblage of the lower levels includes unifacially flaked choppers and cobble flake tools in the lower levels (c. 20,000–25,000 B.P., Tsang et al. 2009; 2011), made of pebbles sourced from nearby beaches (Tsang 2013) and knapped on site based on refit data (Lien 2015). Upper levels (c. 15,000–19,000 B.P.) are characterised by smaller flake tools of higher quality raw materials, such as chalcedony (Tsang et al. 2011). Bone needles, hooks, and other tools indicative of hunting and fishing are also present in later occupations (Tsang et al. 2009, 2011; Lien 2015). Hearths have been found at Baxiandong, but thus far no implements or features associated with

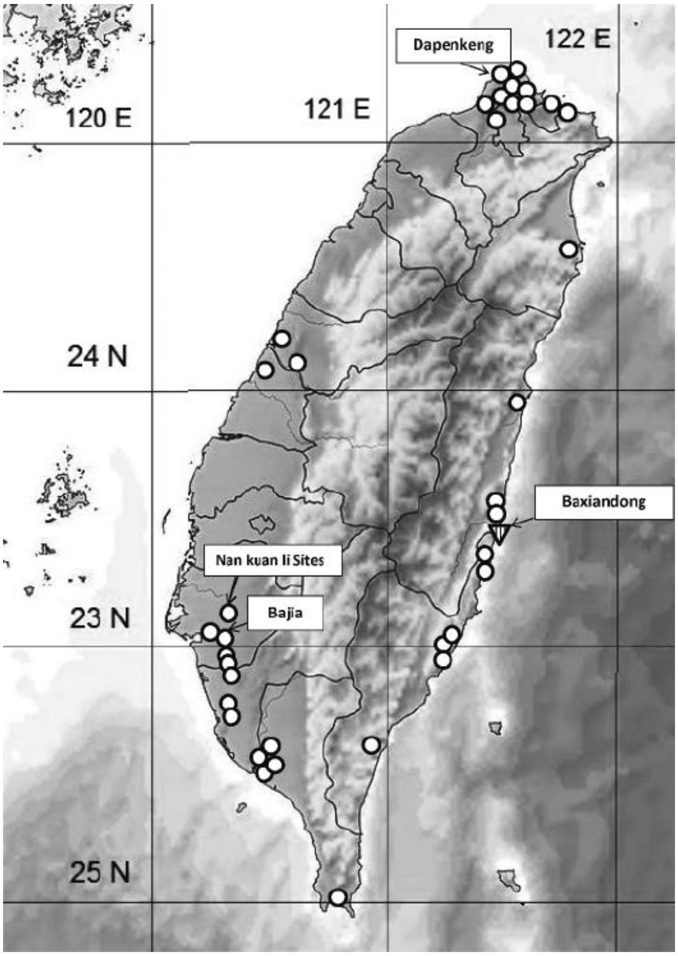

Figure 1 Major Palaeolithic and Neolithic sites of Taiwan (Illustrated by P. Yu)

plant processing (e.g., grinding, pounding, leaching, or baking) have been found.

The Changbin culture evolved into regional foraging variants that persisted from about 15,000 to 5,000 B.P. as evidenced by chipped stone lithic technologies that have been identified in the north near Taipei (Sung 1980; Liu et al. 2004), in the central-western region near Miaoli and Taichung (Liu 1989; Liu et al. 2007), in the southwest near Tainan (Sung 1980), on the southern 'beak' at O-luan-pi, Xiaoma, and Longkeng (Li 1985), and in the southeast near Pingtung (Li et al. 1983; Huang et al. 1987) and Taitung (Huang and Chen 1990). The time period of 6,500−5,000 B.P. is well-represented at the southern sites. The Wangxing Culture terminates at c. 6,000 B.P. and is described as a northwest Palaeolithic adaptation (Liu et al. 2007; Liu 2011). These sites are termed 'pre-ceramic' or 'Persistent Upper Palaeolithic' due to the retention of Palaeolithic technological systems and a lack of ceramics into the Holocene (Chen, W. C. 2017). Faunal and floral preservation are not robust at Palaeolithic sites (Chen, W. C. 2017).

In sum, the early Palaeolithic cultural sites of Taiwan are represented by core/flake pebble technological systems, with affinities with the Palaeolithic cultures of the Ryuku Islands and the Philippines (Tsang 2013). After the Pleistocene to Holocene transition, Persistent Upper Palaeolithic cultures went through a technological shift to smaller lithics of higher quality raw materials, retouching, and the presence of bone tools, as well as emergent regional variations. Palaeolithic foraging was a successful adaptation that persisted for thousands of years after the Neolithic had become established on the mainland, and archaeological evidence suggests that Taiwanese foraging remained focused on coastal aquatic resources, with some hunting and plant gathering in the uplands. It is noteworthy that Taiwan's Palaeolithic cultures were evolutionarily dynamic and locally adapted, reflecting diverse habitats and social organisation.

Low-Level Food Production in Southeast China

Across the strait in coastal southeast China, agriculture was being practised by c. 8000 BP. A diverse diet included a suite of wild food plants, in addition to rice and millet. The transitional Neolithic site of Shangshan contains the remains of non-domesticated plant foods throughout the sequence from c. 8800 to 6600 cal. BC (Zhao 1998; Zhejiang 2007; Wu et al. 2012). At the early Neolithic Kuahuqiao culture site (6200−5000 cal BC), macrobotanical remains include water chestnut, gorgon fruit (*Euryale* spp.), walnut, pinecone, and jujube (*Zizyphus* spp.) (Zhejiang 2004; Jiang 2013). Starch grain analysis from Kuahuqiao pottery vessels recovered eight genera of non-domesticated plants (Yang and Jiang 2010). Notably, pits filled with acorns (*Quercus* spp.), as well as leaching equipment, have been found at Kuahuqiao, and as late as Middle Neolithic levels of the Hemudu site (Zhejiang 2003), suggestive of continued intensification of wild tree nuts. At the Xincun site (c. 5300−4400 BP; Yang et al. 2012), sago palm and tuber starches suggest arboriculture and vegeculture. Even as late as the middle Neolithic, wild and semi-domesticated plants persisted alongside fully domesticated crops in Southeast China (Liu et al. 2011; Jiao 2013, 2016). The prolonged Neolithic transition of Southeast China included coastally adapted hunter-gatherers who used ceramics, lived in semi-sedentary villages, and created cemeteries as late as 3000 BP (Zhang and Hung 2012; Hung and Carson 2014; Jiao 2016). Thus, the co-existence of mixed foraging-fishing-gardening economies and coastally-adapted hunter-gatherers in Southeast China are directly relevant to Taiwan's Neolithic transition.

THE NEOLITHIC TRANSITION IN TAIWAN

Evidence for Taiwan's first agriculture appears between 6000 and 4500 BP, apparently resulting from interactions between the Palaeolithic Taiwanese hunter-gatherers and immigrant farmers from the Chinese mainland (Chang 1969, 1989; Bellwood 1997; Tsang 2005; Liu 2009, 2011; Hung and Carson 2014). There are two major regional variants of the Early Neolithic in Taiwan: the Dapenkeng Culture in the northwest and the Bajia Culture in the south (Chen, W. C., 2017). Neolithic cultural markers include distinctive coarse cord-marked pottery, polished stone adzes (some with shoulder steps), harvesting knives, drilled slate projectile points (Figure 2), perforated disks, and baked clay spindle whorls (Chang 1989) that show affinities with contemporary cultures of Southeast China. Other material culture traits include thick-walled sand-tempered pottery with cord impressions, stone adzes that are quadrangular in cross-section and usually polished, pecked pebbles that likely served as net sinkers, and bark-cloth beaters (Pearson 1968; Chang 1969, 1989; Huang 1974; Tsang 1992; Li 2013). The common presence of bark beaters and adzes suggest the importance of cordage and wood in the technological repertoire, although organic materials are rarely preserved. In fact, the relative paucity of stone tools and limited date range may indicate the technological use of bamboo and other organic materials that are not preserved (Chang 1989). Sites were often positioned on coastal and stream terraces and at river mouths.

Hung and Carson (2014) describe a total of 40 sites with Dapenkeng-type ceramics (although only 17 are securely dated [Li 2013: 617]). The presence of early Neolithic sites on the southern, northern, and eastern coasts, as well as surrounding islands such as the Pescadores, suggests that ceramic-using cultures dispersed rapidly around the island. Hung and Carson note that alluvial plains accumulated mostly after 3000 BC, especially along the western coastline (2014: 1125). Therefore, early Neolithic sites are most likely under-represented, as swampy nearshore environments became in-filled with alluvium.

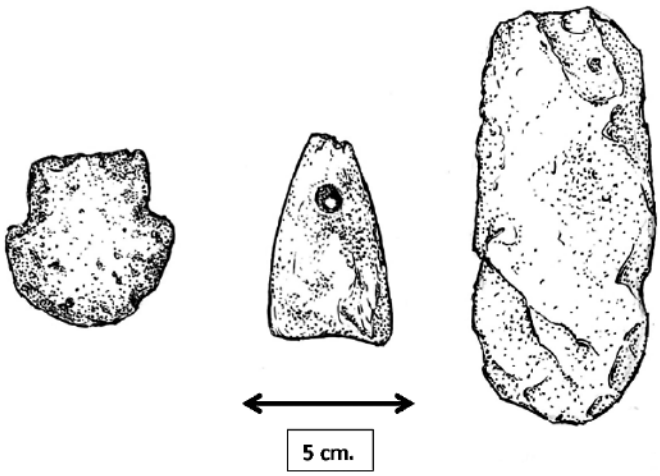

Figure 2 Artefacts from the Dapenkeng Type Site. a=shouldered adze, b=perforated/drilled point; c=chipped stone adze. (Illustrated by Pei-Lin Yu. Artefacts photographed courtesy of National Taiwan University’s Museum of Anthropology.)

Recent excavations at the sites of Nan-kuan-li and Nan-kuan-li East have revealed large-scale Dapenkeng culture occupations dating to between 5,000 and 4,300 B.P. (Tsang et al. 2006; Li 2013; Tsang and Li 2018. These sites yielded toolkits and faunal remains suggestive of a coastally adapted subsistence, including hunting, fishing, farming, and collecting, with fishing and shellfish predominating (Li 2013). This is similar to later Dapenkeng assemblages in other locations dating to c. 3000 BC (Hung and Carson 2014: 1122). At Nan-kuan-li, seeds of the nigaki shrub (*Picrasma quassioides*) and hackberry tree (*Celtis sinensis*) (Li 2013: 618) signal use of the fruits for food, similar to Donghulin and other transitional Neolithic sites on the Southeast Chinese mainland (Liu et al. 2010; Chen and Yu 2017). Carbonised rice and millet at Nan-kuan-li indicate that Dapenkeng people were already engaged in cereal agriculture, with millet appearing earliest in the sequence and rice somewhat later (Li 2013).

There is evidence for a complex adaptive history of Taiwanese rice. Seed morphology suggests that a local landrace of rice may have been domesticated *in situ* at Nan-kuan-li (Li 2013: 619), whereas rice from the west coast appears to originate in the Yangtze river basin, and yet a third strain has been identified in the east coast by c. 4,800 B.P. using phyolith morphology (Wu et al. 2016). Foxtail millet (*Setaria* spp.) found in early Neolithic sites more likely arrived from China. It is not yet clear why Nan-kuan-li people were cultivating seed crops that require two very different methods: wet versus dry fields, maintenance, and harvest techniques (Li 2013: 20). The hunting-fishing-gathering-farming lifeway supported sizeable communities, including designated cemeteries (Li 2013). By around 4500 BP, fully agricultural Neolithic cultures had spread to most of the island, continuing the Palaeolithic trends of local adaptation and regionalisation (Bellwood 1997; Liu 2009; Li 2013; Chen, W. C. 2017).

Data Gaps, Questions, and Expectations

Details about the transition from a diverse foraging adaptation to committed agriculture in Taiwan are still being explored. The low number of chronologically secure sites during the time of interest is due to alluvial in-filling and a series of marine transgressions in the early Holocene (Chang 1989; Liu 2009; Lin et al. 2012; Hung and Carson 2014). However, some interesting patterns are emerging from the growing sample of transitional period sites (Chen, W. C. 2017: 289):

1. Late Palaeolithic subsistence was diverse, relatively stable, regionally differentiated, and gradually intensifying using high-quality technological systems; and
2. Dapenkeng-era subsistence, which combined foraging subsistence alongside seed crops, dispersed rapidly and continued the process of regionalisation.

This gives rise to some important questions.

1a. How did Taiwan's diverse ecosystems influence the Neolithic transition?

1b. What was the role of the pre-existing social organisation, subsistence, and mobility of Taiwan's hunting and gathering societies? Of immigrating Chinese farmer-gardeners?
1c. Were crops adopted as a package, or incrementally, and why?

Most researchers agree that Taiwan's Neolithic cultures are not directly descended from the Palaeolithic (Li 2013: 614) due to dramatic differences in the archaeological evidence of subsistence, settlement, and material culture. However, we may surmise that the transition was likely a blend of immigration, displacement, knowledge transfer, and exchanges. As mentioned above, it is highly likely that Chinese Neolithic farmers at c. 6000 BP practised low-level agriculture, retained some foraging knowledge, and had long-standing relationships with hunter-gatherer neighbours.

This study proceeds from the assumption that Taiwan's latest Palaeolithic hunter-gatherers directly encountered Chinese Neolithic immigrants, and some level of information exchange about cultivation took place. In cases where knowledge was transferred directly from farmers, agro-ecological knowledge and practices would have been observable by hunter-gatherers who could determine whether including crops was worthwhile. In places where information transfer was mediated by distance and time, and transfer was indirect and peer-to-peer between hunter-gatherers, cultivation knowledge was likely filtered and incomplete. The importance of individual decision-making, and socio-environmental opportunities and constraints, would likely have been higher in mediated settings.

THEORETICAL BACKGROUND, DATA, AND METHODS

The objective of this paper is to use behavioural ecology and information from an environmental and ethnographic frame of reference to develop working expectations about the nature of pre-existing Upper Palaeolithic hunting and gathering, and its influence on the tempo (timing and pace) and mode (variability) of Neolithic crop adoption. Three areas of reference knowledge are used: human behavioural ecology (HBE) concept models, ethno-archaeological information about traditional Taiwanese crops and cultivation practices, and data and projections from the Binford Environmental and Ethnographic Database of Hunter-Gatherers.

Theoretical Background: HBE Concepts

HBE seeks to explain evolutionary phenomena that result from the accumulation of factors that influence individual decision-making. HBE models of foraging behaviour, largely derived from economics, use four main concepts: a goal, currencies, opportunities, and constraints (Gremillion and Piperno 2009; Kelly 2014). HBE models are germane to agro-ecological transitions as the consequence of many cumulative decisions made by foraging individuals or groups, to optimise benefits and minimise costs (goals) in response to (or in anticipation of) environmental and societal factors (opportunities and constraints). HBE generally defines currencies as energetic (such as kilocalories) or reproductive success (completed family size and number of lineal descendants). Because these kinds of currencies are nearly impossible to measure for ancient societies and individuals, HBE models are used here to derive working expectations for environmental opportunities and constraints.

Neolithic Subsistence Transitions

HBE models for foraging-to-farming transitions combine plant ecology and micro-economic principles (Winterhalder and Kennett 2006; Gremillion and Piperno 2009; Pearsall 2009; Miller 2018) to frame decision-making within a template of 'complex mechanisms of individual and social learning that have been shaped by millennia of natural selection to yield a highly flexible system of phenotypic adjustment to varying environmental conditions' (Gremillion and Piperno 2009: 615). Four models are considered here: diet breadth, opportunity cost, future discounting, and marginal value.

The *diet breadth model* predicts that as highly ranked resources become scarce, search costs eventually overwhelm the economic advantages of being selective. Gremillion and Piperno employ diet breadth to predict the manipulation of low-ranked plants, which eventually became domesticated seed crops in fully developed agricultural economies (Gremillion and Piperno 2009: 616). This is pertinent to intensification (*sensu* Binford 2001), in which hunter-gatherers increase food yields per unit area by adding lower-ranked food plants. Winterhalder and Goland (1997) have noted that crop species, which may initially be perceived as low-ranked foods from a hunter-gatherer's point of view, might attain new importance under conditions of wild food scarcity.

Opportunity cost describes the cost of a chosen action relative to the value of the next-best possible action. In the case of foraging, opportunity costs are incurred when strategies are changed to include new resources. This may include diet breadth expansion, as well as a more comprehensive change to cultivate domesticated plants. The opportunity costs of cultivation to a hunter-gatherer (as stated by hunter-gatherers themselves) include the loss of mobility needed to access preferred wild foods, raw materials, and social connections and information (Yu 1997; Binford 2001; Kelly 2014). Benefits of cultivation would need to outweigh these opportunity costs before adoption becomes a viable, alternative means of subsistence.

A related model, *future discounting,* predicts that the benefits of short-term (but smaller) yields may outweigh higher yields that are delayed. Compared to foraged resources, the spatio-temporal scale of agricultural production increases the time between the initial investment and availability of yields (Winterhalder and Kennett 2009; Bowles 2011). Bowles's comparison of 'productivity' between foraging and farming queries long-standing assumptions about superior agricultural yields: they might not be a sufficient incentive for a heavy investment of labour and a long wait for returns (Bowles 2011: 4760). This is emphasised by other factors such as lower productivity of early domesticates, costs of storage and pilfering, and the perceived costs of waiting (Bowles 2011).

The *marginal value theorem* describes an individual foraging optimally in a system where food resources are located in widely separated patches. In the interests of minimising search costs, a hunter-gatherer may choose to harvest from a central place rather than search extensively, with a focus on estimating round-trip search times (Zeanah 2017: 11). In this case, increasingly dispersed wild resources could eventually incur higher search costs than crops located centrally.

Diet breadth, opportunity costs, future discounting, and the marginal value theorem all seek to predict optimisation behaviours for a hunter-gatherer weighing costs, benefits, and trade-offs for an array of options. Wild resources involve lower labour needs and lower risk, and offer short-term rewards, which might outweigh hypothetical harvests that are weeks or months in the future. Given that crops—and associated costs and benefits—are varied, we might expect hunter-gatherers to evaluate crop types individually. For example, most cereals occupy the high end of the foraging cost spectrum: they require significant labour to sow, fertilise, water, weed, deter pests and predators, harvest, and store, and the risk of crop failure is relatively high (Marshall 2001; Bowles 2011; Greaves and Kramer 2014; Yu 2015). In sub-tropical habitats, water-adapted seed crops such as rice have an edge on dryland crops such as millet.

Vegeculture crops, by contrast, were domesticated from tropical or sub-tropical progenitors (Mitsuru 2002), and can be propagated easily by planting cuttings. Tubers and tree crops are adapted to local soil and water conditions, often contain pest-resistant phytochemicals, may be harvested and eaten year-round, come in large package sizes, and are self-storing (Mitsuru 2002; Pollock 2002; Wilson and Dufour 2002; Greaves and Kramer 2014). On the low end of the spectrum, edible weeds that grow in or near fields have received less scholarly attention, but can provide a consistent dietary contribution (Turner et al. 2012). These species, usually exotic or naturalised hitch-hikers, readily colonise disturbed areas and offer low (but near-immediate) nutritional yields, with nearly zero processing costs (Marshall 2001; Lo and Hu 2014; personal observation in Donghe, Taiwan).

Overall, wild plants, edible weeds, vegeculture crops, and seed crops would have comprised a spectrum of opportunities for the discerning hunter-gatherer-gardener (Table 1). Early crop adopters could hedge against risk by maintaining a broad spectrum of diverse plant foods, a practice that maintained local diversity, reduced travel and processing costs (also see Marshall 2001 and Turner et al. 2012), and provided opportunities for continued foraging. The proportion of high-cost seed crops could increase with sedentism and a growing labour force. Thus, HBE models agree with the archaeological record in indicating the first part of a working hypothesis: that *selective forces during the Neolithic transition of Taiwan actively favoured mixed economies that varied in tempo and mode according to properties of crop species and local habitats.*

Table 1 Taiwan Neolithic plant food types organised by costs and returns

Costs of crop type =>	Seed crop	Cultivation/ Search costs	Processing costs	Harvest seasonality	Time to returns	Risk	Productivity (relative wts)
		High	High	Seasonal	Delayed	High	Variable/ high
	Low-level crops (vegeculture/ arboriculture)	Moderate	Moderate	Most of the year	After first planting, continual	Low	Moderate
	Edible weeds	Low	Low	Year-round	Immediate	Low	Low

The evolutionary implications of knowledge exchange or transfer are less well-studied than for subsistence, but principles from hunter-gatherer studies and economics are relevant. *The Missing Market model* seeks to understand the characteristics of an existing market, exchange network, or household that either draws the household into this market or precludes gainful participation (Demps and Winterhalder 2019: 60). *Central Place Marketing* assesses the benefits and costs to a foraging group faced with the decision to initiate and engage in an exchange of knowledge and/or goods (Demps and Winterhalder 2019).

Both concept models expect that the benefits must outweigh the costs for a foraging household to participate in exchanges or transfers, including those in which the item of exchange is information. Barriers to be overcome between Chinese Neolithic farmers and Taiwanese hunter-gatherers likely included language differences, fear of strangers or the inability to predict behaviours, and mutually valued items or knowledge for engaging in exchanges. Demps and Winterhalder predicted that certain conditions would reduce these barriers and incentivise exchanges (2019: 49):

(1) the differentiation of households by production advantages (environmentally determined);
(2) pre-existing social mechanisms that minimise transaction costs;
(3) family size, gender role differentiation, or seasonal restrictions on household production, lessening opportunity costs to participate in exchanges;
(4) low travel and transportation costs; and
(5) the existence of commodities/currency.

Household production type and quantity were certainly differentiated between hunter-gatherers and farmers, and the persistence of foraging in Southeast China suggests that immigrating farmers already had experience interacting with hunter-gatherer neighbours. Opportunity costs and travel and transportation costs would be lower in areas where groups could easily interact, most likely zones first colonised by farmers. In the early phases of the Neolithic transition, commodities or currency likely did not exist. However, local ecological knowledge of hunter-gatherers was likely valuable to newly arrived farmers. This allows for an addition to the working hypothesis for Taiwan's Neolithic transition: *In areas where costs and barriers to exchange were low, information exchange was likely more frequent and the risks of crop adoption lower. In addition, demographic pressure and competition from arriving farmers may have reduced the viability of wild resources.*

If we accept the expectation that crops were incorporated initially through the expansion of hunter-gatherers' diet breadth, and then in greater numbers as the ratio of costs to benefits (relative to wild resources) changed, a threshold was ultimately reached where the commitment to agriculture required the abandonment of most foraging. The rate of this process is expected to vary according to habitat, which influences pre-existing societal conditions and information exchanges. Certain habitats were likely viewed favourably by immigrating farmers, such as flat, well-watered locales near river confluences. It is reasonable to expect that the adoption of cultivation was more rapid where the transfer of crops and agro-ecological knowledge went directly from farmers to hunter-gatherers, and where population densities were increasing. Adoption would have been more gradual in habitats that did not favour cultivation, such as mountainous areas and remote coastlines. In these zones, wild resources would have maintained their importance (Li 2013; Hung and Carson 2014).

The working hypothesis can be revised as follows:

Taiwanese hunter-gatherers adapted to the introduction of cultigens and agro-ecological knowledge in at least two modes (Table 2) that were conditioned by habitat characteristics and the directness of exposure to immigrating farmers.

> Mode 1: Direct. The influence of future discounting, opportunity costs, and marginal value to hunter-gatherers was less important where the flow of information and cultigens from farmers was direct, rapid, and continuous, and pressure on wild resources and the land base increased as farmers settled and expanded. Crops would likely be adopted in a package as barriers to knowledge exchanges between groups were reduced. This mode is expected in areas that favour cultivation, such as flat, well-drained locales near river confluences and terraces, along the western and southern coastal plains, and hilly flanks.
>
> Mode 2: Indirect. Incentives to maintain foraging lifestyles such as future discounting, opportunity costs, and marginal value were more important where wild resources were abundant, exposure to cultivation knowledge was indirect, gradual, and sporadic, and pressure on wild resources and the land base was not strong. Crops would be adopted sequentially in ascending order of cost and risk as part of diet breadth expansion. This mode is expected in rugged mountainous terrain, lake basins, and/or the southeast coast.

Table 2 Preliminary hypothesis for Taiwan's Neolithic transition

Transition	Mode 1	Mode 2
Habitat type	Flat river confluences and terraces, western and southern coastal plains, and hilly flanks	Mountainous centre, lake basins, southeast coast
Binford's foraging projections	Lower mobility, lower dependence on fishing, lower population density, smaller periodic aggregations	Higher mobility, higher dependence on fishing, higher population density, larger periodic aggregations
Rate of immigration	Farmers rapidly occupy and settle	Farmers gradually occupy and settle
Interchanges between hunter-gatherers and farmers	Direct and continued inter-group contact, few barriers to exchanges	Delayed, sporadic inter-group contact, multiple barriers to exchanges
Immigrant population pressure	Farmers contribute to rapid increase in population density	Farmers not part of pop. density
Wild resources availability	Decreasing	Stable
Incentives for hunter-gatherers to adopt crops	Cost: benefit of crop adoption = high	Cost: benefit of crop adoption = low
Crop adoption	Crops adopted as a package	Crops adopted in rank order of cost and risk/diet breadth

Methods: Ethno-Archaeological and Environmental Reference Data

Ethno-archaeological methods were used to elicit qualitative information regarding the decision-making process for crop selection. In 2017, I conducted a series of semi-structured interviews with Amis tribal elders in the community of Fafokod (Donghe, in Mandarin) to learn about cultivation methods used in kitchen gardens and traditional fields. The interviews totalled approximately ten hours. In some cases, family members and friends offered useful information, which was appended to the data set. Women and men were represented, with participants between the ages of 60 and 74 years. The interviews were conducted in Chinese, Hoklo (the Taiwanese dialect), and Japanese, then translated into English by my father Dr. J. S. Yu, aged 81 at the time of data collection.

The interviews were semi-structured. Questions included participants' perceived level of effort for the cultivation and harvest of different traditional crop types; the involvement of children in these activities; and the estimated frequency of consumption of weedy adjuncts and their use during times of food scarcity. Unanticipated but informative responses included the topics of human health and nutrition value, landscape and community health, cultural identity, and the roles and influence of local and national markets. The interviews were coded for key words and phrases.

Cultivation strategies described in the interviews by Amis farmer-gardeners included:

- Vegeculture/arboriculture (taro, yam, sweet potato, coconut, and other tree

crops)
- Cereal agriculture (Taiwanese *chenopodium*, dry and wet rice, millet)
- Opportunistic encouragement of wild plants (e.g., ferns and fungi) and adventitious commensal species of edible weeds that are actively encouraged at field and garden margins.

In the interviews, the Amis elders agreed that cereal crops are quite high in cultivation costs. They require sophisticated field preparation, sowing, fertilising, pest control, and irrigation methods as well as thinning, weeding, harvest, and storage. Children are rarely allowed to assist. In contrast, tubers and tree crops, as well as weedy commensals and the occasional wild edible, are much lower in labour costs. Tubers can be planted vegetatively, require little maintenance, are better adapted to local soil and water conditions, are self-storing underground, and have evolved phytochemical defences against pests. Cultivation methods are straightforward, and children often assist with sowing, maintenance, and harvest. Newer crop types (onions, cabbage, maize, pumpkin, daikon, and others) were mentioned, but are not included in the analysis as they are not associated with the Neolithic transition.

An interesting historical observation concerns World War II and the subsequent hardships of the White Terror martial law period. During times of hardship, tribal farmers reported that families largely abandoned rice and millet due to the conscription of men, labour shortages, and government requisitioning of entire rice crops. To feed their families, many farmers 'downshifted' to vegeculture, arboriculture, and commensal edible weeds. Some Amis elders recalled that they did not taste their first rice until their teenage years. My father, who interpreted during the interviews, fled as a child with his family to the mountains during the war. The family farm was left behind, and my father recalled foraging for sweet potatoes and taro in burning fields after American bombing runs, as well as picking weeds and wild plants in abandoned mountain homesteads.

Overall, the ethno-archaeological interview data suggest that Neolithic crop types are diverse in costs and returns. Therefore, Palaeolithic hunter-gatherers would have been thinking strategically about adoption. In some cases, low-cost tubers and tree crops with smaller yields would have been favoured over high-cost cereals with higher but delayed yields. K.C. Chang (1969) predicted that tuber cultivation preceded cereal cultivation in the earliest Neolithic in a broad sense. Although rice and millet do appear very early in the west (Li 2013; Tsang and Li 2018), the possibility of 'vegeculture first' in other areas of Taiwan remains open.

Frames of Environmental and Ethnographic Reference from the Binford Hunter-Gatherer Database

To refine working expectations for Taiwan's Neolithic transition, this paper develops an informed estimate of wild resource type and distribution and expected foraging modes for Taiwan. Lewis R. Binford's database of hunting and gathering peoples (Binford 2001; Binford and Johnson 2014) is grounded in environmental data for climate, topography, soils, and primary (plant) and secondary (animal) biomass from individual weather stations around the globe. Johnson (in press) demonstrated that habitat data could be used to project hunter-gatherer subsistence, social organisation, and demography where foraging societies are longer exist, based on regressions of variables of climate data and living hunter-gatherer societies (for details on calculations, visit http://ajohnson.sites.truman.edu/data-and-program/). The Binford database has been used to calculate projections for foraging behaviours based on a global sample of 339 ethnographically documented hunting and gathering societies, and is geo-referenced to meet climatic and environmental parameters.

The Binford projections for expected foraging subsistence, mobility, and social organisation were generated for Taiwan using data from 27 weather stations (Figure 3). Some figures include weather stations from neighbouring regions of Southeast China and the Philippines for comparative purposes.

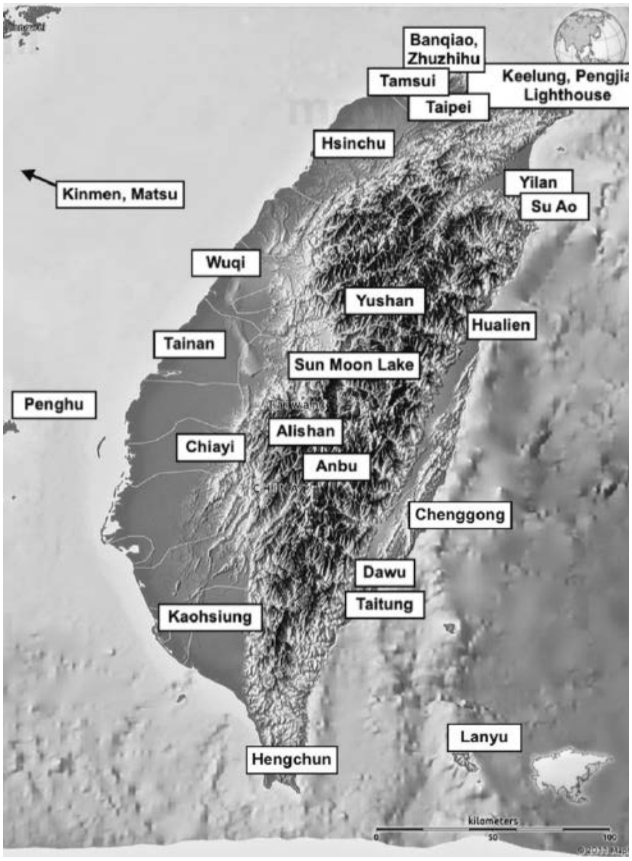

Figure 3 Taiwan weather stations used to derive Binford's environmental and ethnographic projections. (Illustrated by P. Yu)

Although the climate of early-late Holocene Taiwan was periodically warmer than today (Li et al. 2017) and seasonal wind patterns likely differed, the island's physiography probably had a similar influence on relative temperature and humidity: mountain habitats are cooler and more rugged, the western plains and valleys were somewhat protected from oceanic typhoons, and the southern tip of the island was warmer. Hence, the weather station data are used here to generate reasonable expectations for hypothesis-building (rather than to assert accurate past climate and environmental conditions).

The Binford database will be used to make projections for three areas of information (Table 3).

Table 3 Binford's variables used in this study

Area of inquiry	What is measured	Binford variable
1. **Key environmental characteristics.** Estimates the structure and availability of terrestrial foods (Southeast China, Taiwan, Philippines).	Projected primary biomass (plant matter accumulation rate)	NAGP ($gm/m^2/yr$)
	Projected ungulate biomass	EXPREY (kg/km^2)
2. **Expected foraging lifeways.** Subsistence emphasis is an ordinal measure of the predominant subsistence mode. The subsistence diversity index estimates the evenness or skewness of foraging around one mode. Projected number of camp moves/year estimates mobility for groups foraging in a point-to-point manner (the 'residential foraging' pattern, sensu Binford 1980). (All three regions; also Taiwan only)	Expected subsistence focus	SUBSPE (for packed >9.1 persons/km^2; for unpacked <9.1 persons/km^2). Hunting; gathering; or aquatic resources/fishing
	Expected diversity of subsistence	SUBDIV (Simpson's [1949] Diversity Index **(D= Σ[n/N]2),** where D = diversity index and n/N = Binford's expected percentage of packed dependence on hunting, gathering, and fishing (SUBSPE).
	Number of moves per year by residentially foraging groups	EXNOMOV1 (Expected number of moves/year, residential foraging pattern)
3. **Expected population structure and aggregations**. Projected population density estimates foraging pressure upon wild food resources and eventual need to intensify productivity per unit area and/or widen diet breadth. Size of periodic aggregations estimates peaceful seasonal interactiveness of hunter-gatherer groups (Taiwan only).	Projected population density	WDEN (N persons/100 km^2)
	Periodic (annual/multi-annual) aggregations	GROUP3 (estimated mean size of periodic aggregations, in N persons)

These variables will refine expectations for the influences of the environment and social organisation on Taiwan foraging type, diversity, and stability. Simple quantitative comparisons and visual analyses of the clustering of variables (charted in scatterplots) are used.

RESULTS

The first Binford projection assesses terrestrial ecosystem characteristics relevant to foraging: plant and ungulate biomass. Ungulate biomass, which estimates prey abundance, tends to be highest within a range of plant productivity: between 1,000 and 2,000 gm/m[2] added annually. This indicates a zone of grassy annuals and shrubs suitable for ungulates.

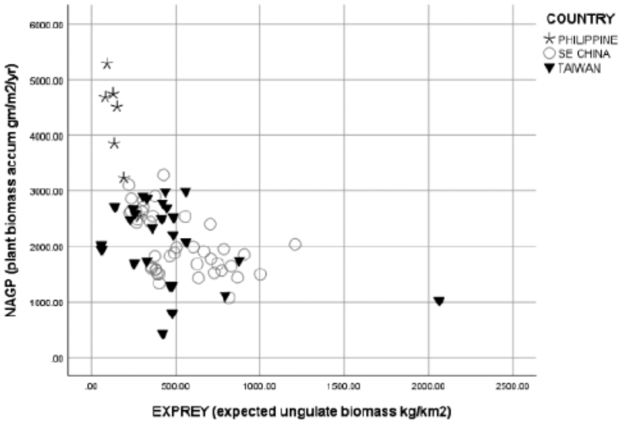

Figure 4 Net above ground productivity (gm/m[2] of plant matter added each year) and expected prey (kg/km[2] of expected ungulate biomass), evaluated by region. (Illustrated by P. Yu)

Across all three regions, there is a loosely negative relationship between plant biomass accumulation and ungulates (Figure 4), suggesting that sub-tropical forests are not optimal for grazers. In the Philippines, a cluster indicates high plant

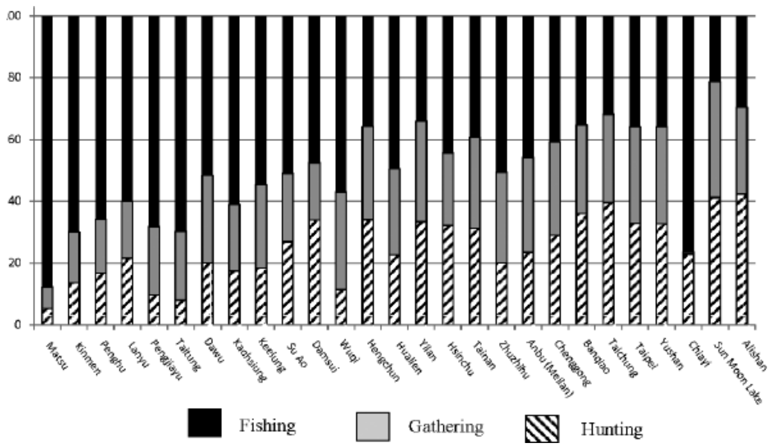

Figure 5 Binford's estimated % contribution to foraging subsistence, by distance to the coast (Taiwan only). (Illustrated by P. Yu)

productivity and low ungulate biomass, whereas Southeast China and Taiwan overlap into two loose clusters, implying environmental and resource similarities. Chinese Neolithic immigrants were already experienced in augmenting crops with wild foods. Hence, major adaptations were probably not needed for initial colonisation.

The estimated distribution of foraging subsistence types for Taiwan shows a high reliance on fishing (never less than 20%) that depends mostly on the distance to the coast (excepting Chiayi, which may indicate high productivity of the Bazhang River; Figure 5). Terrestrial plant gathering only reaches maximum values of about 35%, which likely reflects the relative scarcity of endemic food plants in Taiwan (Wu et al. 2004; Chauchin Lin, personal communication 2017). Thus, as the distance to the coast increases, hunting (rather than gathering) contributes more to subsistence.

With regard to hunting, Taiwan's only high ungulate biomass station is Alishan, a major mountain peak. This chart shows that Taiwan has relatively low ungulate biomass compared to the mainland, although not as low as the Philippines. However, historical records exhibit relatively high productivity of Sika deer in Taiwan's mountainous foothills, which served as a major component of indigenous diets and also provided large quantities of hides for trade with the mainland from the 1600s to the 1800s. Taiwan's other ungulate species, such as serow and muntjac, favour forested areas; the larger sambar lives in mountainous habitats, including meadows and upland drainages. Further, major Taiwan indigenous prey species, such the Formosan boar, along with numerous arboreal species, are not grazers and hence not counted by the Binford database. Therefore, Taiwanese prey abundance during the Neolithic transition was almost certainly higher than that suggested by the Binford projections.

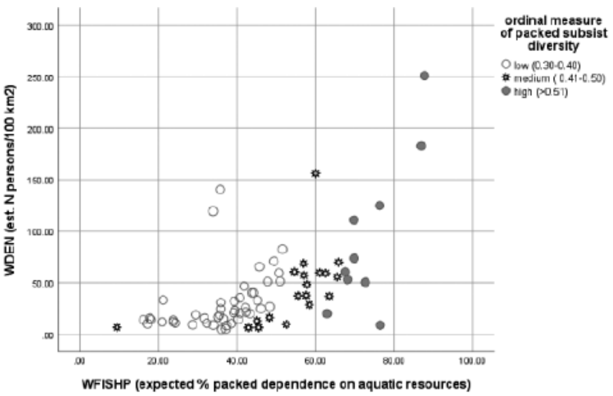

Figure 6 Projected packed population density in persons/100 km^2 (residential foraging pattern) and percentage of dependence on fishing by packed foraging population, by ordinal measure of subsistence diversity (all three regions). (Illustrated by P. Yu)

The expected percentage of packed fishing and estimated population density in persons/100 km^2 were calculated using foraging data from similar environments globally. For evenness or a diversity measure among the foraging subsistence modes of hunting, gathering, and fishing, Simpson's Diversity Index (1949) is used. The calculation is ($D= \Sigma[n/N]^2$), where D = diversity index and n/N = Binford's expected percentage of dependence on hunting, gathering, and fishing.)

Figure 6 shows a strong, positive relationship between dependence on fishing and other aquatic foods and estimated population density across Taiwan, Southeast China, and the Philippines. As fishing dependence increases, so does projected subsistence diversity and populations. This suggests that foraging diet breadth is expanded by adding aquatic resources, which allows for population density growth. Growing populations can improve catch ratios through technological means and cooperative labour, both in terms of nearshore (e.g., nets, traps, and other facilities) and offshore fisheries (e.g., boats, nets, harpoons, floats). The only non-Taiwan station in this group is the Xisha weather station on the Southeast China coast.

In Binford's 2001 analysis of 339 global cases of hunting and gathering peoples, 9.098 persons/100 km^2 marks a packing threshold in which human neighbours begin to constrain access to resources. Under these conditions, HBE models expect diet breadth expansion as lower ranked resources are accepted into the diet, and Binford predicts foraging intensification strategies to increase yields per unit area. If Figure 6 is followed to the highest possible fishing percentages, Taiwan's population density tops out at about 200 persons/100 km^2, an intriguing possibility for the carrying capacity of aquatic resources and possible threshold for the adoption of high-cost cultigens. The upper limit of c. 200 persons/100 km^2, projected as the maximum amount supportable by Taiwan's aquatic resources, exceeds Binford's packing threshold by a factor of nearly 20. Given that Binford's

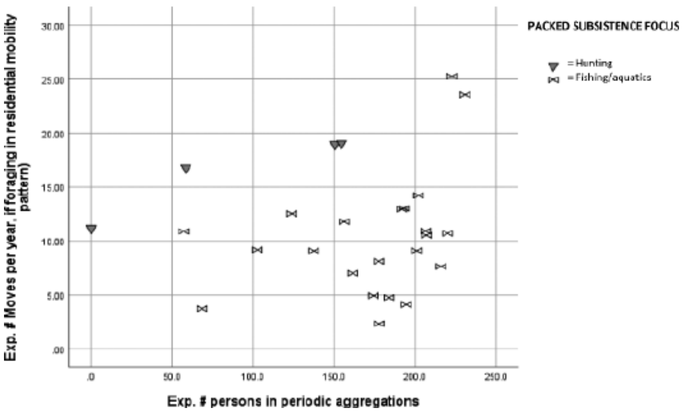

Figure 7 Expected number of foraging camp moves per year (presuming a residential foraging mobility pattern) and expected number of persons in seasonal aggregation, evaluated by foraging subsistence focus. Taiwan cases only. (Illustrated by P. Yu)

projections for packing were originally estimated for groups primarily dependent on gathering (Johnson, in press and personal communication), the packing threshold for coastally focused hunter-gatherers is shown as much higher. Archaeological evidence for the persistence of foraging well into the Neolithic (Chen, W. C. 2017) suggests that aquatic resources were able to support a stable and diverse Palaeolithic lifeway. Overall, areas with access to coasts, river deltas, and lake basins are predicted to have high hunter-gatherer aquatic specialisation and dense populations.

The relationship between mobility and periodic aggregations (for activities like exchanges, ritual purposes, or labour pooling) is used as a proxy for opportunities for peer-to-peer exchanges of knowledge and material items. Figure 7 indicates a predictable relationship for those who rely on hunting in Taiwan's mountain settings, and a looser relationship for aquatic-focused groups. As the annual foraging distance for each group becomes greater, the size of periodic aggregations increases somewhat. Interestingly, the most mobile fishing groups are projected with the largest periodic aggregations. These cases are located on the eastern side of the island along rugged coastlines with close access to the mountain foothills of the Coastal Range and associated drainages. Mountain hunters are projected as having a higher number of moves overall and somewhat smaller aggregations.

Figure 7 suggests that peer-to-peer crop adoption among fishing-dependent groups of the east coast could have been facilitated by periodic aggregations. This contrasts with the direct farmer-to-forager mode of transfer suggested by the Missing Markets exchange model, which predicts success based on inter-group and inter-household differences, as well as direct and frequent contact with farmers. It is reasonable to expect that the transfer of crops and cultivation knowledge was incremental in the peer-to-peer mode compared to the direct contact mode.

DISCUSSION

The results from the Binford Hunter-Gatherer database offer expectations regarding characteristics of the habitat and foraging lifeway of late Middle Holocene Taiwan.

1. The availability of mammalian prey in Taiwan is probably underestimated by the Binford ungulate biomass projection. This is due to the importance of boars (non-grazers) and arboreal and burrowing mammalian prey. The scarcity of endemic plant foods would have created the conditions for low (but consistent) use of food plants.
2. Taiwan's Palaeolithic hunting and gathering included a sizeable aquatic component, and foraging diet breadth and subsistence diversity are increased by including aquatic resources.
3. Specialised aquatic hunter-gatherers are projected as having the highest population densities. The Binford model projects c. 200 persons/100 km^2, suggestive of a productive subsistence base. This would impose a high threshold

and delayed timing for diet breadth expansion and incentives to experiment with new foods such as cultigens, even taking into account opportunity costs, future discounting, and marginal value. This situation pertains especially to the east coast.

4. However, hunter-gatherers-fishers of Taiwan's southeast coast (and potentially lake basins) are projected as more mobile and likely to aggregate periodically in large numbers. Once the transition was initiated, large seasonal aggregations may have facilitated knowledge transfer.
5. In the mountainous centre, hunting predominated, and aggregations were somewhat smaller.

Similarities with the plant and animal biomass and ecosystems of Southeast China imply that Neolithic immigrants to Taiwan would have been on relatively familiar ground. By combining crops with local wild species, farmers could adapt and disperse quickly. Evidence for the earliest Neolithic subsistence and settlement of Taiwan offers an opportunity to predict preferred habitat types that influenced modes of dispersal, interactions, and crop adoption.

In sites distributed around the island, the subsistence niche during the transitional Neolithic was broadly based, with faunal remains indicative of fishing and shellfish collection predominating (Hung and Carson 2014; Tsang and Li 2018; Kuo 2019). Terrestrial prey were diverse, including deer, rats, mustelids, reptiles, and small cats (Tsang and Li 2018; Kuo 2019). Although differences in the preservational environment could allow for better species identification in Neolithic depositional contexts, the evidence signals that the Neolithic non-crop diet included plenty of aquatic species, diverse terrestrial genera, and smaller body-size prey compared to the Palaeolithic.

Taiwan's first farmers cultivated two major crops using diverse techniques, dryland (millet) and wet paddy (rice), which suggests influences from the northern and eastern regions of mainland China (Sagart et al. 2018; Tsang and Li 2018). Other crops, such as geophytes and tree crops, were also likely grown. During the Early Neolithic, sizeable communities, burial grounds, and irrigation features, along with distinctive vessel shapes and tapa bark beaters and genetic affinities of millet and rice, point to ongoing influences and interchanges with the cultures of what are now the Fujian coast and the Guangdong/Pearl River delta regions in Southeast China (Chen, W. C. 2017; Kuo 2019; Tsang and Li 2018).

If farmer-fishers' preferred habitats were cultivable flatlands with easy access to aquatic resources, a rank order can be estimated. High-ranked habitats were coastal plains, valleys, and hilly flanks adjacent to coasts, lakes, and wetlands. These regions are in the northwest, west, and southern areas of the island. Piedmont, forested uplands, and the east coast would have been occupied after preferred habitats became infilled. The last habitats to be used consistently by early farmers were high mountainous regions that are sub-alpine today, and were likely forested during the warmer mid-Holocene, as well as small mountainous islets (Yu

2020).

Using information concerning the subsistence and preferred habitats of both hunter-gatherers and small-scale farmers, the two modes of Taiwanese Neolithicisation that were described in the working hypothesis can be revised, as follows (Figure 8):

Direct Mode of Crop Adoption

The direct mode is expected in habitat zones that favour cultivation and were attractive to immigrant farmers. These include flat, well-drained areas near river confluences and terraces, northern lake basins, the western and southern coastal plains, coastal valleys, and hilly flanks. Dependence on fishing, foraging population densities, annual foraging distance, and the size of periodic aggregations are projected as being lower in these habitat types.

The influence of future discounting, opportunity costs, and marginal value was

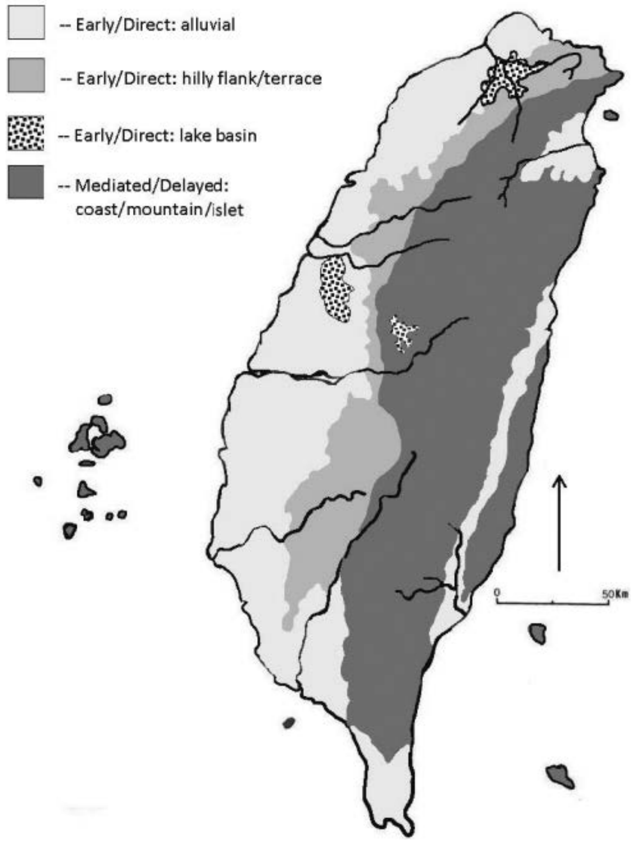

Figure 8 Predicted geographic areas and modes for Neolithic crop adoption in Taiwan. (Illustrated by P. Yu)

less important to hunter-gatherers where the flow of information and cultigens was directly from farmers to hunter-gatherers, and pressure on wild resources and the land base increased with the dispersal of farmer settlements. Crops would likely be adopted relatively rapidly, as well as in tandem.

Indirect: Mediated and Delayed Modes

The mediated mode of crop adoption is expected along the southeast coast. This zone is projected as having more dependence on fishing, higher foraging population densities, longer annual foraging distances, and larger periodic aggregations. Hence, aggregations are expected to be the major means of dispersal of cultivation materials and knowledge.

The delayed mode of crop adoption is expected in the steep mountainous centre of the island. This area shows very little archaeological evidence for a Palaeolithic presence. Binford projections for the mountains indicate more dependence on hunting, low foraging population densities, longer annual foraging distances, and smaller periodic aggregations. The dispersal of cultivation materials and knowledge among groups who hunted in the mountains was delayed relative to the plains and coasts.

It is expected that foraging considerations such as future discounting,

Table 4 Working hypothesis for Taiwan's Neolithic transition

Transition theme	Direct mode	Mediated mode	Delayed mode
1. Habitat type	River confluences and terraces, lake basins, alluvial plains, and hilly flanks	Southeast coast	Rugged mountainous centre
2. Rate of immigration	Farmers rapidly occupy and settle	Farmers gradually occupy and settle	Farmers settle late
3. Exchanges between hunter-gatherers and farmers	Direct and continued inter-group contact, few barriers to exchanges	Indirect contact with farmers; geographic barriers, peer-to-peer forager transfer of crops/knowledge	No contact with farmers; major geographic barriers, peer-to-peer forager transfer of crops/knowledge
4. Immigrant population pressure	Farmers contribute to rapid increase in population density	Delay in farmer contribution to population density	Long delay in farmer contributions to population density
5. Wild resources availability during the Neolithic	Decreasing; terrestrially oriented	Stable and intensifying with aquatics	Stable, hunting-oriented
6. Incentives for hunter-gatherers to adopt crops	Cost: benefit of crop adoption = high	Cost: benefit of crop adoption = low at first	Cost: benefit of crop adoption = low for long-term
7. Crop adoption	Both low and high cost types adopted rapidly	Crops adopted in rank order of cost and risk (likely vegeculture/arboriculture first)	Crops adopted in rank order of cost and risk (likely vegeculture/arboriculture first)

opportunity costs, and marginal value were more important where wild resources were abundant, exposure to cultivation knowledge was peer-to-peer between hunter-gatherers, and immigration pressure on wild resources and the land base was weak. Along the southeast coast and in the mountainous centre, crops would have been adopted sequentially by hunter-gatherers as a part of diet breadth expansion in ascending order of cost and risk. In these cases, arboriculture and vegeculture, with their lower labour costs, should be early adoptions, with intensive cultivation of seed crops adopted later (Table 4).

Preliminary Expectations for Archaeology

Evidence for subsistence, settlement, and technology are expected to vary along a continuum of farming, mixed strategies, and foraging according to the mode of Neolithic transition. The apparently rapid pace of Neolithicisation, and the low number of securely dated sites from the Neolithic transition period, present challenges to evaluating the utility of these expectations. However, the growing number of site discoveries may offer opportunities in the near future. The three proposed transition modes implicate certain lines of evidence (Table 5).

Table 5 Archaeological implications for modes of Neolithic transition of Taiwan

Evidence type	Direct mode	Indirect/mediated mode	Indirect/delayed mode
Settlement	-early sedentarised village settlements on alluvial plains -sizeable cemeteries	-focus on coastal and flat near-shore environments including rock shelters -repeated occupations	small, ephemeral occupations in high mountains, repeated use of valleys
Artefacts and features	-ceramics prevalent -Adzes and other woodworking tools -architectural remains -polished stone	-ceramics infrequent -fish spears, net sinkers, chopping tools, chipped stone -little architecture	-ceramics rare -chopping tools, chipped stone -more projectile weaponry
Floral/faunal	-early taro, yams, tree crops, rice/millet, domesticated chenopodium -continued moderate use of fish, shellfish -early appearance of pigs, chickens	-early appearance of taro, yams, tree crops -continued dependence on fish, shellfish -delayed rice, millet, chenopodium, pigs, chickens	-delayed appearance of taro, yams, tree crops -strong, potentially seasonal dependence on terrestrial game -long delays for rice, millet, chenopodium, pigs, chickens

CONCLUSIONS AND FUTURE RESEARCH

These results and current archaeological evidence suggest that selective forces during the Neolithic transition of Taiwan favoured mixed economies that varied according to the properties of the local habitat, social and subsistence organisation of hunter-gatherer groups, and the degree and timing of exposure to immigrating farmers. The coastal plains of the west and the lacustrine basins of the north were ideal zones for initial colonisation by Neolithic Southeast Chinese farmers.

Familiar plant and animal species would have facilitated rapid adaptation and expansion into new territories. Neolithic farmers likely maintained some degree of foraging and had a long history of experience with full-time hunter-gatherers as neighbours. In these zones, farmer-to-hunter-gatherer encounters and knowledge transfer was likely direct and continuous, facilitating the rapid adoption of cultivation. Land pressure and resource competition from immigrants would decrease the costs of crop adoption from the hunter-gatherers' perspective.

The tightly packed yet mobile fisher-hunter-gatherers of Taiwan's eastern coast were at the opposite end of the adoption spectrum. Habitat complexity increased foraging subsistence diversity, and proximity to the coast facilitated high dependence on fishing and dense yet mobile populations. In the mountainous interior, hunting is likely to have predominated, and mobility was high. In both zones, the transfer of crops and cultivation knowledge was likely delayed and mediated by distance. The influence of future discounting, opportunity costs, and marginal value to hunter-gatherers probably delayed the adoption of cultivation practices, especially in the mountains.

Taiwan's early Neolithic farmers practised intensive and diverse cultivation, yet their reliance on wild foods continued. In areas where aquatic foods could be procured, hunter-gatherers and farmers alike maintained diet breadth, offset opportunity costs of cultivation, eased incentives for future discounting, and maintained marginal value. The regional differentiation already underway during Taiwan's Latest Palaeolithic continued into the early Neolithic. This implies that immigrating Chinese farmers did not over-print or displace Taiwan's hunting and gathering societies. Rather, the immigrants likely blended in and assimilated with regionally diverse Taiwanese foraging groups during the dispersal process, and exchanged information with these groups about cultivation, local habitats, and resources.

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