Abstract No: A-031

FLAMING PEAT: SYNERGISTIC EFFECTS OF FIRE AND FOREST CLEARANCE ON TROPICAL PEAT SWAMP FORESTS

Lydia E. S. Cole[1, 4*], Shonil A. Bhagwat[2, 4] and Katherine J. Willis[1, 3, 4, 5]

[1]*Oxford Long-term Ecology Laboratory, Department of Zoology, University of Oxford, United Kingdom*
[2]*Department of Geography, Faculty of Social Sciences, the Open University, United Kingdom*
[3]*Department of Biology, University of Bergen, Norway*
[4]*Biodiversity Institute, Oxford Martin School, Department of Zoology, University of Oxford, United Kingdom*
[5]*Royal Botanical Gardens, United Kingdom*

**Corresponding author: lydcole@gmail.com*

SUMMARY

Recent burning in the tropical peat swamp forests of Southeast Asia, linked with anthropogenic land-use change, has resulted in widespread environmental degradation across the region. Yet little is known about the long-term natural fire regime in these landscapes. Using fossil pollen and charcoal data from three peat cores collected from Sarawak, Malaysian Borneo, we looked at the incidence and impact of local and regional fire on coastal peat swamp forests over the last 7000 years. Results show that burning has occurred in these wetland ecosystems throughout their history. However, prior to the Colonial era *c.* 1839, when human presence in the peat swamp forest was comparatively limited, neither local nor regional burning significantly impacted on the forest vegetation. After the mid-19th Century, at the onset of intensified land-use change, fire incidence elevated significantly within these coastal peat swamp forests. Although fire does not correlate with past vegetation changes in these ecosystems, the long-term data reveal that open vegetation, a proxy for human forest clearance, does to a greater extent. However, results suggest that human activity may be strongly influencing and acting synergistically with fire in the recent past, leading to the enhanced degradation of these peatland ecosystems. These findings support present-day concerns about the increase in fire incidence and combined impacts of fire and human disturbance on peat swamp forests, with serious implications for biodiversity and global climate change.

***Keywords**: fire, burning, peat swamp forest, long-term ecology, anthropogenic disturbance*

INTRODUCTION

The peat swamp forests of Southeast Asia, covering an area of 25 million ha, hold *c.* 12% of the total carbon stored in the world's peatlands (Page *et al.,* 2011). The performance of these peat swamps as a carbon sink relies on a tight interrelationship between the landscape, vegetation and hydrological conditions (Page *et al.,* 1999; Dommain *et al.,* 2010; Posa *et al.,* 2011), making the forest component of this ecosystem vital for its maintenance. Despite this, peat swamp forests are being lost at a rapid pace: in Southeast Asia between 2000 and 2010, 56% were converted to plantations (Miettinen *et al.,* 2012a), in addition to the area lost through logging and other development (Koh *et al.,* 2011). In particular, fire is considered one of the most important drivers of land-use change and vast areas of these tropical peat swamps burn every year (Razali *et al.,* 2010; Phua *et al*., 2012), especially on the island of Borneo (Langner & Siegert 2009; Hoscilo *et al*., 2011).

Burning has increasingly affected the peat swamp forests of Southeast Asia in the last two to three decades (Taylor 2010) and is claimed to be one of the most insidious threats to peat-swamp habitats (Razali *et al*., 2010), as well as to all rainforest ecosystems (Laurance 2003). However, natural fires, predominantly caused by lightning strikes, have constituted an important part of the ecosystem dynamics in these tropical peat swamps (Taylor *et al.*, 2001), by creating gaps in which succession can occur. A study of peat swamp forests in Western Kalimantan suggests that fire has been a component of the landscape for at least the last 30,000 years (Anshari *et al.* 2001), and in Singapore, for the last 23,000 years (Taylor *et al.,* 2001).

Small-scale forest burning by humans, largely as part of shifting cultivation practices (Haberle *et al.,* 2001), has been recorded in forests in Sarawak from the early Holocene (Hunt & Premathilake 2012). More recently however, fires are reported to have increased in frequency, magnitude and impact in peat swamp forests in eastern Kalimantan (Hope *et al.,* 2005), in Australasia over the last few centuries (Mooney *et al.,* 2011), and across other areas of Southeast Asia in the last two or three decades (Taylor 2010). How much recent fire frequency has increased relative to historical levels, and what impact it has had in shaping ecosystem dynamics in the peat swamp

forests of Sarawak, is still poorly understood.

This study aimed to investigate the patterns of fire, both local and regional in scale, in Sarawak's coastal peat swamp forests, using a long-term ecological approach. The overall objective was to determine the change in frequency and magnitude of fire through time in these ecosystems, and how/if this has influenced forest composition. Through reconstructing past burning regimes and vegetation change from fossil records contained in three sedimentary sequences extracted from peatlands on the coast of northern Borneo, this study addressed two key research questions: (i) What is the natural fire regime in these swamps, and how has it changed through time?, and (ii) How do the changing fire regimes impact the peat swamp forest vegetation?

METHODS

The State of Sarawak contains the greatest proportion of Malaysia's peat swamp forests, covering an area of approximately 3000 km^2 or 2% of the State (Miettinen *et al*., 2012b), and of its deforested peatlands, which extend over an additional 11% (FAQ, 2012). Until recently, the peat swamp forests of Sarawak were denounced as "marginal wastelands" (Sawal, 2003), of little use except in the absence of alternative land. As such, large-scale conversion has occurred (Miettinen *et al*., 2012a), predominantly for agricultural production (Koh *et al*., 2011), where fire is commonly used to clear the forest vegetation (Wooster *et al*., 2012).

Sedimentary cores were extracted using a hand-held coring device, from three peatlands across the Miri and Batu Niah Districts of north-east Sarawak: Deforested Peatland from Senadin, Kuala Baram (04°30'47"N, 114°2'47"E), an area of degraded peatland covering >50 km^2; Peat Swamp Fragment from Sungai Dua Forest Reserve (04°21'24"N, 114°0'21"E), a *c.* 2 km^2 fragment of secondary peat swamp forest; and Converted Peatland from Sungai Niah (03°52'4"N, 113°42'43"E), an agriculture-forest matrix of *c.* 1 km^2. Though these three sampled sites cover a relatively narrow geographical range of 80 km along the coast of northern Borneo, since there is limited variation in climate, geology and land-use across the region, they are sufficiently representative of the coastal peat swamp ecosystems of Sarawak, and to an extent, of Borneo and parts of Southeast Asia.

Using standard palaeoecological techniques (Bennett & Willis, 2001), the sedimentary cores were analysed at set intervals through the sequences for fossil pollen, microfossil and macrofossil charcoal and mineral magnetic material (magnetic susceptibility). Once counted, fossil pollen grains were divided into different ecological groups, defined as follows: total PSF (TotPSF), which encompasses all peat swamp forest (PSF) associated taxa; the mature PSF community (PSF); the pioneer PSF community (PSF+); taxa of degraded peatlands (DP); taxa of other forests (OF); coastal vegetation (CV), and open vegetation, comprising taxa which dominate open-canopied areas of greater spatial and temporal scale than tree-fall gaps, for example Poaceae, Cyperaceae and ferns (both of monolete and trilete morphologies). This latter ecological group is used as an indicator of human impact. A size-class analysis of fossil charcoal, *i.e.* differentiating between macrofossil and microfossil charcoal was performed to investigate changes in local and regional fire regimes, respectively, in each site through time (Whitlock and Larsen, 2002). To determine the age-depth relationship of the sedimentary cores, samples containing organic material suitable for ^{14}C dating were extracted from each and analysed with AMS radiocarbon dating techniques, at the ^{14}Chrono Centre in the Archaeology and Palaeoecology Department, at Queen's University Belfast, and the SUERC AMS Laboratory, at the NERC Radiocarbon Facility.

KEY RESULTS

i. What is the natural fire regime in these coastal peat swamps? How has it changed towards the present day?

Fire has been present in all three sites through time (Figure 1). Fluctuations in macrocharcoal and microcharcoal levels vary within and between cores, though there are two distinct phases of elevated magnitude and frequency of burning: between *c*. 2800 and 1800 Cal. yr BP and from *c*. 200 Cal. yr BP to the present.

ii. How do the changing fire regimes impact the peat swamp forest vegetation?

Peat swamp forest is the baseline vegetation at all three sites over the late Holocene period that these coastal swamps have been present, dominating the vegetation profile. Since the inferred onset of peat swamp development (varying in each core), the percentage of pollen from the total PSF ecological group (aggregate dark and light green components on the pollen sum diagram, Figure 1) has been relatively constant in each site through time, fluctuating *c.* 80%. However, in the Peat Swamp Fragment and Converted Peatland sites, the total PSF proportion declines in the last *c.* 500 years. The indicator group of disturbance within the peat swamp forest, PSF+, does not appear to follow a pattern within or across sites, thus demonstrating internal dynamism throughout the past. Open vegetation levels in all sites remain low until *c*. 200 Cal. yr BP, with the exception of an anomalous peak in the Peat Swamp Fragment prior to 2000 Cal. yr BP. This notable increase in open vegetation taxa suggests that there was a higher incidence of open-canopied areas in the vicinity of these sites in the last several hundred years.

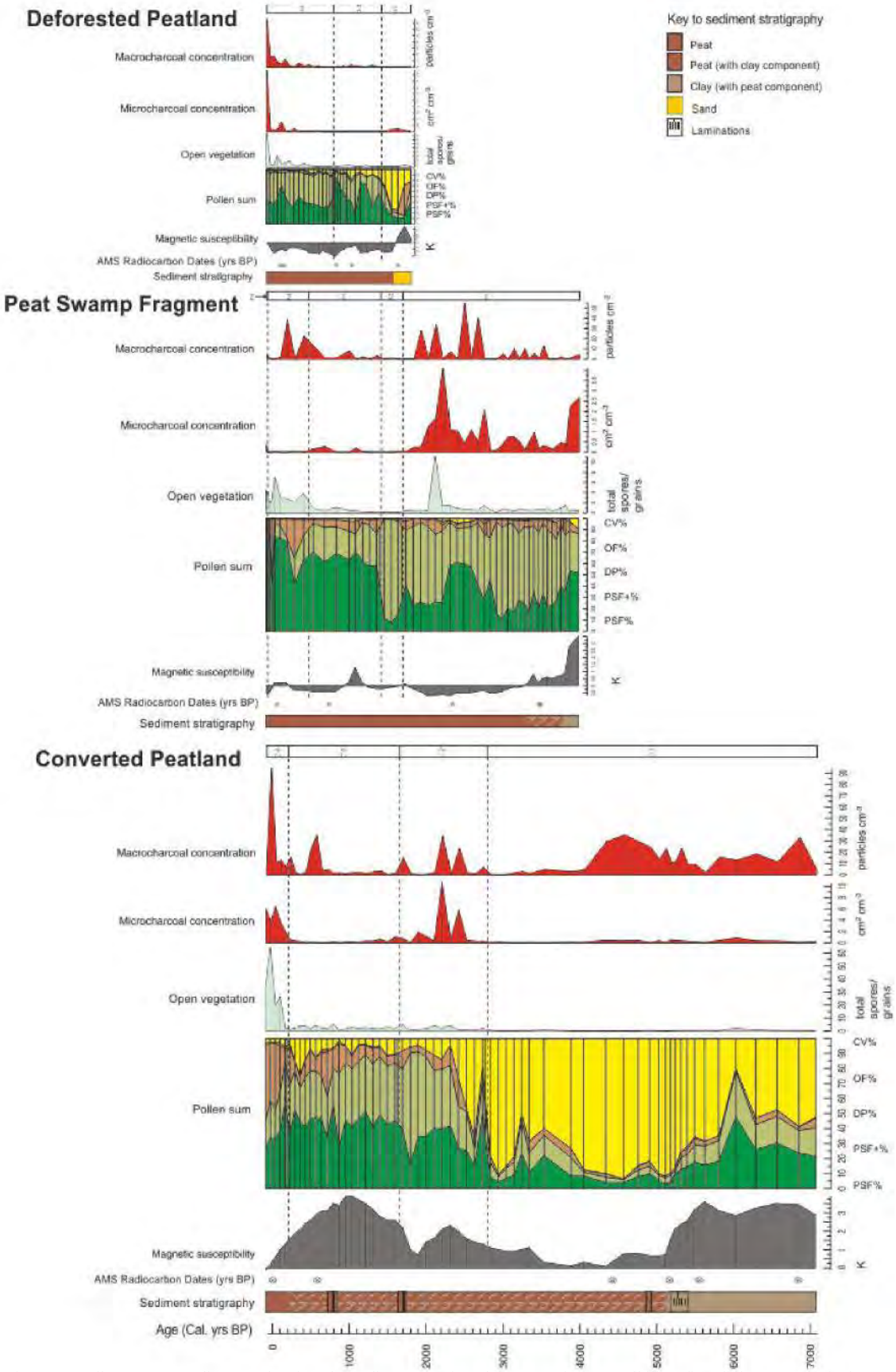

Figure 1: Pollen summary diagram showing the sediment stratigraphy, magnetic susceptibility, five different ecological groups (represented by the following colours: PSF dark green, PSF+ light green, DP brown, OF orange and CV yellow), open vegetation (light grey) and macrocharcoal and microcharcoal (red) for the Deforested Peatland, Peat Swamp Fragment and Converted Peatland sites. Cores have been adjusted to enable their chronological correspondence against one timescale. Significant pollen zones are shown for each. TotPSF% comprises the sum of PSF% and PSF+%, and is represented by the division between PSF+% and DP%.

DISCUSSION

This investigation found there to be no consistent fire regime across the three studied peat swamp forest ecosystems on the coast of Sarawak over the last 2000 to 7000 years. It also demonstrates that fire has not had a significant impact on either internal peat swamp forest vegetation communities or ecological change within the wider landscape through time. Rather, patterns of burning appear to be predominantly idiosyncratic and drivers of vegetation change predominantly anthropogenic.

(i) What is the natural fire regime in these coastal peat swamps? How has it changed towards the present day?

Results from this study demonstrate that fire has been present throughout the past within these coastal peat swamp forests, in accordance with findings from elsewhere in the region (Anshari *et al.,* 2001; Taylor *et al.,* 2001). However, there is no apparent ‗natural' or predictable baseline local or regional burning regime. Instead, evidence suggests that there were two notable episodes of increased fire across sites, overlaying a background of heterogeneity. The first episode, between *c.* 2800 and 1800 Cal. yr BP, coincides with a period of climatic drying in the Tropics that is reported to have occurred in the interval 2000 – 3000 Cal. yr BP (Selvaraj *et al.,* 2007; Woodroffe *et al.,* 2003). The latter episode, from *c.* 200 Cal. yr BP to the present, is likely to have resulted from increased human interaction with and impact on Sarawak's coastal peat swamp forests. Until several hundred years ago, local fires (those within peat swamp forest) would predominantly have been driven by natural disturbances such as lightning strikes, especially during dry climatic periods, *i.e. El Niño* years (Hope *et al.,* 2005). Human disturbance would have been minimal (Sawal, 2003), restricted to activities such as subsistence sago cultivation. Within the last 200 years however, the coincidence of data showing dramatic increases in the magnitude and frequency of local and regional fire (and open areas), with the reporting and documenting of increased human interaction with Sarawak's coastal peat swamp forests, suggests that humans were responsible for these elevations in burning. Significant landscape exploitation by people, in a great part through the use of fire, is likely to have started after Colonial Rule was established in Sarawak approximately 170 years ago. More recently, further and more dramatic increases in the burning of peatlands have been recorded in Sumatra (Miettinen *et al.,* 2012c) and across Southeast Asia (Van Eijk *et al.,* 2009).

(ii) How do the changing fire regimes impact the peat swamp forest vegetation?

Results from this study suggest that fire has not caused significant disturbance to these three coastal peat swamp forests through time. Even during episodes of elevated burning in the past, for example during the hypothesised dry phase between *c.* 2800 - 1800 Cal. yr BP, there is no decline in the peat swamp forest or apparent impact on the vegetation within these ecosystems. In terms of internal peat swamp forest dynamics through time, the fluctuation between mature and pioneer taxa does not correlate with fire incidence, again suggesting that, in general, burning has not played a significant role in the regeneration of these ecosystems. Since anthropogenic burning is hypothesised to have only started in the last two centuries, it appears that the natural burning regimes in each site, which have been predominantly idiosyncratic, have not had a significant negative impact on these peat swamp forests.

In conjunction, the results from the three studied sedimentary cores strongly suggest that fire has been present in tropical peat swamp forests for thousands of years and that it is not the most prominent driver of long-term or recent changes in coastal peat swamp forest vegetation, contrary to the common concern expressed in the literature on the sustainable management of tropical peat swamp forests today (for example Razali *et al.,* 2010; Miettinen *et al.,* 2012c). Instead, human impact has had the most influence on internal peat swamp forest dynamics and peat swamp forest decline, and this disturbance has manifested only in the last *c.* 200 years. In reality however, it is likely that forest clearance, drainage and fire occur simultaneously and act synergistically in these landscapes, exacerbating impacts, reducing forest regeneration potential and thus jeopardizing the resilience of these peat swamp forests. Management implications The causes of fire are complex, and include underlying cultural, political and socio-economic conditions, not simply environmental or climatic factors (Stolle *et al.,* 2003; Langner & Siegert, 2009; Carlson *et al.,* 2012), such as the recent *El Niño* event. The interaction between different drivers of disturbance requires further investigation when considering management interventions. If recent elevated trends in burning can be prevented, predominantly through halting forest clearance and drainage, this and other studies (e.g. Hope *et al.,* 2005) provide evidence that peat swamp forests are resilient to less frequent and less intense fire. However, in the face of current conversion rates and future land-use planning in the region (Miettinen *et al.,* 2012a), potential disturbance by fire must be a central consideration in the more sustainable management of these carbon-rich ecosystems.

ACKNOWLEDGEMENTS

Authors would like to thank Samantha Jones, Kho Lip Khoon and several kind reviewers, and acknowledge NERC, the NERC Radiocarbon Dating Facility (Radiocarbon Analysis Allocation Number 1565.0411) and SUERC Dating Lab for their financial support with this project.

REFERENCES

1. Anshari, G., P. Kershaw, A. & Van Der Kaars, S. (2001). A Late Pleistocene and Holocene pollen and charcoal record from peat swamp forest, Lake Sentarum wildlife reserve, West Kalimantan, Indonesia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 171, 213–228.
2. Carlson KM, Curran LM, Ratnasari D, et al. (2012) Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 7559–7564.
3. Dommain, R., Couwenberg, J. & Joosten, H. (2010). Hydrological self-regulation of domed peatlands in south-east Asia and consequences for conservation and restoration. *Mires and Peat*, 6, 1–17.
4. Haberle, S.G., Hope, G.S. & Van Der Kaars, S. (2001). Biomass burning in Indonesia and Papua New Guinea: Natural and human induced fire events in the fossil record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 171, 259–268.
5. Hope, G., Chokkalingam, U. & Anwar, S. (2005). The stratigraphy and fire history of the Kutai Peatlands, Kalimantan, Indonesia. *Quaternary Research*, 64, 407–417.
6. Hoscilo, A., Page, S.E., Tansey, K.J. & Rieley, J.O. (2011). Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. *International Journal of Wildland Fire*, 20, 578–588.
7. Hunt, C.O. & Premathilake, R. (2012). Early Holocene vegetation, human activity and climate from Sarawak, Malaysian Borneo. *Quaternary International*, 249, 105–119.
8. Koh, L.P., Miettinen, J., Liew, S.C. & Ghazoul, J. (2011). Remotely sensed evidence of tropical peatland conversion to oil palm. *Proceedings of the National Academy of Sciences of the United States of America*, 108, 5127–5132.
9. Langner, A. & Siegert, F. (2009). Spatiotemporal fire occurrence in Borneo over a period of 10 years. Global Change Biology, 15, 48–62. Laurance, W.F. (2003). Slow burn: the insidious effects of surface fires on tropical forests. *Trends in Ecology & Evolution*, 18, 209–212.
10. Miettinen, J., Shi, C., Tan, W.J. & Liew, S.C. (2012a). 2010 land cover map of insular Southeast Asia in 250-m spatial resolution. *Remote Sensing Letters*, 3, 11–20.
11. Miettinen, J., Shi, C. & Liew, S.C. (2012b). Two decades of destruction in Southeast Asia‘s peat swamp forests. *Frontiers in Ecology and the Environment*, 10, 124–128.
12. Miettinen, J., Hooijer, A., Wang, J., Shi, C. & Liew, S. (2012c). Peatland degradation and conversion sequences and interrelations in Sumatra. *Regional Environmental Change*, 12, 729–737.
13. Mooney, S.D., Harrison, S.P. & Bartlein, P.J. (2011). Late Quaternary fire regimes of Australasia. *Quaternary Science Reviews*, 30, 28–46.
14. Page, S.E., Rieley, J.O. & Banks, C.J. (2011). Global and regional importance of the tropical peatland carbon pool. *Global Change Biology*, 17, 798–818.
15. Page, S.E., Rieley, J.O., Shotyk, Ø.W. & Weiss, D. (1999). Interdependence of peat and vegetation in a tropical peat swamp forest. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 354, 1885–1887.
16. Phua, M.-H., Tsuyuki, S., Soo Lee, J. & Ghani, M.A.A. (2012). Simultaneous detection of burned areas of multiple fires in the tropics using multisensor remote-sensing data. *International Journal of Remote Sensing*, 33, 4312–4333.
17. Posa, M.R.C., Wijedasa, L.S. & Corlett, R.T. (2011). Biodiversity and conservation of tropical peat swamp forests. *BioScience*, 61, 49–57.
18. Razali, S.M., Nuruddin, A.A., Malek, I.A. & Patah, N.A. (2010). Forest fire hazard rating assessment in peat swamp forest using Landsat thematic mapper image. *Journal of Applied Remote Sensing*, 4, 043531.
19. Sawal, P. (2003). Threats to Peat Swamp Forest of Sarawak. Malaysia/The Netherlands Joint Working Group on Sustainable Forest Management, Kuching, Malaysia, Available from: http://www.alterra.wur.nl/NR/rdonlyres/78164A36-BDC0-471F-BB80-08D10A55F689/135280/JWGRAM05.pdf.
20. Selvaraj, K., Chen, C.T.A. & Lou, J.-Y. (2007). Holocene East Asian monsoon variability: Links to solar and tropical Pacific forcing. *Geophysical Research Letters*, 34, L01703.
21. Stolle, F., Chomitz, K.M., Lambin, E.F. & Tomich, T.P. (2003). Land use and vegetation fires in Jambi Province, Sumatra, Indonesia. *Forest Ecology and Management*, 179, 277–292.

22. Taylor, D. (2010). Biomass burning, humans and climate change in Southeast Asia. *Biodiversity and Conservation*, 19, 1025–1042.
23. Taylor, D., Yen, O.H., Sanderson, P.G. & Dodson, J. (2001). Late quaternary peat formation and vegetation dynamics in a lowland tropical swamp; Nee Soon, Singapore. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 171, 269–287.
24. Van Eijk & et al. (2009). Regeneration and restoration of degraded peat swamp forest in Berbak NP, Jambi, Sumatra, Indonesia. *Malayan Nature Journal*, 61, 223–241.
25. Whitlock, C. & Larsen, C. (2002). *Charcoal as a Fire Proxy*. In: Tracking Environmental Change Using Lake Sediments: Developments in Paleoenvironmental Research (eds. Smol, J.P., Birks, H.J.B., Last, W.M., Bradley, R.S. & Alverson, K.). Springer Netherlands, pp. 75–97.
26. Woodroffe CD, Beech MR, Gagan MK (2003) Mid-late Holocene El Niño variability in the equatorial Pacific from coral microatolls. *Geophysical Research Letters*, 30, 10–1.
27. Wooster, M.J., Perry, G.L.W. & Zoumas, A. (2012). Fire, drought and El Niño relationships on Borneo (Southeast Asia) in the pre-MODIS era (1980-2000). *Biogeosciences*, 9, 317–340