A 2300 yr record of sago and rice use from the southern Kelabit Highlands of Sarawak, Malaysian Borneo

S E Jones, C Hunt and P J Reimer

The Holocene published online 6 February 2013
DOI: 10.1177/0959683612470180

The online version of this article can be found at:
http://hol.sagepub.com/content/early/2013/02/06/0959683612470180

Published by:
SAGE
http://www.sagepublications.com

Additional services and information for The Holocene can be found at:

Email Alerts: http://hol.sagepub.com/cgi/alerts

Subscriptions: http://hol.sagepub.com/subscriptions

Reprints: http://www.sagepub.com/journalsReprints.nav

Permissions: http://www.sagepub.com/journalsPermissions.nav

>> OnlineFirst Version of Record - Feb 6, 2013

What is This?
A 2300 yr record of sago and rice use from the southern Kelabit Highlands of Sarawak, Malaysian Borneo

SE Jones,1 C Hunt1 and PJ Reimer1

Abstract

Rice and sago are today important staples for many subsistence farmers and nomadic hunter-gatherers living in interior Borneo, but the cultural antiquity of these staples remains poorly understood. This study examines a 2300 yr sedimentary record from a palaeochannel near the village of Pa’Dalih in the southern Kelabit Highlands. Pollen and phytolith evidence indicate significant use of the sago palm Eugeissona near the channel during this period. Oryza phytoliths likely belonging to domesticated rice varieties are also recorded, although rice may have been used to a lesser extent than the sago palms. A rise in cultural activity takes place between c. 1715 and 1600 cal. BP, shown by increased frequency of fires.

Keywords

cultural, Eugeissona, Kelabit Highlands, late Holocene, Oryza sativa, Pa’Dalih, rice, sago palms

Received 23 July 2012; revised manuscript accepted 31 October 2012

Introduction

Rice and sago are today important staples for many subsistence farmers and nomadic hunter-gatherers living in interior Borneo, but until now no evidence existed for the cultural antiquity of these staples. According to Doherty et al. (2000) it has generally been assumed that wet rice cultivation, in the Kelabit Highlands of central Borneo (Figure 1), is ancient, and that the lack of evidence for rice in inland sites may be associated with poor preservation of organic matter in tropical soils. Barton (2012) on the other hand argues that rice is an illogical choice for cultivation in tropical rainforests, as it is difficult to grow and prone to failure, and therefore may not have become a popular choice of crop until the historic period. Barton (2012) also suggests that other high-yielding plants such as taro and sago may have instead been utilised.

The timing, importance and the arrival of domesticated rice (Oryza sativa) into island SE Asia remains hugely debated. Rice is thought to have expanded into island SE Asia via Taiwan and the Philippines (Bellwood et al., 1992), although archaeological evidence remains sparse. In the Philippines evidence is based on one archaeological site at Andarayan, northern Luzon and on one charcoal piece dating between 3900 and 3000 cal. BP (Snow et al., 1986). The site yielded large quantities of earthenware in which rice inclusions were common. On the island of Bali rice may have appeared by 2300–3000 cal. BP (Bellwood et al., 1992; Lansing et al., 2004), although the sherds of pottery containing rice husks is from an imported vessel and therefore some uncertainties of its origin remain. The island of Borneo is the only other SE Asian island which has yielded evidence of early rice cultivation/use. The earliest confirmed evidence for rice usage in Borneo is in coastal lowland sites dating to c. 4300 cal. BP at the cave of Gua Sireh (Ipoi and Bellwood, 1991) and c. 5400–5900 cal. BP at the Great Cave of Niah (Doherty et al., 2000). Close to Niah at Gan Kira, pollen and sedimentary evidence suggests forest disturbance and that rice may have been utilized as early as 6480 cal. BP (Hunt and Rushworth, 2005). This evidence is however, incomplete, but highlights the need for further investigations into the timing and arrival of domesticated rice into Borneo. Rice is today a staple food and culturally important to the Kelabit people in the highlands of Borneo (Janowski, 2005); whilst the nomadic hunter-gathering Penan in the region rely substantially on sago palms, particularly Eugeissona utilis (Brosius, 1993). Large stands of sago palm can also be found surrounding Kelabit settlements, suggesting that the palms were of central importance to the Kelabit inhabitants and other inland groups in the not so distant past (Barton, 2012).

Early hunter-gatherers on the islands of SE Asia probably already had an intricate knowledge of tropical plant use. Evidence for this is suggested by the presence of stone tools c. 49,000–43,000 cal. BP, located in the Ivale valley, New Guinea, which may have been used to remove trees to promote the growth of useful plants. Evidence from the Iname valley is also suggested by the presence of charred nuts and starch grains, consistent with starch from the yam Dioscorea (Summerhayes et al., 2010). The use of fire may also have been an important tool in early plant management. Hunt et al. (2007, 2012) suggest a rise in Justicia and palytomorph evidence within the mouth of Niah cave as indicative of anthropogenic fire, during the Late Pleistocene, presumably to maintain forest-edge habitats. Forest fires have also been reported by Anshari et al. (2001, 2004) 30,000 years ago at Lake Sentaram, West Kalimantan. Anshari et al. (2004) for example, attributes an increase in charcoal prior to 30,000 years ago, which is not clearly related to any changes in vegetation or stratigraphy, to initial human impact. At the Great Cave of Niah in the lowlands of Sarawak, evidence of Late Pleistocene plant use is

1Queen’s University, UK

Corresponding author:
Samantha Elise Jones, School of Geography, Archaeology and Palaeoecology (GAP), Queen’s University Belfast, Belfast BT7 1NN, UK.
Email: sjones13@qub.ac.uk
further demonstrated by the presence of charred nut, fruit, plant tissues and starch, c. 45,000 cal. BP, although possibly older (Barker et al., 2002, 2007; Paz, 2005). The earliest evidence of sago use in Borneo appears c. 40,000 cal. BP, with the identification of palm starch granules at Niah Cave (Barton, 2005). Later during the early Holocene, at Loagan Bunut in the lowlands of Borneo, Hunt and Premathilake (2012) recorded signs of consistently intense forest burning and disturbance, associated with abundant pollen of four genera of sago palms. The palm trees recorded included the lower montane species Eugeissona (native to Borneo) and Metroxylon which originates in Papua New Guinea, but also Arenga and Caryota. Despite these early sites, as well as extensive evidence of plant exploitation from early–mid Holocene sites in the upper Waghi valley, New Guinea (Denham and Haberle, 2008; Denham et al., 2003, 2004; Haberle, 2003) the history of tropical plant exploitation in island SE Asia remains poorly understood. There are two possibilities: A gradual transition from simply encouraging useful plants through the burning of vegetation, to a more systematic management and propagation or more abrupt changes associated with the arrival of new cultures or following major environmental events.

Beyond the oral histories transcribed by Janowski (2003, 2005) very little is known about the antiquity of rice and other ethnobotanical plants in interior Borneo. We provide the first evidence for the past use of sago and rice in interior Borneo through pollen and phytolith evidence near the village of Pa’Dalih in the southern Kelabit Highlands.

**The study site**

The Kelabit Highlands is an area of 90 km × 60 km, about 900–2500 m above sea level. It is situated mainly in Sarawak, Malaysia but includes part of Kalimantan and forms the headwaters of a number of rivers including the Baram and Kerayan (Janowski, 2005). Vegetation at this altitude consists predominantly of lower montane forest, although upper montane gymnosperms were identified by Beaman (1999) between 2300 and 2400 m. Rautner et al. (2005) describe lower montane forests as beginning between 900 and 1000 m up to 3300 m with dipterocarps being replaced by more temperate families such as the Fagaceae. Beaman (1999) also identified oak-laurel forests above 1775 m. Other taxa that can be found in lower montane forests, which would be scarcer in the lowlands, include Araliaceae, Celastraceae, Elaeocarpaceae, Ericaceae, Ilex, Myrsinaceae, Myrtaceae, Symplocaceae, Polygalaceae and Theaceae (Van Steenis, 1964).

Pa’Dalih (03°34′ and 115°33′ and at an altitude of 957 m) is a small Kelabit longhouse village in the southern part of the Kelabit Highlands (Figure 1), situated next to the Diit, a tributary of the Baram River. The village lies in a steep-sided valley, floored by the deposits of a number of fluvial palaechannels, which indicates a very dynamic landscape with unstable fluvial activity in the past. The ancient palaechannels provide extremely fertile soils and are used extensively by the local inhabitants for rice cultivation. One of the palaechannels is also currently being used as a fruit grove. Several additional fruit groves, herb and

![Figure 1. Location of core PDH 223 at Pa’Dalih, in the Kelabit Highlands of Sarawak, Malaysian Borneo.](image-url)
vegetable gardens surround the village and coconut palms grow at the back of one of the longhouses.

Material and methods

A 2.7 m core was obtained using a Livingstone piston corer and clay-cutting auger at 03°33′51.4″ and 115°33′20.2″ in a palaechannel on a low terrace with a surface 4–5 m above the River Diti. The site is now a fruit tree grove. Rice fields in the Kelabit Highlands are today usually constructed via excavation of sediments. The planting and harvesting of wet rice lead to mixing within the field sediments. This core was therefore drilled in a site less prone to disruption, so that a continuous record might be obtained. Sediments between 130 and 20 cm were too dry and hard to be obtained using the piston corer and were therefore augured out at 10 cm intervals and placed into bags. Piston core segments were placed in guttering and wrapped in cling film and strong tape for air-freighting to Queen’s University Belfast (QUB). Aluminium foil was not used because experience shows that highly acid sediments quickly corrode the foil. Storage in the field was in the coolest, darkest place available under the longhouse. Storage at QUB was at 4°C until analysis could be done.

In the laboratory, the core was cleaned and lithologically described (Table 1). The organic content was determined by the loss-on-ignition (LOI) method at all depths where samples were taken for pollen analysis. One gram of sediment per sample was placed in crucibles and left over night in a drying cupboard at 30°C. The dry weight minus crucible weight was then measured and samples were placed in an oven heated to 550°C for 4 h. After 4 h burn weight minus crucible weight was recorded. LOI was calculated using the equation [(dry weight–burnt weight)/dry weight] ×100 (Heiri et al., 2001). Magnetic susceptibility is used primarily to identify erosional in-wash, although volcanic ash and precipitation of iron from groundwater will also affect the magnetism (Hilton and Lishman, 1985). Magnetic susceptibility of the core was undertaken using a Bartington MS2 meter and core scanner using MS2F server but was not carried out on the bagged sections at 130–20 cm.

Three samples were selected for radiocarbon dating, which was carried out at the 14CHRONO Centre, QUB (Table 2). Calibration was made according to Stuiver and Reimer (1993) using Calib 5.0.2 and the IntCal04 calibration curve (Reimer et al., 2004). All samples are in chronological order. The age of the base of core PDH 223 dates to 2352–2322 cal. BP at 2 standard deviations (95.4%). Organic-rich sediments are present until 1715–1604 cal. BP, after this period inorganic grey clays, iron mottling and sandy clays appear. Organic sediments reappear in the top 14 cm, but no dating material was available for the uppermost sediments. In order to provide calibrated age ranges for other depths, a potential age/death relationship over the last 2300 years (Figure 2) was calculated using the statistical modeling program clam (Blauw, 2010), assuming that the top of the core was 0 cal. BP. A smooth spline model was chosen from the clam program as this produced the most reasonable approximation for the calibrated age sequence (Figure 3). It should, however, be noted that other age–depth models could also be presented, particularly the linear option, where the top of the clays are ~ 1200 cal. BP. With the linear option infilling of the palaeochannel may have been completed by 1200 cal. BP, which would mean a hiatus is present between the upper recent 10 cm organics and clays below. This is possible given that C14 ages could not be obtained from 140 cm to the surface.

Pollen preparation was mainly derived from the methods described by Moore et al. (1991) and Hunt (1985). Samples were boiled in 10% KOH for 20 min. The suspension was sieved through a 0.12 mm nylon sieve to remove larger particles and on a 6 μm nylon sieve to remove fines and solutes. Silt and fine sand were removed by swirling on a clock-glass using the techniques outlined by Hunt (1985). Samples were then mounted in Gurr Aquamount. An Olympus BX 51 high-powered microscope was used for identification. Counts of 300 pollen grains (excluding spores and other palynomorphs) were recorded, where possible. Pollen has been identified using a number of resources including the authors own reference material of 213 species, reference material collected by Dr B Maloney stored at Queen’s University Belfast, Huang (1972), Roubik and Moreno (1991), Davis (2001), APSA (2006–2007) and Stevens (2005). Palynomorphs were identified using Van Geel (1978) and Limaye et al. (2007). Spores and other palynomorphs were counted until maximum pollen counts had been achieved. Pollen counts have been calculated as a percentage of total pollen, excluding spores. Spore counts have been calculated as a percentage of total pollen and spores, whilst palynomorphs have been calculated as a percentage of total palynomorphs. Charcoal particles greater than 5 μm in diameter, as well as all other thermally mature plant debris (a byproduct from biomass burning) have been counted on the same slides as the pollen and other palynomorphs, and are expressed as total counts of charcoal and burnt plant debris.

Phytolith slides were prepared using methods derived by Dr R Premathilake (personal communication, 2009), following Piperno (2006), in which 25 ml of hydrogen peroxide was added to 2 g of sediment in 100 ml pyrex beaters and boiled for 2 h at 100°C until samples became oxidised. Water was then added to the 80 ml mark, mixed well and left for 2 h before being pipetted off. Water

Table 1. Lithology of the PDH 223 core.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lithological description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–4</td>
<td>Brown organic silty clay, 2.5Y N4</td>
</tr>
<tr>
<td>4–10</td>
<td>Brown very organic silty clay, 2.5Y N7</td>
</tr>
<tr>
<td>10–14</td>
<td>Brown organic silty clay, 2.5Y R 4/1</td>
</tr>
<tr>
<td>14–17</td>
<td>Iron mottled orange clay, 2.5Y N7</td>
</tr>
<tr>
<td>17–23</td>
<td>Grey sandy clay with iron mottling and a possible charcoal band at 120.5 cm, 2.5Y N4</td>
</tr>
<tr>
<td>23–133</td>
<td>Very orange mottled sandy clay, 2.5Y 3/2</td>
</tr>
<tr>
<td>133–135.2</td>
<td>Light grey clay with charcoal bands between 137 and 135.2, 134 and 133 cm and a very thick charcoal band between 131.5 and 128.5 cm, 2.5Y N2</td>
</tr>
<tr>
<td>135.2–138</td>
<td>Very dark grey sandy clay with three possible charcoal bands at 146.5 cm, 144.5 cm, between 142 and 140.5 cm and between 138.5 and 138 cm, 2.5Y 4/4</td>
</tr>
<tr>
<td>138–142</td>
<td>Light grey-brown silty clay, a thick woody layer; 167–163 cm and a charcoal band; 162–159 cm, 2.5Y 5/2</td>
</tr>
<tr>
<td>142–146.5</td>
<td>Very dark grey-brown clay with a burnt layer between 178 and 177 cm, organic woody layers at 176 cm, 174 cm, 173 cm and 171 cm, 2.5Y 4/2 cm</td>
</tr>
<tr>
<td>146.5–151</td>
<td>Grey-brown clay with an organic band at 190 cm and a thick woody layer at 182–181 cm, 2.5Y 4/4</td>
</tr>
<tr>
<td>151–160</td>
<td>Light brown sandy clay, 2.5Y 6/4</td>
</tr>
<tr>
<td>160–175</td>
<td>Brown sandy clay, 2.5Y 5/2</td>
</tr>
<tr>
<td>175–180</td>
<td>Grey-brown clay, 2.5Y 3/2</td>
</tr>
<tr>
<td>180–207</td>
<td>Grey-brown silty sand with charcoal at 219 cm, 2.5Y 6/2</td>
</tr>
<tr>
<td>207–222</td>
<td>Brown sandy clay with two charcoal bands at 228 and 226.5 cm, 2.5Y N4</td>
</tr>
<tr>
<td>222–232</td>
<td>Brown-grey black sandy clay with thick charcoal, 2.5Y N7</td>
</tr>
<tr>
<td>232–238</td>
<td>Dark grey gravelly sand, 5YR 6/8</td>
</tr>
<tr>
<td>238–241</td>
<td>Dark grey clayey sand, 2.5Y N5</td>
</tr>
<tr>
<td>241–246</td>
<td>Light grey clayey sand with a dark grey clay band between 244 and 243.5 cm, 5YR 6/8</td>
</tr>
<tr>
<td>246–251.5</td>
<td>Dark grey clayey sand with charcoal pieces and a thick charcoal piece at 251 cm, 10YR 5/3</td>
</tr>
<tr>
<td>251.5–260</td>
<td>Light grey silty clay, 10YR 3/4</td>
</tr>
<tr>
<td>260–270</td>
<td>Dark grey sandy clay with charcoal and one seed, 10YR 5/3</td>
</tr>
</tbody>
</table>
Table 2. Radiocarbon dates and calibrated ages of charcoal samples extracted from core PDH 223.

<table>
<thead>
<tr>
<th>UBA no.</th>
<th>Site code</th>
<th>Depth (cm)</th>
<th>14C age ± yr BP</th>
<th>AMS δ13C</th>
<th>Cal. age 2σ BP</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>UBA-10593</td>
<td>PDH 223</td>
<td>144–146</td>
<td>1751</td>
<td>19</td>
<td>−23.0</td>
<td>1715–1604</td>
</tr>
<tr>
<td>UBA-10594</td>
<td>PDH 223</td>
<td>178–182</td>
<td>1867</td>
<td>18</td>
<td>−28.0</td>
<td>1868–1734</td>
</tr>
<tr>
<td>UBA-10595</td>
<td>PDH 223</td>
<td>275–278</td>
<td>2308</td>
<td>18</td>
<td>−28.3</td>
<td>2352–2322</td>
</tr>
</tbody>
</table>

Figure 2. Lithology, loss on ignition and magnetic susceptibility for core PDH 223.

was added again for 1 h and pipetted off. Water was added to the 80 ml mark and left for 4 s, the supernatant was added to a clean beaker and left for 4 min and the supernatant was then pipetted off leaving the heavier phytoliths at the bottom of the beaker. This was repeated three times. Phytoliths samples were then mounted onto slides using naphrax, counted using an Olympus BX 51 high-powered microscope and identified using modern reference material held at QUB, Piperno (2006), Lu et al. (2002), Mercader et al. (2000) and the University of Missouri (MU) Phytolith Database (1998–2008). All phytoliths with *Oryza* characteristics have been photographed and measured. *Oryza* produces at least three different types of phytolith, which include bilobates (Figure 6f, right-hand side), produced in the leaf cells (Gu et al., 2012; Harvey and Fuller, 2005; Piperno, 2006), double peaked glume phytoliths (Figures 5 and 6c), produced in the epidermis of the rice glume (Piperno, 2006) and bulliform phytoliths (Figures 4, 6a, b, d), produced in the leaf cells. Diatoms have also appeared frequently on the phytolith slides, so phytoliths have been calculated as the percentage of total phytoliths and diatoms. Pollen, spore, phytolith and other palynomorph results were compiled and plotted using Tilia and TG View (Grimm, 1991–1993). The majority of the rice phytoliths identified from core PDH 223 were bulliform phytoliths. According to Pearsall et al. (1995) the bulliform lengths, thickness and width measurements of some Oryzeae and Bambuseae tribes overlap and therefore these measurements alone should not be used to determine domesticated rice (*Oryza sativa*). Lu et al. (2002) describe bulliform phytoliths in *Oryza* as generally characterised by numerous small shallow scale-like decorations on the half round side. Other grass phytoliths do not have such specific decoration. Their study identified a larger on
average number of scale/plate like decorations (8–14) on domesticated rice compared with wild varieties (<9). A recent paper produced by Gu et al. (2012) argues against these results, by further demonstrating a wide overlapping between *Oryza sativa* bulliform cells and other *Oryza* groups, such as *Oryza ridleyi* and *Oryza rufipogon*. Their study includes scale counts. Taking the findings of Pearsall et al. (1995), Gu et al. (2012) and Lu et al. (2002) into account a statistical test, developed by Dr R Premathilake, from the University of Colombo, Sri Lanka (personal communication, 2009), was used in combination with scale counts in an attempt to determine the presence of potential *Oryza sativa*. Potential *Oryza sativa* types were identified based on the statistical analysis described below. A gradual change in

**Figure 3.** Age–depth model for core PDH 223 from the program clam. The grey band shows the 95% confidence interval. Modelled ranges of sedimentation rates are given in boxes.

**Figure 4.** *Oryza* bulliform (not drawn to scale) and the measurements needed to carry out discriminant function analysis. Adapted from Fujiwara (1993).

**Figure 5.** An example of the measurements of glume phytoliths, adapted from Zhao et al. (1998).
the morphological features of bulliforms identified in core PDH 212 (described in Jones et al., unpublished data, 2013) has also been used as a guide for the potential representation of *Oryza sativa* in core PDH 223. It should be noted that the statistical analysis, which is described below, has not been used as a measure of confidence for *Oryza sativa*. This is due to the uncertainty in overlap between other Oryzeae and Bambuseae tribes. Instead the test has been used as a guide for the potential occurrence of *Oryza sativa*.

Statistical analysis for bulliform phytoliths of cf. *Oryza sativa*:
L2/W: 0.35–1.0 (average: 0.62), L1/W: 0.25–0.80 (average: 0.50), L1/L2: 0.4–1.6 (average: 0.85), TH: 23–14 (average: 20.00) and PL: >3 rows >20 plates (see Figure 4).

To support the bulliform results from the statistical analysis, one double-peaked glume phytolith was also identified between 2180 and 1760 cal. BP (171–173 cm). According to Zhao (1998) it is possible to determine domesticated rice from wild varieties using glume phytoliths. This is achieved through discriminant function analysis (see Figure 5 for measurement criteria). Discriminant function analysis, adapted from Itzstein-Davey et al. (2007), was therefore carried out on the glume phytolith from core PDH 223 (see Table 5 and Figure 8).

### Results

Table 3 provides a summary zonation of pollen and palynomorphs identified in core PDH 223. Figures 7–8 provide a more in-depth representation of pollen and palynomorph patterns. Preservation is variable with the best preservation located in zones 223-2, 223-3 and 223-4. Phytolith counts are summarised in Table 4. Table 5 provides *Oryza* measurements and Figure 6 provides photographic illustrations, including other phytoliths, diatoms and testate amoebae. Complete phytolith and diatom counts are illustrated in Figure 8c. Zonation of the pollen diagrams (Figures 7–8) is based on Constrained Incremental Sum of Squares (CONISS) cluster analysis (Grimm, 1987), of pollen percentages with a minimum value of 0.3%. The value of 0.3% was selected because the pollen data sets showed a wide diversity of taxa, with lower percentage representation than would be found in European pollen data sets with a smaller diversity of taxa. Zones have been divided into 223-1 to 223-5 and calibrated ages are based on the age/depth model (Figure 3).

**Zone 223-1: c. 2350–2180 cal. BP**
Pollen and other palynomorphs (Figures 7–8). Pollen representation is low (17–86 grains per sample depth analysed). This zone is characterised by high Cyathaceae, Compositae, Poaceae and Eugeissona, appearing at 261 cm (c. 2300 cal. BP). Eugeissona represents 10.6–32.6% total pollen (10.6% at 241 cm), which is a much higher percentage representation compared with most other plant species recorded. This is with the exception of Cyperaceae, which is 30% at 241 cm.

PDH 223-1 is also represented by open ground taxa (40.7–77.1%) and shrubs (0–3%) including Meliaceae (0–5.8%) and Oleaceae (0–5.8%), some kerangas (0–5.9%), montane (6.5–17.7%) and general forest (0–33.7%) taxa have also been observed. There is also a high representation of the forest spores Cyathaceae (24.3–71.7%), Pteridaceae (1.5–31.2%) and Polypodiaceae (21.7–33.2%). Large scabrate Poaceae occur throughout this zone (4.4–35.3%) and Zyg nemataceae are also present. Burnt organic material represents (80.7–33.7% total palynomorphs).
Diatoms and phytoliths (Figure 8c). In the phytolith record, one cf. *Oryza sativa* bulliform is present between 251 and 253 cm, which fits all size criteria for domesticated rice. The shape of the identified *Oryza* bulliform is, however, slightly different to that of modern *Oryza sativa* and the number of plates could not be counted.

Zone 223-2: c. 2180–1760 cal. BP

Pollen and other palynomorphs (Figures 7–8). Pollen counts reach a maximum of over 300 grains in this zone, although 109 grains were recorded at 183–181 cm (c. 1860–1850 cal. BP). This zone is represented by *Eugeissona* (0.3–11.3%), Cyathaceae (8–60.4%), Polypodiaceae (10.2–47.1%) and by the montane taxa (*particularly at 231 cm, c. 2150 cal. BP*), *Dacrydium* (0.7–4.7%) and *Podocarpus* (1.4–5.9%). Kerangas taxa are present between 241 and 221 cm with the appearance of *Casuarina*, *Rhododendron* type and *Ericaceae*. Catholic taxa (1.2–20.6%) and small trees to shrubs (2.9–6.8%) increase and include *Sapindaceae* (0–1.4%); open ground taxa also increase (from 43.2% to 90.5%) and include large scabrate Poaceae (*particularly between 211 and 183 cm*), general Poaceae and Cyperaceae. There also seems to be high species diversity of shrubs/small trees, shown by the appearance of *Myrsinaceae*, *Macaranga*, *Meliaceae*, *Sapotaceae* and *Theaceae*. The aquatic taxa *Myriophyllum* and *Urticularia* are also present between 203 and 193 cm. The spore *Lygodium* is present but representation fluctuates. At 201–203 cm (c. 1970–1980 cal. BP) hyphae (from 0.1% to 5.6%), xylem (from 0 to 1.6%) and cells (0.1% to 7.8%) all increase. Burnt organic material represents 33.9–85.5%. The lowest burnt representation of burnt organic material coincides with an increase in hyphae, xylems and plant cells. Above 183 cm, percentages drop for both scabrate Poaceae (from 9.8% to 2%) and general Poaceae (from 14.3% to 5.2%), although Cyperaceae percentages rise (from 20.3% to 2.8%). The spore *Lygodium*, which is frequently present in zones 223-1 and 223-2, disappears completely above 173 cm and the spore Cyathaceae also shows a sharp decline (from 60.4% to 8%) after 183 cm.
Figure 7. Pollen diagrams for core PDH 223. (a) Montane and general forest. (b) Catholic (taxa that could not be classified into any specific group) and Open-ground. (c) Lianes, Small trees-shrubs, Kerangas and Aquatic.
Figure 8. Pollen, palynomorph and phytolith diagrams for core PDH 223. (a) A pollen summary. (b) A summary of other Palynomorphs, burnt material and charcoal. (c) A phytolith and diatom summary for core PDH 223.
wild bulliform has an elaborate network of scales similar to domesticated rice. Ehrhartoideae bilobates are present at 193 cm.

**Zone 223-3: c. 1760–1490 cal. BP**

*Pollen and other palynomorphs (Figures 7–8).* This zone is characterized by a significant decline in *Eugeissona* (0.17–0.47%, absent at 143 cm), Cyathaceae (4.7–8.7%) and Polypodiaceae (7.1–14.5%). Open ground taxa remain the dominant group (71.4–97% total pollen) and particularly at 147 cm (c. 1600 cal. BP) include large scabrate Poaceae, general Poaceae and Scrophulariaceae. Cyatheaceae rise at 173 cm, but then decline. This zone is also characterised by the presence of shrubs/small trees: *Macaranga, Trena, Meliaceae, Myrsinaceae Myrica;* the montane taxa Fagaceae and Podocarpus; and the aquatics Potamogeton, Urticularia and *Equisetum.* Microscopic burned material shows the lowest overall representation in this zone (5.9% at 163 cm, although rises to 37.4% by 133 cm). There is also a higher representation of plant cells (6.55–14.24%) than in zones PDH 223-1 and PDH 223-2.

*Diatoms and phytoliths (Figure 8c).* Pennate diatoms are present, but only at 133 cm. No *Oryza* phytoliths occur in this zone.

**Zone 223-4: c. 1490–730 cal. BP**

*Pollen and other palynomorphs (Figures 7–8).* This zone is represented by very low pollen counts of between 0 and 6 grains per sample depth. Individual pollen grains of Fagaceae (at 84 cm), Loranthaceae (62 cm), *Eugeissona* (at 84 cm) and Araliaceae (103–84 cm) are present in the pollen record, as are the spores Pteridaceae (between 103 and 83 cm), Polypodiaceae (between 103 and 78 cm), Gleicheniaceae (between 103 and 84 cm), as well as Cyathaceae and Davalliacae (between 103 and 80.3 cm). Large scabrate Poaceae are present at 103 cm and at 78 cm. There is a rise in VAMs (11.9–45.2%, except 1.9% at 103 cm). Burned organic material represents 43.5–65%.

*Diatoms and phytoliths (Figure 8c).* Cyatheaceae type phytoliths increase to 25% at 62 cm and at 103 cm. No cf. *Oryza sativa* types occur in the phytolith record, whilst wild *Oryza* bulliforms are present and appear more consistently (0–3%) than in zones 223-3 to 223-1. Ehrhartoideae bilobates appear at 78 cm (2%) and become more consistent from 78 to 0 cm (0–3%).

**Zone 223-5: c. 730–0 cal. BP**

*Pollen and other palynomorphs (Figures 7–8).* Pollen counts remain low in this zone (0–2 grains) until 10 cm and then recover slightly (42 to 59 grains). The montane taxa *Dacrydium* (0–8.47%), Fagaceae (0–7.1%), *Phyllocladus* (0–5.7%) and *Podocarpus* (0–10.2%) generally increase within the top 10 cm, but particularly in the top 2 cm. These results may, however, have been influenced by the very low pollen counts. Open ground taxa fluctuate, but in the top 10 cm represent 45.8–54.8%, and include large scabrate Poaceae, Compositae, Solanaceae, Cyatheaceae and Caryophyllaceae. Small trees/shrubs such as *Malottus, Meliaceae, Myrica, Myrsinaceae, Sapotaceae and Sapindaceae* also appear to increase in the top 10 cm as well as the spores Cyathaceae, Pteridaceae, Polypodiaceae and Davalliacae. The aquatic spore *Equisetum* increases to 7.1–3.4%. Burned organic material represents 46.6–26.1% with lowest percentages occurring in the top 15 cm. An increase in plant cells (from 2.9% to 17.9%) and appearance of testate amoebae also take place in the top 10 cm.

*Diatoms and phytoliths (Figure 8c).* At 10 cm *Oryza* bulliforms appear, which display some characteristics of *Oryza sativa*; however, measurements are closer to that of wild *Oryza* sp., whilst achene phytoliths, possibly sedge type increase in the top 2 cm from 0.4% to 13.5%. Ehrhartoideae bilobates are also present (1–3%).

**Discussion**

Between 2400 and 2200 cal. BP a low-energy fluvial channel probably existed at the site of PDH 223. This channel appears to have been influenced by fires taking place within the catchment area, demonstrated by alternating sands and clays, organic bands, charcoal in the lithology and in the palynomorph record, low loss on ignition and generally low pollen representation, as well as a peak in magnetic susceptibility to 71.5 SI units, reflecting erosional in-wash.

The general vegetation during this period was dominated by open ground taxa, although some shrubs/small trees, general forest and montane forest types also existed in the pollen catchment. High representation of forest spores, such as Cyathaceae, Pteridaceae and Polypodiaceae might further reflect a predominantly open environment. An alternative explanation for the appearance of high fern spores could be the normal taphonomic processes in rivers, which lead to enrichment of fern spores (Hunt, 1987, 1994). The presence of Zygnemataceae is consistent with semi-permanent water, at least in the channel. These filamentous algae require sun-warmed, shallow, usually fairly still water (Van Geel, 1976), so the low numbers may reflect either continued current activity or a partly shaded channel.

Around 2300 cal. BP representation of the sago palm tree *Eugeissona* appears much higher in comparison with most other plant species growing near the channel, with the exception of Cyperaceae, whilst charcoal flecks and pieces are present throughout this period. *Eugeissona* is hapaxanthic (Fisher et al., 1989) and under natural conditions it would be unlikely or indeed rare to find *Eugeissona* pollen grains amongst the pollen counts. These results therefore provide the earliest indication of sago management in the Kelabit Highlands. The pollen evidence is further complemented by recent excavations near Pa’Dalih, which uncovered a broken section of a stone pounder from a stone wall feature. This is thought to have been used to process sago. Charcoal recovered from the packing of this wall feature produced an age of 1700–1500 cal. BP (Beta-280499) (Barton, 2012). Kedit (1982) reports sago is today an important food source for Penan families living in the Gunung Mulu National Park, some of these families are actively involved in the planting of sago palms. Barton (2012) and Christensen (2002) also suggest sago may have been an important crop before rice. Rice was identified in core PDH 223 c. 2200 cal. BP with the presence of one cf. *Oryza sativa* bulliform. It is possible some form of experimental rice cultivation was taking place during the same period; perhaps some form of dry rice as the palaeo-channel would have been a low-energy fluvial channel at the time. Conversely, the shape of the identified *Oryza* bulliform is slightly different to that of the other *Oryza* bulliforms identified and the number of plates could not be counted, therefore the presence of wild rice cannot be ruled out either. Large scabrate Poaceae occur throughout and these could either belong to domesticated or wild varieties of rice.

The pollen representation of *Eugeissona* between c. 2200 and 1800 cal. BP suggests continued sago use, although an absence at 221 cm is probably linked to a major burning event, which took place c. 2150–2130 cal. BP. The burning event is represented by a thick charcoal band in the lithology, a small increase in magnetic susceptibility and also by the appearance of gravelly sand. With no protection of forest cover, runoff must have been intense, causing a major flood event and the deposition of gravels. Even though natural burning cannot be ruled out, anthropogenic burning seems more plausible, given the evidence for sago use.

After the major fire a rise in open ground taxa indicate the establishment of regeneration flora. Catholic taxa and small trees/shrubs
shrubs also increase, which, as with the open ground taxa, probably reflect a rise in regeneration flora after the burning event. There also appears to be wider species diversity, which again appears to be reflective of a more open environment. Increased diversity is shown by the appearance of Myrsinaceae, Meliaceae, Sapotaceae, Sapindaceae and Theaceae. Certain species of Sapotaceae, Sapindaceae and Euphorbiaceae are fruit trees; however, percentage representation is insufficient to suggest arboreal activity. This remains a possibility but the fruit trees could equally be growing wild. Macaranga is also frequently present between 2200 and 1800 cal. BP. According to Slik et al. (2003), who carried out a study examining the distribution of Macaranga and Mallotus species in relation to disturbance in East Kalimantan, Macaranga is a common indicator of disturbed forest and frequently found in burned forest, but absent or rare in primary forest. Slik et al. (2003) suggest only a low count of Macaranga is sufficient to indicate disturbance and secondary forest. An increase in montane forest c. 2150 cal. BP, particularly Dacrydium and Podocarpus, is unlikely to be associated with climate change, but rather with the burning and high intensity fluvial event described above. Upper montane pollen grains could have been washed into the channel during the high energetic fluvial event. Alternatively a more open environment, caused by the burning of vegetation, could have allowed the accumulation and higher representation of wind dispersed pollen from further distances.

By c. 2000 cal. BP, the sediments change from grey to brown sandy clays. Pollen counts also reach a maximum of over 300 per sample and these results may signify a reduction in fluvial activity and the stabilisation of sediments to allow sedimentation of organic particles; although flood events still continued, shown by alternating sands, silts and clays. It could be argued that these flood events are linked to anthropogenic burning in the local vicinity between 1900 and 1800 cal. BP, as several organic layers alternating with burnt layers are observed in the lithology.

The presence of Urticaria at c. 2000 cal. BP suggests pond or swampy conditions in the channel at the time, whilst pennate diatoms further represent the presence of an aquatic environment between 2100 and 1800 cal. BP. The appearance of these shallow-water plants and diatoms coincide with two cf. Oryza sativa buliforms between c. 2000 and 1800 cal. BP and one cf. Oryza sativa glume also at c. 1800 cal. BP. These results might be representative of rice cultivation near or possibly within the channel during this period. A wild Oryza bulliform was also identified at c. 1900 cal. BP and a cf. wild/domesticated Oryza bulliform at c. 2000 cal. BP, although the cf. wild bulliform has an elaborate network of scales, similar to potential domesticated rice. Ehrhartioideae bilobates are present at c. 1900 cal. BP (193 cm). These could belong to domesticated rice, but are also representative of wild varieties and grasses within the Ehrhartioideae family (Piperno, 2006). Large scabrate Poaceae also rise between c. 2100 and 1900 cal. BP (211–183 cm), whilst loss on ignition drops to 1900 cal. BP and a cf. wild/domesticated Oryza phytolith is present (except at 143 cm) until 1500 cal. BP and may be representative of continued Eugeissona use. Percentages are however, significantly lower than previously recorded and might be indicative of a reduction in use, although a higher frequency in burning episodes would also cause a sharp decline. Open ground taxa remain the dominant group. Cyperaceae declines after 173 cm, and this may be related to drier soils caused by the burning. Poaceae and large scabrate Poaceae increase by 1600 cal. BP, as do Scrophulariaceae, and this might be reflective of an open landscape around the channel with the presence of wild rice rather than domesticated varieties, as no cf. domesticated rice phytoliths were identified during this period. Cultivation may have moved to a site which did not yield phytoliths to the deposition site. The percentage of rice phytoliths, identified as cf. Oryza sativa in the PDH 223 record, is low and therefore it is also possible that domesticated rice may have been present within the vicinity of the site, but not recorded.

After 1500 cal. BP iron mottled clays appear indicating wetting and drying in the channel. No evidence of domesticated rice has been identified at this time, although cultivation might be one explanation for the wetting and drying. The wetting and drying, is however, probably associated with the gradual lowering of the water-table in the channel. Pollen preservation is poor during this period and further reflects the gradual lowering of the water-table in the channel, causing oxidation of the channel sediments. Individual pollen grains of Fagaceae, Loranthaceae, Eugeissona and Araliaceae indicate some forest, open forest and shrubs surrounded the channel. The presence of Pteridaceae, Polypodiaceae, Gleicheniaceae, as well as Cyathaceae and Davalliacceae spores demonstrate that the surrounding area is likely to have remained relatively open between 1500 and 700 cal. BP (according to the age–depth model in Figure 3, or between 1500 and 1200 if the linear model is used). The presence of Eugeissona might signify continued sago use, but evidence is limited to just one pollen grain because of poor pollen preservation and therefore this grain could equally represent Eugeissona growing naturally near the channel. After 1400 cal. BP Ehrhartioideae bilobates appear more frequently in the record. This may represent increased rice cultivation, although no cf. Sativa buliforms or glume types were identified. Large scabrate Poaceae are present within the most recent sediments (the last 10 cm), as are Oryza buliforms, which display some characteristics to Oryza sativa; however, measurements are closer to that of wild Oryza sp. Today there is a rice field in another palaeochannel within 50 m of the coring site. Continued wetting and drying in the channel is likely to have
taken place until either relatively recently (c. 150 cal. BP, according to the age–depth model in Figure 3), or until 1200 cal. BP (if the linear model is used). This is followed by the eventual drying up of the channel. An increase in plant cells probably represents soil formation and stabilisation by plants; however, a relatively open–semi-open environment probably existed on and within the vicinity of the site. This can be demonstrated by the presence of small trees/shrubs such as Mallotus, Meliaceae, Myrica, Myrsinaceae, Sapotaceae and Sapindaceae, as well as open ground pollen taxa and Poaceae phytoliths. Today a fruit grove on the site contains species of fruit trees belonging to Sapindaceae, Sapotaceae and Moraceae (Ficus), all of which are represented in the pollen record. It is likely that grass and wild rice varieties, as well as a number of other herbs and shrubs such as Oleaceae, Cyperaceae, Compositae and Scrophulariaceae were growing amongst the semi-open fruit grove as it became established.

Conclusion
This research illustrates how multiproxy studies can provide a valuable insight into past cultural activities and plant use within tropical environments. The results from this paper have provided evidence for both fluctuating fluvial activity and anthropogenic manipulation of the landscape around Pa’Dalih over the last 2300 years. Above-average representation of Eugeissona pollen grains in the pollen record, between 2300 and 1800 BP, suggests a significant use of sago palms near the channel during this period. These results are so far the oldest record for sago cultivation/manipulation in the interior highlands of Borneo.

Pollen and phytolith evidence (scabrate Poaceae, bilobates, bulliforms and one double-peakd glume) suggests that cf. Oryza sativa was being used by at least 1800 cal. BP. Recent excavations in the Kelabit Highlands have provided good evidence for the construction of large settlements and megaliths 2000 cal. BP (Lloyd-Smith, 2012; Lloyd-Smith et al., 2010), which coincides with the appearance of both sago and rice use. This evidence may be associated with the arrival of Neolithic settlers into the interior Highlands of Borneo, although further investigations would be needed to confirm this. Between 1700 and 1600 cal. BP, more intense activity is recorded on the landscape with an increase in the frequency of habitation sites, and within the last 1400 years an increase in the frequency of Ehrhartioideae bilobates is recorded. This could either be associated with an opening of the canopy or potentially a gradual increase in rice cultivation. It is interesting to note that Anshari et al. (2001) also suggest increased human activity, in west Kalimantan within the last 1400 years. Iron mottled sediments appear on the channel after 1600 cal. BP; however the quality of the pollen and phytolith record deteriorates after c. 1500 cal. BP, which would have masked any further evidence for sago and rice use. This might explain why there is no evidence, to support the theory proposed by Barton (2012), that rice production increased during the historic period. A rise in Ehrhartioideae bilobates within the top sediments could potentially support this theory, however, wild Oryza, Ehrharta or Leersia should not be ruled out either (Piperno, 2006). In more recent times the palaeochannel has dried up completely and is today being used as a fruit grove.

Acknowledgements
We would like to thank the Sarawak Forestry Department and Kuching Herbarium for permission to carry out fieldwork, the extraction of samples and use of facilities at the Sarawak Herbarium (SAR). We are very grateful to Dr Kit Pearce who assisted in the collection and identification of plants for a modern pollen reference collection, Ipoi Datam from the National Museum of Sarawak, Ulum from Bario and Belaan Paran for their assistance in the collection of modern samples. Thank you to Reedy in Bario and Henry in Pa’Dalih for their assistance in the field. We would also like to thank everyone from the Cultured Rainforest Project for the assistance and support provided in the field: Dr Graeme Barker, Jefferory (Zyrtec Mchanagan), Ian Ewart, Rose Ferraby, Chris Gosden, Dr Huw Barton, Daniel Britton, Ben Davenport, Dr Monica Janowski, Dr Lindsay Lloyd-Smith, Borbala Nyiri, Beth Upx and Dr Lucy Farr. Thank you also for the advice provided by Dr Premathilake, and John Davidson who assisted in some of the laboratory preparations as well as Ron Reimer. Professor Valerie Hall, Professor Joanthan Pilcher and Dr Maarten Blauw. Finally we would like to thank the reviewers and editor whose comments have significantly helped to improve the manuscript.

Funding
This project was funded by the AHRC.

References

Anshari G, Kershaw AP, Van der Kaars S et al. (2004) Environmental change and peatland forest dynamics in the Lake Sentarum area, West Kaliman-


Barker G, Barton BM, Beavitt P et al. (2002) Prehistoric foragers and farmers in south-east Asia: Recent investigations at Niah Cave, Sarawak. Proce-
ddings of the Prehistoric Society 68: 147–164.

Barker G, Barton BM, Bird M et al. (2007) The human revolution in lowland tropical Southeast Asia: The antiquity and behaviour of anatomically modern humans at Niah Cave (Sarawak, Borneo). Journal of Human Evo-


Blauw M (2010) Methods and code for ‘classical’ age-modelling of radiocar-
bon sequences. Quaternary Geochronology 5: 512–518.


Christensen H (2002) Ethnobotany of the Iban & the Kelabit. Forest Depart-
ment Sarawak. Malaysia. NEPCon. University of Aarhus.


Denham TP and Haberle SG (2008) Agricultural emergence and transforma-


Denham TP, Haberle SG and Lentfer C (2004) New evidence and interpreta-


sylvania.


Huang TC (1972) *Flora of Taiwan*. Taiwan: Taiwan University Press.


Ipi D and Bellwood P (1991) Recent research at Gua Sireh (Serian) and Maliau Basin (Sabah) in the highlands of New Guinea. *Archaeology in Oceania* 7–38.

Janowski M (2003) Recent research at Gua Sireh (Serian) and Maliau Basin (Sabah) in the highlands of New Guinea. *Archaeology in Oceania* 7–38.


