Quantifying Historical Rice Patterns

An evaluation and development of the current HYDE total rice agricultural area maps for the Southeast Asian region.

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Word count: 5471

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1. Introduction

The environmental impacts of how humans have utilised and modified the land over time are still yet to be completely quantified. What has currently already been observed about historical land use change and its connection to many environmental and societal processes is associated with high levels of uncertainty. As society works towards a more sustainable period of land use, it is critical to understand how the impacts of past human intervention to biogeochemical cycles have altered the planet. Reconstructions of global land use changes over time will provide framework for policy makers to advise future decisions regarding the world's limited resources. Increasing populations and the resulting increase in demand for food have been major drivers in global agricultural advancements and conversion of land for agriculture (FAO, 2015).

Rice is a staple crop and is the primary food source for over half of the world's population and is the most influential staple crop today (FAO, 2015). Rice was once the basis of social order in past Asian civilizations and arguably fuelled the transformation from nomadic hunter-gatherers in China to small-scale farmers (GRiSP, 2013). Rice agriculture is known to be a significant source of greenhouse gas emissions (Houghton, 2015) and its contribution to the changing global climate is yet to be quantified. The first domestication of rice is believed to have occurred in approximately 8000 BCE in the Yangtze River Valley in China (Fuller et al., 2009). Over time, rice agriculture spread throughout mainland China, reaching the northern parts of India and further south through Taiwan into today's Southeast Asian region (Silva et al., 2015). Today, approximately 31 percent of global total rice harvested is harvested in Southeast Asia alone (FAOSTAT, 2012). This region is particularly vulnerable to the effects of climate change and threatens the future stability of not only their rice production systems, but also the region's economies and food security (FAOSTAT, 2012).

The History Database of the Global Environment (HYDE) has developed global maps that display both the location and farming intensity of rice agriculture from 10000 BCE up until 2012 AD (Goldewijk, Beusen, Drecht, & de Vos, 2011). The maps have been created with information from a range of scientific sources and literature, however, a high level of uncertainty exists with these maps as it is largely based on educated guesses. This creates the need for further qualitative research into whether these current historical rice pattern maps are accurate representations of where rice agriculture actually occurred and further, how and if these maps can be improved.

2. Problem Specifics

2.1 Aim

This research project aims to collate and analyse information that will further quantify and spatially define the historical conversion of land for rice cultivation in Southeast Asia. The results of the research can then be utilised for a regional comparison with current HYDE total rice land area estimates. After a comparison has been made, the analysis will provide evidence to further verify, improve or at the very least, reduce some level of uncertainty that exists for the HYDE total rice area maps.

2.2 Societal Relevance

Improved accuracy of the HYDE rice agricultural maps will contribute to multiple integrated assessment models. These models incorporate information from a range of scientific disciplines to make projections to inform policy makers about the potential environmental changes that will occur in the future (Ackerman, DeCanio, Howarth, & Sheeran, 2009). These policies will benefit society by preventing, mitigating and adapting to likely future climatic changes. Integrated assessment models are built upon past observations, so the information from this research will contribute to advice particularly considering the effects of greenhouse gas emissions and other associated impacts with land use change.

2.3 Hypothesis and Research Questions

The background information and understanding of the importance of this research has led to several research questions being formed. These questions will provide the foundations and direction of the literature analysis.
Research Questions:

- *Do the current HYDE database maps displaying the total rice agricultural areas in Southeast Asia accurately portray popular rice expansion theories within literature?*
- *Where was rice grown in Southeast Asia at different time steps since the commencement of the Holocene?*
- *What is the difference between wild and domesticated rice?*
- *When did rice domestication occur?*
- *How can the HYDE database maps for total rice agriculture area in the Southeast Asian region be improved?*

Before answering these research questions the following hypotheses have been made:

Hypothesis 1: HYDE *does not* reflect current evidence for rice agriculture.
Hypothesis 2: HYDE *does* reflect current evidence for rice agriculture.

At the conclusion of this research data obtained will be able to accept one hypothesis and reject the other.

3. Theoretical Approach

The theoretical approach will involve extensive qualitative analysis of literature concerning primarily historical rice agriculture and land use change, but will also consider settlement movement and population changes for the Southeast Asian region. The spatial focus will begin in China, then to Taiwan, the Philippines, and into peninsular and mainland Southeast Asia to provide direction for the research. A wide range of resources will be utilised including scientific articles and archaeological evidence from historical texts. Results from the qualitative research can then be compared to current HYDE total rice area maps. From this step, the evidence can either support, reject, or remain inconclusive to the changes in total rice area the HYDE maps suggest.

4. Data: design for analysis

Qualitative data that describes the known and assumed changes in the location of rice agriculture in Southeast Asian countries at different time steps will provide the basis for data analysis. The analytical research framework that will be followed has been summarised in Figure 1. Qualitative literature review will form the major foundations for this research. The research will first begin at the oldest time steps (the origins of rice agriculture in Asia) and work chronologically to 2000 BCE, when rice agriculture is believed to be established in Southeast Asia. Information will be grouped to different time steps and countries. Then, once when a picture begins to form about the locations of rice in each country at a particular time step, comparisons to the HYDE database can be made.

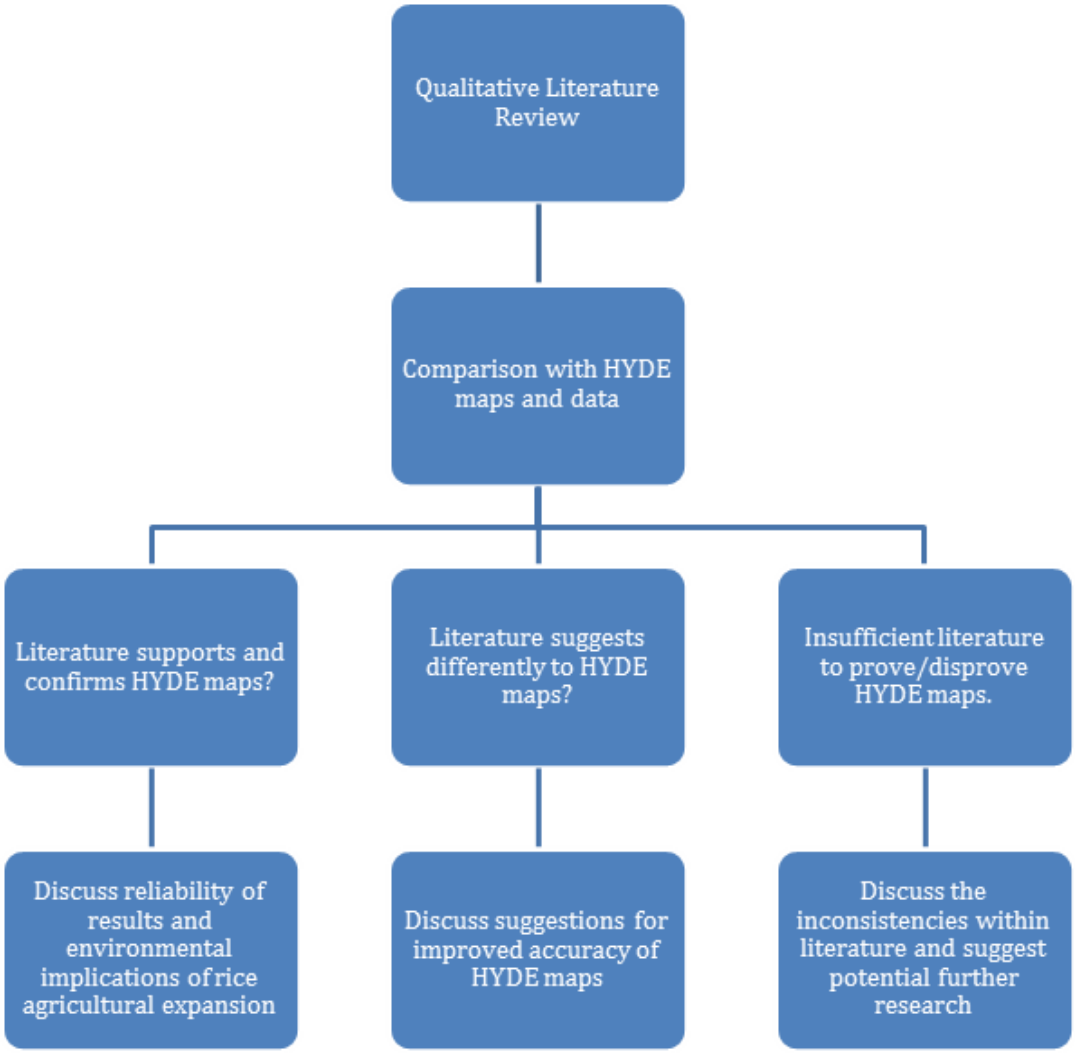

Figure 1. Analytical framework design for Quantifying Rice Patterns research project. Light blue indicates if time is available.

5. Results

Discussions regarding the advancements of Southeast Asia over the past 5000 years are dominated by the farming/language dispersal hypothesis, pioneered by Peter Bellwood (1997). This Austronesian dispersal is regarded as an archetypal example of a successional global phenomenon of history. The hypothesis suggests that the dispersal of many of the major language families of both tropical and temperate latitudes occurred as a result upon the establishment of reliable agricultural practices (Bellwood, 2005). Neolithic Austronesian farmers dispersed from mainland China through Taiwan to the Philippines and Indo-Malaysia peninsular. It is this migration of people that produces the presumption that these people were accompanied and enabled by agricultural technologies, primarily based on rice (Donohue & Denham, 2010). The following sections will follow the language/dispersal hypothesis and review literature and archaeological evidence for each area within Southeast Asia that either agrees or disagrees with Bellwood's hypothesis regarding *when* rice agriculture was established in each region.

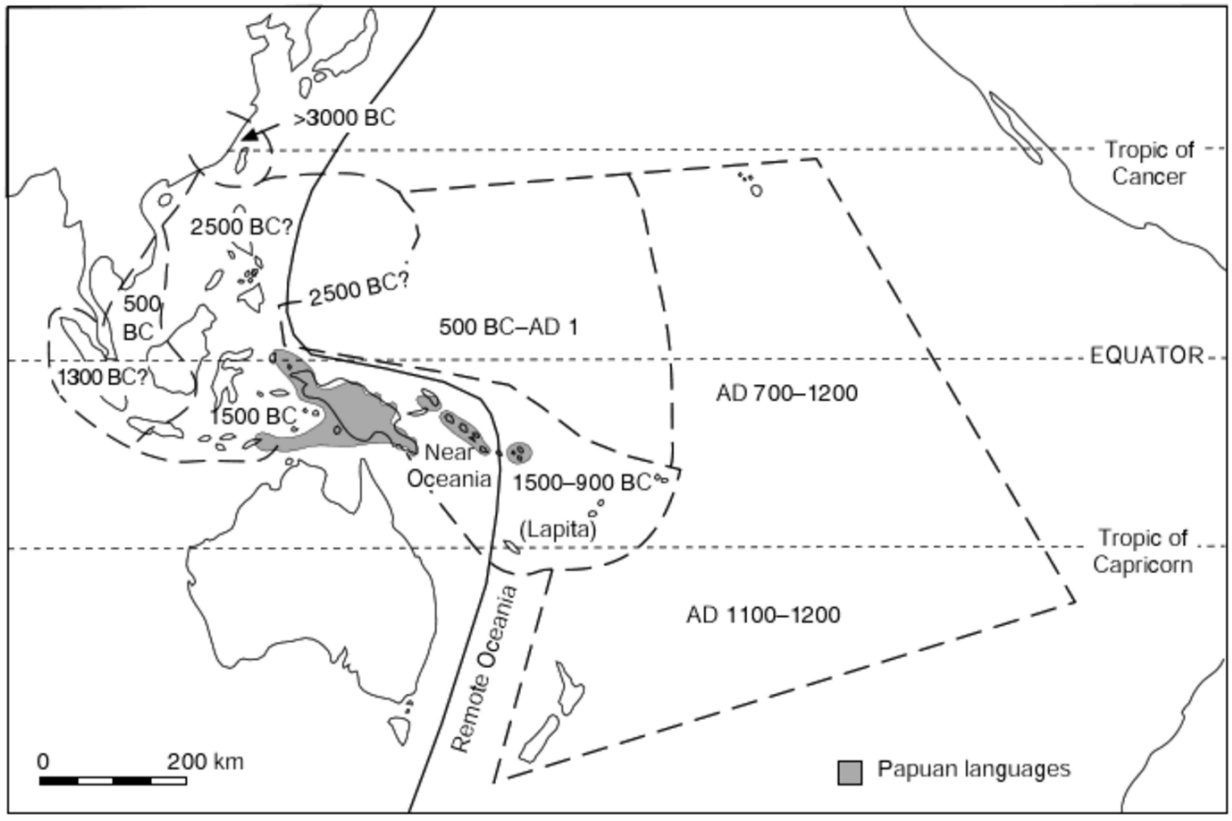

Figure 2. Peter Bellwood's model, with approximate dates, for the expansion of Austronesian-speaking farmers across South-East Asia into the Remote Pacific; the solid line marks his division between Near Oceania and Remote Oceania (Bellwood, 1997).

5.1 Origins of the domestication of rice

In addition to the evidence found for the movement of languages through Asia, the spread of domesticated rice is dependent on archaeobotanists' interpretation of whether rice residues recovered from archaeological sites belong to either wild or domestic strains (Barker, 2006). This interpretation and subsequent classification of rice residues is a significant point of debate which exists throughout archaeological

literature. For the purpose of this report, domesticated rice can be defined as "wild rice that has been changed at the genetic level, through generations of selective breeding, to accentuate traits that ultimately benefit the interests of humans" (Vaughan et al., 2008). The term domesticated rice is interpreted in literature in other ways. Some researchers prefer to give more credit to natural selection, a process outside of human control that can cause some members of a species more compatible for human cultivation (Izawa, 2008). The selective breeding and wild plant management can also be referred to as the evolutional processes that lead towards domestication (Harris, 1989).

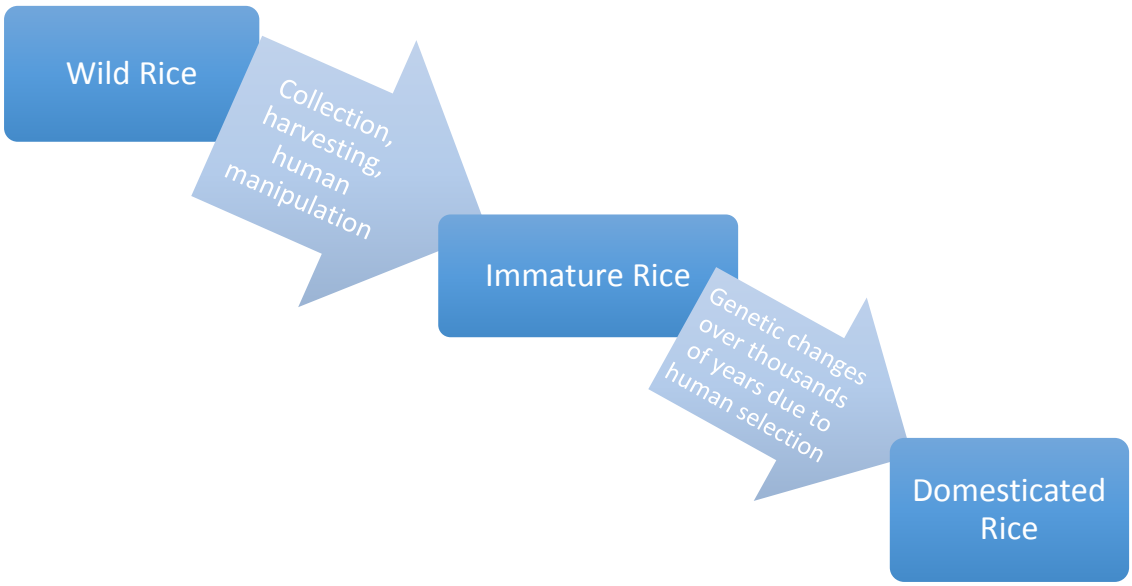

Figure 3. Simplified version of the rice domestication process (Huang et al., 2012).

5.1.1 Single origin and multiple origins theories

As modern genetics studies advance, support for either a single or multiple domestication events for Asian rice is discussed. This discussion is not only limited to rice crops, as Diamond (2002) discusses, but is debated for all forms of plant domestication.

In earlier years, some authors have argued for a single origin, in which northern Chinese millet agriculture developed secondarily based on early southern rice-farming traditions (Cohen, 1998). This hypothesis has generally been abandoned by most researchers. By contrast, Chinese archaeologists tend to emphasize the distinctiveness of regional cultural traditions and their own historical trajectories, therefore argue for multiple domestication events outside of the Yangtze Valley (Li et al., 2009). The multiple origins model indicates two centres of rice domestication, the earliest being in China ca. 6000 BCE and the other in South Asia (India) ca. 2000 BCE (Fuller, Qin & Harvey, 2007).

Londo et al. (2006) through genetic testing of rice remains proposed that rice was domesticated at least twice – the *indica* species in India, Myanmar and Thailand; and *japonica* in southern China and Vietnam.

Vaughan et al. (2008) state that a dual domestication of *indica* and *japonica* rice in different geographic regions does not align with information on rice domestication and key domestication related traits. The researchers state that all Asian rice strands come from a single domestication event. The single origin theory is also further supported by studies such as Sang & Ge (2007). Sang & Ge (2007) developed two rice domestication models, one with a single origin (named the Snowball model) and the other with multiple origins (Combination model). In the Snowball model, domestication of rice started from a small wild population and continued for a relatively long period of time. This cultivar was then *introduced* to other parts of Asia as the Neolithic period progressed.

A similar discussion that exists concurrent to the single vs. multiple origins of plant domestication debate is the early vs. late rice domestication debate. The proponents of an early domestication of rice include Liu et al. (2007). The researchers centre their argument on the fact that small grains (argued by others to be wild rice) have been found in both early and later periods in more northerly regions like the Yellow River Valley dating to ca. 3000-2500 BC. Archaeologists accept these rice remains to be agricultural and therefore argue that small rice grains found much earlier in time (discussed further in *6.1*) could also be evidence of domestication. Liu et al. (2007) also claim that for these rice remains to have reached the Yellow River region as early as 8000 BCE, human intervention to the rice species life cycle was critical.

Proponents for the late domestication of rice species dispute this and have found evidence of high quantities of certain wild foods, such as acorns, at the archaeological sites which Liu et al. (2007) believe indicate early domesticated rice. These finds indicate a predominantly hunter-gatherer-fisher lifestyle. Fuller et al. (2007; 2008) believe that only with a later (ca. 4500-4000 BCE) domestication of rice, communities gave up gathering such high quantities of nuts and would focus solely on farming rice.

5.2 Yangtze Valley

In order to adequately discuss the timeline of events that allowed the domestication of rice in Southeast Asia, we must first consider the preceding agricultural advances in China.

There appears to be a general consensus between researchers that the origins of rice agriculture began in the Lower Yangtze River valley in east china (Zhang & Wang, 1998; Barker, 2006; Bellwood, 2001; Li et al., 2009, Fuller et al., 2007). This process was established by the initial management of wild rice species (*Oryza sativa*) by hunter-gatherer inhabitants of east China. As the process of cultivating rice species developed, so too did the transition of hunter-gatherers into Neolithic farmers (Barker, 2007).

The actual timeframe for when this domestication process began in the middle-lower Yangtze River valley is not so certain. There is, however, a range of discussed timeframes in the current rice domestication debate. There have been some reported findings of rice remains that predate 6000 years old (Cohen, 2011). However, Fuller et al. (2007, 2008) believe that these finds do not exhibit a continuous tradition of

cultivation and are most probably wild, uncultivated rice remains. These are discussed further in Appendix 9.1.

A different rice domestication theory that is supported by several archaeological studies has proposed the origins of rice agriculture to be earlier than 10000 BCE (Zheng & Jiang, 2007).

Zheng et al. (2009) report on domesticated rice spikelet bases found at a site called Kuahuqiao along the Yangtze River in East China. These findings form the basis for the hypothesis that rice cultivation that led to domestication began in 6000 BCE. During the period between 6000 BCE until around 4000 BCE, systematic cultivation of rice species had become well established.

5.3 Taiwan

Taiwan experienced the earliest Austronesian colonization of the islands (Bellwood, 2007). Domesticated rice was introduced to Taiwan by people from mainland China around 4000 BCE (You, 1986). This comes from the earliest known evidence of rice remains in Taiwan that were found at the Zhishanyan site. This is further supported by Bellwood (2007) who states that he no longer supports an initial movement of Austroasiatic speaking people from mainland Southeast Asia through to Borneo. Bellwood believes that the route of Taiwan through to the Philippines is a far more likely origin/path. Tsang (2005) also claims the Neolithic people on the island of Taiwan to be fully agricultural by at least 3000 BCE through both rice and millet cultivation. Bellwood and Donohue (2005) go further and state that rice cultivation was not only present but well established on Taiwan by at least 4000 BCE.

5.4 Philippines

Both Taiwan and the Philippines were early rice economies (Bellwood, 2007). One of the most reliable and best-dated sites of early rice cultivation throughout Southeast Asia was found on Luzon, the most northern island of the Philippines. The site of Andarayan, has been excavated several times and was found to include rice grains associated with organic materials in pottery that likely date to 3700-3500 BCE (Paz, 2002).

Literature that focuses on linguistics and the movement of languages suggests the dispersal of people from Taiwan to the Philippines began ca. 4500-4000 years BCE (Bellwood, 2007). Due to the coastal nature of Luzon it is suggested that the group who stayed in this area focused on coastal foraging and fishing, dropping rice to a minor crop and explains the lack of archaeological evidence for rice (Bellwood, 2007). Rice is thought to have moved southward through the islands of the Philippines and into island Southeast Asia after 3000 BCE (Higham, 2011).

5.5 Thailand

Prehistoric evidence for rice agriculture in Thailand is limited, but some known archaeological sites are indicated in Figure 4. It is hypothesised that cultivated rice was

introduced into Thailand no earlier than 3500 BCE, but more likely after 2500 BCE (Bellwood, 2001, 2005; Higham, 1989; Higham and Lu, 1998).

When Higham began archaeological work at the site Khok Phanom Di (KPD) (as seen in Figure 4, site 9) they discovered the first occupants to have settled there around 2000 BCE. For the first two to three hundred years there was no evidence of food production at KPD as they lived a marine-orientated hunter-gathering lifestyle. Then the sea level fell and the group of people began to cultivate rice. This was concluded from rice remains found in human faeces remains, pottery and digested food from a prehistoric woman's pelvis (Higham, 2011). The sea level rose once more and due to the reappearance of brackish swamps, rice cultivation was made too difficult and the community reverted back to marine based hunting (Higham, 2011). The evidence of domesticated rice found at KPD dates back to 2000-1500 BCE and is believed to be the first evidence of domesticated rice use in Thailand (Thompson, 1996). Later evidence of domesticated rice in other areas of Thailand is often in the form of ceramics. These finds are explained further in Appendix 9.2.

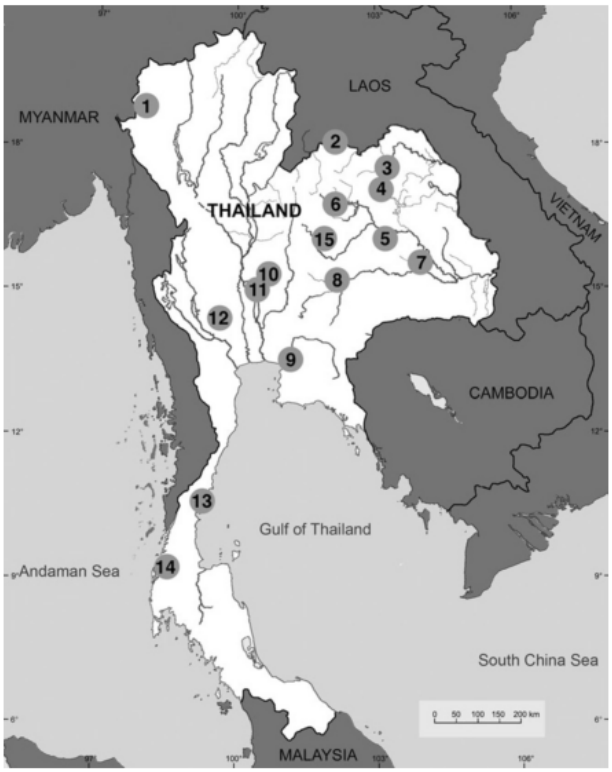

Figure 4. Map showing sites with evidence of rice. 1 Banyan Valley Cave; 2 Phu Lon; 3 Ban Chiang; 4 Nong Han Kumpha- wapi, Ban Na Di; 5 Ban Chiang Hian, Non Noi, Ban Kho Noi; 6 Non Nok Tha; 7 Non Dua, Don Taphan; 8 Ban Non Wat, Phi- mai, Noen U-Loke, Non Muang Kao, Ban Tamyae; 9 Khok Phanom Di, Nong Nor; 10 Khok Charoen; 11 Non Pa Wai, Nil Kham Haeng, Non Mak La, Lopburi, Ban Tha Kae; 12 Ban Don Ta Phet, Ban Na Khun Saen 2; 13 Khao Sam Kaeo; 14 Phukhao Thong; 15 Non Khao Wong. (Castillo, 2011).

5.6 Malaysia, Borneo & Indonesia

As previously mentioned in section 5.4, there are two archaeological sites deemed to be the best dated for rice remains, one in Northern Philippines and one at Gua Sireh, western Sarawak, Malaysia. This site was found to contain rice grain inclusions in pottery that were dated to before 4000 BCE (Paz et al., 2002). The Niah cave archaeological site, also in Sarawak, evidence for early rice cultivation was also found

that dated to around the same time (Bellwood, 1992). While this may be the case, other archaeologists argue that rice only became an important staple crop across the Southeast Asian region only after open-farming practices were established, ca. 2000-1500 BCE (Barton & Denham, 2011). Despite the early finds of rice agriculture at Gua Sireh and Niah caves, it is generally believed that domesticated rice had reached Borneo, Malaysian and Indonesian peninsula's by ca. 2000-1500 BCE and continued to spread further into the millennia. Further evidence that argues for and against this theory is discussed in Appendices 9.3.

6. Discussion

The following section of this report will use the timeline of rice agriculture discussed above to create a comparative analysis with the HYDE total rice area maps. Each time step will be evaluated for accuracy beginning with 9000 BCE to 2000 BCE.

6.1 9000 BCE

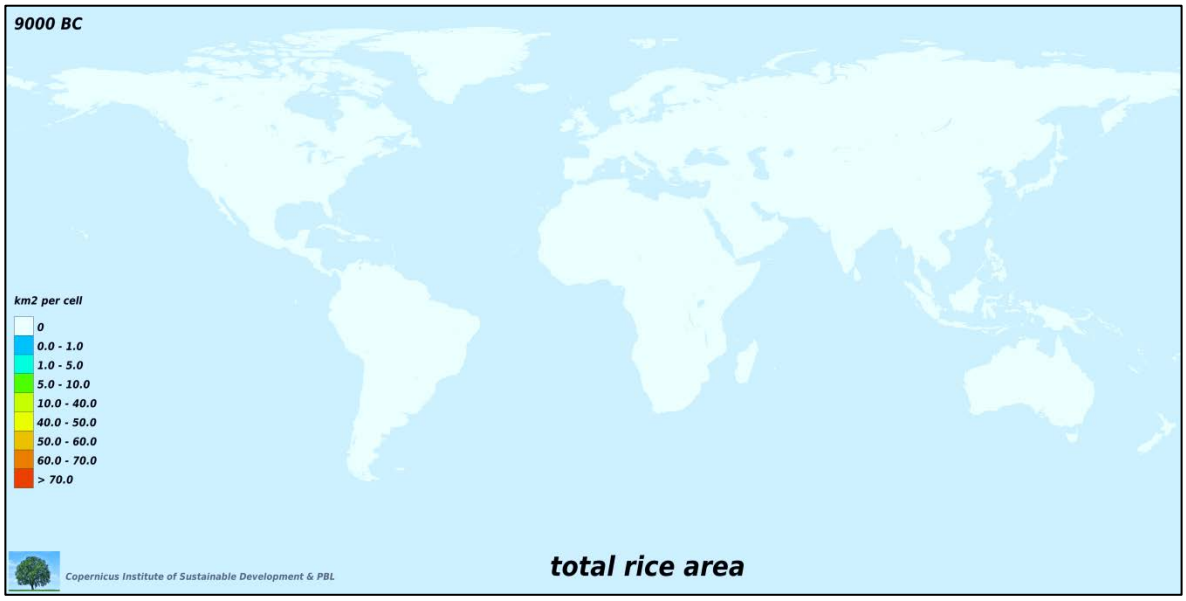

Figure 5. HYDE map displaying total rice area for 9000 BCE. The map shows a global total rice area of 0 km2 of rice area.

The earliest known cultivated rice remains excavated were found embedded in potsherds at Shangshan (Lower Yangtze Valley, no 8 in Figure 7) and date back to 11000-9000 BP (Jiang & Liu, 2006). The discussion on whether these remains represent wild or domesticated rice is heavily debated by western and eastern authors. Majority of literature supports Fuller's theory in that these remains morphologically are inconsistent with domesticated rice and therefore have been incorrectly identified by Jang & Liu (2006). At the very least, however, these remains which were found in storage pits indicate that these early communities were collecting rice and harvesting in methods which were advancing towards more typical domestication practices (Liu et al., 2007).

Liu et al. (2007) stated that archaeological evidence found at Jiahu (by Henan Jiahu in 1999) indicates habitual use of cultivated rice in the northern regions by 9000 BCE. The

rice grains found at Jiahu are very small and an increasing number of researchers are suggesting that the remains merely indicate wild rice collection and cannot be classified as domesticated rice (Crawford 2011; Fuller and Qin, 2008; Fuller, Qin and Harvey, 2008a, 2008b; Fuller et al., 2009). What makes the excavation site at Jiahu intriguing is the fact that most other cultural sites near the area share a primary focus on millet cultivation, whereas at Jiahu rice was abundant (Zhao and Zhang, 2009).

As discussed earlier, Ruddiman et al. (2008) who focused on the historic links of rice agriculture and methane trends chose to include rice agriculture as a source of anthropogenic interference with natural methane trends beginning at 10000 BCE. It should be noted then that some sources do cite and classify these rice remains as domesticated.

As this evidence does not confidently exhibit evidence of rice *domestication* during the period 11000- 9000 BP, the HYDE map (figure 5) is correct. It is most probable that the 10000 BCE time period was the true beginnings of the domestication of wild rice, a process spanning thousands of years and commencing in the Lower Yangtze valley.

6.2 8000 BCE

By the year 8000 BCE the HYDE maps display areas of rice agriculture appearing in East China (Figure 6). Cohen (2011) has produced a map displaying the location of early Neolithic communities in Eastern China which will be used for the analysis.

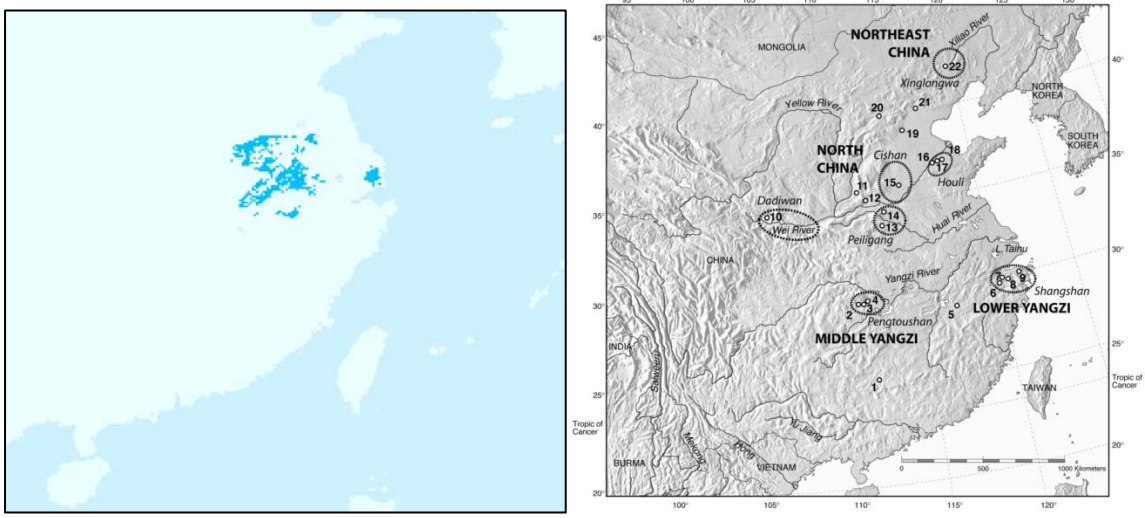

Figure 6 (Left). HYDE total rice area map for 8000 BCE, focused on East China.
Figure 7 (Right). Map of early Neolithic cultures and sites in China. 1, Yuchanyan; 2, Chengtoushan; 3, Pengtoushan; 4, Bashidang; 5, Xianrendong and Diaotonghuan; 6, Shangshan; 7, Kuahuqiao; 8, Xiaohuangshan; 9, Hemudu and Tianluoshan; 10, Dadiwan; 11, Shizitan; 12, Xiachuan; 13, Jiahu; 14, Peiligang; 15, Cishan; 16, Yuezhuang; 17, Xiaojingshan; 18, Houli; 19, Nanzhuangtou; 20, Yujiagou; 21, Zhuannian; 22, Xinglonggou. (Cohen, 2011).

Literature discussed in 5.2 regarding the timeline of rice domestication in China suggested that the very early domestication of rice had begun ca. 6000 BCE (Fuller et al., 2008). The immature rice remains that predate this period (appendix 9.1) were discovered in the Lower and Middle Yangtze River Valleys.

By looking at Figures 6 and 7, it is evident that the areas highlighted in blue on the HYDE map do not accurately represent archaeological sites at both the Lower and Middle Yangtze Valley areas. The HYDE map shows area of rice agriculture on the upper side of the Hangzhou Bay, whereas the literature, and Figure 7, depict the origins of rice at the Lower Yangtze Valley on the south side of the Hangzhou Bay. The HYDE map also displays the total rice area belonging to the early Neolithic community as situated between the Yangtze and Yellow Rivers. If it is determined that the HDYE maps consider it to be necessary to include immature rice remains, the current version of the map for 8000 BCE is indicating the incorrect area. It could be recommended to display the major rivers on the HYDE maps to assist in geographically placing total rice agriculture areas on a global scale.

It has been documented that beginning around 8000 BCE China´s climate began to cool and the monsoon total rainfall decline (Vaughan et al., 2008). This climate change would have decreased the northern limits of the natural growth area for wild rice. These changing natural distribution of wild rice would have promoted a faster rate of domestication as other food sources, such as nuts, were also in decline (Vaughan et al., 2008). This acceleration in the domestication process would continue into 7000 BCE and further.

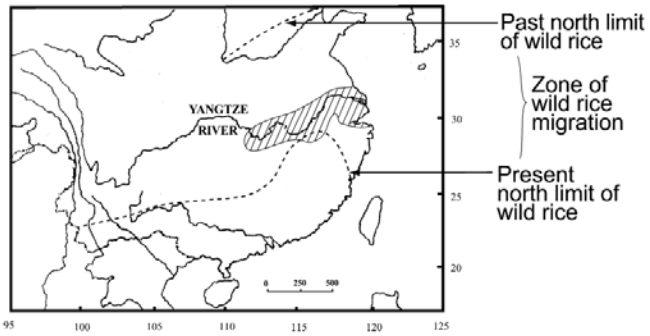

Figure 8. Changes to the northern limit of past wild rice distribution in China (Vaughan et al., 2008).

6.3 7000 BCE

By the year 7000 BCE the HYDE map (Figure 8) depicts rice agriculture as existing at inland East China, being significantly established in Papua (East Indonesia) and commencing in India.

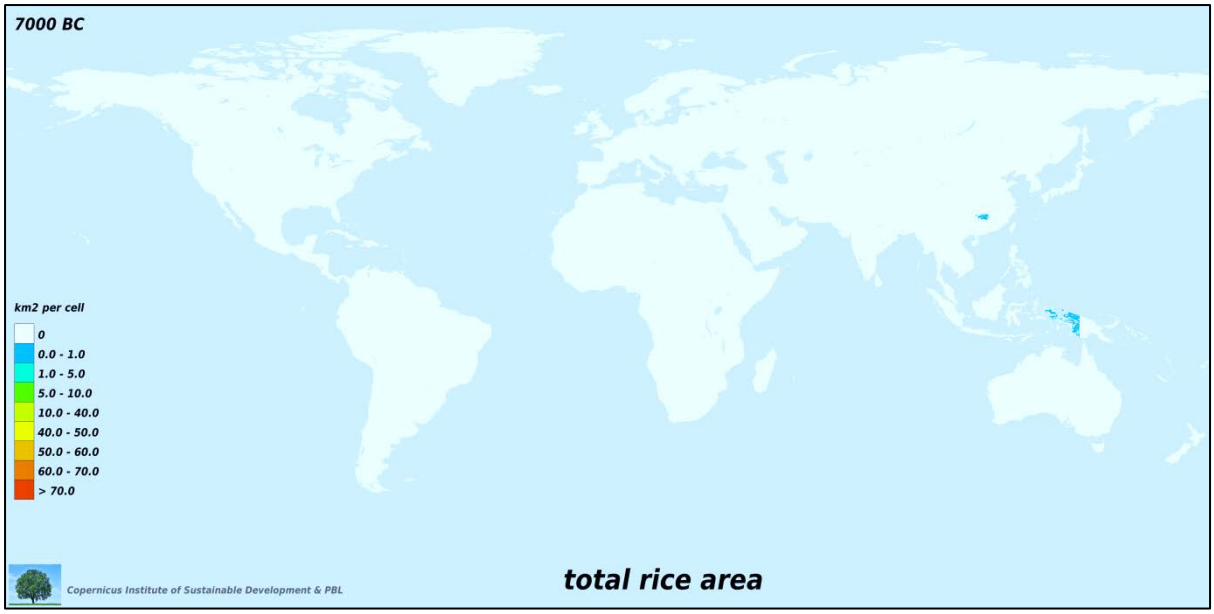

Figure 9. HYDE map displaying total rice area for 7000 BCE. The map shows areas used for rice agriculture in India, East China and Papua (East Indonesia).

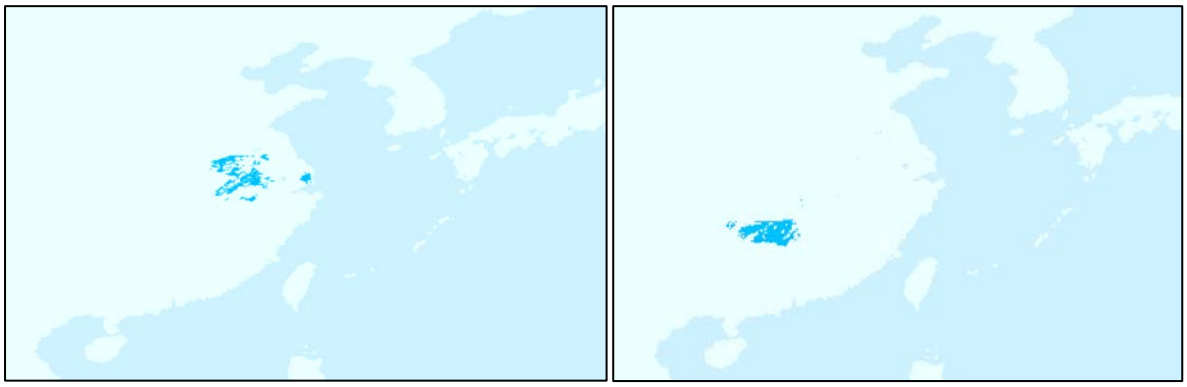

Figure 10 (Left) and Figure 11 (Right). Screenshots of the HYDE maps which display the total rice area for East China in 8000 BCE and 7000 BCE respectively.

When analysing Figures 10 and 11 the change in total rice area over the previous 1000 years becomes clear. The HYDE map suggests that during this timeframe there was a significant inland and southward movement, along the Yangtze River to the Middle Yangtze region of the entire agricultural community.

Comparing this movement to current archaeological evidence provides some differences. Fuller et al (2007) discussed archaeological rice remains that were found at the Kuahuqiao site and were dated to age between 6000 BCE and 5400 BCE. The Kuahuqiao site can be found in the Lower Yangtze Valley (as shown in Figure 7). These remains infer that rice agriculture still existed in the Lower Yangtze Valley and was not completely abandoned by the inhabitants who did not migrate outwards.

Crawford, Chen and Wang (2006) discuss the excavation of the Yuezhuang site, which is located at the mouth of the Yellow River (as shown in Figure 7) and dated to around 7900 BCE. A flotation analysis recovered 26 rice grains, which the authors believe proves the arrival of rice (*Oryza Sativa*) in the Lower Yellow River Valley.

The literature suggests that the HYDE total rice area for 7000 BCE should most probably include the region of the lower Yellow River Valley. The HYDE total rice areas should also remain at sites mentioned in sections 6.2, the lower and middle Yangtze River Valley.

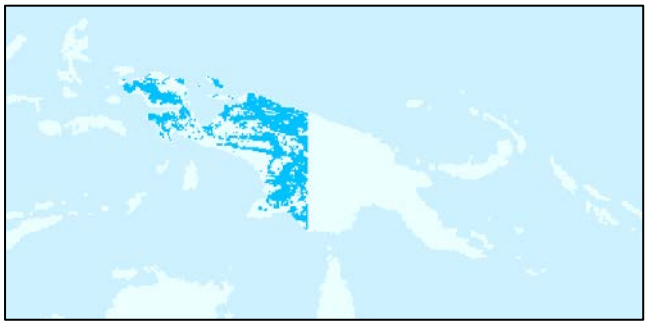

Figure 12. HYDE map displaying total rice area for 7000 BCE. The map zooms on Figure 7 for the Eastern Indonesian region.

Figure 12 focuses on the HYDE total area of the Eastern Indonesian region and suggests a well-established total rice area by 7000 BCE. Extensive literature review could not find any evidence to support this being the case. As stated in 5.6, the current literature does not support rice agriculture being present in Indonesia until 2000 BCE. Knowing this, the HYDE total rice area for East Indonesia is *not* reflective of current literature and the data input for this region should be removed to reflect the absence of evidence in literature. This applies to the succeeding HYDE maps discussed in this paper.

6.4 6000 BCE

By the year 6000 BCE the HYDE map (Figure 13) depicts slight changes to rice agriculture areas in India, East China and Papua (East Indonesia).

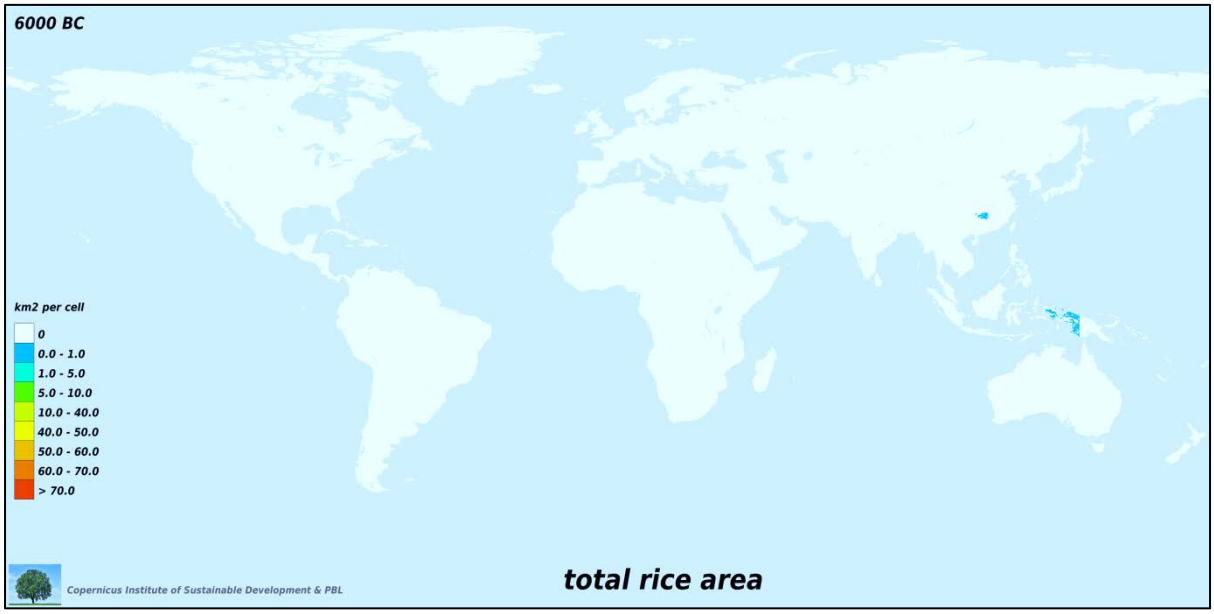

Figure 13. HYDE map displaying total rice area for 6000 BCE. The map shows area for rice agriculture (as indicated in blue) in India, East China and Papua (east Indonesia).

From 6000 BCE the process of rice domestication and cultivation practices really start to become well established (See 5.2 for further evidence). The timing of the first

planting of rice as a crop is unclear, however Fuller et al. (2007) state that it was unambiguously underway by 6500-6000 BCE. Figure 14 displays the proportions of domesticated spikelet bases found at a site in the lower Yangtze Valley at three different time periods within the 7000-6000 BCE time period (Fuller et al., 2009). As time progresses, the proportion of domesticated rice spikelet's increases, indicating the advancement of the domestication process. In addition to this, rice consumption increases a significant amount as well, with excavated rice remains increasing from 8% to 24% of total plant remains in this time period (Zheng et al., 2009).

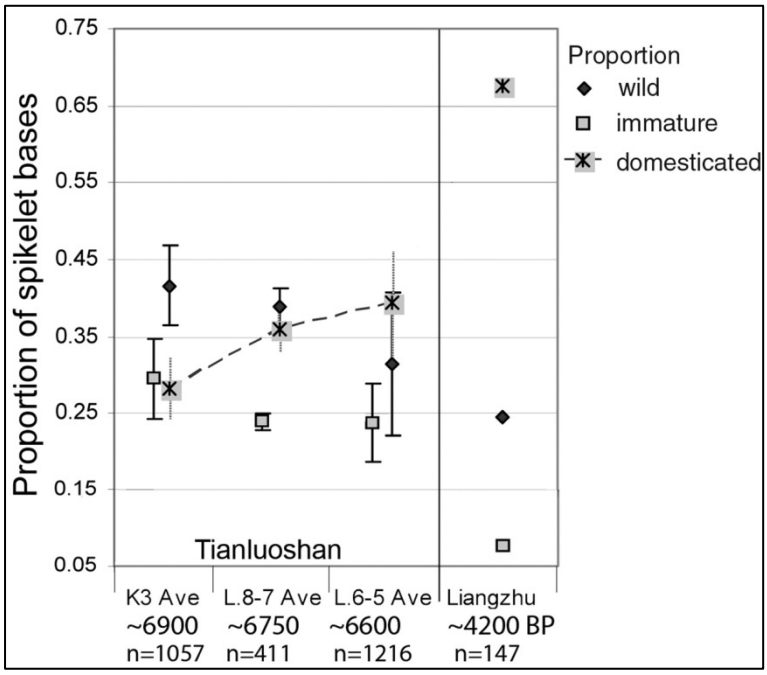

Figure 14. Proportions of wild, immature and domesticated rice spikelet bases from three sequential periods at Tianluoshan, with later Liangzhu for comparison. Means and standard deviations are calculated on the basis of all samples of 25 or more spikelet bases (Fuller et al., 2009).

The archaeological sites of Nanjiakou and Huizui (seen in Figure 15) were found to have rice remains through publications from Wei et al. (2000) and Lee et al. (2007) respectively. Liu et al (2009) suggest that these finds demonstrate the dispersal of rice agriculture into the middle Yellow River region by 6000-5500 BCE.

The Hemudu site, located on the coastal plain in the Lower Yangtze Valley (seen in Figure 15), was found to have an enormous quantity of domestic rice, that was remarkably similar to modern rice. The finds dated to late 6000 BCE and are also evidence of the advancement of rice domestication that had taken place in the last thousands of years (Bellwood, 2007).

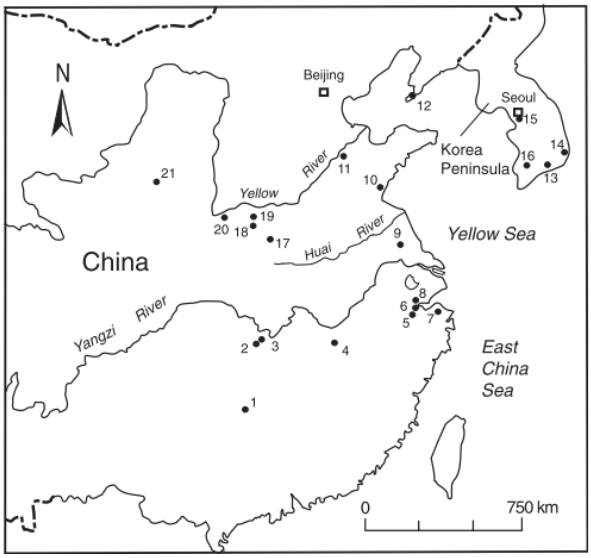

Figure 15. Location of archaeological sites: 1, Yuchanyan; 2, Pengtoushan; 3, Bashidang; 4, Xianrendong - Diaotonghuan; 5, Shangshan; 6, Kuahuqiao; 7, Hemudu; 8, Luojiajiao; 9, Longqiuzhuang; 10, Liangchengzhen; 11, Yuezhuang; 12, Dazuizi; 13, Nam R.; 14, Daundong; 15, Bojeongri; 16, Shinchangdong; 17, Jiahu; 18, Lilou; 19, Huizui; 20, Nanjiaokou; 21, Qingyang (Liu et al., 2007).

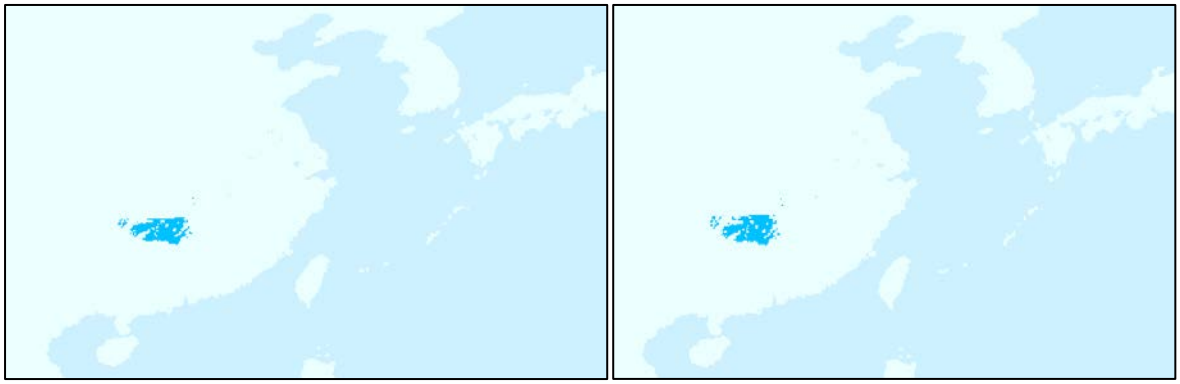

Figure 16 and Figure 17. Total rice area for the East China region during 7000 BCE and 6000 BCE respectively.

Examination of the HYDE maps for East China (as seen in Figures 15 and 16) indicate the changes in total rice area between 7000 BCE and 6000 BCE. According to the literature discussed above and in 5.2, this timeframe should see rice agriculture intensifying. Over the 1000 year period the HYDE maps display a slight expansion of the existing (7000 BCE) total rice area situated on the middle Yangtze River Valley. Like the issue with HYDE maps for 7000 BCE, the 6000 BCE map does not indicate the lower Yangtze River Valley or any parts of the Yellow River Valley as areas of rice agriculture, despite archaeological evidence saying otherwise. As the rice species reaches domestication it could be assumed that these existing rice agricultural areas would expand too and the HYDE map should reflect this.

6.5 5000 BCE

During the millennia prior to 5000 BCE, the HYDE maps propose substantial expansion of rice agriculture occurred out of China and into the Southeast Asian region (seen in Figure 19).

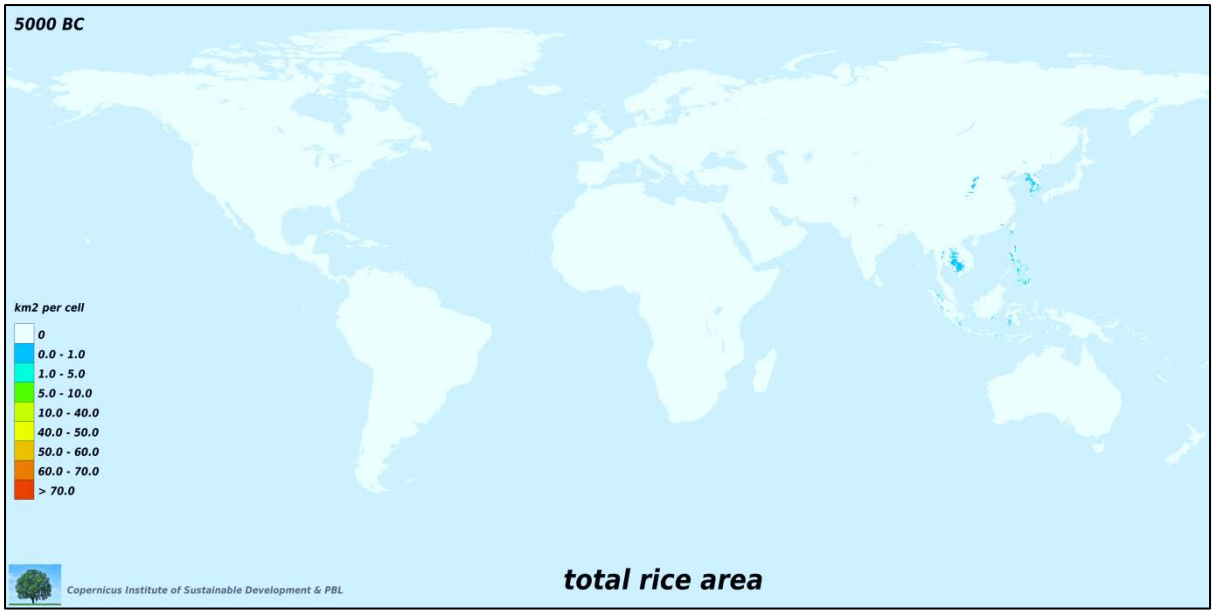

Figure 18. HYDE map displaying total rice area for 5000 BCE. The map shows areas used for rice agriculture in India, East Chin, Korea, Taiwan, Philippines, Indonesia, Malaysia and Thailand/Cambodia/Laos.

The literature analysed also supports the expansion of rice agriculture out of China and into Southeast Asia. Through global methane trends, Ruddiman et al. (2008) report a reversal of the downward trend in methane levels (ppb) around the 5000 BCE time. Their research states that this is the increase in human agricultural activities during the Bronze and Iron ages. Although this is caused from other forms of human activities other than ice agriculture, the expansion of rice agriculture does support this change in global methane levels.

According to the language/dispersal hypothesis, rice agriculture moved over water to Taiwan and further south and also moved northward further into the Middle and Lower Yellow River basin and possibly Korea, all by 5000 BCE (see Bellwood 2006, 2011; Fuller and Qin, 2009).

In China, it was suggested that rice agriculture expanded both north and south from the Yangtze and Yellow River basins. Rice is present by 5000-4400 BCE at Shixia (see Figure 20), a site situated lower than the Yangtze River, closer to the Xun River (Yan, 1992). Prior to that, around 5500-5000 BCE, rice agriculture continued to spread to the upper Yellow River Valley to the site Qingyang (Figure 20) (Zhang, 2000).

Botanical evidence excavated at the Niah Caves in Sarawak uncovered finds of domesticated rice that were AMS radiocarbon dated to as early as 5000 BCE (Barker, 2005). These finds seem to go against Bellwood's language/dispersal hypothesis as he suggests that rice agriculture or domestication of plants had not reached that far south in this timeframe. Hill (2010) argues that the rice remains in the Niah Caves favour Lui et al.'s theory for multiple independent domestication events in Southeast Asia.

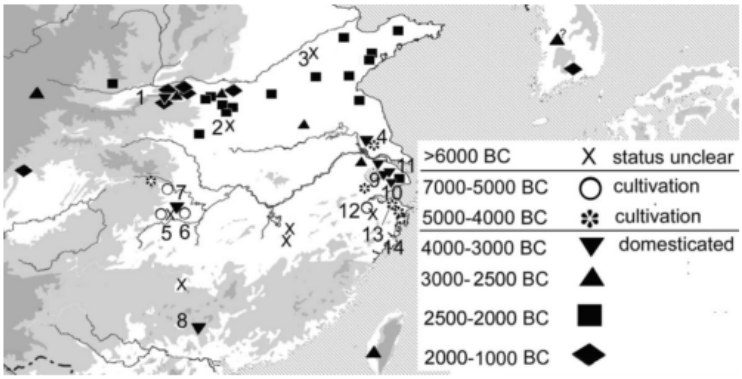

Figure 19. Map showing representative sites with rice evidence in China including sites: 1. Nanjiaokuo, 2. Jiahu, 3. Yuezhuang, 4. Longqiuzhuang, 5. Pengtoushan, 6. Bashidang, 7. Chengtoushan, 8. Shixia, 9. Chuodun, Caoxieshan and Chenghu, 10. Qingpu, 11. Guangfulin, 12. Kuahuqiao, 13. Tian Luo Shan, 14. Loujiang and Hemudu (Fuller & Qin, 2009).

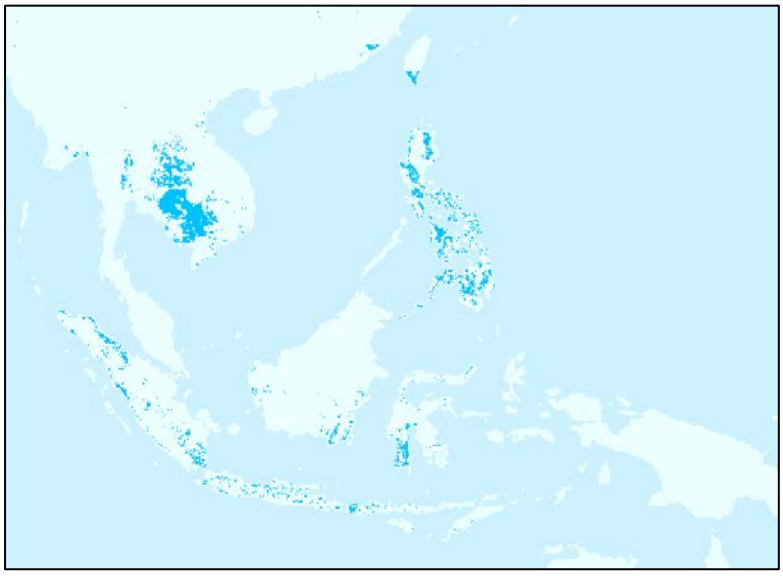

Figure 20. HYDE map of the Southeast Asian region showing total rice agricultural expansion in 5000 BCE

According to the HYDE maps for the year 5000 BCE (Figure 20) rice agriculture had expanded significantly throughout Southeast Asia, through the Philippines archipelago, Malaysian islands, extensively through Indonesia and Central Thailand/Vietnam/Cambodia area. The map also shows the disappearance of the entire region on Papua that had been utilized as land for rice agriculture so extensively in the 6000 BCE map (Figure 12).

With reference to the literature and archaeological evidence discussed above, the HYDE map for 5000 BCE would be expected to appear quite different. For China, rice agriculture should *still* exist around the lower and upper Yangtze River valley, lower and upper Yellow River Valley, as well as further upwards and southwards around sites like Qingyang and Shixia. The HYDE map should also indicate areas in Taiwan as rice agriculture spread across the ocean. Although the rice remains are controversial, it is likely the Niah Caves in Sarawak should be included as sites of rice agriculture. Bellwood (2007) states that it is these remains that are the oldest evidence of rice agriculture in the Indo-Malay Archipelago. How these remains got there is still debated. There is no evidence of rice agriculture being practised on Indonesia, Thailand/Vietnam/Cambodia, peninsular Malaysia or the Philippines that has been found to date.

6.6 4000 BCE

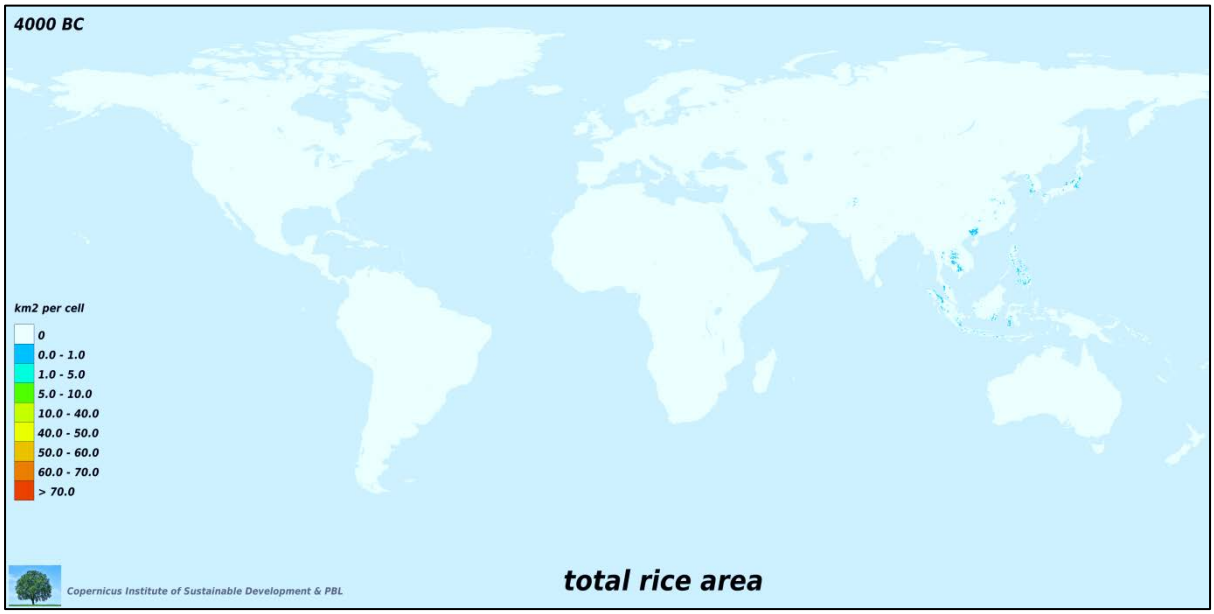

Figure 21. HYDE map

By 4000 BCE the HYDE map shows that rice agriculture has reached Southern China, expanded into the Indonesian peninsular, Thai peninsular and the Thailand/Cambodia/Vietnam area (Figure 22).

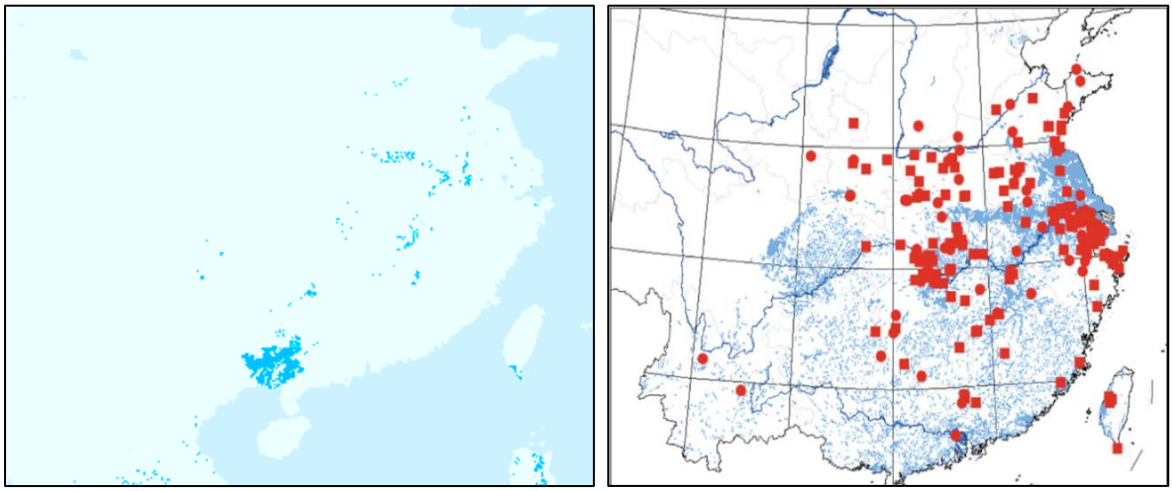

Figure 22 (Left). Snapshot of East China in 4000 BCE HYDE total rice area map. Figure 23 (Right). Rice agriculture by 4000 years ago. Archaeological sites (red) show that rice irrigation was present across most of China where rice is grown today (blue). Red circles show sites with ^{14}C dates; red squares show sites with ages constrained by limits of ^{14}C-dated cultural intervals (Ruddiman et al., 2008).

A combination of archaeological evidence and extensive literature review enabled Ruddiman et al (2008) to produce a map indicating rice agricultural sites in China by 4000 BCE (Figure 24). The map shows the densest areas of rice agriculture located around the lower and middle Yangtze River. The HYDE map suggests that the largest and densest area of rice agriculture to be at the South of China, close to today's border with Vietnam. From research conducted for this project there was so found evidence of rice agriculture any further south than the Shixia site (Figure 20) by 4000 BCE.

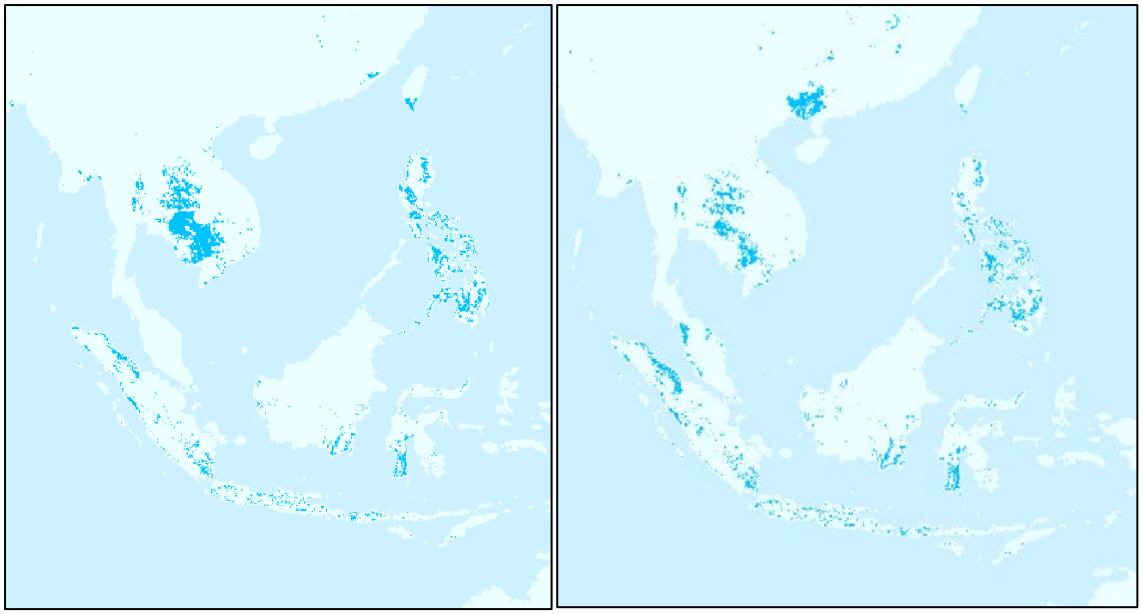

Figure 24 (Left) and Figure 25 (Right). Rice agricultural areas (shown in blue) of the Southeast Asian region in 5000 BCE and 4000 BCE respectively.

Analysis of Figures 25 and 26 shows that the HYDE databases suggests during the fifth millennia BC there was not such a significant development of rice agriculture in Southeast Asia, primarily an expansion of existing areas. The literature however states that, as mentioned before, according to Fuller et al. (2007) by 4000 BCE the domestication process was truly complete. The rice species being cultivated in the original rice growing areas of East China was even said to be very similar to modern day rice. There is no current evidence that indicates domesticated rice was being cultivated in Indonesia, Malaysia the Philippines or mainland Southeast Asia. The HYDE map should therefore be adjusted to reflect this.

6.7 3000 BCE

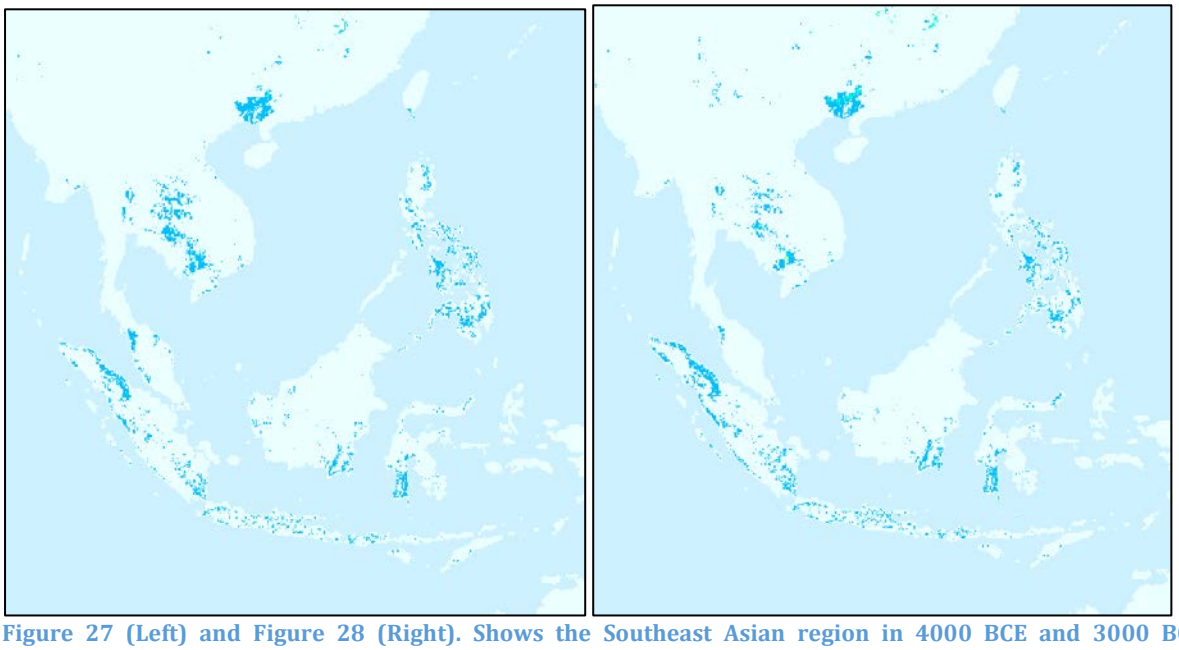

Figure 27 (Left) and Figure 28 (Right). Shows the Southeast Asian region in 4000 BCE and 3000 BCE respectively.

To focus on the Southeast Asian region, Figures 30 and 31 display changes to rice agricultural area that occurred during the fourth millennia BCE, according to the HYDE database. The most significant differences are an increase in green areas (higher yield of rice farming) in China, the beginning of green areas starting to appear in mainland Southeast Asia, the expansion of existing rice areas in Indonesia, Philippines. Overall, the maps indicate a southward movement of rice agriculture. This is congruent with the language/dispersal hypothesis that suggests that the colonists understand the equatorial climates are much more suited and supportive of wet rice agriculture (Bellwood, 2007). These higher rice crop yields also support population growth.

Along with the rice remains found at Gua Sireh (Sarawak), the site of Andarayan in Luzon (North Philippines) is believed to be the best dated site of rice remains in Southeast Asia (Donohue & Denham, 2011). The remains come from organic materials associated with pottery and are dated to 3700-3500 BCE (Paz, 2002). This evidence shows that by the mid fourth millennia BCE rice agriculture had spread from Taiwan to the Philippines.

However, there still is no conclusive evidence that rice agriculture had reached Indonesia, southern Philippines or Thailand like the HYDE maps (Figures 27 and 28) suggest.

6.8 2000 BCE

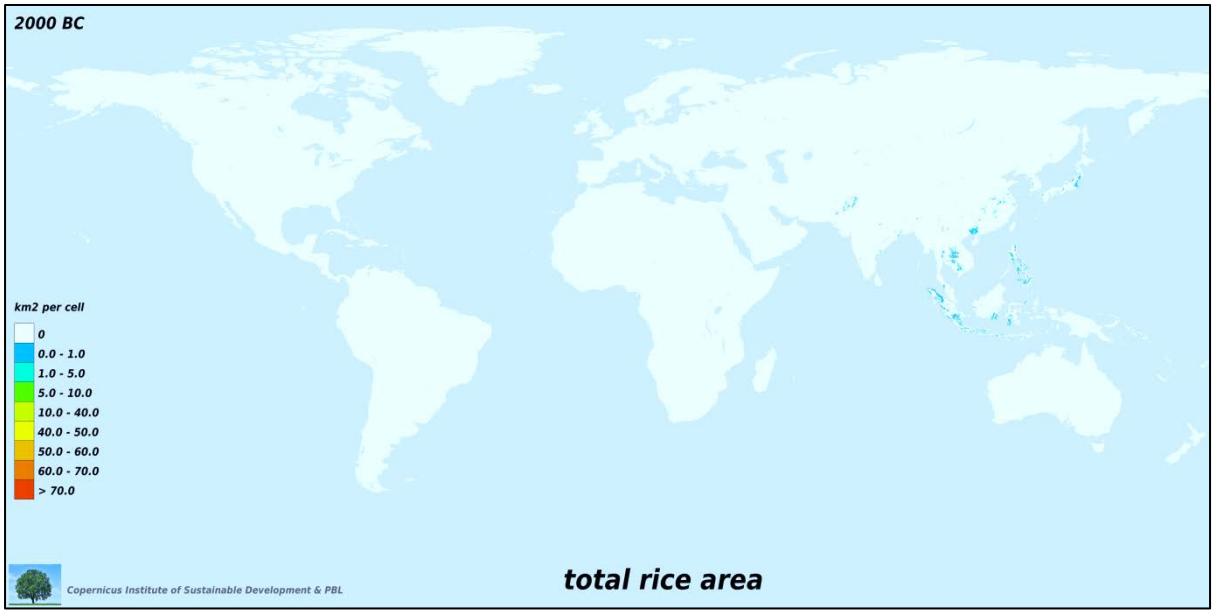

Figure 29. HYDE map displaying total rice area for 2000 BCE. The map shows rice agriculture having expanded extensively through China, North and East India and South East Asia.

There is abundant archaeological evidence to suggest that rice agriculture had expanded and truly established itself as a major farming practice in Southeast Asia by 2000 BCE.

Higham (2005) suggests that from Luzon, rice and farming dispersed into Southeast Asia through the river valleys of mainland Southeast Asia, reaching central Thailand and Cambodia by 2000 BCE. The earliest remains of domesticated rice in Thailand were also

discovered during this period (as discussed in 5.5) at KPD. Bellwood (2007) states that by this time, large scale expansion and movement of people through the Malay and Indonesian peninsulas. In China, rice agriculture was also evident to have dispersed south west, with rice remains being discovered that date to this timeframe in the area that borders with Vietnam (Fuller et al., 2010).

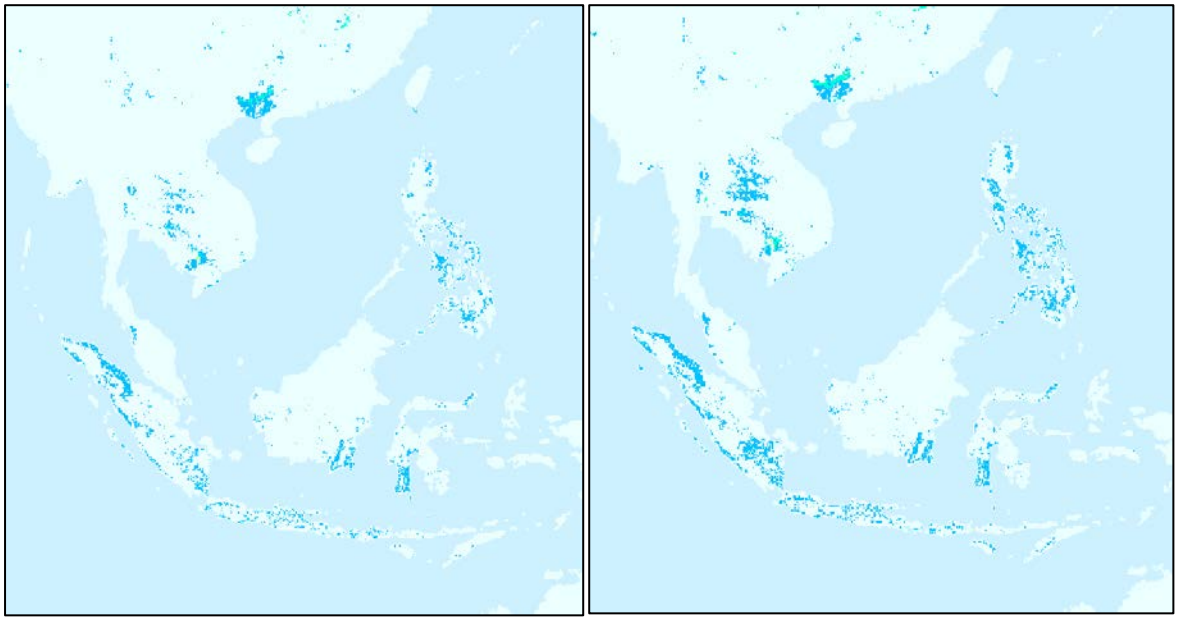

Figure 30 (Left) and Figure 31 (Right). The Southeast Asian region in 3000 BCE and 2000 BCE respectively.

The literature analysed suggests a large dispersal of rice agriculture southwards throughout Southeast Asia, however, the HYDE maps (Figures 30 and 31) do not accurately reflect this. This is primarily due to the fact that the HYDE map for 3000 BCE displays much more expansion than what is thought to have occurred. As discussed in 5.5, rice agriculture is thought to have spread into Southeast Asia through Taiwan, the Philippines and then into island Southeast Asia (Bellwood, 2007). The HYDE maps do not support this notion and rice agriculture appears far too early and extensively then what the literature suggests. The fact that the timesteps of the HYDE maps are only at 1000 year intervals also makes it difficult to reflect the true progression of rice domestication.

7. Conclusion

This interdisciplinary research aims to calculate how human interference with natural biogeochemical cycles have affected the development and health of the planet. The HYDE database aims to develop global maps that display the spatial information, as well as farming intensity of rice agriculture from 10000 BCE until 2012 AD. Despite incorporating information from a number of studies, literature and archaeological evidence, high uncertainty still exists around the HYDE rice agricultural maps which must be reduced.

The HYDE database needs to indicate how domesticated rice is defined and what level of human interference is required for it to be included in the HYDE maps. It also becomes clear that where the HYDE maps divulge the most from contemporary literature is the absence of existing rice agricultural areas from the previous years.

Often an area that had been indicated as used for rice agriculture at one time step, was absent in the following time step, which was not supported by the literature. Another reoccurring issue for the HYDE maps was the overall timeline for the spread of rice being too early. Not only early, but much too large of an area at one timestep (for example the HYDE map for 5000 BCE). For these reasons, hypothesis 1, that HYDE *does not* reflect current evidence for rice agriculture, can be accepted. It is recommended that the rivers should be indicated on the HYDE maps to improve the clarity of geographical locations and the movements of people.

It must be noted that as archaeological dating technology advances and more rice remains excavated, the timeline of rice agriculture is likely to change also. This paper focused on the Southeast Asian region for a specific timeline, the conclusions cannot be applied for the rest of the HYDE database.

The task of developing the HYDE maps is extremely difficult, but as more archaeological evidence becomes available the accuracy of the maps can be improved. Due to the prehistoric timeframe the maps cover, they can never be completely accurate, nor can they be fully falsified. It´s hoped that the research presented in this paper has at the very least provided a summary of current information and a starting point for further work to lower the uncertainty with the HYDE database.

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9. Appendices

9.1 Supporting evidence for establishment of rice agriculture in China

Rice remains discovered at the Bashidang site, in the Middle Yangtze Valley, date to around 8800 BCE (Cohen, 2011). Again, just like the Jaihu site rice remains, some authors describe the remains as showing signs of human selective pressure, consequently being typed as domesticated rice (Zhang, 2000). Later, Fuller, Harvey and Qin (2007) analyse the same remains and note that due to the thin size of the rice, they exist as morphologically wild. Fuller et al. (2007) also state that the remains are wild due to the fact that the water management systems of channels in the area had not been developed yet, systems that are fundamental for the rice domestication process.

9.2 Supporting evidence for establishment of rice agriculture in Thailand

An example of this is rice casts from ceramics at Ban Chiang (as seen in Figure 5, site 5), which date to around 2000 BCE (Kealhofer, 2002). The discovery of coprolites containing beetles known to be common rice pests at KPD by Thompson (1996) also indicate that rice was being stored in *large* quantities by 1500 BCE. Literature generally agrees that the Neolithic people inhabiting Thailand had a well-established cultivated rice system by 1000 BCE. Many of the rice remains found earlier than this are based on accelerator mass spectrometry dating (White, 2008). Higham (2009) calls the accuracy of this type of dating procedure into question and believes that the clays used may contain old carbon, ultimately dating the samples as older than they really are.

Castillo (2011) proposes that the early contact period of Thailand with South Asia happened around 300 BCE onwards. The interactions between Thai and Indian cultures influenced a change in the rice agriculture regime of Thailand, from a predominantly dry cropping rice agriculture regime, to incorporate wetland systems.

9.2 Further discussion of theories for rice establishment in Borneo, Malaysia and Indonesia (section 5.6)

The period between 2000 BCE and 1500 BCE saw the Neolithic colonization of the Malay Peninsula (Barker, 2007). The movement of these people spread from Northern Borneo out to Indonesia and mainland Malaysia. Current information suggests that by 2000 BCE the island of Borneo as well as the Malay Peninsula had been reached by Neolithic groups who presumably brought rice agriculture with them. This theory is criticised by Denham and Donohue (2011) though, due to the rice remains in Niah cave being so much older, it is possible that earlier Neolithic inhabitants travelled through mainland China, through Malaysia to Borneo that route. However, as Bellwood stated, this is most probably unlikely to have occurred prior to outward expansion from China through Taiwan and the Philippines.

9.3 Links between global methane trends and rice agriculture

Ruddiman et al (2008) focus on the links between early rice farming and anomalous global methane trends (see Figure 27). For their research they chose to follow Liu et al.'s timeline of including early rice cultivation sites (those dating between 10000 BCE and 7000 BCE). However, the authors acknowledge the significant increase in the number of *new* rice cultivation sites between 6000 BCE and 4000 BCE. Although this is only representative of archaeological sites which have been excavated, not those that

have been destroyed or simply not found yet, the current evidence does align itself with Ruddiman et al.'s reported methane trends from the Holocene (Figure 34).

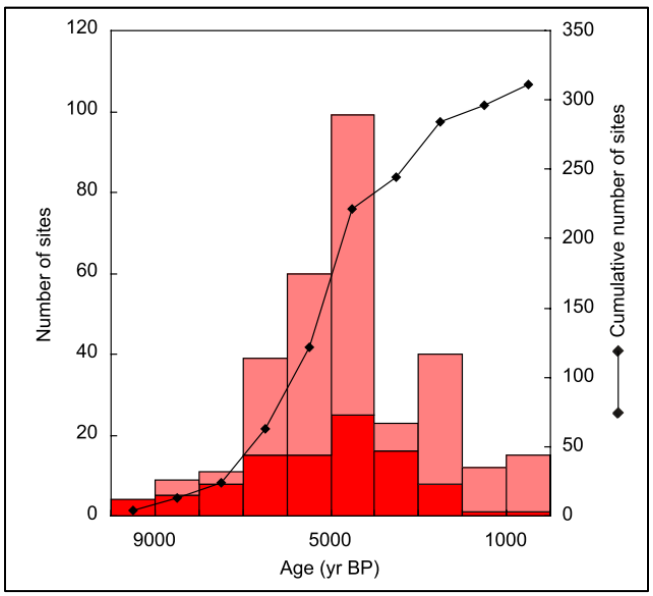

Figure 26. Appearance of rice sites since 10000 years ago. Histogram displays the appearance of new rice-cultivation sites per 1000-year interval. Dark red bars are sites with ^{14}C dates; light red bars are sites from dated cultural intervals. Black line shows the cumulative number of rice sites. (Ruddiman et al., 2008).

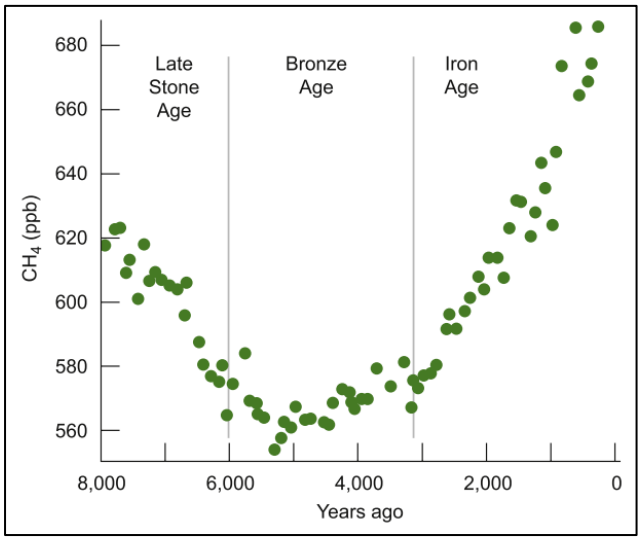

Figure 27. Holocene methane trends during the last 8000 years of the Holocene from Antarctic Dome C (EPICA Community members, 2004). The reversal of the downward trend near 5000 years ago and subsequent increase coincide with increased human agricultural activities during the Bronze and Iron Ages. (Ruddiman et al., 2008).

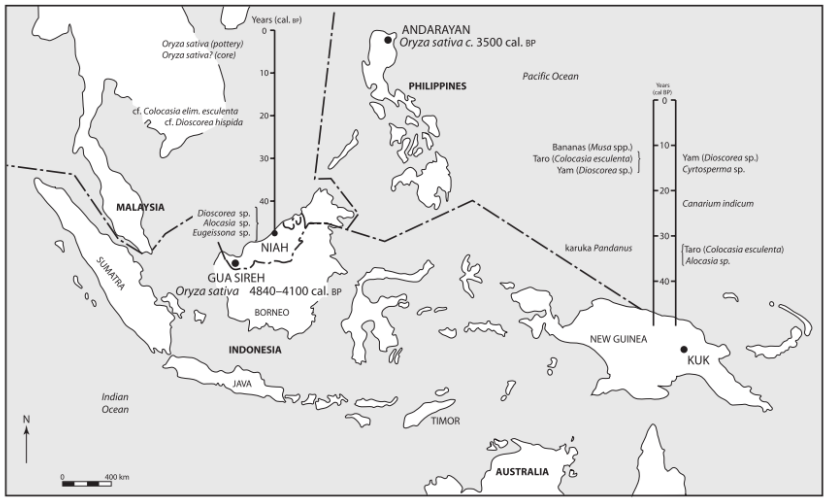

Figure 28. Geographical and historical representation of key trends in plant exploitation for Indo-Malaysia and New Guinea. (Barton & Denham, 2011)

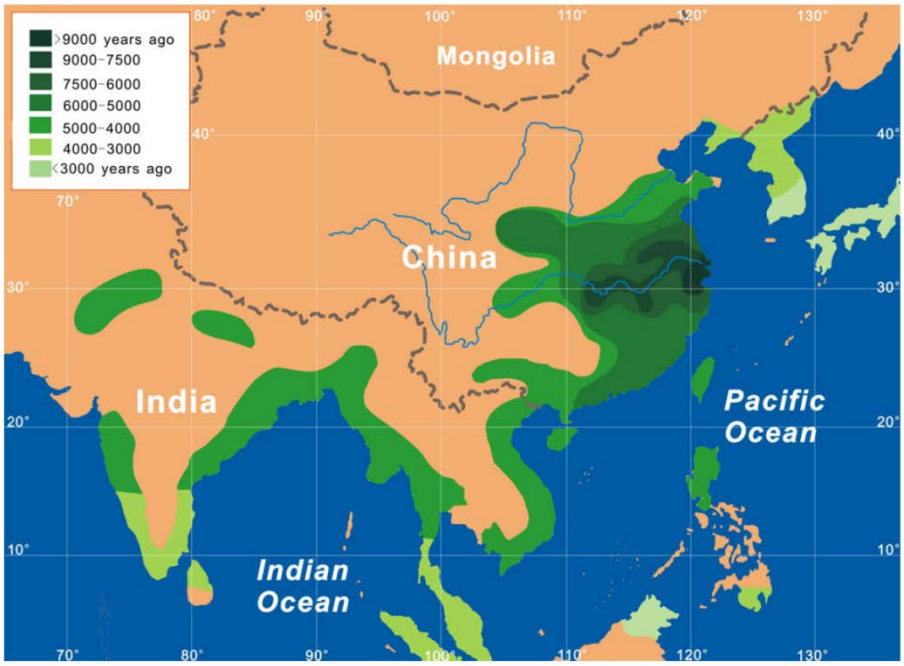

Figure 37. Estimated rice agriculture regions in Asia during the Neolithic. The distribution regions of rice agriculture in six time periods (Li et al., 2009).