Changes in Tree Phenology across Africa: A comparison across 17 sites

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Introduction

The factors that trigger flowering and fruiting in tropical trees are poorly known. What cues do they use? If climatic cues how might these be affected as the world starts to warm. Few studies have considered the implications of climate change on phenologies of tropical trees (Corlett and LaFrankie, 1998). Tropical trees may be quite sensitive to increasing temperatures, exhibiting lower growth rates (Clark *et al* 2003; Feeley *et al.* 2007), a narrow range of response for photosynthetic acclimation (Cunningham and Reid 2002;2003), and re-allocations of root and above-ground biomass (Reichart and Borchert, 1984; Körner, 1991). Climate changes are expected to affect a number of proximate cues for tropical tree phenologies. Proximate cues include onset of rain in seasonal climates (Sakai *et al.* 2006), drought in aseasonal climates (Ashton *et al.* 1998), cold snaps (van Schaik *et al.* 1993), increasing temperature (Wright and van Schaik, 1994; Thomas and Vince-prue 1997), seasonal changes in solar irradiance (Borchert *et al.* 2005; Kinnaird, 1992), changes in daylength (Cleland *et al.* 2007), changes in timing of sunrise and sunset (Kinnaird and O'Brien, 2007), and soil moisture (Wright and Calderon, 2006).

Recent research on the long term changes in flowering and fruiting of tropical forest trees in Africa is showing that there have been significant reductions in the percentage of trees fruiting at some sites (Plumptre, 2012). In Budongo Forest Reserve in western Uganda fruiting of trees >10cm DBH has dropped from 17% of trees in 1992 to 2% in 2009. Similarly if only trees >30cm DBH are considered there has been a decline from 70% to 25% over the same period (Babweteera *et al. 2012*). For some individual tree species such as *Celtis zenkeri* the percentage of trees fruiting has dropped from 80% to less than 10% of trees and this is one of the most abundant species in the forest. In the Nyungwe National Park the percentage of fruiting trees has significantly declined during the main fruiting periods of the year between 1996 and 2009 (Chao *et al.* 2012). However, in Kibale National Park the percentage of fruiting trees declined between 1970-1983 but increased between 1990-2002 (Chapman *et al.* 2012;2005a; 2005b) . Some species such as *Parinari excelsa*, a dominant tree in this forest, fruited regularly in the 1970s but has rarely fruited between 1990 and 2002 (Chapman *et al.* 2012*)*. What is leading to these changes and can climate change explain them? These results led to the idea to analyse phenology changes in tropical trees across Africa to assess what patterns exist and to start to look at whether there is any evidence of climate change influencing these changes.

As part of a grant for the "Comprehensive Monitoring for Climate Change Adaptation and Management in the Albertine Rift Protected Area Network" project funded by the John D. and Catherine T. MacArthur Foundation some funding was given to support long term monitoring of the phenology of trees at selected sites within the Albertine Rift. At the end of this grant there was some funding available to hold a meeting to analyse data coming out of these sites as well as invite people together with data from other sites across Africa to jointly analyse the data using similar methods. The Budongo Conservation Field Station (BCFS) kindly provided additional funds to allow the meeting to take place.

Many research stations collect phenology data but few have analysed these data and as a result there exist several long term data sets in Africa which had never been analysed and published in the literature. This short report summarizes the activities and outputs of a workshop held at the Institute for Tropical Forest Conservation in Uganda which brought together people who had long term data on the flowering and fruiting of trees at 17 sites in Africa, for many of these sites it was the first time their data had been analysed.

Methods Used

Scientists from seventeen sites participated in this workshop by either attending personally or contributing data for analysis. These included:

1. Mpala Research centre, Kenya – Tim O'Brien and Margaret Kinnaird
2. Kakamega Forest, Kenya – Marina Cords
3. Amani Nature Reserve, Tanzania – Henry Ndangalasi and Norbert Cordeiro
4. Mahale Mountains National Park, Tanzania – Nori Itoh and Kazuhiko Hosaka
5. Gombe Stream National Park , Tanzania – Ian Gilby and Anne Pusey
6. Nyungwe National Park, Rwanda – Felix Mulindahabi
7. Bwindi Impenetrable National Park, Uganda – Badru Mugerwa, Frederick Ssali, Dougla Sheil and Martha Robbins.
8. Kibale National Park, Uganda – Colin Chapman
9. Budongo Forest Reserve, Uganda – Fred Babweteera and Andrew Plumptre
10. Okapi Wildlife Reserve, Democratic Republic of Congo – Floribert Bujo, Corneille Ewango and Terese Hart
11. Lope Reserve, Gabon – Kate Abernethy and Kath Jeffrey
12. Loango National Park, Gabon – Martha Robbins and Leo Polansky
13. Mbeli Bai, Nouabale Ndoki Park, Congo Republic – Mireille Hockemba and Thomas Breuer
14. Goualuogo, Nouabale Ndoki Park, Congo Republic – Sydney Ndolo, Dave Morgan, and Crickette Sanz
15. Mondika, Central African Republic – Dian Doran and Natasha Shah
16. Mbaiki, Central African Republic – Adeline Fayolle
17. Tai National Park, Ivory Coast – Christophe Boesch, Leo Polansky

At most sites researchers visited their trees once every month but scored the flower and fruit abundance differently. Therefore we focused analyses on whether the tree was flowering/fruiting (exhibiting a phenophase) rather than relative abundances of each phenophase. Three main analyses were made:

A. General patterns in flowering and fruiting were made over the time period records existed at each site for trees that had survived the whole period of monitoring. Anomalies from the mean number of trees exhibiting that phenophase in each month were also calculated as a measure of the departure from the mean over time.

B. Trend analyses were made to each data set fitting five GAM models (Table 1):
   a. Model 1: Nonlinear trend + seasonality : Non linear increase or decrease of phenophase incorporating variation of seasonality
   b. Model 2: Linear trend+seasonality : looks for seasonality and a linear trend over time
   c. Model 3: Nonlinear trend + no seasonality:for species that react erratically - no seasonal trends
   d. Model 4: No trend +seasonality :related to month (m) of year – seasonal variation
   e. Model 5: Random– Probability of phenophase

Generalized Additive Models (GAM) were initially fitted but these don't strictly take into account the fact that repeated measures are being made for the same individuals. Generalized Additive Mixed Models (GAMM) are better model to fit as they can incorporate individual variability (Table 1). However they are also computationally very demanding and for the large data sets we did not have computers that could analyse them. Those sites with shorter time periods did compare the GAM and GAMM analyses and found very little difference in the results though – the trends were the same using both models.

Table 1. Summary of models abbreviations. Species level fits can include an additional random intercept term b_k to accommodate intraspecific heterogeneity, but we didn't do this for the forest models because of computation issues. g1, g2, etc are model names for group level (gam) analyses, and re1, re2, etc are names for random effects model (gamm) analyses.

Models	Equation	Description
Model 1 (g1,re1)	$g(\mathrm{E}[y_{i,k}]) = \beta_0 + s_1(t) + s_2(t)$	Nonlinear trend and seasonal production
Model 2 (g2,re2)	$g(\mathrm{E}[y_{i,k}]) = \beta_0 + \beta_1 t + s_2(t)$	Linear trend and seasonal production
Model 3 (g3,re3)	$g(\mathrm{E}[y_{i,k}]) = \beta_0 + s_1(t)$	Nonlinear trend only
Model 4 (g4,re4)	$g(\mathrm{E}[y_{i,k}]) = \beta_0 + s_2(t)$	Seasonal production only
Model 5 (g0,re0)	$g(\mathrm{E}[y_{i,k}]) = \beta_0$	Null random effects model

C. Correlations with four indices of El Nino/La Nina events in the Pacific ocean. We sourced data on six indices of ENSO activity. These where the Southern Oscillation Index (SOI) obtained from the Australian Bureau of Meteorology (http://www.bom.gov.au/) and five indices of sea surface temperature (ONI, Niño 1+2, Niño 3, Niño 3.4, and Niño 4) obtained from the National Oceanic and Atmospheric Administration (www.cpc.noaa.gov/). The Australian Bureau of Meteorology utilises the Troup method to calculate SOI which is the standardised anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin with a base period of 1933 to 1992. Sustained negative values of the SOI often indicate El Niño episodes. Positive values of the SOI are associated with stronger Pacific trade winds and warmer sea temperatures to the north of Australia, popularly known as a La Niña episode. ONI is derived from a three month running mean of sea-surface temperature (SST) anomalies (Smith et al. 2008) in the Niño 3.4 region (5°N-5°S, 120-170°W), based on the ERSST.v3b data set for the 1971-2000 base period. El Niño conditions are characterised by positive ONI greater than or equal to +0.5°C and La Niña conditions characterised by negative ONI less than or equal to -0.5°C. For historical purposes full-fledged El Niño and La Niña episodes are defined when the threshold is met for a minimum of five consecutive over-lapping months. The remaining sea surface anomalies were also derived from the ERSST.v3b data set and same base period for windows of the Pacific Ocean spanning progressively from the east coast of Australia to the west coast of South America - Niño 4 (5°N-5°S, 160°E-150°W), Niño 3.4 (5°N-5°S, 170-120°W), Niño 3 (5°N-5°S, 150-90°W), and Niño 1+2 (0-10°S, 90-80°W) (Figure 1).

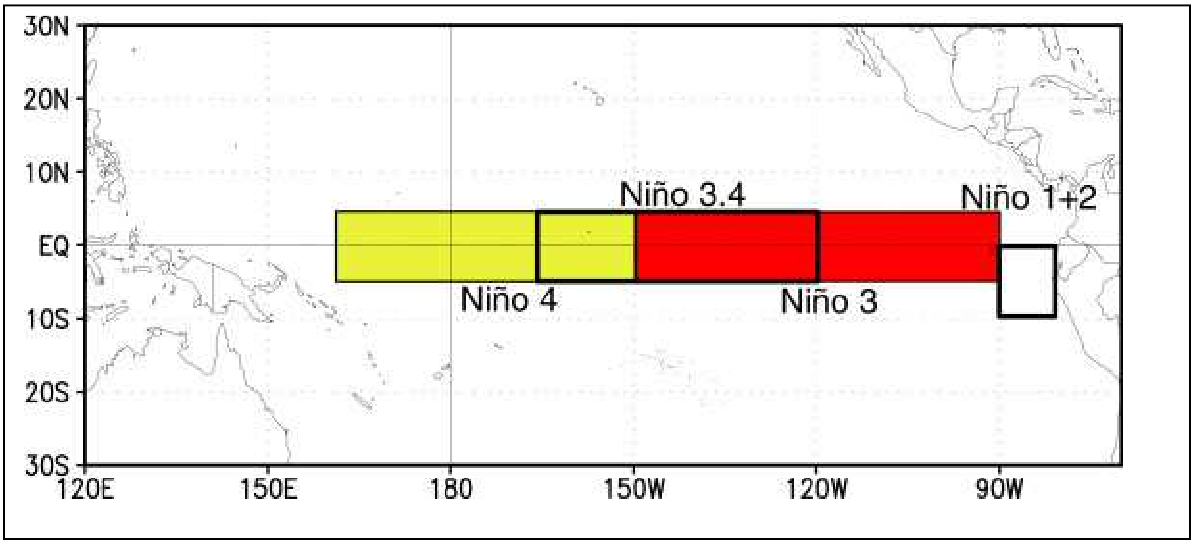

Figure 1. The location of the four Niño sea surface anomaly indices in the Pacific. ONI and SOI are indices for the whole region.
(Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/nino_regions.shtml)

It became clear during the workshop that for Africa ENSO sea surface anomalies may not be the best measure of climate as ENSO influences but does not have a direct correlation with the Indian Ocean Dipole or the North Tropical Atlantic Index which more directly affect climate in east and west/central Africa respectively. Follow up work is looking at these indices and their correlation with phenology.

Statistical analyses

Everyone provided data on the species they monitored in advance and these were cleaned for spelling errors and updated to the latest names using online databases such as the Plant List (http://www.theplantlist.org/) and the African Plants Database (http://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php). Dioecious trees were then identified because while these trees will show male and female flowers on separate individuals, only female trees will produce fruit and we wanted to omit male trees from any analysis of fruiting.   Analyses were all made in the R software (http://cran.r-project.org) and scripts used are given in the appendices of this report. Scripts were run from within Tinn-R (http://sourceforge.net/projects/tinn-r/).

Main results

A summary of results across sites is presented here because each site will want to publish their site data separately and we agreed to share data for the across Africa comparison. We also present only the preliminary results as there is a need to work on the data further. A total of 17,464 trees were monitored from 588 species of plant (mostly trees but 29 lianas were also monitored).

General patterns in phenology

The initial analyses aimed to analyse the general patterns in the flowering and fruiting of all trees as well as specific species and were made for individual species (figure 2a) where the number of tree monitored was greater than 6 and also the summary across the forest for all species monitored (figure 2b).

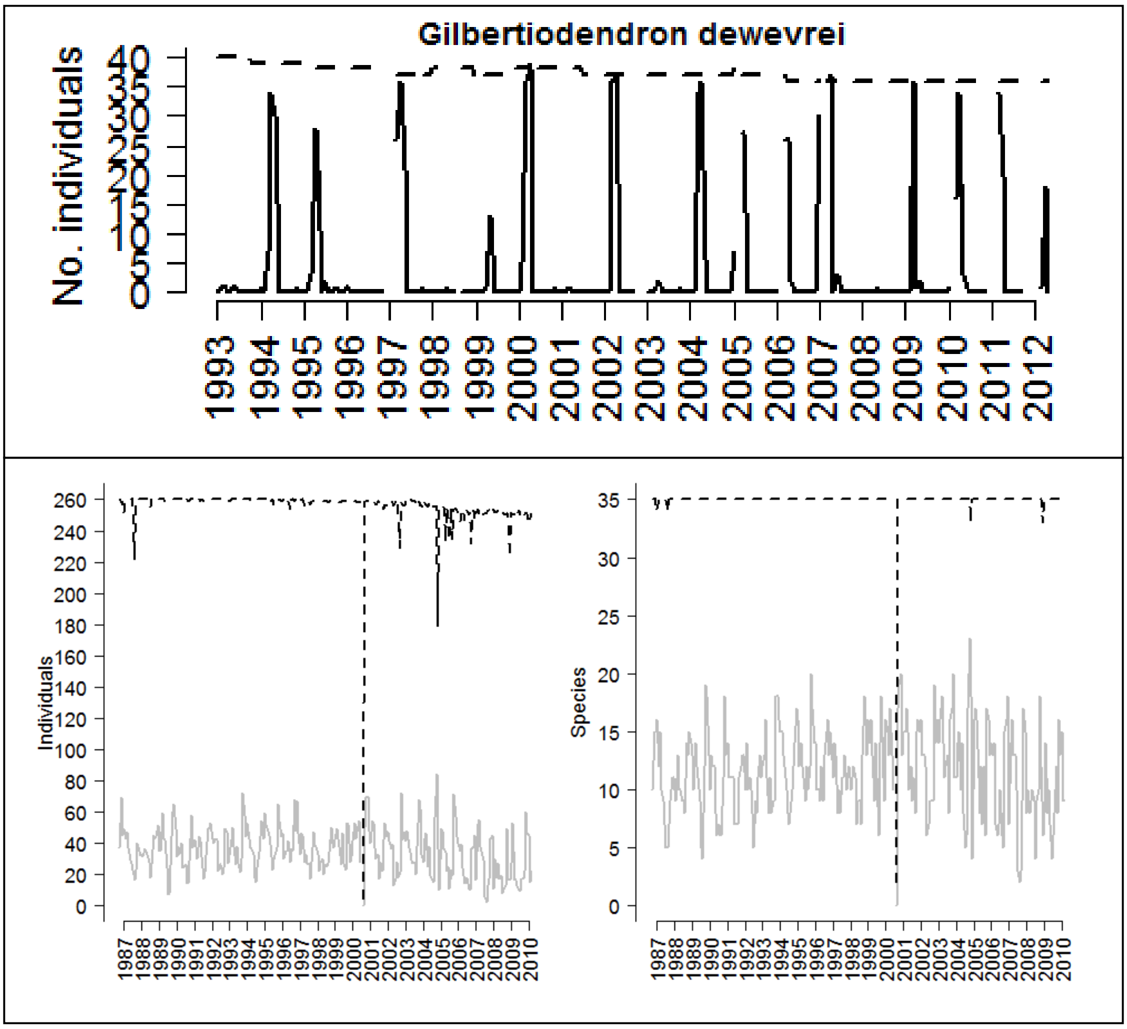

Figure 2. a) The number of Gilbertiodendron dewevrei trees flowering at the Okapi Faunal Reserve (top). **b)** The number of individuals flowering per month at Lope Reserve in Gabon (left) and number of species flowering per month (right). The black dotted lines at the top indicate the number of individuals/species being monitored in any month.

The anomaly values were then calculated for each species and for the forest as a whole comparing the value in that month with the mean across all years to see if any general patterns could be detected for the forest as a whole or for individual species (Figures 3 and 4). These anomalies were then compared across all forests (Figure 5) to look for any obvious patterns in the data.

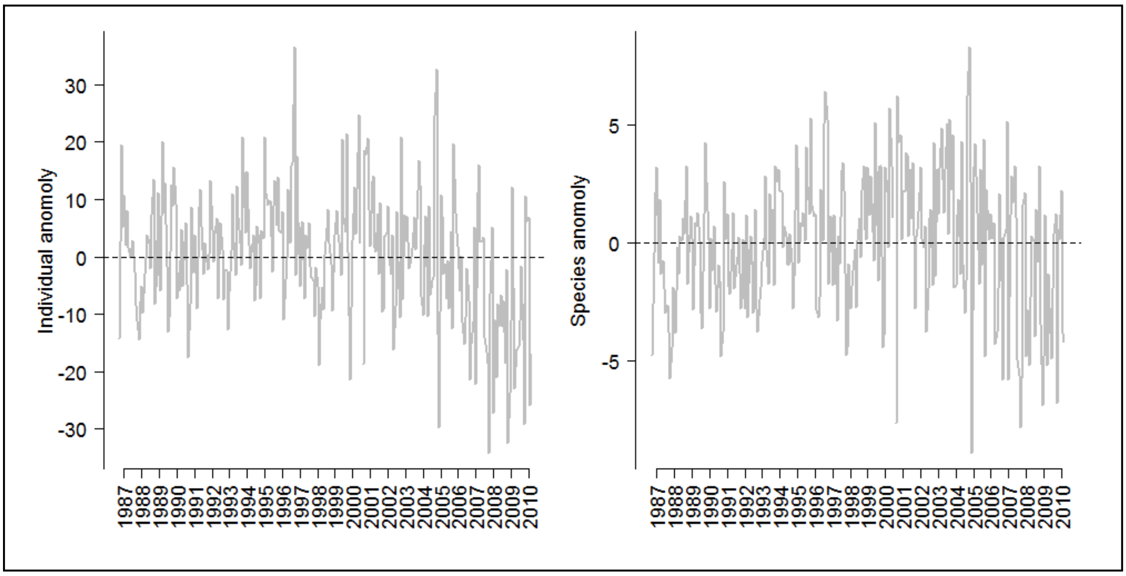

Figure 3. The anomaly between the value that month and the mean across the time period for flowering in the number of individuals (left) and the number of species (right) for Lope Reserve in Gabon. The anomaly indicates that there seems to have been a decrease in the number of individuals and species flowering since 2004.

No clear patterns emerge from the anomalies figures for each site in Figure 4 whether you consider sites in East vs Central Africa or sites north or south of the equator. It is clear that phenology is likely to vary depending on more site specific characteristics.

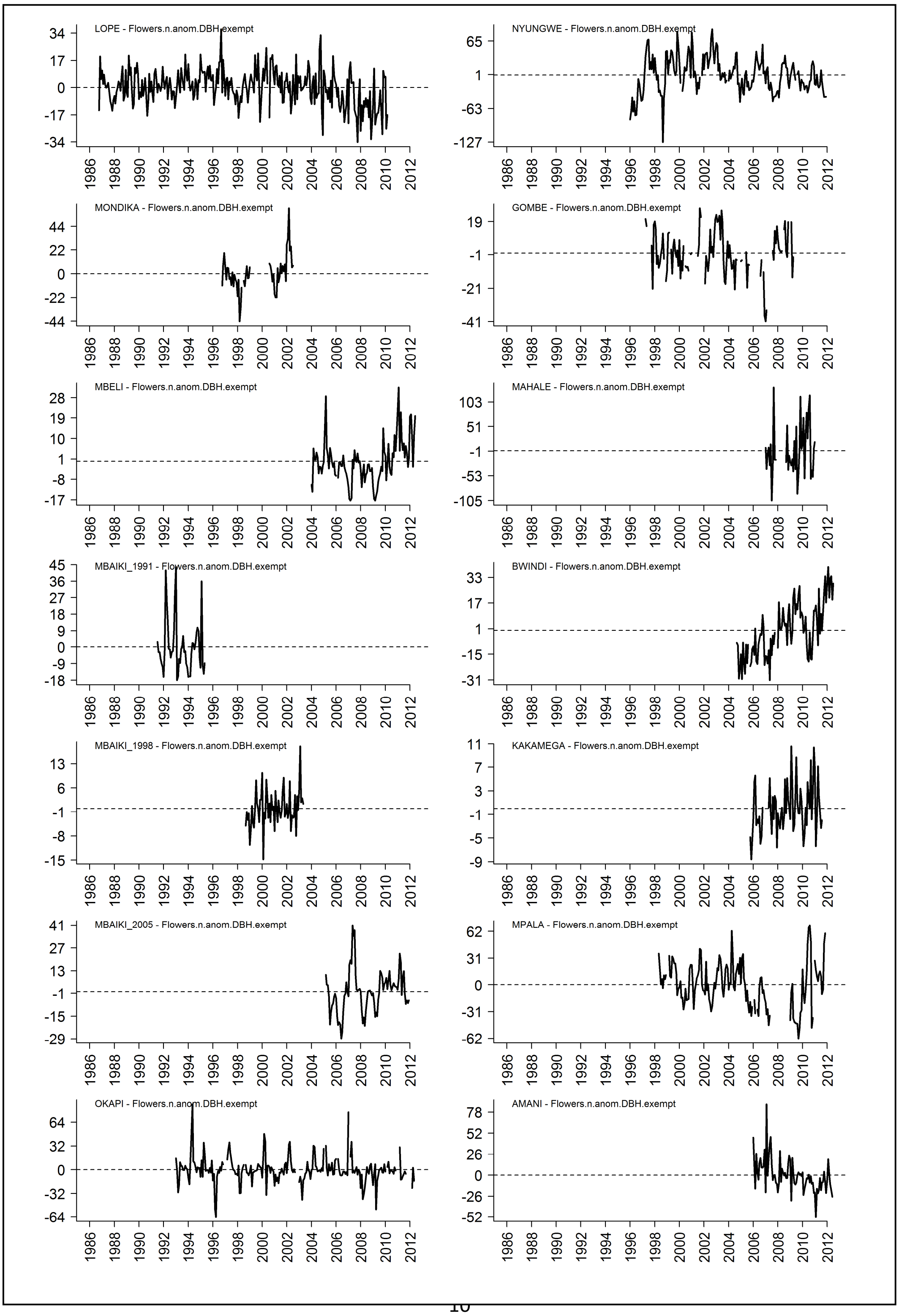
LOPE - Flowers.n.anom.DBH.exempt
NYUNGWE - Flowers.n.anom.DBH.exempt
MONDIKA - Flowers.n.anom.DBH.exempt
GOMBE - Flowers.n.anom.DBH.exempt
MBELI - Flowers.n.anom.DBH.exempt
MAHALE - Flowers.n.anom.DBH.exempt
MBAIKI_1991 - Flowers.n.anom.DBH.exempt
BWINDI - Flowers.n.anom.DBH.exempt
MBAIKI_1998 - Flowers.n.anom.DBH.exempt
KAKAMEGA - Flowers.n.anom.DBH.exempt
MBAIKI_2005 - Flowers.n.anom.DBH.exempt
MPALA - Flowers.n.anom.DBH.exempt
OKAPI - Flowers.n.anom.DBH.exempt
AMANI - Flowers.n.anom.DBH.exempt
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012

Figure 4. Comparison of the flowering anomalies of individual trees across 14 sites plotted on the same time line.

Trends in flowering and fruiting

Of the five models used for estimating trends over time in flowering and fruiting, model 1 was selected the most frequently (Table 2).

Table 2. The model selected (1-5) with lowest AIC value for trends in phenophase at forest level at each site using the GAM Analysis and where possible the GAMM analysis. +ve = increasing trend; -ve = decreasing trend

Site	GAM Flower	GAM Unripe Fruit	GAM Ripe Fruit
Mpala, Kenya	1: -ve P<0.001		1: -ve P=ns
Kakamega, Kenya	1: +ve P<0.05	1: +ve P<0.001	1: +ve P<0.001
Amani, Tanzania	1: -ve P<0.001	1: -ve P<0.001	1: -ve P<0.001
Mahale, Tanzania	1: +ve P<0.001	1: +ve P<0.001	1: -ve P<0.01
Gombe, Tanzania			
Nyungwe, Rwanda	1: -ve P=ns	1: -ve P=ns	1: -ve P<0.001
Bwindi, Uganda	1: +ve P<0.001	1: +ve P<0.001	1: +ve P<0.001
Kibale, Uganda			
Budongo, Uganda			
Okapi, DRC	1: -ve P=0.055	1: +ve P=ns	1: +ve P=ns
Loango, Gabon			
Lope, Gabon	1: -ve P<0.001	1: -ve P<0.001	1: -ve P<0.001
Goualougo, RDC	1: +ve P<0.001	3: +ve P<0.001	1: +ve P<0.001
Mbeli, RDC	1: +ve P<0.001	1: +ve P<0.001	1: -ve P<0.01
Mondika, CAR	1: +ve P<0.001	1: +ve P<0.001	1: -ve P<0.001
Mbaiki, CAR	1: -ve P=ns		1: -ve P<0.001
Tai, Ivory Coast			

Seasonality in flowering and fruiting over the year at each site shows that at many of the sites flowering peaks in February, March or April (figure 5) although there are a few exceptions, and that most ripe fruit is produced in either May-July or in October-January (Figure 6) depending on the locations. These differences may be due to the types of fruits being monitored. Wind and dehiscent fruits tend to be produced during drier times of the year whilst fleshy fruits tend to be produced at wetter times of the year. So the relative contribution of these fruiting strategies within the mix of trees being monitored will have an impact on the seasonality figures obtained here.

We also are uncertain at present how much the trees being monitored are representative of the trees found at each site. At many sites primate foods have been monitored rather than a representative sample of the forest trees. So in future analyses we plan to assess the relative proportion of the basal area and/or density monitored for tree species at each site so that we have a better assessment of the representativeness of the forest each sample. We also plan to analyse the data by plant functional type to assess when wind dispersed, dehiscent and fleshy fruiting trees tend to flower and fruit.

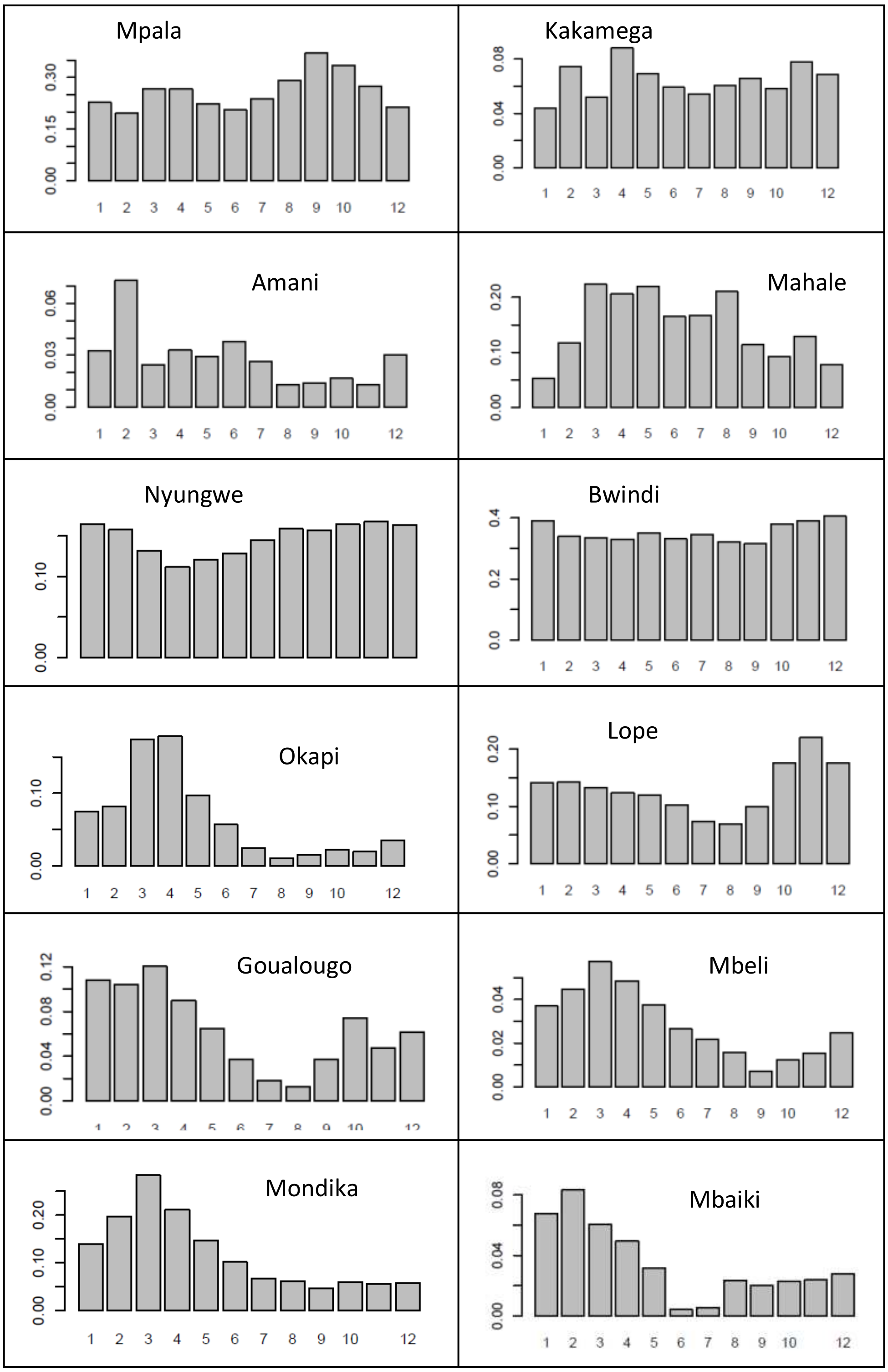

Figure 5. Seasonality in flowering at the sites plotting the proportion of trees flowering for each month of the year (1=January to 12=December).

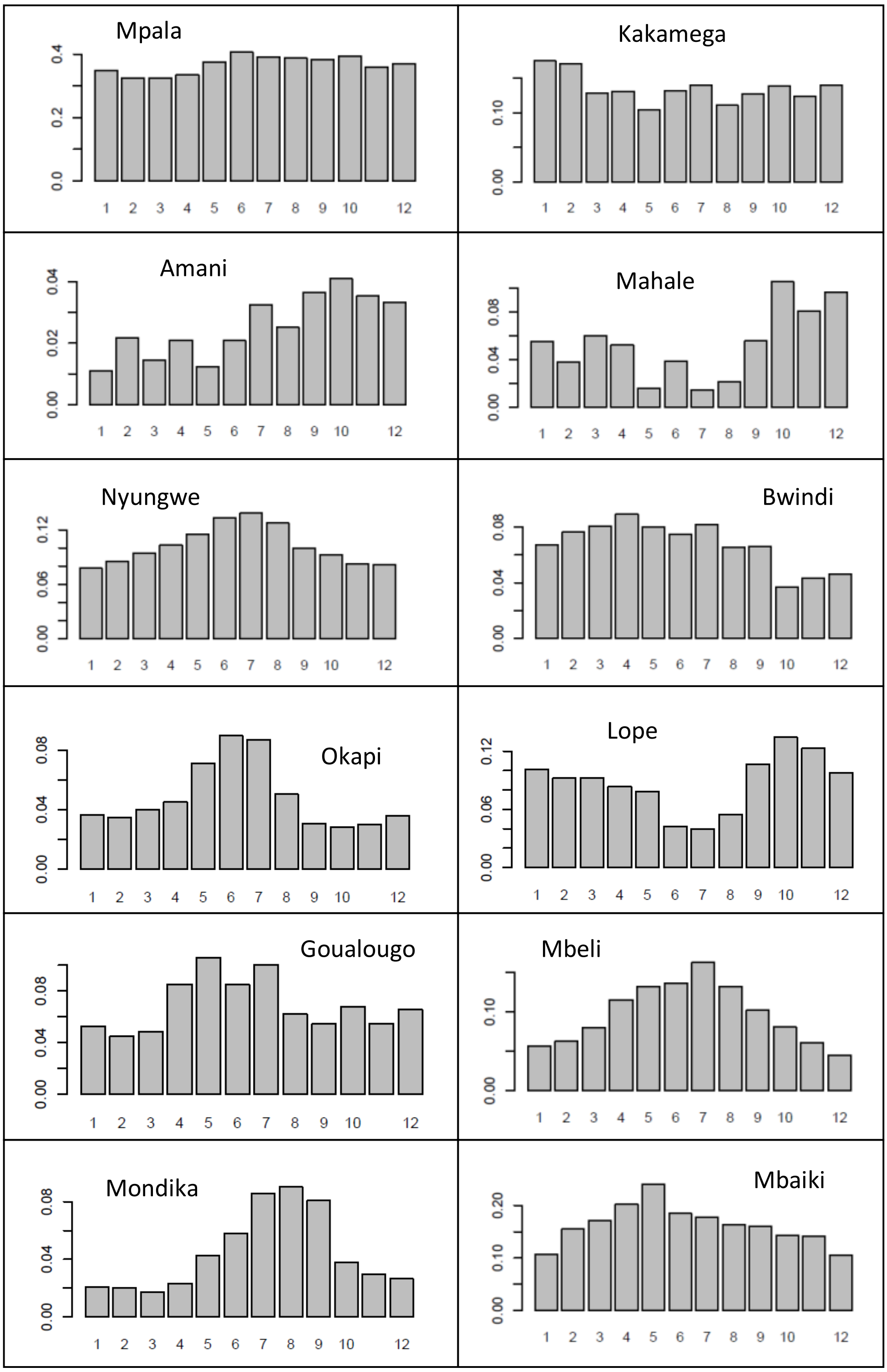

Figure 6. Seasonality in production of ripe fruit at the sites plotting the proportion of trees with ripe fruit for each month of the year (1=January to 12=December).

Plotting the trends obtained per site in Table 2 against latitude did not give any clear pattern in trends in flowering or production of ripe fruit (figure 7), except for a slight tendancy for an increase in ripe fruit production north of the equator and a decrease south of the equator. Given these trends are over different time periods it is planned to calculate trends for the same time periods in a future analysis to assess such patterns.

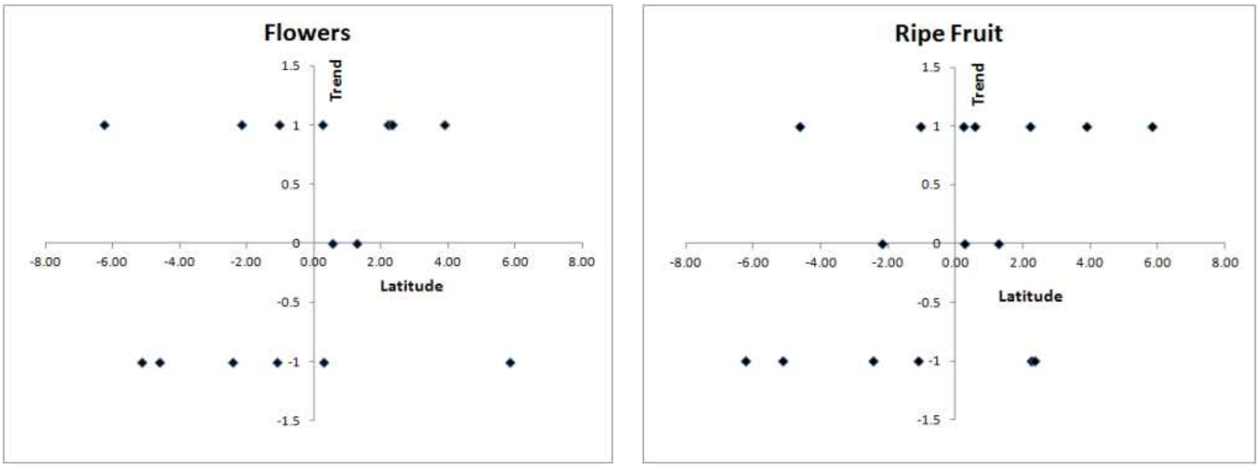

Figure 7. Plots of the trend at a site against latitude for flowers (left) and production of ripe fruit (right). If a positive trend was identified then the vertical axis was given 1, if negative trend (-1) and if no significant trend (0).

Correlations with ENSO events in the Pacific

The impacts of ENSO events in the Pacific Ocean on global climate are well recognized these days, and research shows that the relative difference in temperature between the east and west of the Pacific lead to either drought or higher rainfall in different areas of the World (Nicholson and Kim, 1997; Wright and Calderon, 2006). Other effects contribute to climate forcing in Africa in particular which is a continent that is surrounded primarily by the Indian Ocean and Atlantic Ocean which each have their own oscillations also that affect the climate and dampen or exacerbate the effects of the ENSO events. Of particular relevance to the study of phenological changes across Africa are the Tropical North Atlantic, Tropical South Atlantic and the Indian Ocean Dipole which are all linked to ENSO events but can modify the impact and subsequent climate in Africa (Rajogopalan *et al.* 1998; Williams and Hanan, 2011). This workshop focused solely on ENSO indices but we plan to also look at these other oscillations to investigate their potential impacts on phenology of tropical trees.

Correlations with the six indices were made for the month of phenology data and up to 12 months prior to the phenophase event. However, fruiting is likely to be dependent on whatever triggers flowering and then the time lag following flowering is determined by the time it takes a plant to develop ripe fruit (which is probably correlated with fruit size also). So we decided to focus on the ENSO indices that best correlated with flowering events. In many cases there were significant correlations between lags of different months (grouped around a central month) and ENSO indices. We selected the most significant correlation and only use probabilities less than P=0.01 because of the multiple correlations being made (Table 3).

Table 3. The correlation coefficient (+ = green; -ve = blue), lag time (months) and probability for correlations between individual tree flowering at a site and the six ENSO Indices. As multiple correlations are being made we only selected those that were significant at P<0.01.

Site	SOI	ONI	Niño 1+2	Niño 3	Niño 3+4	Niño 4
Mpala, Kenya	ns	ns	ns	ns	ns	ns
Kakamega, Kenya	1, P<0.01	ns	ns	ns	ns	ns
Amani, Tanzania	5, P<0.01	ns	4, P<0.01	ns	ns	ns
Mahale, Tanzania	ns	ns	ns	ns	ns	ns
Gombe, Tanzania	ns	ns	ns	ns	ns	ns
Nyungwe, Rwanda	ns	ns	ns	ns	ns	ns
Bwindi, Uganda	8, P<0.001	7, P<0.001	ns	6, P<0.001	7, P<0.001	7, P<0.001
Kibale, Uganda	5, P<	5, P<	2, P<	5, P<	5, P<	5, P<
Budongo, Uganda						
Okapi, DRC	ns	ns	ns	ns	ns	ns
Loango, Gabon	1, P<	2, P<	4, P<	4, P<	2, P<	2, P<
Lope, Gabon	ns	ns	ns	ns	ns	ns
Goualougo, RDC	ns	ns	ns	ns	ns	ns
Mbeli, RDC	ns	ns	1, P<0.001	3, P<0.01	ns	ns
Mondika, CAR	4, P<0.01	4, P<0.01	4, P<0.01	4, P<0.01	5, P<0.01	ns
Mbaiki (2005) CAR	ns	ns	1, P<0.01	1, P<0.01	ns	ns
Tai, Ivory Coast	3, P<	3, P<	ns	3, P<	3, P<	3, P<

The table shows that where lag times were significant they were similar across the various ENSO indices. Positive correlations with ONI or the Niño indices indicate a positive correlation between flowering and an El Niño event, while negative correlations between SOI and flowering also indicate a positive correlation with an El Niño event. Strong negative correlations with ONI or Niño indices or positive correlations with SOI indicate correlations with La Niña events.

Where sites had their own climate data we also looked at the effects of rainfall and maximum/minimum temperature on the flowering at the site (figure 8). The anomalies in these climate variables were examined over time at a site and compared with the anomalies in the phenophases for flowers and ripe fruits to assess which might best correlate with the phenophase (table 4). Again only those correlations significant at P<0.01 were selected. No clear patterns occur with these correlations either and this may be because we need to look at thresholds rather than associating trends between flowering and climate data. Where correlations have a lag of more than 2-3 months it is unlikely that the correlation is biologically meaningful for flower production either.

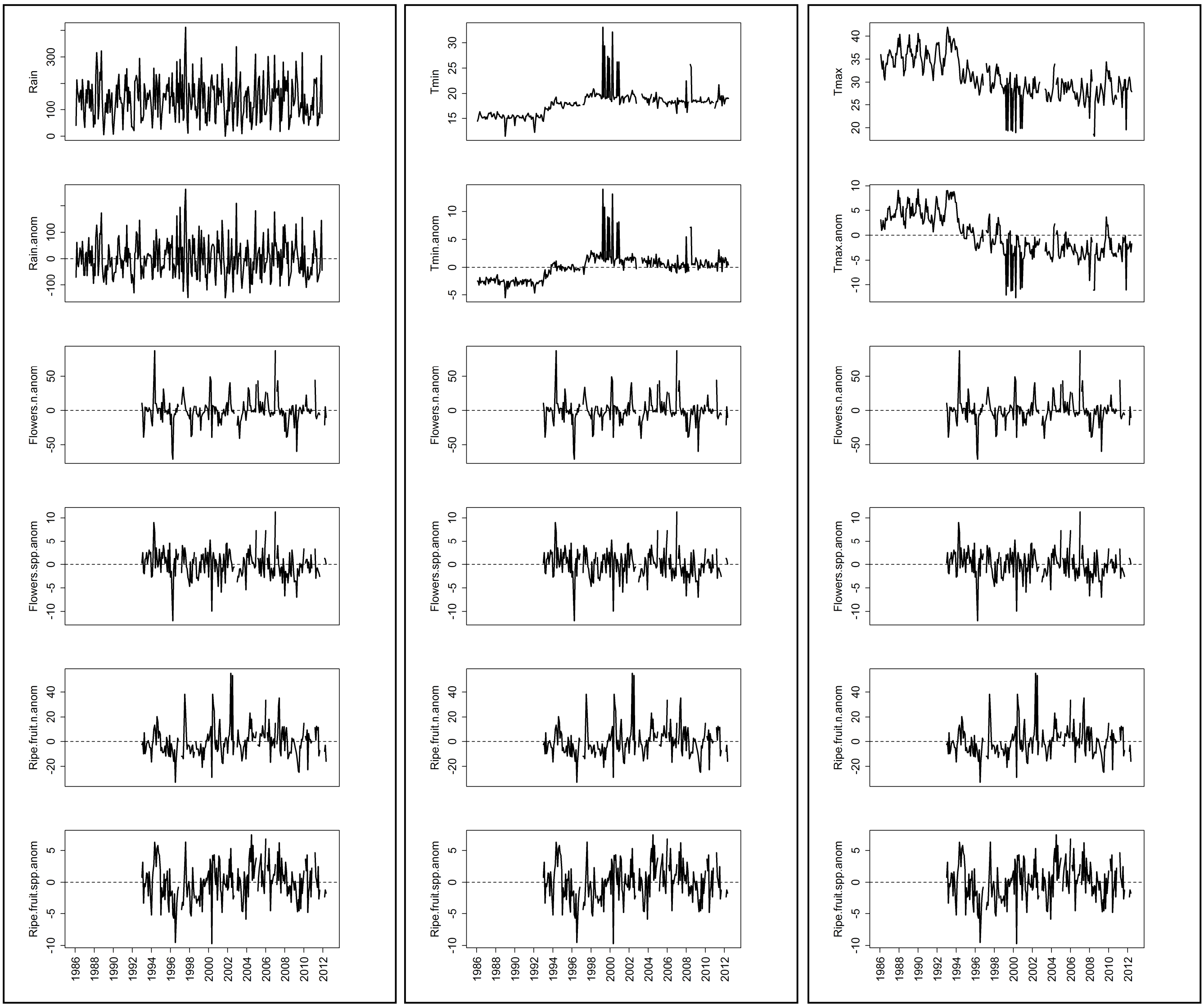

Figure 8. Plots of Rainfall (left), Minimum temperature (centre) and Maximum temperature (right) over time (top) with the anomaly in these climate variables (second from top), flowering individual and

species anomalies (3rd and 4th from top) and ripe fruit individual and species anomalies (bottom two) for the Okapi Wildlife Reserve in DRC.

Table 4. Correlations between climate variable anomalies and individual tree flowering at sites where climate data were available (green=+ve; blue=-ve)

Site	Rainfall	Min temp	Max Temp
Amani, Tanzania	ns	ns	ns
Mahale, Tanzania	ns	3, P<0.01	ns
Gombe, Tanzania	ns	ns	ns
Nyungwe, Rwanda	0, P<0.01	ns	11, P<0.01
Bwindi, Uganda	ns	9, P<0.001	2, P<0.001
Okapi, DRC	ns	ns	**P < 0.001**
Lope, Gabon	ns	ns	3, P<0.01
Goualougo, RDC	ns	ns	ns
Mbeli, RDC	ns	ns	ns
Mondika, CAR	ns	1, P<0.01	ns
Mbaiki (1998) CAR	ns	ns	10, P<0.01

Further analysis will look at the patterns in flowering with measures of the Indian Ocean Dipole and also the Tropical North/South Atlantic Sea Surface Temperature anomalies to assess if these drivers of more local climate may be affecting flowering at these sites. We will also compare the same species of tree across sites for those species found at several sites to look within species as well as across species.

Follow up to the meeting

While the meeting was able to pull together patterns in fruiting and flowering at each site there was not enough time to investigate possible patterns in these phenophases in relation to climate changes in more detail than the general correlations we identified here. Several issues need to be standardized first and we need to look at more of the detail in each data set including:

1. Assessing the representativeness of the trees monitored at each site for that site's phenology

2. Assessing differences between fleshy fruiting trees vs pods and wind dispersed fruits where it is likely that the triggers will vary over the year (predicting that pods and wind dispersed fruit prefer dry periods while fleshy fruits prefer wet periods)
3. Comparing the same species of tree between sites as this will control for the variation that exists between sites where different species are being monitored.
4. Comparing sites during the same time period or looking at incorporating moving trends into analyses with climate data so that where trends show increases in flowering and then declines over time these are analysed as trends rather than a static average.
5. Comparing seasonality within a year across sites to look at where differences occur for similar types of fruits (fleshy, wind dispersed, pods etc) – how does this vary with latitude, climate etc
6. Assessing climate thresholds or full blown El Nino/La Nina years compared with other years rather than just the index which is continuous.

The authors agreed to work together on these analyses following the workshop and we will pull together a paper that gets at some of the detail in these datasets over the coming year.

References

Ashton, P.S., Givnsih, T.J. & Appanah, S. (1988). Staggered flowering in the Dipterocarpaceae: New insights in floral induction and evolution of mast fruiting in the aseasonal tropics. Am. Nat. 132:44-66.

Babweteera, F., Shiel, D., Reynolds, V., Plumptre, A.J., Zuberbuhler, K., Hill, C.M., Webber, A., and Tweheyo, M. (2012). Environmental and Anthropogenic changes in and around Budongo Forest Reserve. In: Plumptre, A.J. (ed). *The Ecological Impact of Long-Term Changes in Africa's Rift Valley*. Nova Science Publishers, New York. Pp 31-53.

Borchert, R., Renner, S.S., Calle, Z., Navarrete, D., Tye, A., Gautier, L., Spichiger, R. & von Hildebrand, P. (2005). Photoperiodic induction of synchronous flowering near the equator. Nature 433:627-629.

Chao, N., Mulindahabi, F., Easton, J., Plumptre, A.J., Seimon, A., Martin, A. And Fimbel, R. (2012). Long-Term Changes in a Montane Forest in a Region of High Human Population Density. In: Plumptre, A.J. (ed). *The Ecological Impact of Long-Term Changes in Africa's Rift Valley*. Nova Science Publishers, New York. Pp 167-202.

Chapman, C.A., Chapman, L.A., Zanne, A.E., Poulsen, J.R., and Clark, C.J. (2005a). A 12-year phenological record of fruiting: Implications for frugivore populations and indicators of climate change. Pp. 75-92 in *Tropical Fruits and Frugivores: The Search for Strong Interactors.* Dew, L. and Boubli J.P. (eds) Springer, Netherlands.

Chapman, C.A., Chapman, L.A., Struhsaker, T.T., Zanne, A.E., Clark, C.J. & Poulson, J.R. (2005b). A long-term evaluation of fruiting phenology: importance of climate change. J. Trop. Ecol. 12:31-45.

Chapman, C.A., Chapman, L.J., Ghai, R., Hartter, J., Jacob, A.L., Lwanga, J.S., Omeja, P., Rothman, J.M., and Twinomugisha, D. (2012). Complex Responses to Climate and Anthropogenic Changes: an Evaluation based on Long-Term Data from Kibale National Park. In: Plumptre, A.J. (ed). *The Ecological Impact of Long-Term Changes in Africa's Rift Valley*. Nova Science Publishers, New York. Pp 73-94.

Clark, D.A., Piper, S.C., Keeling, C.D. & Clark, D.B. (2003). Tropical rain forest tree growth and atmospheric carbon dynamics linked to interannual temperature variation during 1984-2000. *Proc. Natl. Acad. Sci. U.S.A.* **100**, 5852-5857

Cleland, E.E., Chuine, I. Menzel, A. Mooney, H.A., & Schwartz, M.D. (2007). Shifting plant phenology in response to global change. Trends in Ecology and Evolution 22:357-365.

Corlett, R.T. and LaFranckie, J.V. Jr. (1998). Potential impacts of climate change on tropical Asian forests through an influence on phenology. *Climate Change* 39:439-453.

Cunningham, S.C. & Read, J. (2002). Comparison of temperate and tropical rainforest tree species: photosynthetic responses to growth temperature. *New Phytol*. **133**, 112-119

Cunningham, S.C. & Read, J. (2003). Comparison of temperate and tropical rainforest tree species: growth responses to temperature. *J. Biogeogr*. **30**, 143-153

Feeley, K.R., Wright, S.J., Supardi, M.N.N., Kassim, A.R., & Davies, S.J. (2007). Decelerating growth in tropical forest trees. *Ecol. Lett.* **10**, 1-9

Kinniard, M.F. (1992). Phenology of flowering and fruiting in an East African riverine ecosystem. Biotropica 24(1):1-8.

Kinnaird, M.F. & O'Brien, T.G. (2007). *The Ecology and Conservation of Asian Hornbills: Farmers of the Forest.* University of Chicago Press, Chicago, IL.

Körner, C. (1991). Some often overlooked plant characteristics as determinants of plant growth: a reconsideration. *Func. Ecol.* **5**,162-173

Nicholson, S.E., and Kim, J (1997) The relationship of the El Nino southern oscillation to African rainfall. *International Journal of Climatology*, 17, 117-135.

Plumptre, A.J. (2011). *The Ecological Impact of Long-Term Changes in Africa's Rift Valley*. Nova Science Publishers, New York. 308pp.

Rajagopalan, B., Kushnir, Y., and Tourre, Y.M. (1998) Observed decadal midlatitude and tropical atlantic climate variability. *Geophysical Research Letters*, 25, 3967-3970

Reich, P.B. & Borchert, R. (1984). Water stress and tree phenology in a dry tropical forest in the lowlands of Costa Rica. Ecology 72:61-74.

Sakai, S., Harrison, R.D., Momose, K. Kuraji, K., Nagamasu, H., Yasunari, T., Chong, L. & Nakashizuka, T. (2006). Irregular droughts trigger mass flowering in aseasonal tropical forests in Asia. *American Journal of Botany,* 93:1134-1139.

Thomas, B. & Vince-Prue, D. (1997). *Photoperiodism in Plants*. Academic Press, San Diego, CA.

van Schaik, C.P., Terborgh, J.W., and Wright, S.J. (1993). The phenology of tropical forests: adaptive significance and consequences for primary consumers. *Annual Review of Ecology and Systematics.* 24:353-377.

Williams, C.A. and Hanan, N.P. (2011) ENSO and IOD teleconnections for African ecosystems: evidence of destructive interference between climate oscillations. *Biogeosciences*, 8, 27-40.

Wright, S.J. and Calderon, O. (2006). Seasonal El Niño and longer term changes in flower and seed production in a moist tropical forest. Ecology Letters 9:35-44.

Wright, S.J. & van Schaik, C.P. (1994). Light and the Phenology of tropical trees. Am. Nat. 143:192-199.

Program for African Phenology Workshop

3rd September-7th September 2012

Institute for Tropical Forest Conservation, Ruhija,
Bwindi Impenetrable National Park

Aims of the workshop:The African Phenology Workshop will aim to assess how the fruiting and flowering patterns of trees are changing across the continent and whether these changes can be linked at all with climate changes that are occurring. We also hope that it will raise the profile of the importance of long term phenology monitoring. In particular we aim to analyse data at a site level and across the continent and draft a paper on the results of the continental analysis.

Time	**Program**	**Notes**
2rd Sept		
19.30	Welcome and introductions followed by dinner	Arrival by bus from Kampala
3rd Sept		
8.30	Welcome and introduction to the day	
8.45	Presentation on Mpala Phenology –Tim O'brien	Overview of data collection procedures mainly with numbers of trees monitored, time intervals etc An introduction to what data have been collected
9.00	Presentation on Budongo FR Phenology – Fred Babweteera	
9.15	Presentation on Amani Reserve NP Phenology – Henry Ndangalasi	
9.30	Presentation on Nyungwe NP Phenology –Felix Mulindahabi	
9.45	Presentation on Bwindi INP Phenology – Fredrick Ssali/Peter Kabano	
10.00	Presentation on Kibale Phenology – Colin Chapman & Leo Polansky	
10.15	Presentation on Okapi FR Phenology – Corneille Ewango	
10.30	Presentation on Lope NP Phenology – Kate Abernethy	
10.45	Presentation of Noubale Ndoki Phenology – Mireille Hockemba	
11.00	Coffee break	
11.30	Presentation of Goualago Triangle Phenology – Sydney Ndolo	
11.45	Presentation on Mbaiki Phenology – Adeline Fayolle	
12.00	Presentation on Tai Phenology (Loango and Salonga possibly also) – Leo Polansky	
12.15	Presentation on Gombe Phenology – Ian Gilby	
12.30	Presentation on Mahale Phenology – Kazuhiko Osaka	
13.00	Lunch	
14.00-14.30	Introduction to types of analyses we will do in workshop– issues to deal with – Andy Plumptre	
14.30 – 15.00	Introduction to R and basics of running scripts – Sam Ayebare & Leo Polansky	

15.00-17.30	Preliminary data analyses to look at data and check for anomalies	
4th Sept		
Morning	Analyses of site patterns and trends in fruiting/flowering	
Afternoon	Analyses of site patterns with climate variables	
5th Sept		
8.30-11am	Visit to phenology trees in Bwindi and guided visit to some of ITFC research projects – Fredrick Ssali and Badru Mugerwa	
11.30-13.00	Presentation of results by site	
6th Sept		
Morning	Compiling data for analyses across Africa	
Afternoon	Analyses of fruiting and flowering patterns across Africa	
7th Sept		
Morning	Presentation of Across Africa analyses and discussion of paper	
Afternoon	Drafting of paper components	
8th Sept		
8.00	Leave for Kampala and Entebbe	