MAURITIUS RESEARCH COUNCIL

ASSESSING THE IMPACTS OF CLIMATE CHANGE ON THE PHENOLOGY OF NATIVE MAURITIAN PLANTS

Final Report

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Mauritian Wildlife Foundation

Assessing the Impacts of Climate Change on the

Phenology of Native Mauritian Plants

Erythrospermum monticolum flowering

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Table of Contents

1.0   EXECUTIVE SUMMARY

Plant phenology is defined as the scientific study of the timing of recurrent biological events (flowering, fruiting, leaf shading and leaf flushing), the causes of their timing with regard to biotic and abiotic factors, and the interrelation among phases of the same or different species.

Phenology has evolved over millions of years, but ecosystems degradation and climatic changes are affecting the native flora and fauna, and phenological patterns. However, there are relatively few studies on this subject worldwide. The Mauritian Wildlife Foundation initiated a study a decade ago to understand the natural food availability throughout the year across fragmented remnants and to manage supplementary feeding, which has been formalised since 2007. Phenology data has been collected for the period September 2007 to present at five conservation sites in Mauritius (four in the Black River Gorges National Park and the fifth, on the offshore islet of Ile aux Aigrettes) on 48 native and 16 introduced species.

Significant correlations between phenological traits (flower budding, flowering, fruiting and leafing) to month, site and individual trees in declining order have been found.   Phenology calendars have been produced for 43 native and 16 introduced species and these are useful tools for conservation of the species and for studying the impacts of climate change or variability on phenology.   The effects of climate change are still unknown due to the paucity of data. However, initial analysis based on a restricted data set seems to indicate that rainfall variation does not significantly affect phenological traits for native and introduced species studied here.

2.0   INTRODUCTION

2.1   Background

Phenology is the study of the timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species (Lieth 1974). It studies the response of living organisms to seasonal and climatic changes in the environment in which they live. Leaf unfolding, flowering of plants, fruit ripening, colour changes and leaf shedding and migration of birds, hibernation in animals, spawning fish and falling leaves, the timing of animal breeding are all examples of phenological

events. Plant phenology studies record periodically recurring growth stages of plants in relation to environmental conditions on the yearly cycles of development.

During the course of this century the resilience of many ecosystems is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (especially land-use change, pollution and over-exploitation of resources), if green house gas emissions and other changes continue at or above current rates (IPCC 2007). In addition to natural factors, forest ecosystems have long been subjected to many human-induced pressures such as land-use change, over-harvesting, overgrazing by livestock, fire, and introduction of new species (IPCC 2007). Climate change constitutes an additional pressure that could change or endanger these ecosystems. Climate change encompasses temperature increase ("global warming"), sea-level rise, changes in precipitation patterns and increased frequencies of extreme weather events (IPCC 2007).

Global climate change is occurring at a rapid rate and alterations to long-term climatic trends have been reported across latitudes (Zhang *et al*. 2007). Over the past 100 years, the global average temperature has increased by approximately 0.68°C and is projected to continue to rise at a rapid rate (Root *et al*. 2003). By 2100, ecosystems will be exposed to atmospheric CO_2 levels substantially higher than in the past 650,000 years, and global temperatures at least among the highest of those experienced in the past 740,000 years (Jansen *et al*. 2007).

2.2   Rationale

The rapidly increasing atmospheric concentrations of greenhouse gases may lead to significant changes in regional and seasonal climate patterns. Such changes can strongly influence the diversity and distribution of species and, therefore, affect ecosystems and biodiversity. Phenology is perhaps the simplest process in which to track changes in the ecology of species in response to climate change (Walther *et al.* 2002).

2.3   Review of literature

Bakkenes *et al.* (2002) have developed a model, called 'euromove' to assess changes in climate patterns. The model uses climatic data from 1990 to 2050, and determines climate envelopes ('profiles') for about 1400 plant species by multiple logistic regression analysis. The climate envelopes were applied to the projected climate to obtain predictions about plant diversity and distributions by 2050. The results show that on average, 32% of the European plant species that were present in 1990 would disappear in a given area. Models predict that this will occur over 44% of Europe. In reviewing possible future trends, it was found that plant species, in general, would find their current climate envelopes further northeast by 2050.

Climate change has led to shifts in phenology (changes in the timing of growth and breeding events in the life of an individual organism) in many species distributed widely across taxonomic groups (Visser *et al.* 2005). Common changes or shifts in the timing of spring activities include earlier breeding or earlier arrival of migrant birds, earlier appearance of butterflies and earlier shooting and flowering of plants (Walther *et al.* 2002).

Advancement of vegetation activity in spring has been documented using three independent methods i.e. spring appears to be occurring earlier than previously known (Badeck *et al.* 2004). This is based on ground observations, remote sensing, and analysis of the atmospheric CO_2 signal.

Some preliminary indications suggest that trends in spring phenology roughly follow the temporal evolution of the global warming trend (IPCC 2001), with a period of warming from the end of the 19th century through to the 1950s, followed by a period of stabilization and then a second phase of accelerated warming from the late 1970s onward.

Meta-analysis techniques were applied to test if a coherent fingerprint of global warming on wild plants and animals could be detected (Parmesan & Yohe, 2003; Root *et al.* 2003). Results from 143 studies on changes in species densities and ranges, morphology, genetic frequencies and phenology showed that where changes in the first three categories; they significantly changed in the direction expected for the given climatic-change trends (Root *et al.* 2003). For the studies on spring phenology within the past 50 years, linear trends were calculated and the regression slopes

analysed. The analysis is based on 61 studies reporting results on 694 plant and animal species. The studies included had to meet the following three criteria: they examined a time series of at least 10 years, they found a change for at least one trait analysed, and they found either a temporal trend in temperature or a strong association between the trait and site temperature. The estimated mean number of days of advancement in the phenological phases per decade was 5.1.

Parmesan & Yohe (2003) analysed results on more than 1700 species on changes in species abundance, range boundary shifts, and phenology. Observations of birds, butterflies and alpine herbs resulted in an overall significant trend for northward and upward elevational shifts in range boundaries at the poleward and upper distribution limits. Trends in phenology were analysed for 172 species, for which time series of at least 17 years and observations over large geographical regions were available. Meta-analysis resulted in a mean advancement of spring phases by 2.3 days per decade (95% confidence interval, 1.7-3.2 days per decade).

The observed changes in phenology may be a positive sign because species are apparently adapting to changing climatic conditions, or they may be a negative sign because they show that climate change is, indeed, impacting living systems (Parmesan & Yohe 2003). Not all species or populations, however, show a shift in phenology (Visser *et al.* 1998, 2003, Both *et al.* 2004).

Although the majority of studies focus on the negative impacts of climate change, positive changes have also been recorded in ecosystems and populations (Senapati 2009). For instance, warmer water temperatures in rivers have positively influenced the breeding success of fish (Daufresne *et al.* 2004). Lengthening of the growing season due to warming, have resulted in a steady increase in annual forest CO_2 storage capacity leading to more significant net carbon uptake (Nabuurs *et al.* 2002). Northern Hemisphere vegetation activity has increased in magnitude by 12% in Eurasia and by 8% in North America from 1981 to 1999 (Zhou *et al.* 2003). Enhanced colonisation of plants and animals have taken place in de-glaciated terrains as a direct effect of glacier and snow retreat (Jones & Henry 2003) and rice production in India has grown over the period 1950-1999 as a result of increased precipitation during the monsoon (Selvaraju 2003).

Although studies in the tropics are increasing, small tropical island systems are not often studied in depth, even though these areas are home to various endangered and endemic species that

might be significantly affected by changes in climatic factors. Mauritius is one such island which is home to over 300 endemic species belonging to eight genera of which 80% are threatened. Since Mauritius experiences a tropical climate, changes in rainfall patterns would be considered a good indicator of the occurrence of climate change (Senapati 2009).

Mauritius enjoys a mild tropical maritime climate throughout the year, characterised by a warm humid summer extending between November and April and a relatively cool dry winter between June and September. Mean maximum temperature ranges from 26 °C to around 30 °C in summer and from 22 °C to 27 °C in winter when moving from the Centre to the coastal areas. Average minimum temperature varies from 19 °C to around 22 °C in summer and from 15 °C to 19 °C in winter when moving from the Central Plateau to the coastal areas (*Anon* 2010). The warmest months are January and February and the coolest July and August.

Average annual rainfall for the period 1971-2000 over Mauritius amounts to 2010 mm, of which about two thirds (1344 mm) are recorded during summer. The summer rains are very often associated with tropical systems and contribute significantly to replenish the country's reservoirs and aquifers. The wettest month is February and the driest October.

Though no change has been observed over the last 30 years in the number of tropical storm formations in the South West Indian Ocean (SWIO), the frequency of intense tropical cyclones (wind gusts between 234 and 299km/h) has increased. The number of rainy days and the amount of precipitation has decreased but the number of heavy rainfall events has increased in recent years (*Anon* 2010). Consequently, flash floods and temporary disruption of various socio- economic activities have become more frequent. In order to cope with, and improve the preparedness of the population to the threat of potentially devastating climate extremes, the Republic of Mauritius has developed a robust Early Warning System for tropical cyclones and torrential rains.

On the basis of reconstructed tide gauge data for the period 1950-2001 and complementary Topex/Poseidon altimeter data, the cumulative sea level in the SWIO has risen on average by 7.8 cm at Port Louis and 6.7 cm at Rodrigues. Analysis of datasets from the tide gauge sited at Port Louis indicates an average rise of 3.2 cm over the 1988-2007 period. Thus, the rate of rise of the since 1988 exceeds that observed since 1950.

Research is quite recent on climate change issues. A project launched by the Meteorological Services (MMS) to study climatic trends agreed with international results (*Anon* 2010). The results are in agreement with the Inter-Governmental Panel on Climate Change (IPCC) findings and are of regional significance as the coverage of the study spanned the entire Exclusive Economic Zone (EEZ) of the Republic of Mauritius. A few other institutions also have implemented research projects to quantify the impacts of climate change in some sectors and the mitigation potential of some measures, but no studies were set up by other organizations on phenology.

Changes in local climate coupled with habitat loss and degraded habitats and the scarcity of natural foods in the Mauritian native forests are strongly suspected to influence the biological cycles of native fauna and flora and to have led to the decline in the endemic birds of Mauritius (Cheke & Hume 2008). The Phenology Project set up by the Mauritian Wildlife Foundation will help understand the timing and duration of natural food availability in the forest in relation to climatic conditions. Our endemic birds feed on flower buds, flowers, fruits and young leaves of native food plant species (Rane 2005). The phenology project provides information on the availability of these foods every month. The data collected enable field scientists to know when the natural foods are plentiful or scarce and therefore increase or decrease supplementary feeding in consequence. The data collected and analysed will give an indication about the plants which are thriving and can be potential species which can be prioritised for restoration of native forests in the future so as to provide food for our native birds.

3.0   RESEARCH OBJECTIVES

To study the phenology of selected native and exotic plants within the Mauritian forest.
To forecast the impact of climate change on some selected native and exotic species within the Mauritian forest.
To provide recommendations to improve resilience of native forests to climate change

4.0   METHODOLOGY

For the current phenology study, 20 individuals from 48 native and 16 exotic key food plant species are being monitored at five sites (Table 1 and Table 2). Four of the study sites, Bel Ombre, Pigeon Wood, Plaine Lièvre and Combo, are located in the Black River Gorges National Park and one on Ile aux Aigrettes, where the plants have been tagged on a selected track. The selected plants are monitored monthly by field scientists and the occurrence of flower buds, flowers, fruit, and young leaves is recorded. The presence of a parameter is recorded as '1' and absence as '0'. The observations are recorded in phenology observation sheets in the field and the data are entered in a database.

Table 1. List of native plant species monitored (M) at each site.

	Plant species	Plaine Lièvre	Pigeon Wood	Bel Ombre	Ile aux Aigrettes	Combo
1	*Antidesma madagascariensis*	M	M	-	-	-
2	*Apodytes dimidiata*	M	-	-	-	-
3	*Aphloia theiformis*	M	M	M	-	M
4	*Calophyllum eputamen*	M	M	M	-	-
5	*Canarium paniculatum*	M	-	-	-	-
6	*Cassine orientalis*	M	-	M	M	-
7	*Chassalia coriacea*	M	-	-	-	-
8	*Cordemoya integrifolia*	M	-	M	-	-
9	*Dictyosperma album* var. *album*	-	-	M	-	-
10	*Diospyros egrettarum*	-	-	-	M	-
11	*Diospyros tesselaria*	M	-	M	-	M
12	*Dodonaea viscosa*	-	-	-	M	-
13	*Dracaena concinna*	-	-	-	M	-
14	*Dracaena reflexa*	-	-	-	-	M
15	*Erythrospermum monticolum*	M	M	M	-	-
16	*Erythroxylum hypericifolium*	-	-	M	M	-

	Plant species	Plaine Lièvre	Pigeon Wood	Bel Ombre	Ile aux Aigrettes	Combo
17	*Erythroxylum sideroxyloides*	-	-	-	M	-
18	*Erythroxylum laurifolium*	-	-	M	-	
19	*Eugenia pollicina*	M	-	-	-	-
20	*Eugenia lucida*	-	-	-	M	-
21	*Fernelia buxifolia*	M	-	-	-	-
22	*Ficus reflexa*	M	M	-	M	-
23	*Ficus rubra*	-	-	-	M	-
24	*Gaertnera psychotrioides*	M	M	M	-	M
25	*Gagnebina pterocarpa*	-	-	-	M	-
26	*Gastonia mauritiana*	-	-	-	M	-
27	*Grangeria borbonica*	M	-	M	-	M
28	*Hibiscus tiliaceus*	-	-	-	M	-
29	*Hilsenbergia petiolaris*	-	-	-	M	-
30	*Homalium paniculatum*	M	M	-	-	-
31	*Labourdonnaisia glauca*	M	-	M	-	M
32	*Maytenus pyria*	-	-	-	M	-
33	*Nuxia verticillata*	M	M	-	-	-
34	*Ochna mauritiana*	M	M	M	-	-

	Plant species	Plaine Lièvre	Pigeon Wood	Bel Ombre	Ile aux Aigrettes	Combo
35	*Olea lancea*	M	-	M	-	-
36	*Premna serratifolia*	M	-	-	M	-
37	*Protium obtusifolium*	M	-	M	M	
38	*Scaevola taccada*	-	-	-	M	-
39	*Securinega durissima*	M	-	M	-	M
40	*Sideroxylon cinereum*	M	-	-	-	-
41	*Sideroxylon puberulum*	M	-	M	-	-
42	*Syzygium glomeratum*	M	M	M	-	M
43	*Syzygium petrinensis*	-	M	-	-	-
44	*Tabernaemontana persicariaefolia*	M	M	-	-	-
45	*Tarenna borbonica*	-	-	-	M	-
46	*Turraea thouarsiana*	-	-	-	M	-
47	*Warneckea trinervis*	M	M	M	-	M
Number of species monitored TOTAL (47)*		**28**	**13**	**19**	**19**	**9**

* Please note that some species occur in more than one site.

Table 2. List of exotic plant species monitored (M) at each site.

	Plant species	Plaine Lièvre	Pigeon Wood	Bel Ombre	Ile aux Aigrettes	Combo
1	*Camellia sinensis*	-	M	-	-	-
2	*Callistemon citrinus*	-	M	M	-	-
3	*Cordia curassavica*	M	-	-	-	-
4	*Harungana madagascariensis*	M	M	-	-	-
5	*Homalanthus populifolius*	-	M	-	-	-
6	*Ligustrum robustum*	M	M	M	-	M
7	*Litsea glutinosa*	M	M	M	-	M
8	*Litsea monopetala*	M	M	M	-	M
9	*Mangifera indica*	-	-	M	-	-
10	*Morinda citrifolia*	-	-	-	M	-
11	*Pinus ellioti*		M	M	-	
12	*Psidium cattleianum*	M	M	M	-	M
13	*Ravenala madagascariensis*	M	M	-	-	M
14	*Rubus alceifolius*	-	-	M	-	M
15	*Syzygium jambos*	-	-	M	-	M
16	*Tabebuia pallida*	-	-	M	-	-
Number of species monitored TOTAL (16)		**7**	**10**	**10**	**1**	**7**

* Please note that some species occur in more than one sites.

4.1   Setting up of weather equipment

The current climate change component of the phenology project required the setting up of meteorological equipment for recording rainfall and temperature.   The variations in the phenology of the plants with respect to climatic conditions can be shown through analyses of the data collected over the long term.

The setting up of Stevenson screens and rain gauges at Brise Fer, Pigeon Wood, Combo, Bel Ombre and Ile aux Aigrettes field stations were completed (Plates 1), with the help of the technical staff of the Instrumentation Department of the Mauritius Meteorological Services (Plates 2 a, b and c).

Plates 1a   1b   1c

Plates 1 (a, b and c): The installation of Stevenson screens and rain gauges at three of the sites, Brise Fer, Pigeon Wood and Bel Ombre respectively.

Plates 2a   2b   2c

Plates 2 a,b,c. Setting up of weather equipment at Combo, Ile aux Aigrettes and Pigeon Wood respectively with the help of technicians from the Mauritius Meteorological Services.

4.2   Training of staff

After the installation of the weather equipment, field staff of the Mauritian Wildlife Foundation were trained on the use of the equipment and collection of weather data (Plates 3). MWF staff members have been briefed about the operation of the instruments and precautions to be taken to avoid damage to the equipment.

Plates 3a   3b

Plates 3. Training of MWF staff on Ile aux Aigrettes and at Pigeon Wood respectively by staff of the Mauritius Meteorological Service.

Training of field staff on phenology monitoring was also delivered and was continuous due to the high turnover of staff intra and inter-annually. New staff members were trained on plant identification, and how to differentiate between flower buds and fruits, young leaves and mature leaves and where to locate flowers and fruits (cauliflorous (occur directly on stem), axillary (occur at leaf axils) or terminal (occur at the end of branches)). Staff members were trained in plant identification so that they are able to identify the species used as food sources by native birds.

4.3   Phenology monitoring

Phenology monitoring is continuous. Field scientists monitor the flowering, fruiting, budding and young leaf appearance on or close to the 15th of every month. The data are recorded in the phenology monitoring sheets (Figure 1).

PHENOLOGY MONITORING SHEET

Sub-population: PIGEON WOOD   Start time: End time:

Observer (full name):

Date: ^Weather during the walk:

Sr. no.	Observed tree species	Tree no.	Inflorescence	*FlB	*Fl	*Fr	*Yl	*Lv	‾ Comments
Fenced area around house									
1	CALCIT	1	Axillary/Racaeme						
2	NUXVER	1	Terminal/Racaeme						
3	OCHMAU	1	Ter-Axi/Cyme						
4	LITMON	1	Axillary/Cyme						
6	ANTMAD	1	Cauli-Axi/Racaeme						
7	GAESPP	1	Terminal/Cyme						
8	TABPER	1	Terminal/Cyme						
9	LITGLU	1	Axillary/Cyme						
10	HOMSPP	1	Axillary/Racaeme						
11	ERYMON	9	Terminal/Cyme						

^ Fill in the appropriate: - cloudy/drizzling/ light shower/ heavy rain/ windy/ sunny (it can be just sunny or sunny, windy and drizzle or cloudy, light shower and then sunny)
* Note down presence of flower buds (FlB), lowers (Fl), fruits(Fr), young leaves (Yl) and leaves (Lv) on the tree as '1' for presence and '0' for absence
‾ Fill in the appropriate A - exotic/other native bird species seen feeding or pecking (specify the bird species), B - evidence of destruction caused by monkeys to the tree food source (you can illustrate), C - Tree dead, D - any other interesting observation (please specify)

Figure 1. The Phenology monitoring sheet

4.4   Maintenance of tracks

Track maintenance is very important to keep the tagged trees that are monitored monthly accessible to staff conducting the research. During the rainy season tagged plants become overgrown with grasses and small shrubs and need clearing so that the study plants and tags are not missed by field biologists during the monthly monitoring.

4.5   Phenology data collection and data entry

Once collected, the data were entered into the main database (Figure 2). Information such as the year, month and site of data collection as well as tree species, tree number, type of inflorescence and the status of the plants are entered in the database. The presence or absence of flower buds (Flb), flowers (Fl), fruits (Fr), young leaves (Yl) and mature leaves (L) are also entered. Interesting observations or comments were inserted in a 'Comments' column.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Year	Month	Site	Tree.sp	Tree.no	Inflo	Status	Flb	Fl	Fr	Yl	L	Comment
1795	2012	October	IAA	FICREF	10	Cauliflorous	Native	0	0	1	0	1	
1796	2012	October	IAA	FICREF	11	Cauliflorous	Native	0	0	0	0	1	
1797	2012	October	IAA	FICREF	12	Cauliflorous	Native	0	0	0	0	1	
1798	2012	October	IAA	FICREF	13	Cauliflorous	Native	0	0	0	0	1	
1799	2012	October	IAA	FICREF	14	Cauliflorous	Native	0	0	0	0	1	
1800	2012	October	IAA	FICREF	15	Cauliflorous	Native	0	0	0	1	1	
1801	2012	October	IAA	FICREF	16	Cauliflorous	Native	0	0	0	0	1	
1802	2012	October	IAA	FICREF	17	Cauliflorous	Native	0	0	0	0	1	
1803	2012	October	IAA	FICREF	18	Cauliflorous	Native	0	0	1	0	1	
1804	2012	October	IAA	FICREF	19	Cauliflorous	Native	0	0	0	0	1	
1805	2012	October	IAA	FICREF	20	Cauliflorous	Native	0	0	0	0	1	
1806	2012	November	IAA	FICREF	1	Cauliflorous	Native	0	0	1	0	1	
1807	2012	November	IAA	FICREF	2	Cauliflorous	Native	0	0	1	1	1	
1808	2012	November	IAA	FICREF	3	Cauliflorous	Native	0	0	0	0	1	
1809	2012	November	IAA	FICREF	4	Cauliflorous	Native	0	0	1	0	1	
1810	2012	November	IAA	FICREF	5	Cauliflorous	Native	0	0	0	1	1	
1811	2012	November	IAA	FICREF	6	Cauliflorous	Native	0	0	0	1	1	
1812	2012	November	IAA	FICREF	7	Cauliflorous	Native	0	0	0	0	1	
1813	2012	November	IAA	FICREF	8	Cauliflorous	Native	0	0	0	0	0	
1814	2012	November	IAA	FICREF	9	Cauliflorous	Native	0	0	0	0	1	
1815	2012	November	IAA	FICREF	10	Cauliflorous	Native	0	0	1	1	1	
1816	2012	November	IAA	FICREF	11	Cauliflorous	Native	0	0	0	0	1	
1817	2012	November	IAA	FICREF	12	Cauliflorous	Native	0	0	1	0	1	
1818	2012	November	IAA	FICREF	13	Cauliflorous	Native	0	0	1	1	0	

Figure 2.   Screenshot of phenology database showing data collected partly in October and November 2012.

4.6 Weather data collection

Rainfall data has been collected under this project. Readings are taken at 08.00 every day, when staff are present at the field station. Rainfall is measured in milliliters and converted to millimeters by dividing with a conversion factor 10. The data collected is entered in the main database (Figure 3).

Figure 3. Screenshot of database for rainfall data. Please note that data collection under this project began in June 2012. Data labeled 'NA' is due to rainfall not measured during the weekends, when staffs were not at the field stations.

The minimum-maximum thermometers installed at the five study sites stopped working only three weeks following installation. Currently none of the thermometers are working. After the first one started malfunctioning, it was sent to the Mauritius Meteorological Services (MMS) to be fixed. The four others were also sent to MMS to be tested and compared with the standard thermometers used by MMS. It was found that the thermometers were not accurate, despite assurances from the supplier when the equipment was purchased. The thermometers were returned to the supplier. We requested for more robust and reliable options for replacing the

faulty thermometers. The supplier has proposed a data logger instead. A demonstration was made at the Headquarters of the MMS. The equipment has been tested by MMS technical staff to see if its readings correspond to those of the standard thermometer used at the MMS. The report obtained seems satisfactory, with an accuracy of $\pm$ 0.2º c in the range of 16 to 23º C.

4.7　Data Analysis

Data for rainfall were analysed using a Generalised Linear Model (GLM) and Analysis of Variance (ANOVA), using R.2.12.0. General linear models with 'Month' and 'Site' as treatments, and 'Tree number' as a blocking factor, were fitted to determine which of the aforementioned factors affected the number of flower buds, flowers, fruits and young leaves present. Binomial family errors were used. To account for statistical over-dispersion, mean deviance changes were compared with F-tests. Results are shown in Figures 5-24.

5.0　RESULTS

5.1　Phenology Calendars

The data collected has been used to complete a phenology calendars which show the timing of fruiting, flowering, budding and young leaf in all the plants being monitored by the project.

Phenology calendars have been produced for 43 native and 16 exotic species. These calendars are based on phenology data collected from September 2007 to November 2012 (see Figure 4 for an example).

Aphloia theiformis
Aphloiaceae

Common name: Fandamane
Conservation status: Least concern
Distribution: Intermediate and Upland forests

Description: Fandamane is <11m high with lots of spreading branches. Pointed acute apex, rounded base and elliptical lamina, about 4-8 cm, shiny dark green, smooth, serrated margin with reddish tinge. It has white, conspicuous flowers (about 1cm), fragrant, hermaphrodite and produces fruits which are ovoid, soft-fleshy berry, 6-8mm in length and 4-6mm in diameter.

Bel Ombre

	2007	2008	2009	2010	2011	2012
J		Δ✱		NA	Δ⊕	Δ
F		Δ			Δ	ΔO
M		Δ	Δ	Δ	Δ	⊕
A		Δ	Δ	Δ	Δ ✱	Δ
M		Δ	Δ	Δ	Δ	Δ
J		Δ	Δ	Δ	Δ	Δ
J			Δ		Δ	Δ
A			Δ			Δ
S	✱O	Δ	Δ			Δ
O		NA				Δ
N	Δ⊕		NA	Δ	Δ✱O	Δ
D	Δ⊕✱		Δ	Δ		

Combo

	2007	2008	2009	2010	2011	2012
J		Δ⊕	Δ⊕	⊕✱O	Δ⊕✱	Δ⊕✱
F		Δ O	Δ ✱	Δ⊕✱O	Δ⊕✱O	Δ⊕✱O
M		Δ	Δ ✱O	Δ ✱O	Δ ✱O	Δ✱O
A		Δ	Δ ✱O	Δ ✱O	Δ O	ΔO
M			Δ ✱O	Δ⊕	Δ O	ΔO
J		Δ	Δ		Δ⊕ O	Δ⊕
J		Δ	Δ ✱		Δ⊕✱O	Δ
A		Δ	Δ	Δ	Δ⊕ O	Δ
S	Δ	Δ	Δ⊕✱		Δ	Δ
O		Δ⊕	Δ⊕✱O		Δ	Δ⊕
N		Δ⊕✱O	⊕✱			Δ⊕
D		Δ⊕✱O	⊕✱O	Δ⊕✱O		

Simple alternate leaves spread all along the branches

KEY

Young leaves	Δ
Flower Buds	⊕
Flowers	✱
Fruits	O

Plaine Lièvre

	2007	2008	2009	2010	2011	2012
J			Δ O		Δ	Δ✱
F		Δ⊕	Δ⊕✱O	Δ⊕✱O	Δ⊕	Δ⊕✱O
M		Δ ✱	Δ ✱O	Δ ✱	Δ✱O	Δ⊕✱O
A		Δ O	Δ ✱O		Δ⊕	Δ⊕
M		Δ	Δ		Δ O	ΔO
J		Δ	Δ	Δ	Δ	ΔO
J		Δ	Δ	Δ	Δ	Δ
A		Δ	Δ	Δ	Δ	Δ
S		Δ	Δ		Δ	Δ
O		Δ⊕✱			Δ	Δ
N		Δ	Δ O	Δ⊕✱	Δ	Δ⊕✱O
D	Δ⊕	Δ⊕	Δ	Δ	Δ	

Pigeon Wood

	2007	2008	2009	2010	2011	2012
J	Δ⊕ O	Δ⊕✱	Δ⊕✱O	Δ⊕✱O	Δ⊕✱O
F	Δ⊕✱O	Δ ✱O	⊕✱O	Δ⊕✱O	Δ⊕✱O
M	Δ⊕✱O	⊕✱O	Δ⊕✱O	Δ⊕✱O	Δ⊕✱O
A		Δ	O ✱O	Δ	Δ⊕✱O	Δ⊕✱O
M		Δ O	✱O	Δ ✱O	Δ⊕✱O	Δ⊕✱O
J		Δ⊕ O	Δ ✱	Δ⊕✱O	Δ⊕✱O	Δ⊕✱O
A		Δ⊕		Δ⊕	Δ⊕✱O	Δ⊕
S	Δ⊕	Δ⊕	Δ⊕✱O		Δ⊕✱O	Δ⊕✱
O	Δ⊕✱	Δ⊕✱	Δ⊕✱O			
N	Δ⊕✱O	Δ⊕✱O	Δ⊕ O	Δ⊕✱O		
D	Δ⊕✱O	Δ	O Δ⊕✱O	Δ⊕✱O		

Ovoid, round, soft-fleshy berry

KEY

Young leaves	Δ
Flower Buds	⊕
Flowers	✱
Fruits	O

5.2 Percentage flower budding, flowering, fruiting and young leaf

5.2.1 Native species

Antidesma madagascariense **(bois bigaignon bâtard)**
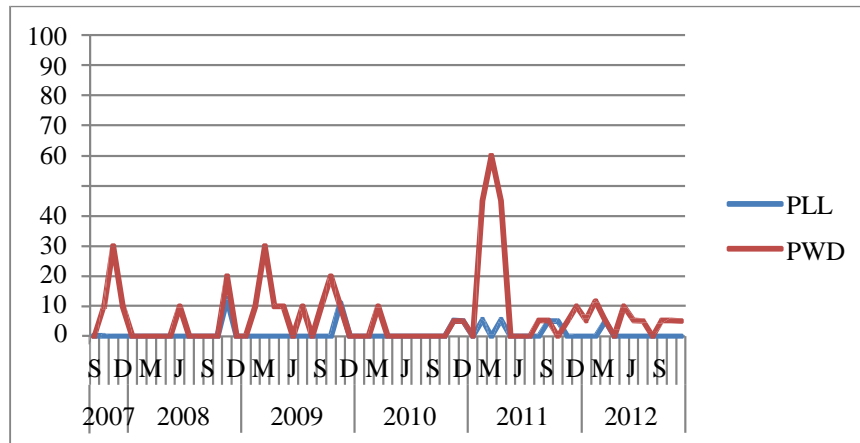
Figure 5.1. Percentage of *Antidesma madagascariense* trees with flower buds at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
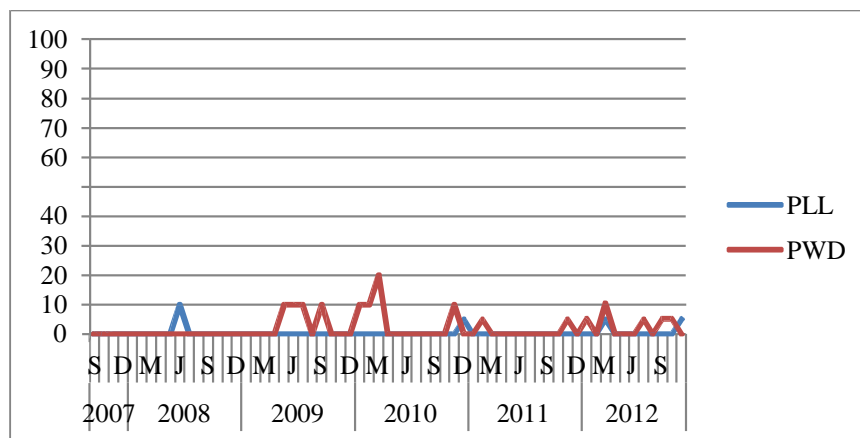
Figure 5.2. Percentage of *Antidesma madagascariense* trees in flower at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
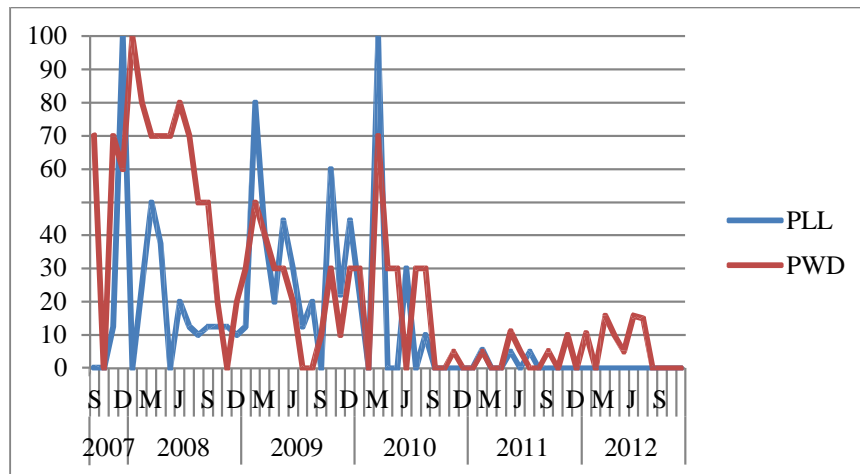
Figure 5.3. Percentage of *Antidesma madagascariense* trees in fruit at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
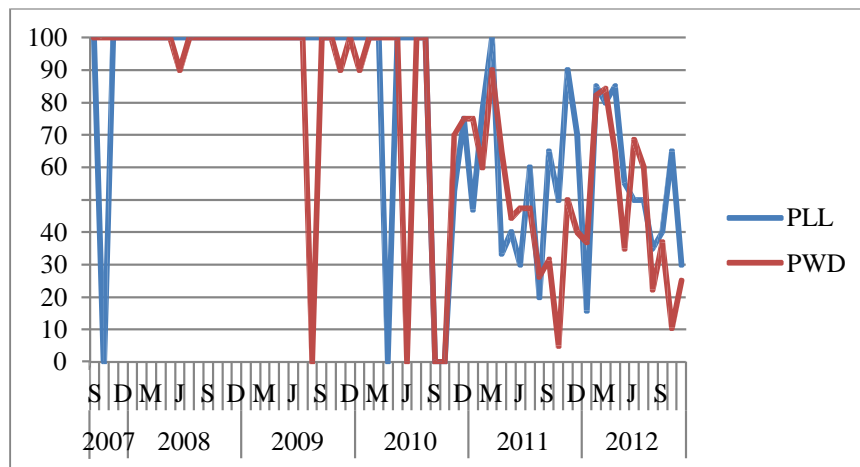
Figure 5.4. Percentage of *Antidesma madagascariense* trees with young leaves at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of *Antidesma madagascariense* trees with flower buds was strongly correlated to the month ($F_{11,1641}$=4.41, P<0.0001) and to the sites ($F_{1,1640}$=54.89, P<0.0001). The individual trees did not influence the proportion of trees observed in flower buds ($F_{1,1639}$=0.05, P=0.875). For the proportion of trees in flower, only the site ($F_{1,1639}$=7.98, P=0.005) had a strong influence.

Month ($F_{11,1640}$=0.89, P=0.550) and individual trees ($F_{1,1638}$=0.89, P=0.135) had no influence on the proportion of trees observed in flower.

The percentage of trees in fruit varied according to the month ($F_{11,1640}$=4.85, P<0.0001) and to the sites ($F_{1,16399}$=18.60, P<0.0001). However, in this species individual trees influenced the observations of trees in fruits ($F_{1,1638}$=53.23, P<0.0001), which may be due to different age of the plants or due to conditions of growth.

For proportion of trees with young leaves, the month ($F_{11,1640}$=8.82, P<0.0001) and the individual tree ($F_{1,1638}$=60.49, P<0.0001) bear a strong influence, but not the sites ($F_{1,1639}$=3.25, P=0.0715).

Aphloia theiformis **(fandamane)**

Figure 6.1. Percentage of *Aphloia theiformis* trees with flower buds at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
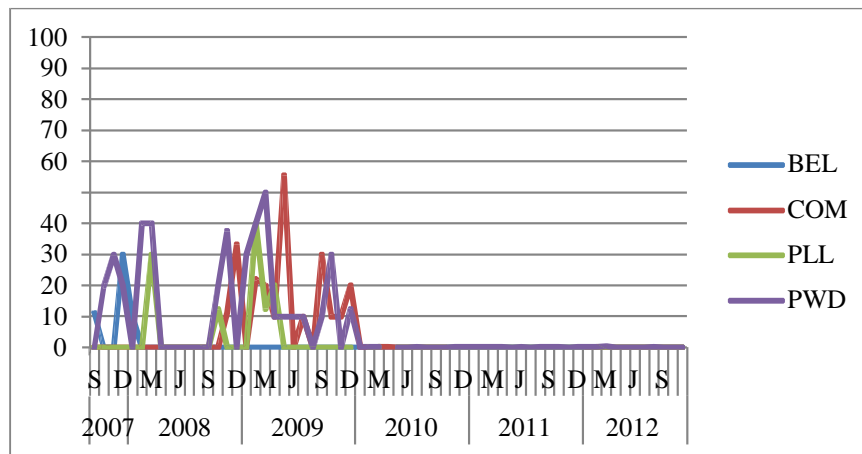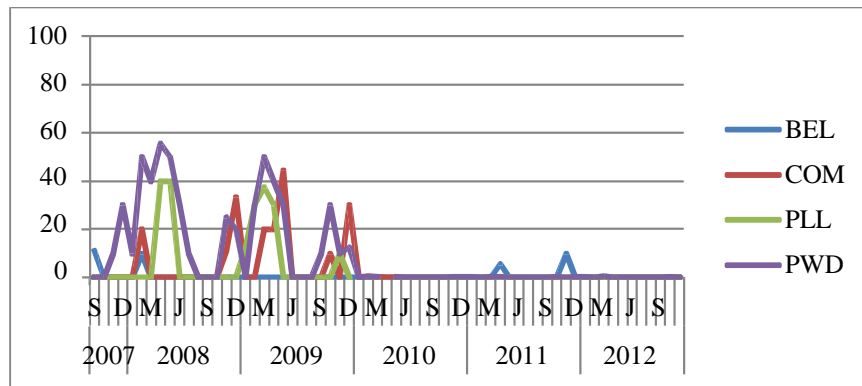
Figure 6.2.   Percentage of *Aphloia theiformis* trees in flower at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
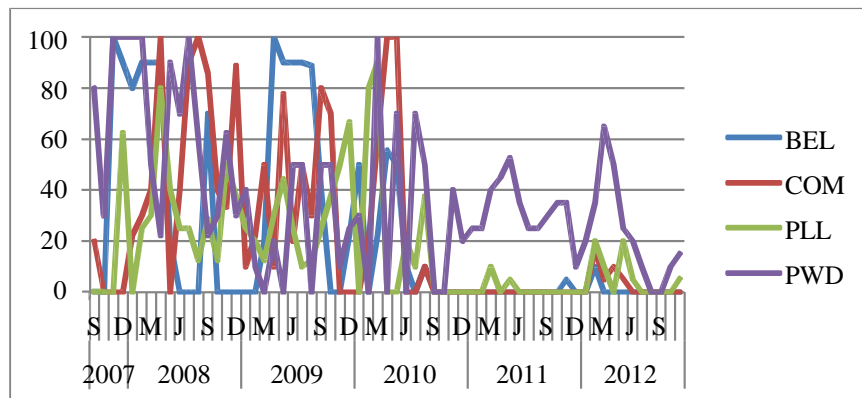
Figure 6.3. Percentage of *Aphloia theiformis* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

24
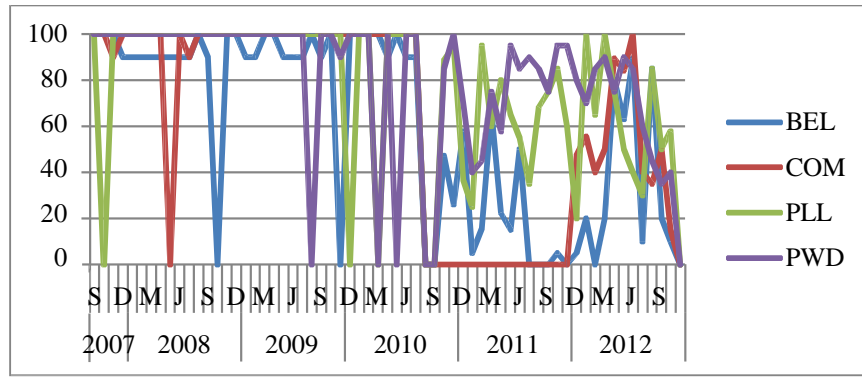
Figure 6.4.   Percentage of *Aphloia theiformis* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

In *Aphloia theiformis*, the proportion of trees with flower buds and flowers observed were heavily influenced by the month ($F_{11,2992}=6.36$, $P<0.0001$), ($F_{11,2992}=10.79$, $P<0.0001$) respectively and the sites ($F_{3,2989}=77.8$, $P<0.0001$), ($F_{3,2989}=85.7$, $P<0.0001$) respectively. The individual tree did not influence the proportion of trees observed to be in flower buds and flowers ($F_{1,2988}=2.3$, $P=0.130$), ($F_{1,2988}=0.49$, $P=0.481$) respectively.

We found the same trend for the proportion of trees in fruits for the month ($F_{11,2992}=6.36$, $P<0.001$) and the sites ($F_{11,2989}=77.8$, $P<0.001$). However, in *Aphloia* the individual trees influenced the proportion of trees observed in fruits ($F_{1,2988}=121.5$, $P<0.0001$), which could be due to differences in the age of the trees monitored or access of trees to resources.

For the proportion of trees with young leaves, a strong influence was found as the one for the fruits for the month ($F_{11,2992}=5.91$, $P<0.001$), the sites ($F_{11,2989}=76.2$, $P<0.001$), and the individual tree ($F_{1,2988}=3.89$, $P<0.0001$).

Calophyllum eputamen (**takamaka**)
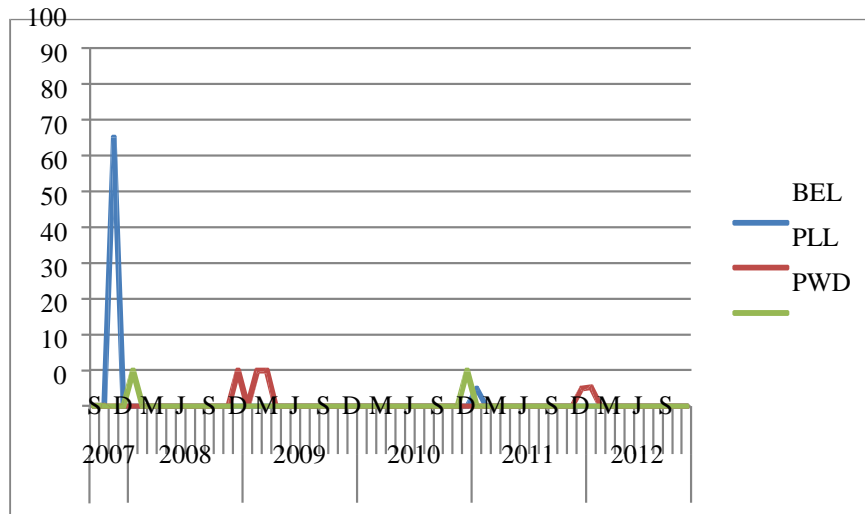
Figure 7.1. Percentage of *Calophyllum eputamen* trees with flower buds at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
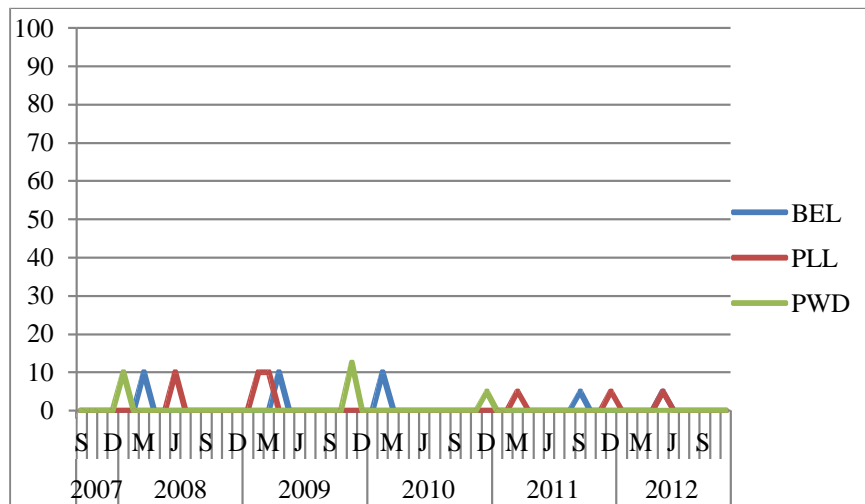
Figure 7.2. Percentage of *Calophyllum eputamen* trees with flowers at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
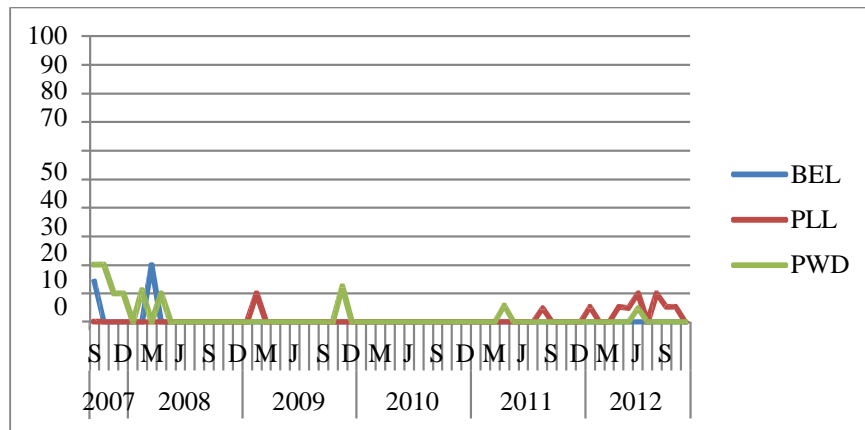
Figure 7.3. Percentage of *Calophyllum eputamen* trees in fruit at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
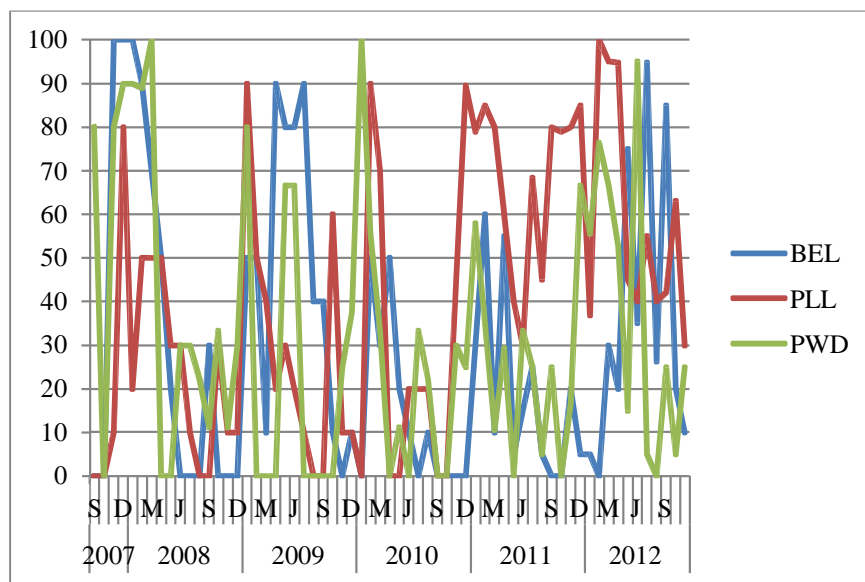
Figure 7.4. Percentage of *Calophyllum eputamen* trees with young leaves at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

In *Calophyllum eputamen*, the percentage of trees recorded with flower buds was strongly correlated to the month ($F_{11,2392}$=2.82, P=0.001), but not to the sites ($F_{2,2390}$=1.09, P=0.334). The individuals ($F_{1,2389}$=9.87, P=0.001) also influenced the proportion of trees observed in flower

buds. For the proportion of trees observed in flower, only the individual trees bear a significant influence ($F_{1,2389}=5.13$, $P=0.023$), whilst the month ($F_{11,2392}=0.95$, $P=0.487$) and the site ($F_{2,2390}=0.43$, $P=0.648$) had no influence.

The proportion of trees in fruit was strongly influenced by site only ($F_{2,2390}=3.25$, $P=0.039$); the month ($F_{11,2392}=0.87$, $P=0.564$) and the individual tree ($F_{1,2389}=1.22$, $P=0.268$) had no influence.

For the proportion of trees with young leaves, a strong correlation to month ($F_{11,2392}=12.96$, $P<0.0001$) and sites ($F_{2,2990}=37.61$, $P<0.0001$) was observed, whilst individual trees did not influence the number of flower buds and flowers observed.

Cassine orientalis **(bois d'olive)**
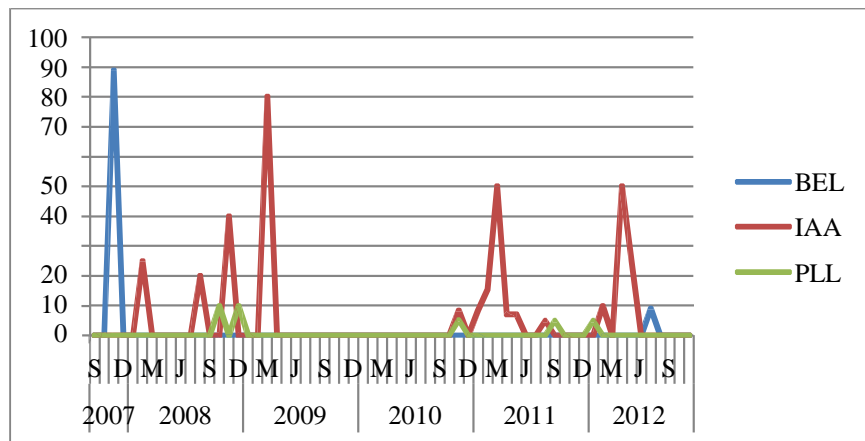
Figure 8.1. Percentage of *Cassine orientalis* trees with flower buds at Bel Ombre (BEL), Ile aux Aigrettes (IAA) and Plaine Lièvre (PLL) between 2007 and 2012.
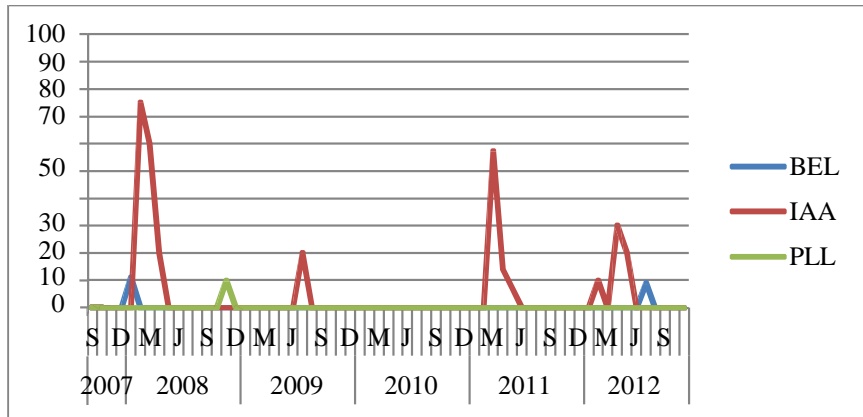
Figure 8.2. Percentage of *Cassine orientalis* trees in flower at Bel Ombre (BEL), Ile aux Aigrettes (IAA) and Plaine Lièvre (PLL) between 2007 and 2012.
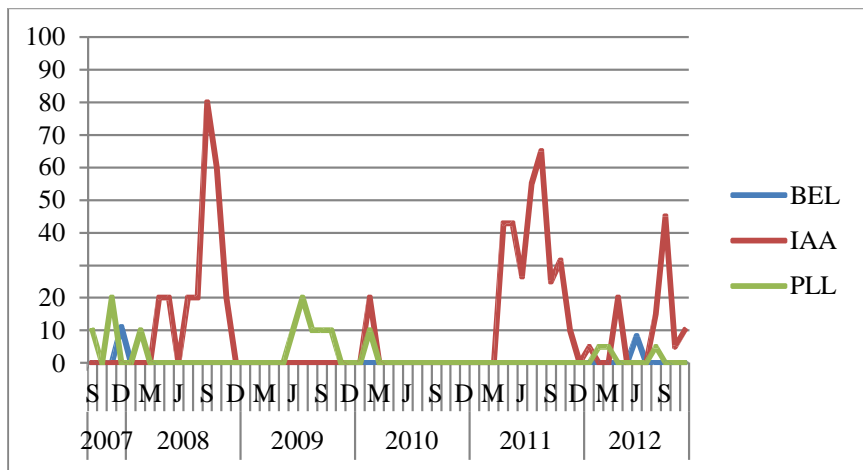
Figure 8.3. Percentage of *Cassine orientalis* trees in fruit at Bel Ombre (BEL), Ile aux Aigrettes (IAA) and Plaine Lièvre (PLL) between 2007 and 2012.

Figure 8.4. Percentage of *Cassine orientalis* trees with young leaves at Bel Ombre (BEL), Ile aux Aigrettes (IAA) and Plaine Lièvre (PLL) between 2007 and 2012.

In *Cassine orientalis*, the proportion of trees bearing flower buds was strongly influenced by the month ($F_{11,1951}$=4.37, P<0.0001) and the site ($F_{2,1949}$=25.09, P<0.0001). However, in this species the individual tree did not influence the percentage of trees with flower buds ($F_{1,1948}$=0.86, P=0.354). For the proportion of trees bearing flowers, the site ($F_{2,1949}$=32.58, P<0.0001) and month bear a strong influence ($F_{11,1951}$=32,58, P<0.0001), but not the individual tree ($F_{1,1948}$=2.46, P=0.116).

The proportion of trees with fruits was influenced by the month ($F_{11,1951}$=5.63, P<0.0001) and the site ($F_{2,1949}$=77.64, P<0.0001) but was not affected by the individual tree ($F_{1,1948}$=0.57, P=0.450).

The proportion of trees having young leaves was influenced by all the factors ; the month ($F_{11,1951}$=6.36, P<0.0001), the site ($F_{2,1949}$=115.01, P<0.0001) and the individual tree ($F_{1,1948}$=39.27, P<0.0001).

Chassalia coriacea (bois corail)
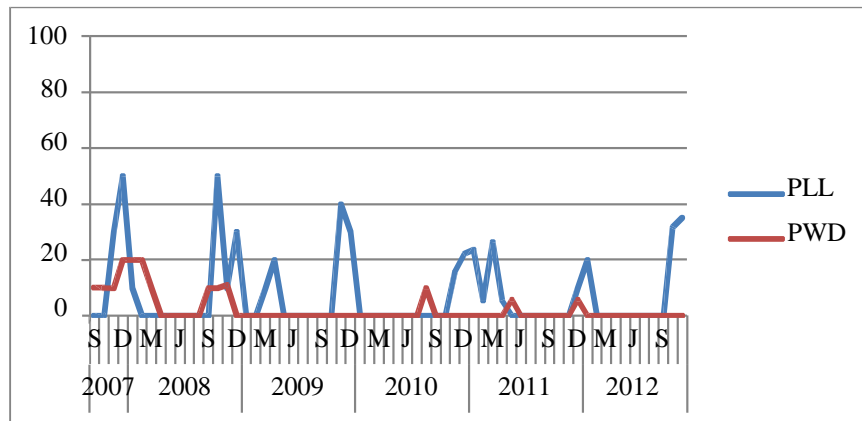
Figure 9.1. Percentage of *Chassalia coriacea* shrubs with flower buds at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
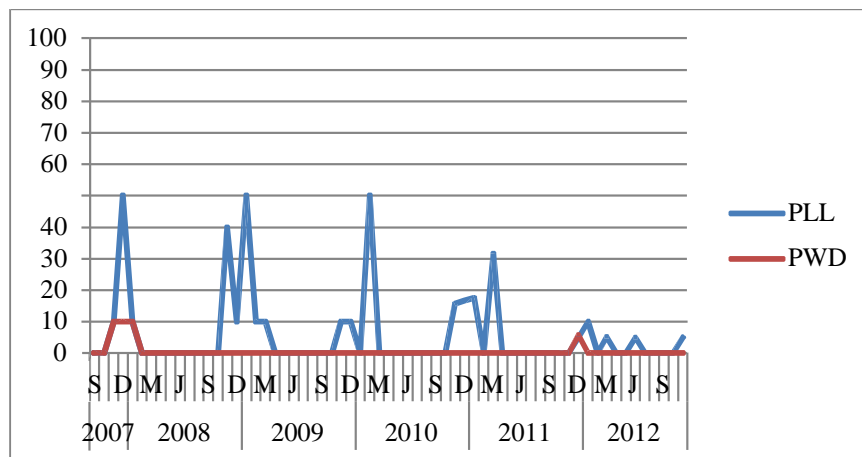
Figure 9.2. Percentage of *Chassalia coriacea* shrubs in flower at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
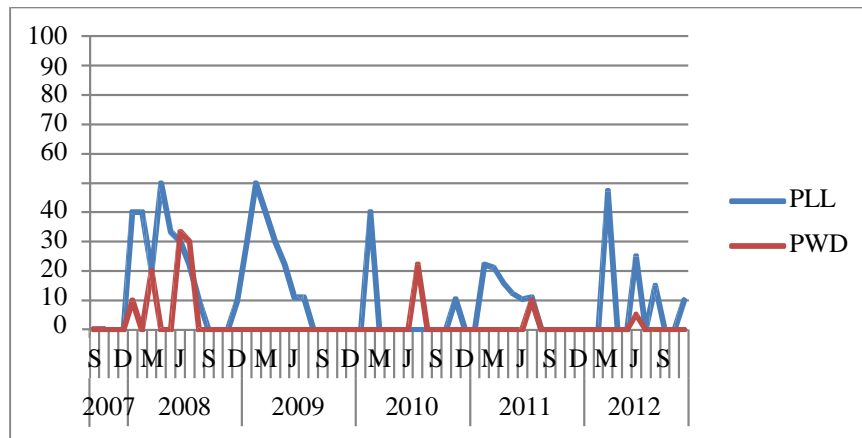
Figure 9.3. Percentage of *Chassalia coriacea* shrubs in fruit at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
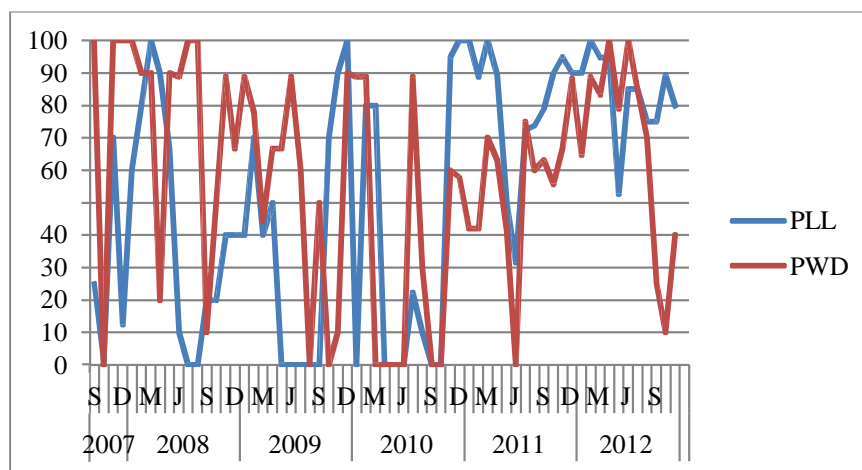
Figure 9.4. Percentage of *Chassalia coriacea* shrubs with young leaves at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

For *Chassalia coriacea*, the proportion of trees bearing flower buds was strongly correlated to the individual tree ($F_{1,1603}=6.55$, $P=0.011$) and not to the site ($F_{3,1604}=0.48$, $P=0.699$) nor the month ($F_{11,1607}=0.45$, $P=0.932$). Proportion of trees having flowers was strongly influenced by the individual tree ($F_{1,1602}=6.55$, $P=0.011$), but not by site ($F_{3,1603}=0.48$, $P=0.699$) nor the month ($F_{11,1606}=0.45$, $P=0.932$).

The number of trees bearing fruits was strongly influenced by the individual tree ($F_{1,1603}$=6.55, P=0.011), but not by site ($F_{3,1604}$=0.48, P=0.699) or month ($F_{11,1607}$=0.45, P=0.932).

Individual trees ($F_{1,1603}$=6.55, P=0.011) bear a strong influence on proportion of trees with young leaves but neither the site ($F_{3,1604}$=0.48, P=0.699) nor the month ($F_{11,1607}$=0.45, P=0.932) did.

Cordemoya integrifolia (**bois pigeon**)
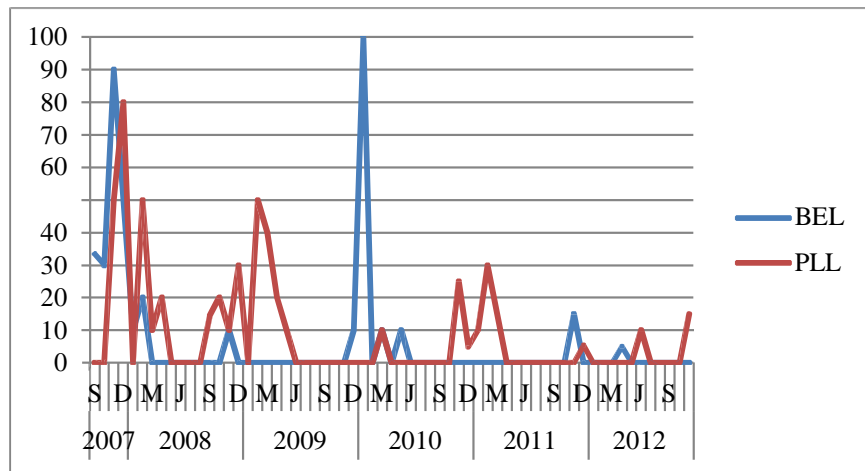
Figure 10.1. Percentage of *Cordemoya integrifolia* trees with flower buds at Bel Ombre (BEL) and Plaine Lièvre (PLL) between 2007 and 2012.
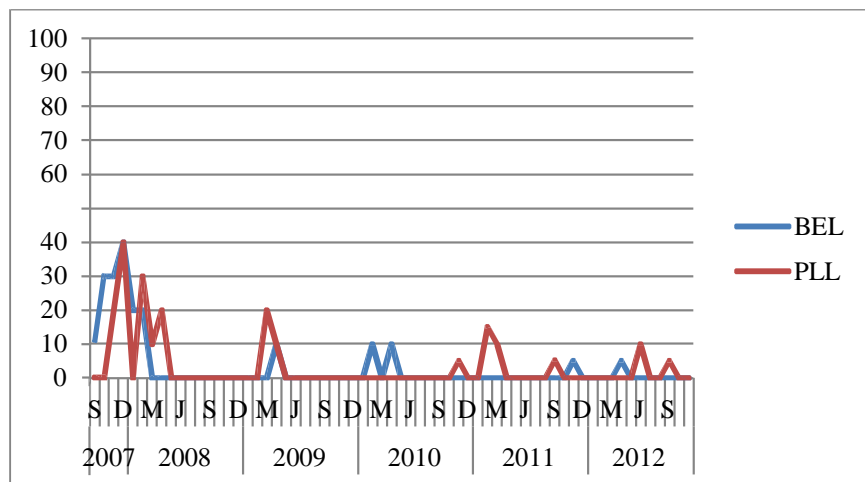
Figure 10.2. Percentage of *Cordemoya integrifolia* trees in flower at Bel Ombre (BEL) and Plaine Lièvre (PLL) between 2007 and 2012.
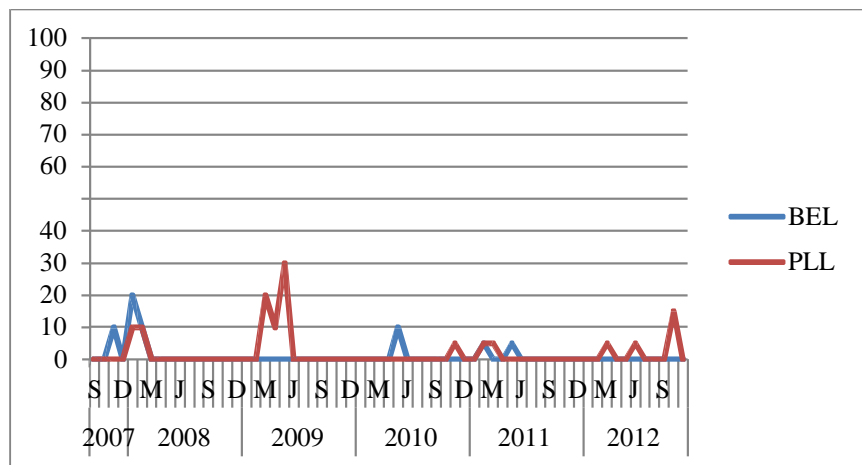
Figure 10.3. Percentage of *Cordemoya integrifolia* trees with fruits at Bel Ombre (BEL) and Plaine Lièvre (PLL) between 2007 and 2012.
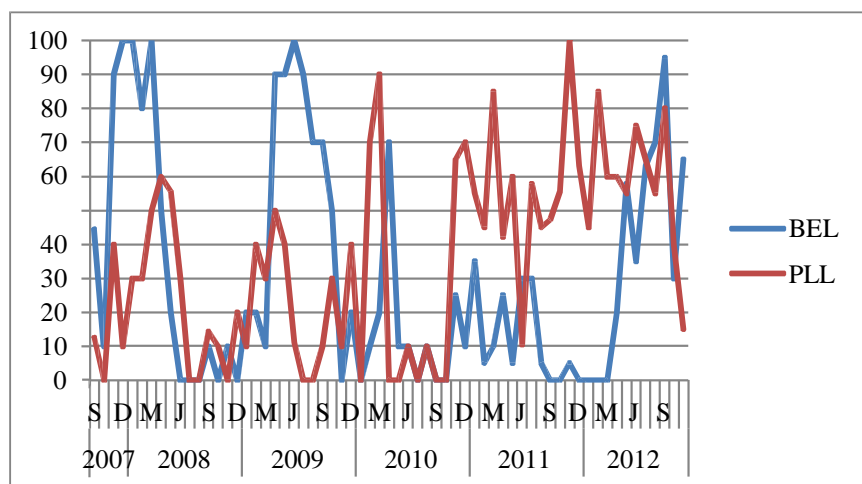
Figure 10.4. Percentage of *Cordemoya integrifolia* trees with young leaves at Bel Ombre (BEL) and Plaine Lièvre (PLL) between 2007 and 2012.

In *Cordemoya integrifolia*, the proportion of trees with flower buds was influenced by all factors studied; month ($F_{11,1936}=8.74$, $P<0.0001$), site ($F_{1,1635}=11.06$, $P<0.0001$) and individual trees ($F_{1,1634}=15.41$, $P<0.0001$). As for the proportion of trees bearing flowers, the month ($F_{11,1636}=3.33$, $P<0.0001$) and individual tree ($F_{1,1634}=5.05$, $P=0.025$) showed a strong correlation, but the site ($F_{1,1635}=0.91$, $P=0.338$) had no influence.

The percentage of trees with fruits was correlated to the month ($F_{11,1636}$=2.27, P=0.009), but not to the site ($F_{1,1635}$=3.72, P=0.054) nor the individual trees ($F_{1,1634}$=0.1.85, P=0.174).

For proportion of trees with young leaves, the site ($F_{1,1635}$=30.35, P<0.0001) and individual tree ($F_{1,1634}$=9.05, P=0.003) bore a strong influence, but not the month ($F_{11,1636}$=1.75, P=0.057).

Erythrospermum monticolum **(bois manioc)**
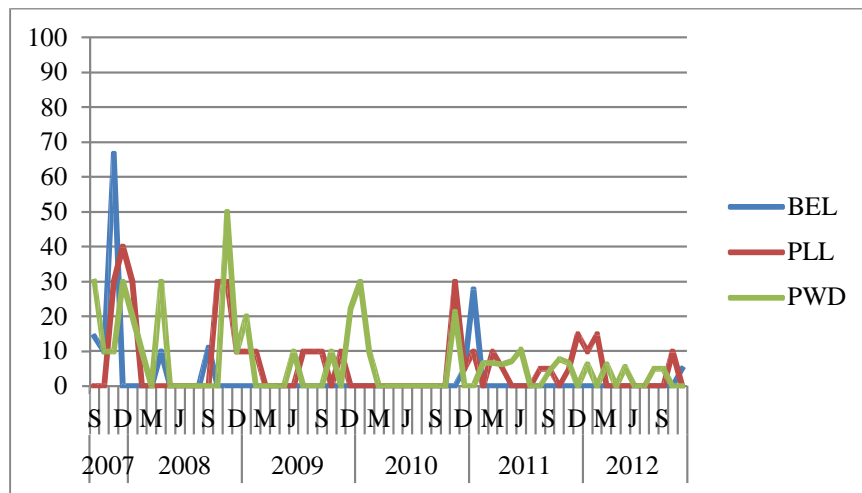
Figure 11.1. Percentage of *Erythrospermum monticolum* trees with flower buds at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
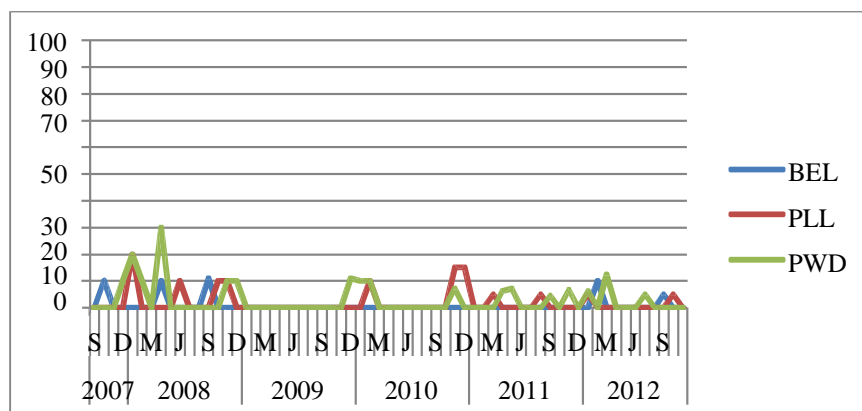
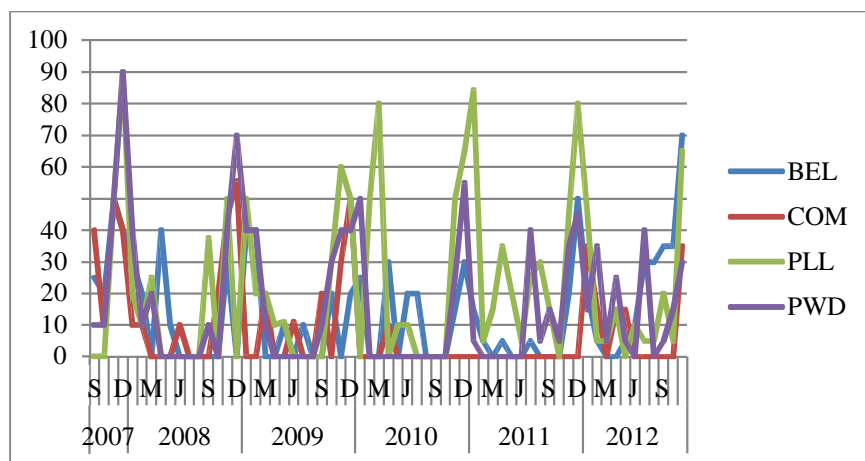
Figure 11.2. Percentage of *Erythrospermum monticolum* trees in flower at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
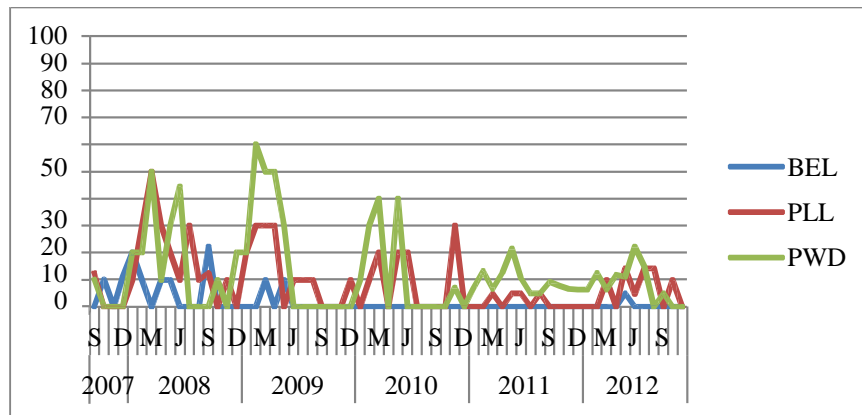
Figure 11.3. Percentage of *Erythrospermum monticolum* trees in fruit at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
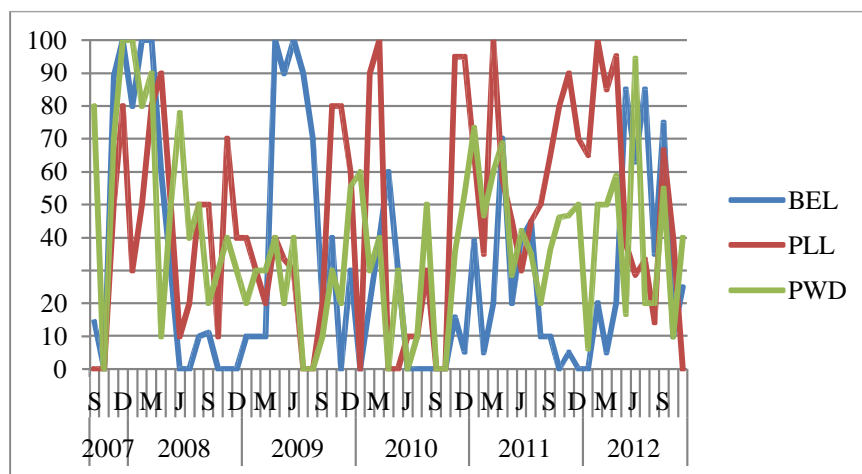
Figure 11.4. Percentage of *Erythrospermum monticolum* trees with young leaves at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

For *Erythrospermum monticolum*, the percentage of trees with flower buds was strongly influenced by all factors (month ($F_{11,2379}$=7.83, P<0.0001), site ($F_{2,2377}$=11.06, P<0.0001) and the individual tree ($F_{1,2376}$=2.067, P=0.003)). For the proportion of number of flowers, the site ($F_{2,2377}$=5.22, P=0.005) and individual tree bear a strong influence ($F_{1,2376}$=2.35, P=0.001), but the month ($F_{1,1635}$=0.91, P=0.338) had no influence.

The proportion of trees with fruits was strongly correlated to all factors; the month ($F_{11,2379}=5.41$, $P<0.0001$), the site ($F_{2,2377}=42.59$, $P<0.0001$) and the individual tree ($F_{1,2376}=5.092$, $P<0.0001$).

The above trend was also observed for young leaves (the month ($F_{11,2379}=7.59$, $P<0.0001$), the site ($F_{2,2377}=38.19$, $P<0.0001$) and the individual tree ($F_{1,2376}=2,02$, $P=0.004$)).

Ficus reflexa (**affouche à petites feuilles**)

Figure 12.1. Percentage of *Ficus reflexa* trees with flower buds at Ile aux Aigrettes (IAA), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 12.2. Percentage of *Ficus reflexa* trees in flower at Ile aux Aigrettes (IAA), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
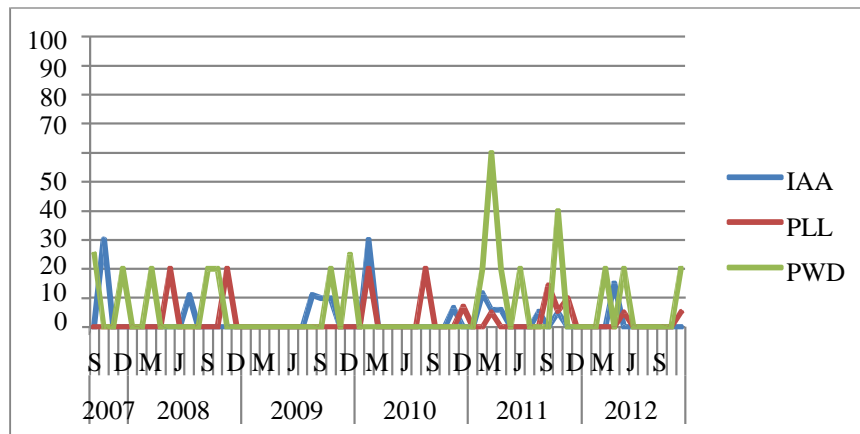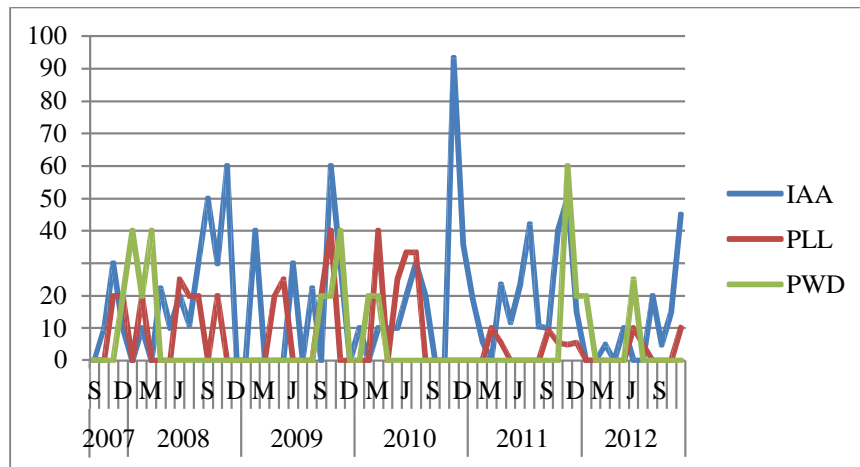
Figure 12.3. Percentage of *Ficus reflexa* trees in fruit at Ile aux Aigrettes (IAA), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
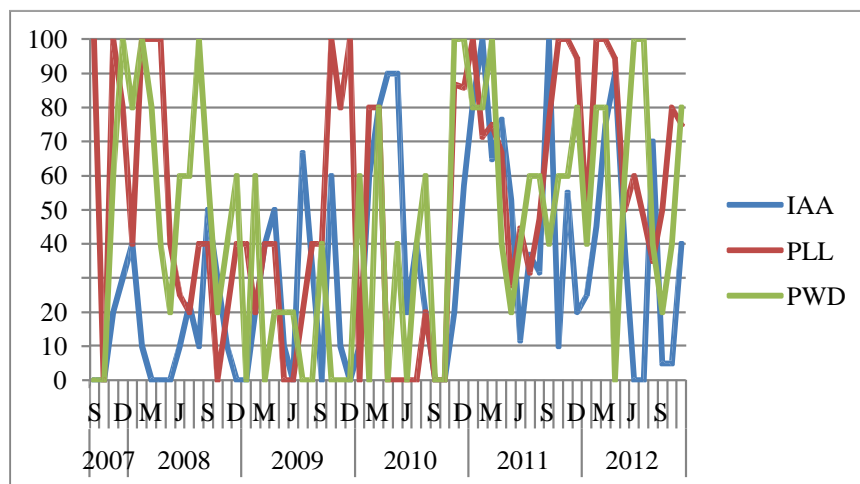
Figure 12.4. Percentage of *Ficus reflexa* trees with young leaves at Ile aux Aigrettes (IAA), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

In *Ficus reflexa*, the proportion of trees in flower buds was strongly correlated by all factors - the month ($F_{11,1639}=1.94$, $P=0.025$), the site ($F_{2,1631}=5.02$, $P=0.007$) and the individual tree ($F_{1,1630}=9.46$, $P=0.002$). For the proportion of trees with flowers, none of the factors bear a

38

significant influence (month ($F_{11,1633}$=1.18, P=0.289), site ($F_{2,1631}$=2.97, P=0.051) and individual tree ($F_{1,1630}$=0.95, P=0.329)).

The proportion of trees with fruits was influenced by the month ($F_{11,1633}$=6.14, P<0.0001) and the site ($F_{2,1631}$=42.97, P<0.0001). However, the individual trees of *Ficus reflexa* did not influence the proportion of trees with fruits observed ($F_{1,1630}$=1.93, P=0.163).

As for the proportion of trees bearing young leaves, all factors bear a significant influence: month ($F_{11,1633}$=7.86, P<0.0001), site ($F_{2,1631}$=43.73, P<0.0001) and individual tree ($F_{1,1630}$=7.93, P=0.005).

Gaertnera psychotrioides **(bois banane)**
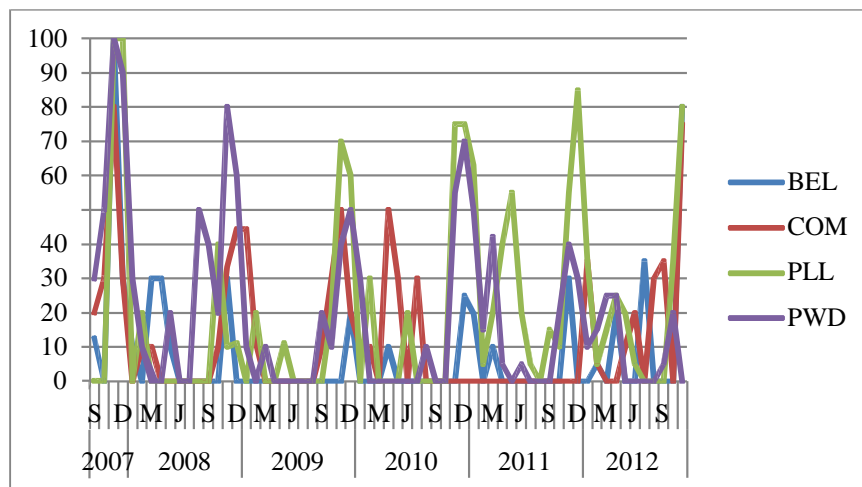
Figure 13.1. Percentage of *Gaertnera psychotrioides* trees with flower buds at Bel Ombre (BEL), Combo(COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 13.2.   Percentage of *Gaertnera psychotrioides* trees in flower at Bel Ombre (BEL), Combo(COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
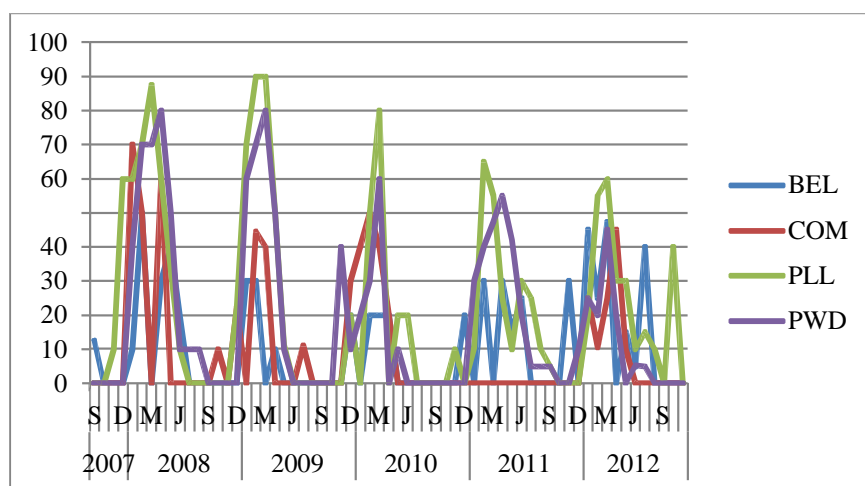
Figure 13.3. Percentage of *Gaertnera psychotrioides* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
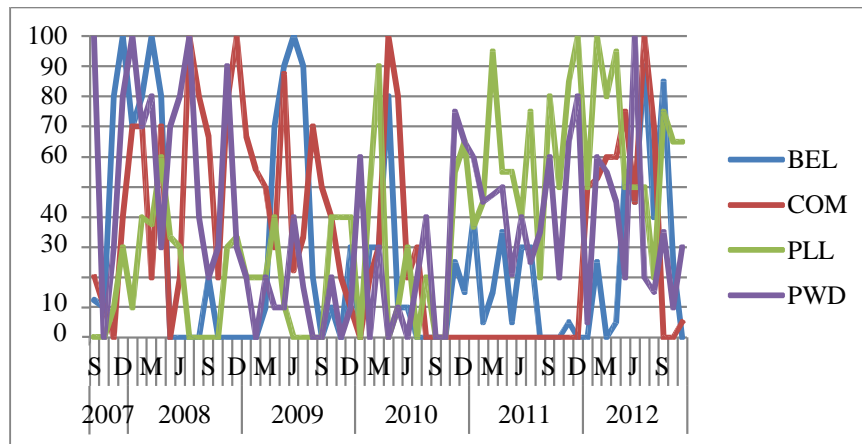
Figure 13.4. Percentage of *Gaertnera psychotrioides* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of trees with flower buds of *Gaertnera psychotrioides* was significantly correlated to all factors: the month ($F_{11,3042}$=42.72, P<0.0001), the site ($F_{3,3039}$=29.00, P<0.0001) and the individual tree ($F_{1,3038}$=24.53, P<0.0001).   Similarly, the proportion of trees having flowers, was strongly correlated to the month ($F_{11,3042}$=34.51, P<0.0001), the site ($F_{3,3039}$=15.59, P<0.0001) and the individual tree ($F_{1,3038}$=24.70, P<0.0001).

The proportion of trees bearing fruits was strongly influenced by all the factors; the month ($F_{11,3042}$=45.92, P<0.0001), the site ($F_{3,3039}$=22.45, P<0.0001) and the individual tree ($F_{1,3038}$=41.63, P<0.0001).

The proportion of trees having young leaves were significantly correlated to the month ($F_{11,3042}$=7.5, P<0.0001) and to the site ($F_{3,3039}$=26.69, P<0.0001). However, in this species the individual tree did not have an influence on the proportion of trees with young leaves ($F_{1,3038}$=0.38, P=0.535).

Grangeria borbonica (bois balais)
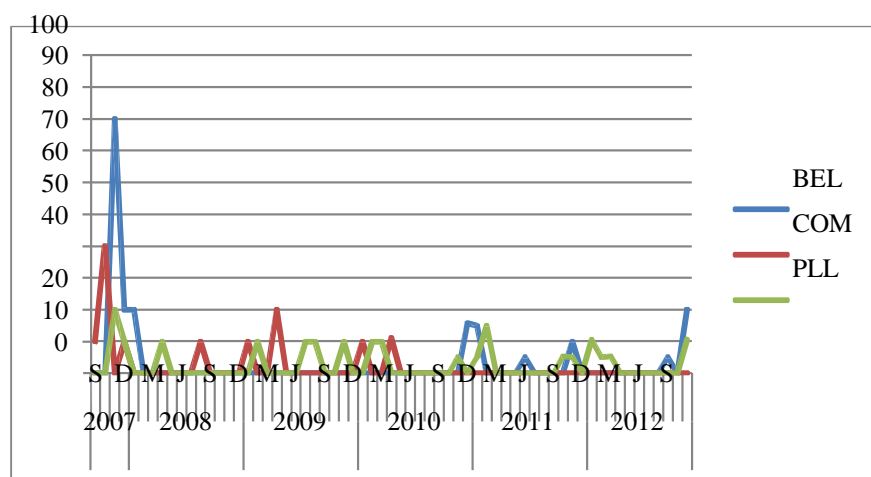
Figure 14.1. Percentage of *Grangeria borbonica* trees with flower buds at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.
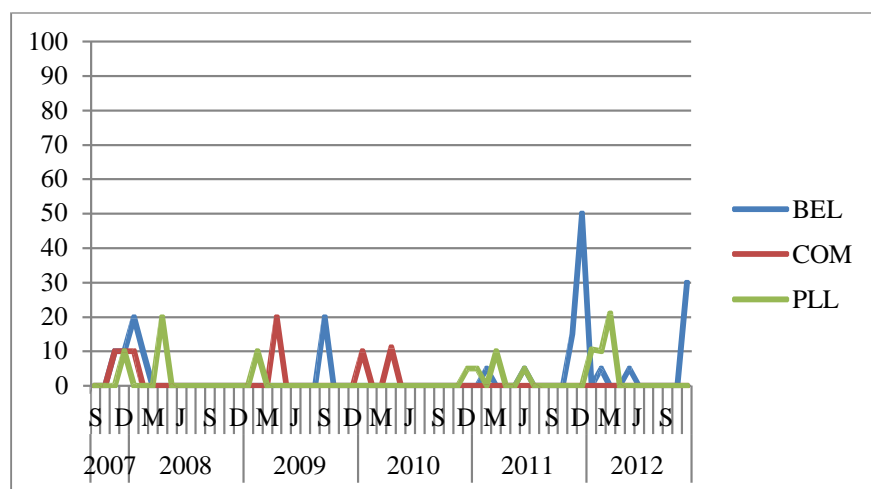
Figure 14.2. Percentage of *Grangeria borbonica* trees in flower at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.
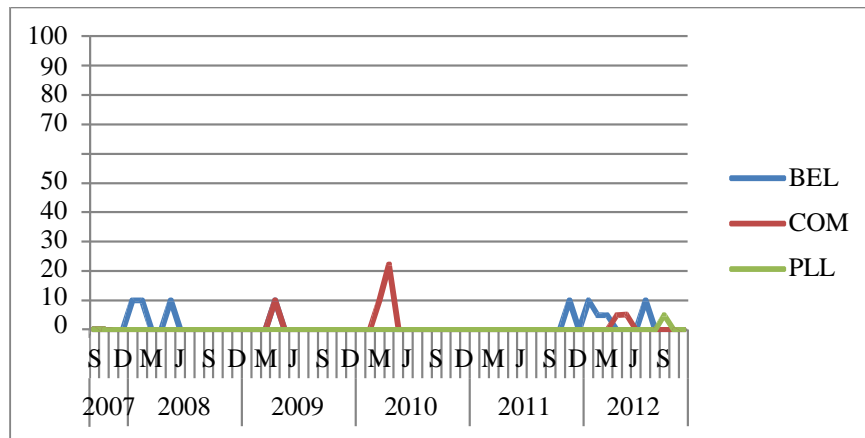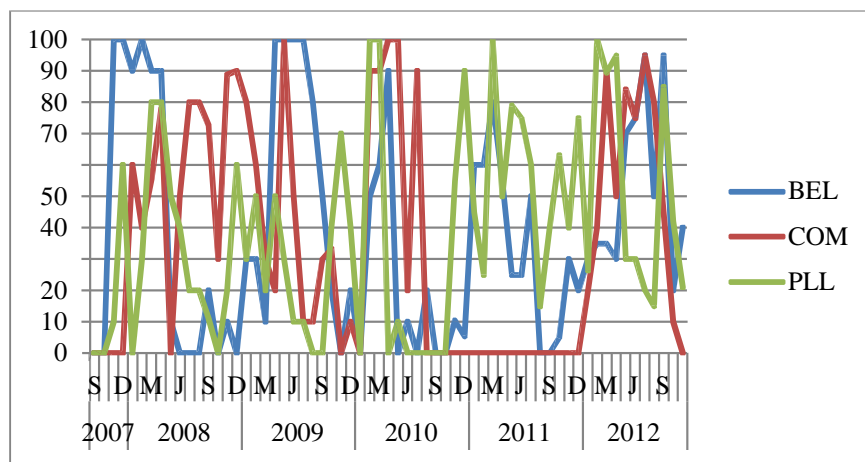
Figure 14.3. Percentage of *Grangeria borbonica* trees in fruit at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.

Figure 14.4. Percentage of *Grangeria borbonica* trees with young leaves at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.

The proportion of *Grangeria borbonica* trees having flower buds varied according to the month ($F_{11,2201}=5.28$, $P<0.0001$), but neither to the site ($F_{2,2199}=0.63$, $P=0.532$) nor to individual trees ($F_{1,2198}=1.21$, $P=0.271$). For the proportion of trees having flowers, the site ($F_{2,2199}=4.07$, $P=0.017$) and month varied ($F_{11,2201}=5.19$, $P<0.0001$), but the individual tree ($F_{1,2198}=1.63$, $P=0.201$) had no influence.

For the proportion of trees having fruits it varied according to the site ($F_{2,2199}=0.37$, $P=0.004$), but not to the month ($F_{11,1635}=1.74$, $P=0.057$), nor to individual trees ($F_{1,2198}=0.38$, $P=0.540$).

The proportion of trees having young leaves, varied according to all factors; the month ($F_{11,2201}=15.65$, $P<0.0001$), the site ($F_{2,2199}=4.27$, $P=0.014$) and the individual tree ($F_{1,2198}=8.46$, $P=0.004$).

Nuxia verticillata (**bois maigre**)
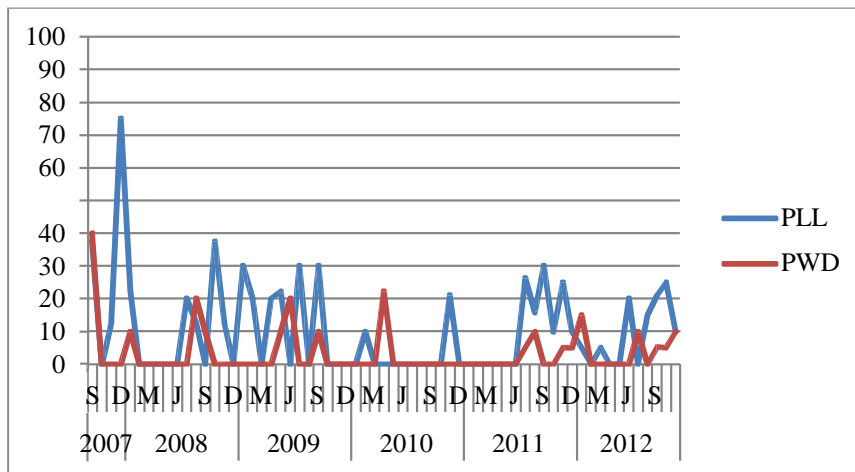
Figure 15.1. Percentage of *Nuxia verticillata* trees with flower buds at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
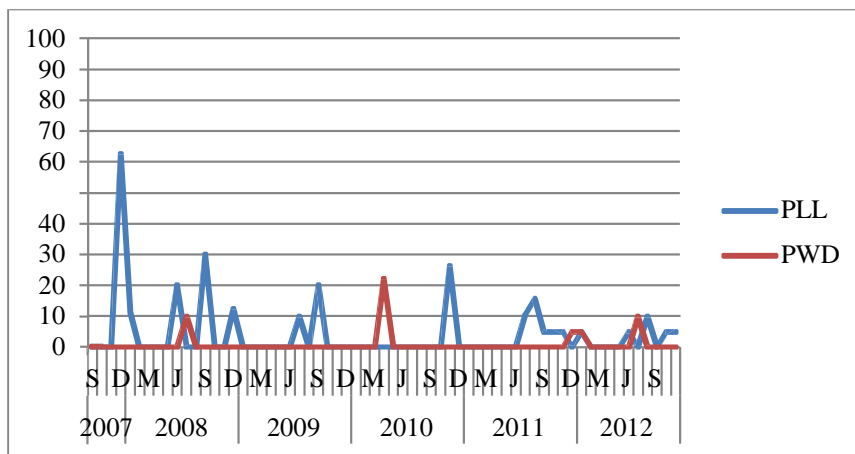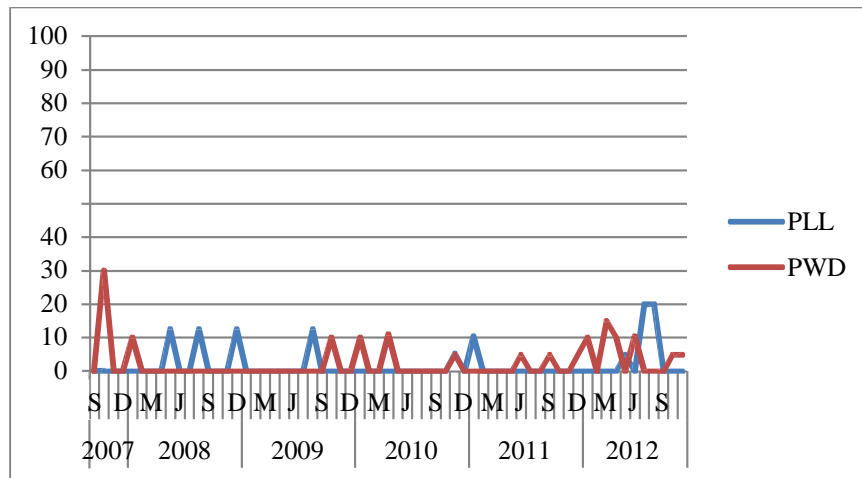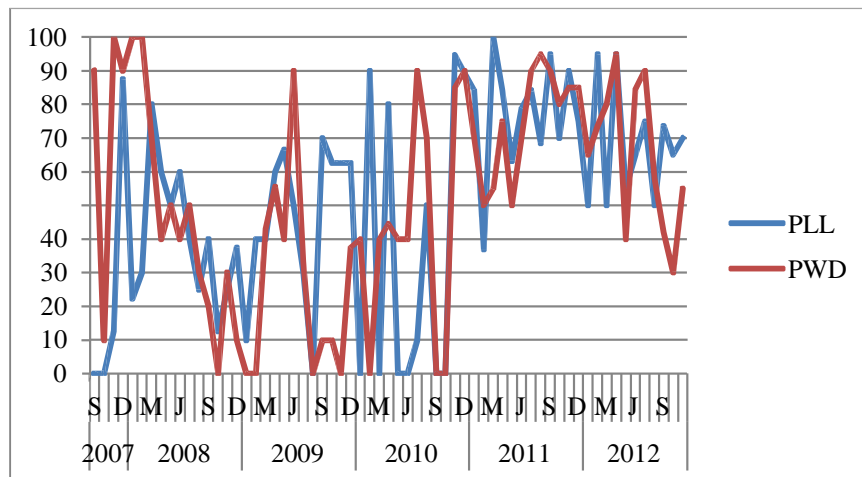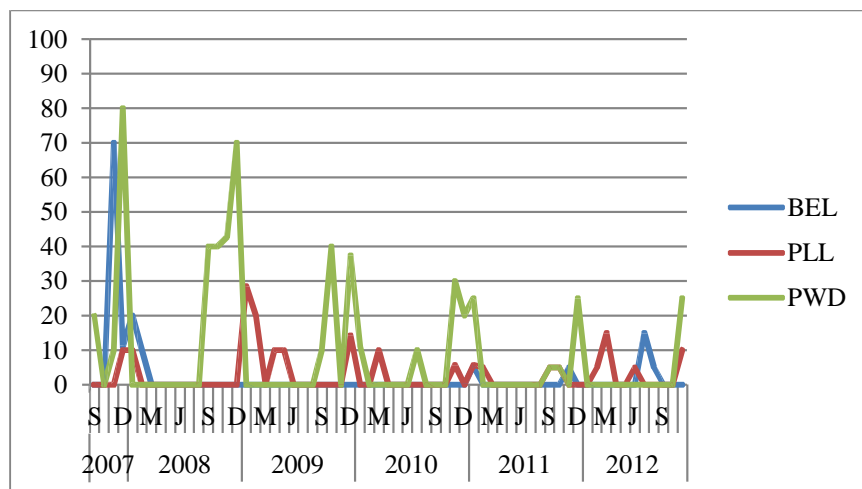

Figure 15.2. Percentage of *Nuxia verticillata* trees in flower at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 15.3. Percentage of *Nuxia verticillata* trees in fruit at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 15.4. Percentage of *Nuxia verticillata* trees with young leaves at Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of *Nuxia verticillata* trees having flower buds varied according to the month ($F_{11,1649}$=4.99, P<0.0001) and the site ($F_{1,1648}$=36.70, P<0.0001). However, individual trees did not influence the proportion of trees having flower buds ($F_{1,1647}$=0.08, P=0.764). For the

proportion of trees having flowers, the site ($F_{1,1648}$=20.97, P<0.0001) and month varied ($F_{11,1649}$=2.92, P<0.0001), but the individual tree ($F_{1,1647}$=1.12, P=0.289) had no influence.

For the proportion of trees having fruits, none of the factors had any influence (the month ($F_{11,1649}$=1.47, P=0.136), the site ($F_{1,1648}$=0,88, P=0.347) and individual tree ($F_{1,1647}$=1.88, P=0.171).

For the proportion of trees having young leaves, the month ($F_{11,1649}$=5.02, P<0.0001) and individual tree varied ($F_{1,1647}$=23.23, P<0.0001), but the site had no influence ($F_{1,1648}$=0.01, P=0.971).

Ochna mauritiana (**bois bouquet bananè**)

Figure 16.1. Percentage of *Ochna mauritiana* trees with flower buds at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
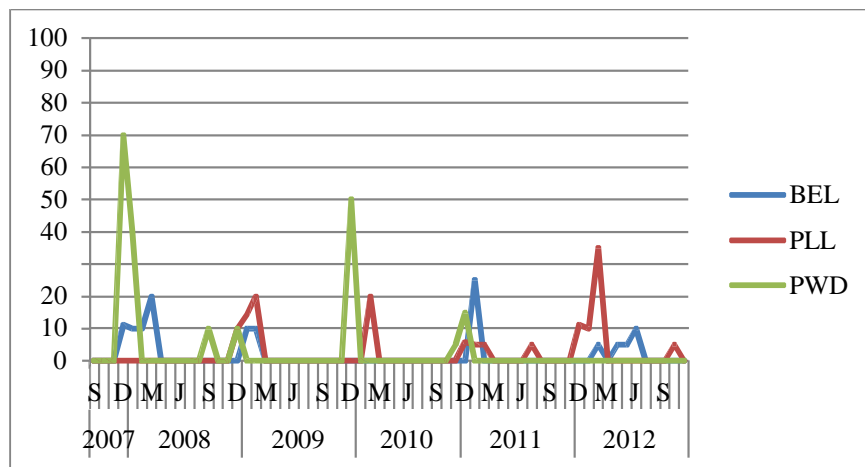
Figure 16.2. Percentage of *Ochna mauritiana* trees in flower at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
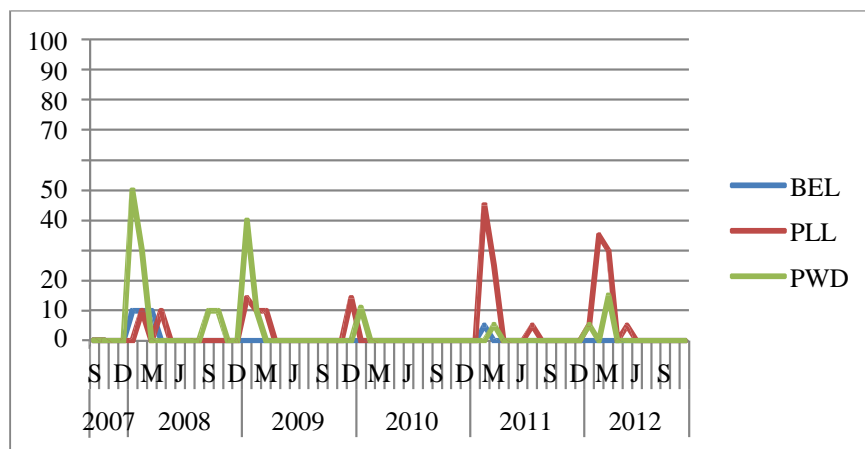

Figure 16.3. Percentage of *Ochna mauritiana* trees in fruit at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
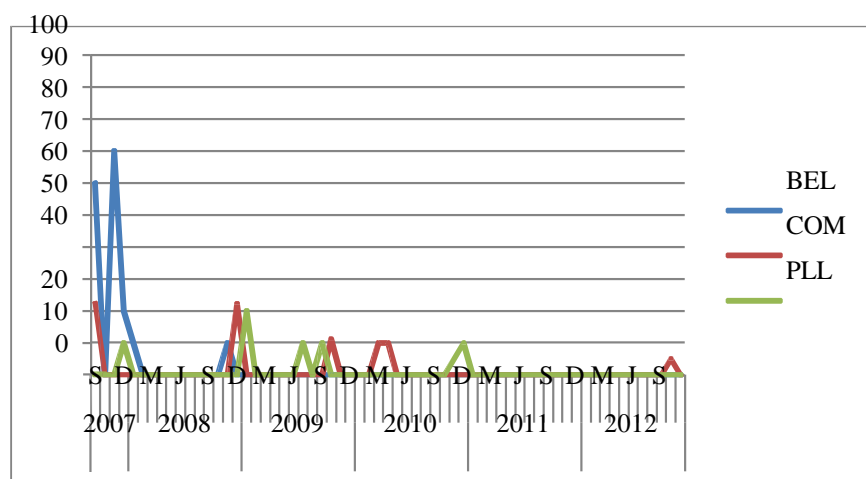
Figure 16.4.   Percentage of *Ochna mauritiana* trees with young leaves at Bel Ombre (BEL), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of *Ochna mauritiana* trees having flower buds varied according to all factors; the month ($F_{11,2414}=9.875$, $P<0.0001$), the site ($F_{2,2412}=20.79$, $P<0.0001$) and the individual tree ($F_{1,2411}=14.96$, $P=0.0001$).   The proportion of trees having flowers, varied according to the month ($F_{11,2414}=7.94$, $P<0.0001$) only; the site ($F_{2,2412}=0.49$, $P=0.612$) and the individual tree ($F_{1,2411}=0.63$, $P=0.427$) had no strong influence.

For the proportion of trees having fruits it varied according to the month ($F_{11,2414}=11.73$, $P<0.0001$) only, whilst the site ($F_{2,2412}=16.60$, $P=0.612$) and the individual tree ($F_{1,2411}=2.06$, $P=0.151$) had no significant influence.

The proportion of trees having young leaves varied according to all factors; the month ($F_{11,2414}=8.97$, $P<0.0001$), the site ($F_{2,2412}=18.57$, $P<0.0001$) and the individual tree ($F_{1,2411}=6.34$, $P=0.012$).

***Securinega durissima* (bois dur)**

Figure 17.1. Percentage of *Securinega durissima* trees with flower buds at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.
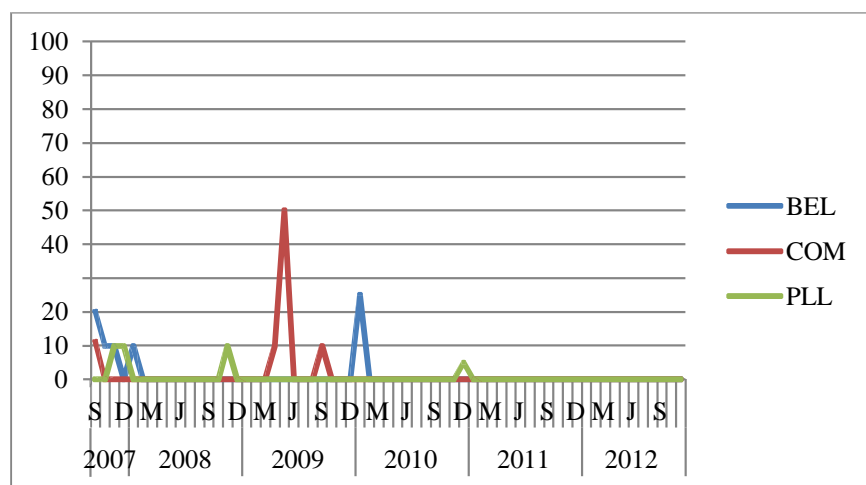

Figure 17.2. Percentage of *Securinega durissima* trees in flower at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.
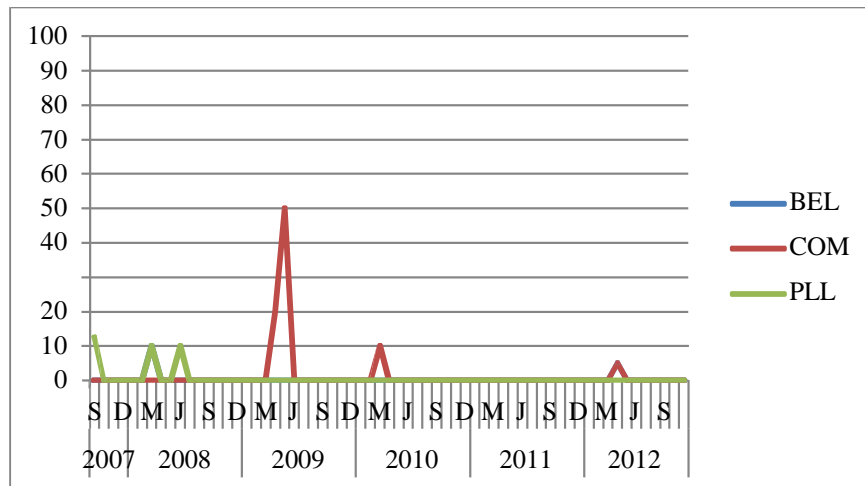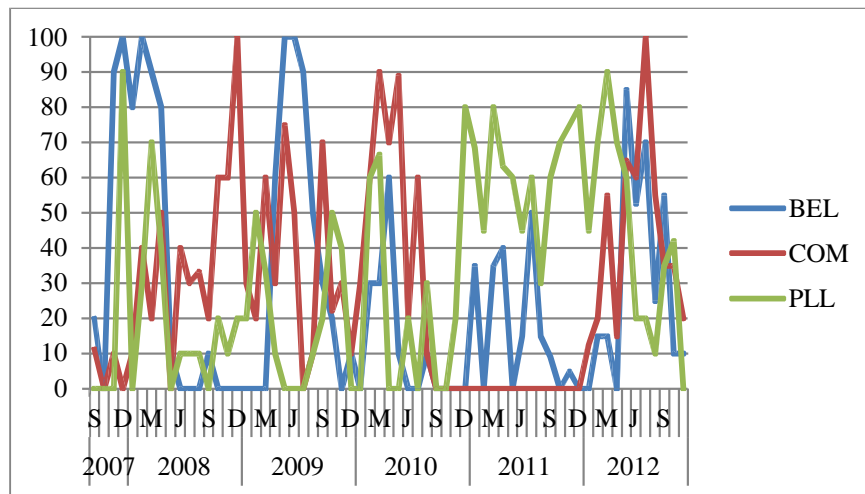
Figure 17.3. Percentage of *Securinega durissima* trees in fruit at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.

Figure 17.4. Percentage of *Securinega durissima* trees with young leaves at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) between 2007 and 2012.

For *Securinega durissima*, the proportion of trees having flower buds varied for the month ($F_{11,2179}=3.94$, $P<0.0001$) and the individual tree ($F_{1,2176}=16.78$, $P<0.0001$), but not the site ($F_{2,2177}=0.76$, $P=0.464$). For the proportion of trees having flowers, it varied for the month

50

($F_{11,2179}=1.92$, $P=0.031$) and the individual tree ($F_{1,2176}=6.91$, $P=0.009$), but not the site ($F_{2,2177}=1.57$, $P=0.208$).

The proportion of trees having fruits varied according to month ($F_{11,2179}=2.45$, $P=0.005$) and the site ($F_{2,2177}=4.05$, $P=0.0181$), but not to the individual tree ($F_{1,2176}=0.01$, $P=0.891$).

For the proportion of trees having young leaves, the number recorded varied for the month ($F_{11,2179}=6.71$, $P<0.0001$) and the site ($F_{2,2177}=21.28$, $P<0.0001$), but not the individual tree ($F_{1,2176}=2.9$, $P=0.089$).

Syzygium glomeratum **(bois pomme)**
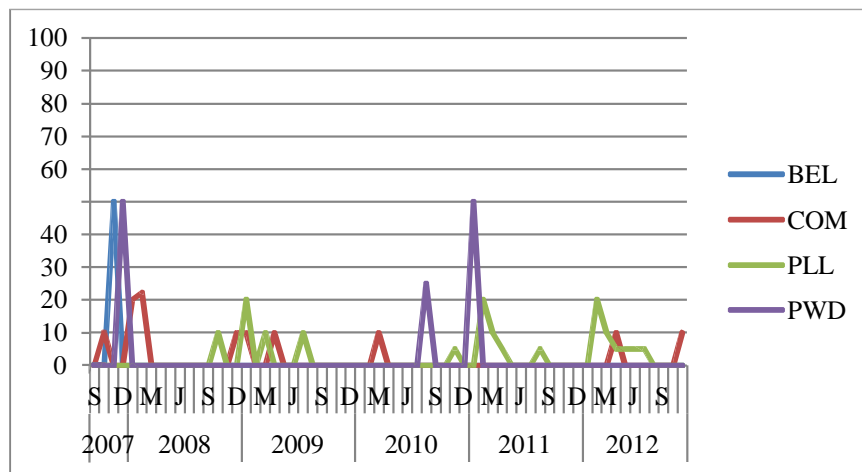
Figure 18.1. Percentage of *Syzygium glomeratum* trees with flower buds at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
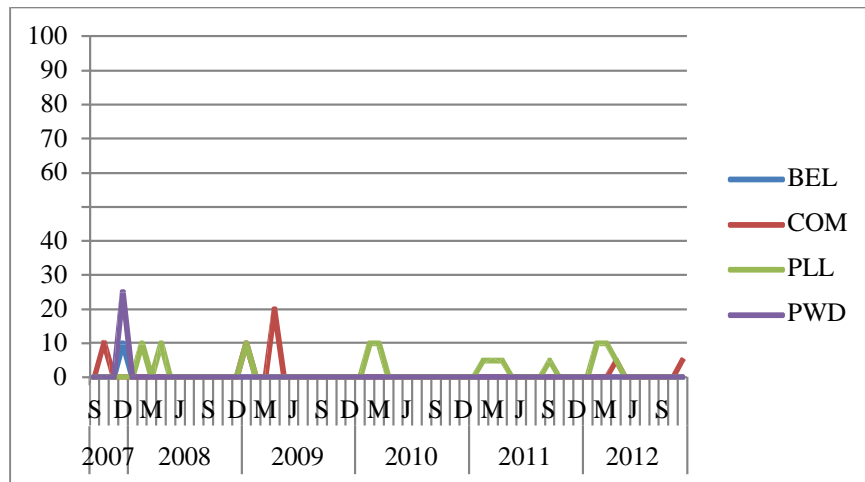
Figure 18.2. Percentage of *Syzygium glomeratum* trees in flower at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
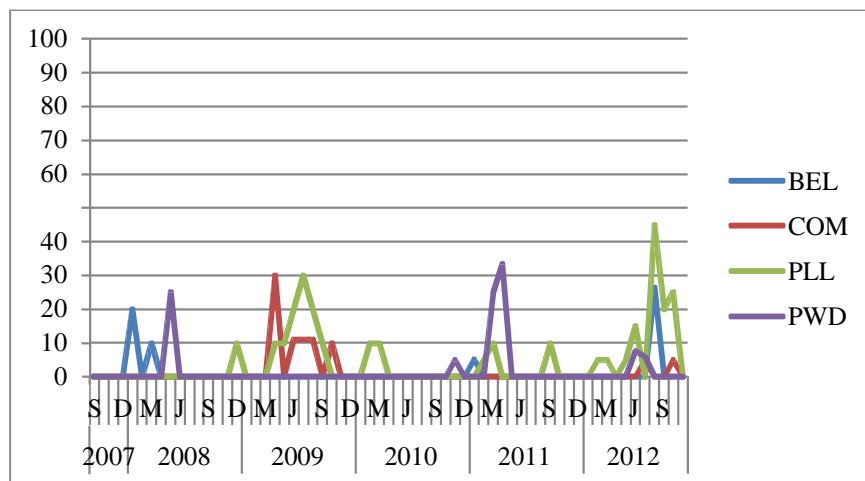

Figure 18.3. Percentage of *Syzygium glomeratum* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
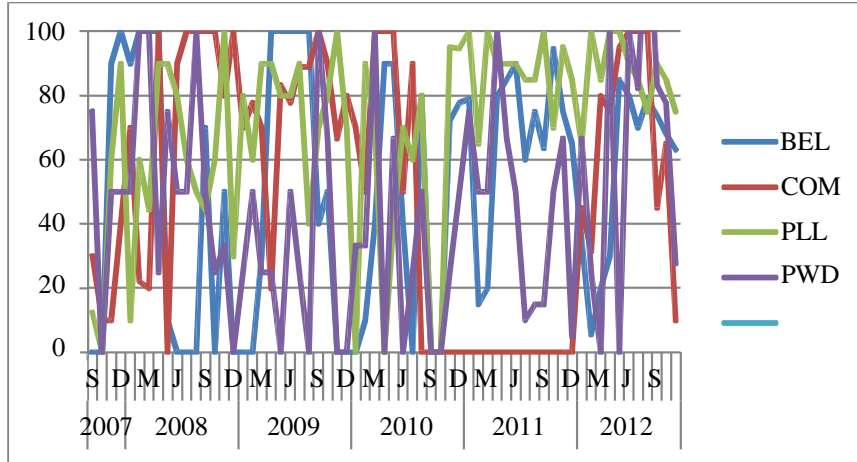
Figure 18.4. Percentage of *Syzygium glomeratum* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

For *Syzygium glomeratum*, the proportion of trees having flower buds recorded varied for the month ($F_{11,2584}=2.93$, $P<0.0001$) and the site ($F_{3,2581}=4.82$, $P=0.002$), but not to the individual tree ($F_{1,2580}=1.44$, $P=0.085$). Similarly, the proportion of trees having flowers varied for the month ($F_{11,2584}=2.73$, $P=0.002$) and the site ($F_{3,2581}=5.07$, $P=0.002$), but not to the individual tree ($F_{1,2580}=1.01$, $P=0.443$).

The proportion of trees having fruits varied according to the month ($F_{11,2584}=2.91$, $P=0.001$) and the site ($F_{3,2581}=10.44$, $P<0.0001$), but not to the individual tree ($F_{1,2580}=1.39$, $P=0.109$).

For the young leaves, the number recorded varied for all the factors; month ($F_{11,2584}=2.93$, $P<0.0001$), site ($F_{3,2581}=54.82$, $P<0.0001$) and individual tree ($F_{1,2580}=1.44$, $P=0.024$).

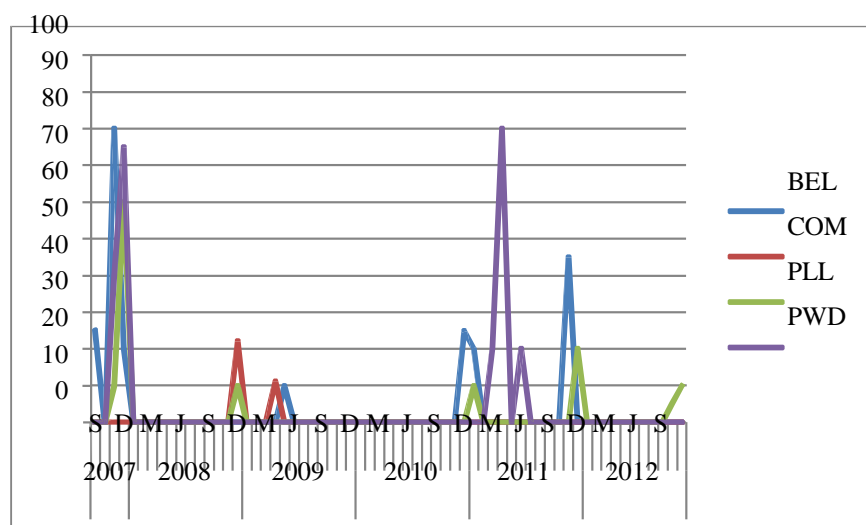*Warneckea trinervis* (**bois canne**)

Figure 19.1. Percentage of *Warneckea trinervis* trees with flower buds at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
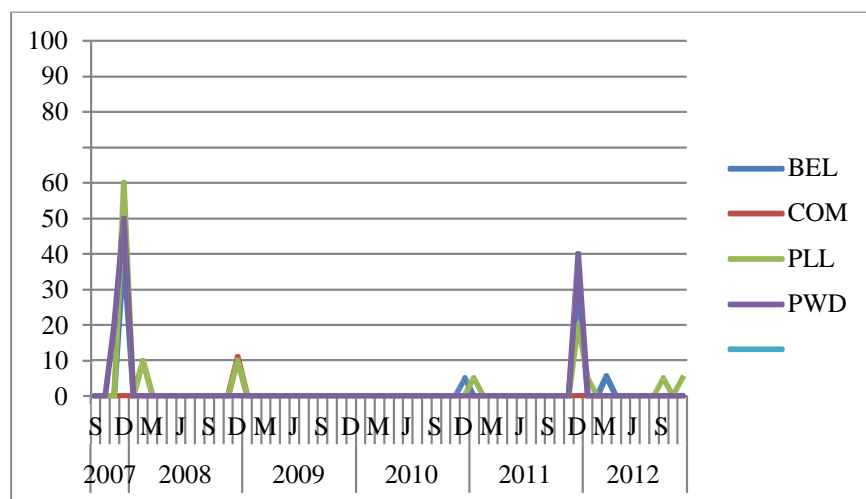

Figure 19.2. Percentage of *Warneckea trinervis* trees in flower at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
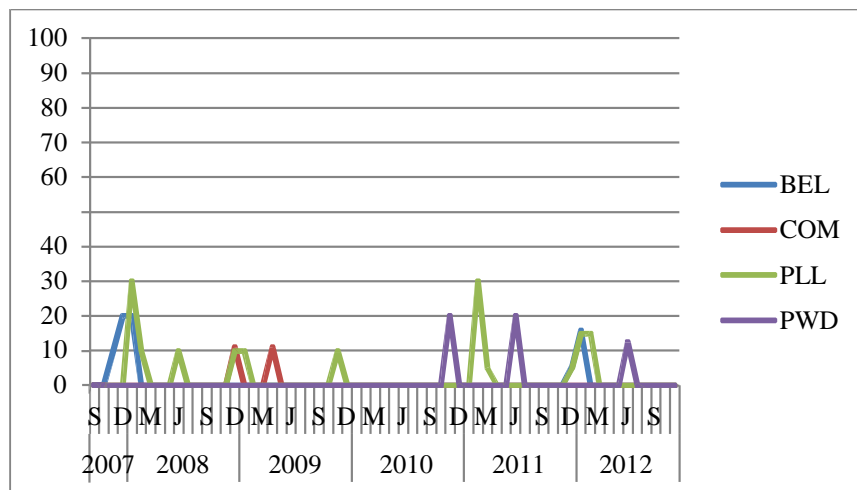
Figure 19.3. Percentage of *Warneckea trinervis* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
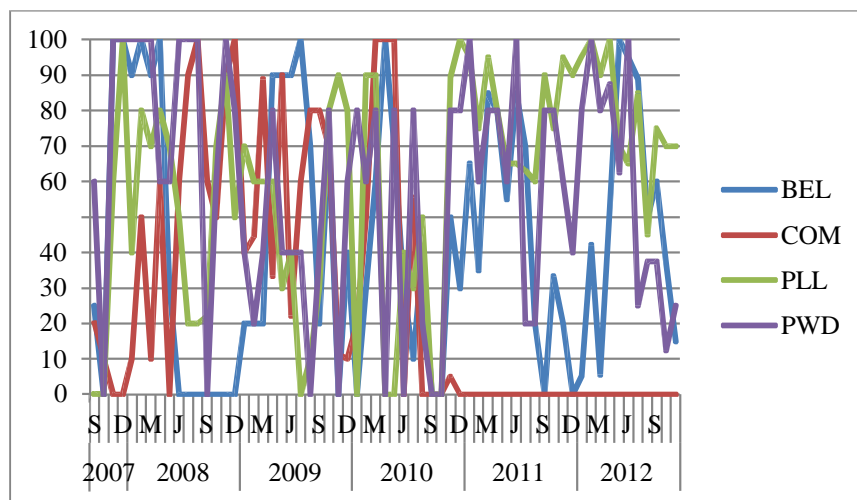

Figure 19.4. Percentage of *Warneckea trinervis* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of *Warneckea trinervis* trees having flower buds varied for the month ($F_{11,2310}$=10.16, P<0.0001) and for the site ($F_{3,2307}$=2.39, P=0.019), but not for the individual tree ($F_{1,2306}$=2,19, P=0.138). For the proportion of trees having flowers, it varied for the month ($F_{11,2310}$=8.87, P<0.0001) and for the site ($F_{3,2307}$=2.85, P=0.006), but not for the individual tree ($F_{1,2306}$=1.57, P=0.209).

55

The proportion of *Warneckea trinervis* trees having fruits varied according to the month only ($F_{11,2310}$=6.48, P<0.0001). The site ($F_{3,2307}$=1.49, P=0.1638) and the individual tree ($F_{1,2306}$=0.31, P=0.574) did not strongly influence the proportion of trees with fruits.

The proportion of trees having young leaves varied for all the factors; the month ($F_{11,2310}$=5.02, P<0.0001), the site ($F_{3,2307}$=132.12, P<0.0001), but not to the individual tree ($F_{1,2306}$=5.28, P=0.021).

5.2.2 Exotic species
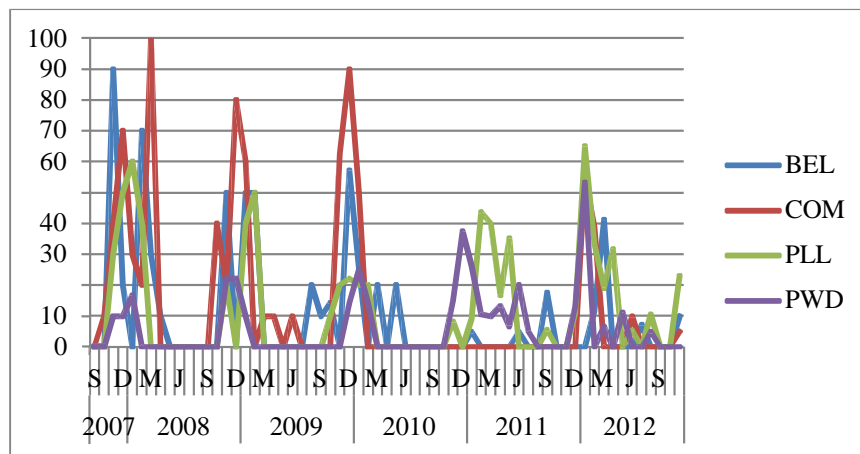
Ligustrum robustum (privet)

Figure 20.1. Percentage of *Ligustrum robustum* trees with flower buds at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 20.2. Percentage of *Ligustrum robustum* trees in flower at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
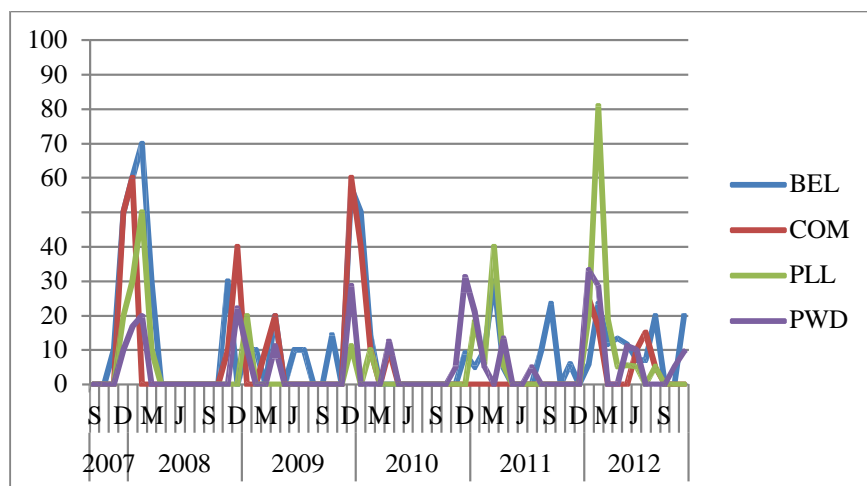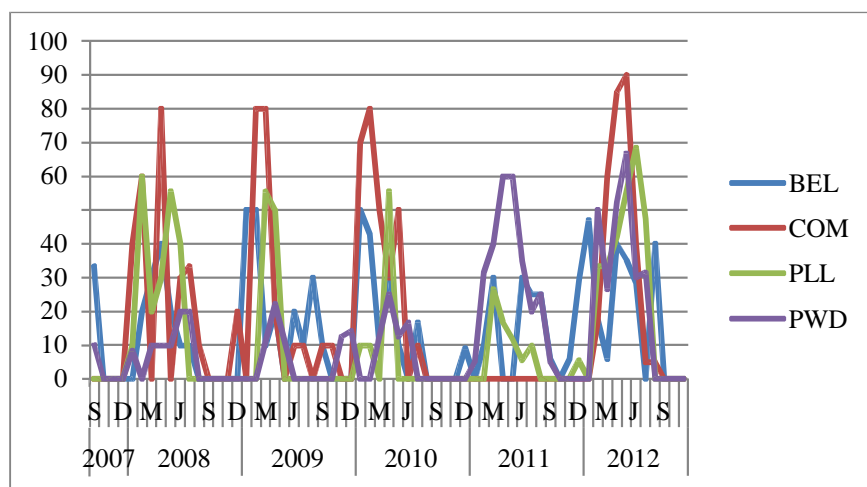

Figure 20.3. Percentage of *Ligustrum robustum* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
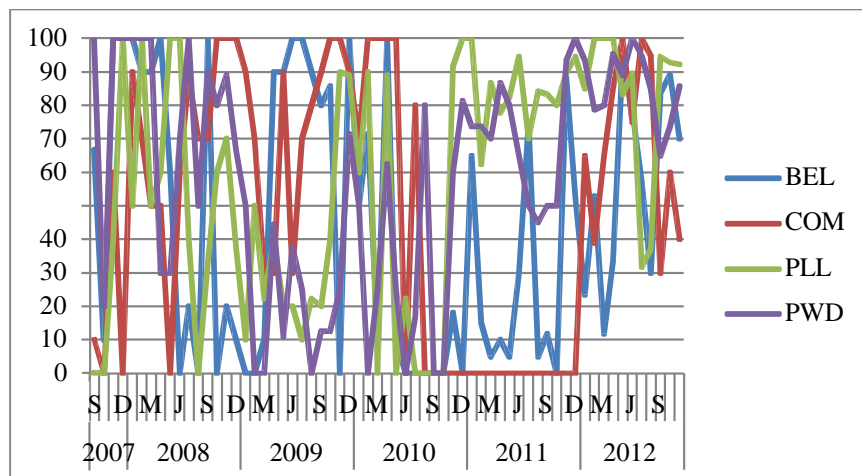
Figure 20.4. Percentage of *Ligustrum robustum* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of *Ligustrum robustum* trees having flower buds varied according to all factors; the month ($F_{11,2796}=26.33$, $P<0.0001$), the site ($F_{3,2793}=11.06$, $P<0.0001$) and the individual tree ($F_{1,2767}=2.66$, $P<0.0001$). For the proportion of trees having flowers, the month ($F_{11,2796}=18.33$, $P<0.0001$) and site varied ($F_{3,2793}=4.01$, $P=0.007$), but the individual tree ($F_{1,2767}=1.24$, $P=0.181$) had no major influence.

For the proportion of trees bearing fruits, it varied according to all factors; the month ($F_{11,2796}=35.04$, $P<0.0001$), the site ($F_{3,2793}=11.58$, $P<0.0001$) and the individual tree ($F_{1,2767}=2.77$, $P<0.0001$).

As for the proportion of trees with young leaves, all factors had a strong influence; the month ($F_{11,2796}=6.02$, $P<0.0001$), the site ($F_{3,2793}=32.23$, $P<0.0001$) and the individual tree ($F_{1,2767}=4.17$, $P<0.0001$).

Litsea glutinosa **(bois d'oiseau à petites feuilles)**

Figure 21.1. Percentage of *Litsea glutinosa* trees with flower buds at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 21.2. Percentage of *Litsea glutinosa* trees in flower at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 21.3. Percentage of *Litsea glutinosa* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

Figure 21.4. Percentage of *Litsea glutinosa* trees with young leaves at Bel Ombre (BEL), Combo (COM) and Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

In *Litsea glutinosa*, the proportion of trees with flower buds varied according to all factors (month ($F_{11,2210}$=31.91, $P<0.0001$), site ($F_{3,2207}$=17.51, $P<0.0001$) and the individual tree

($F_{1,2206}$=32.76, P<0.0001)).   For the proportion of trees having flowers, the month ($F_{11,2210}$=10.30, P<0.0001), the site ($F_{3,2207}$=7.22, P<0.0001) and the individual tree ($F_{1,2206}$=20.79, P<0.0001) were strongly correlated factors.

For the proportion of fruit bearing trees, the month ($F_{11,2210}$=5.42, P<0.0001) and site varied ($F_{3,2207}$=15.08, P<0.0001), but the individual tree ($F_{1,2206}$=2.37, P=0.123) had no influence.

The proportion of trees having young leaves, the month ($F_{11,2210}$=6.34, P<0.0001) and site varied ($F_{3,2207}$=16.9, P<0.0001), but the individual tree ($F_{1,2206}$=2.01, P=0.156) had no major influence.
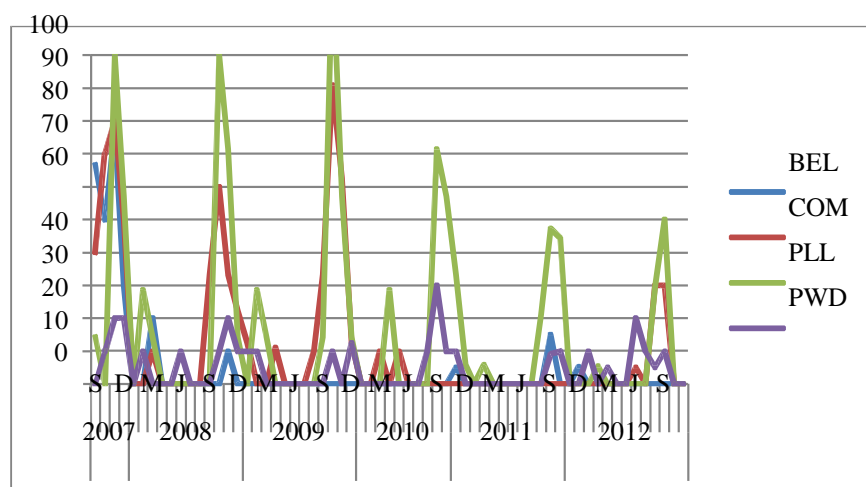
Litsea monopetala (yati)
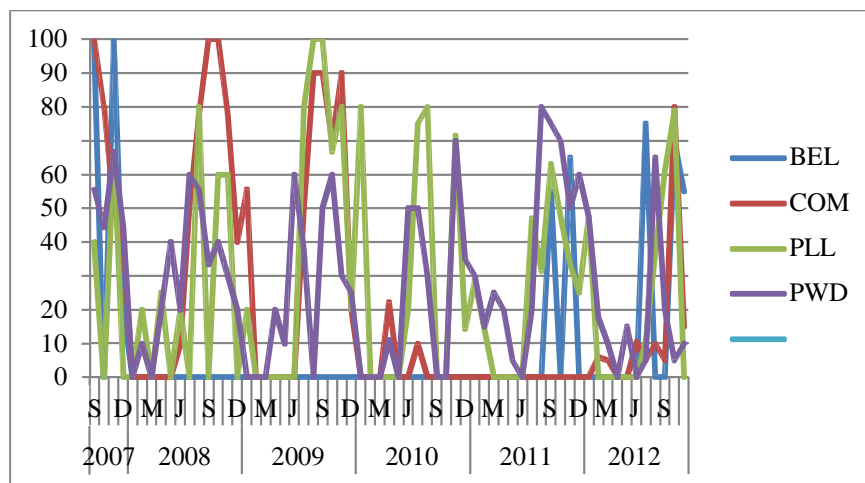
Figure 22.1.   Percentage of *Litsea monopetala* trees with flower buds at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
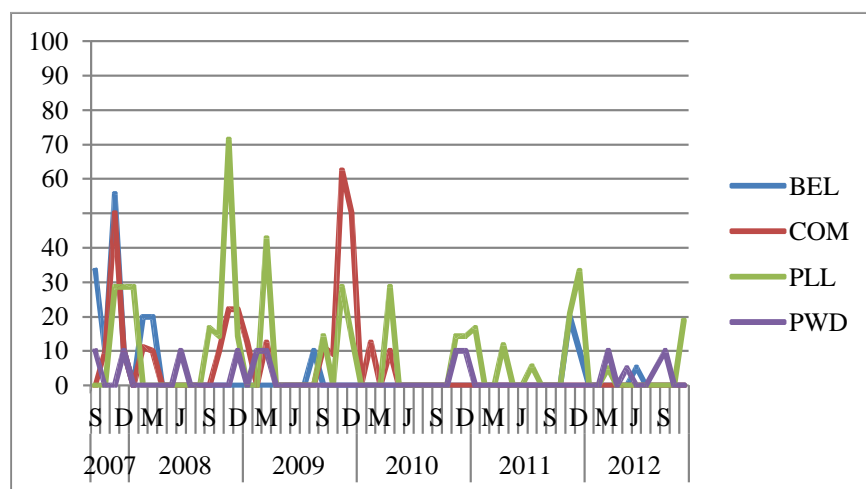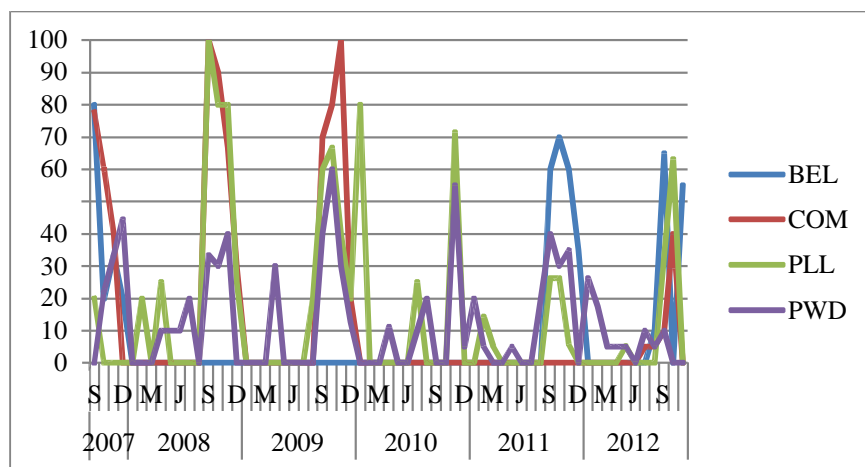
Figure 22.2. Percentage of *Litsea monopetala* trees with flowers at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
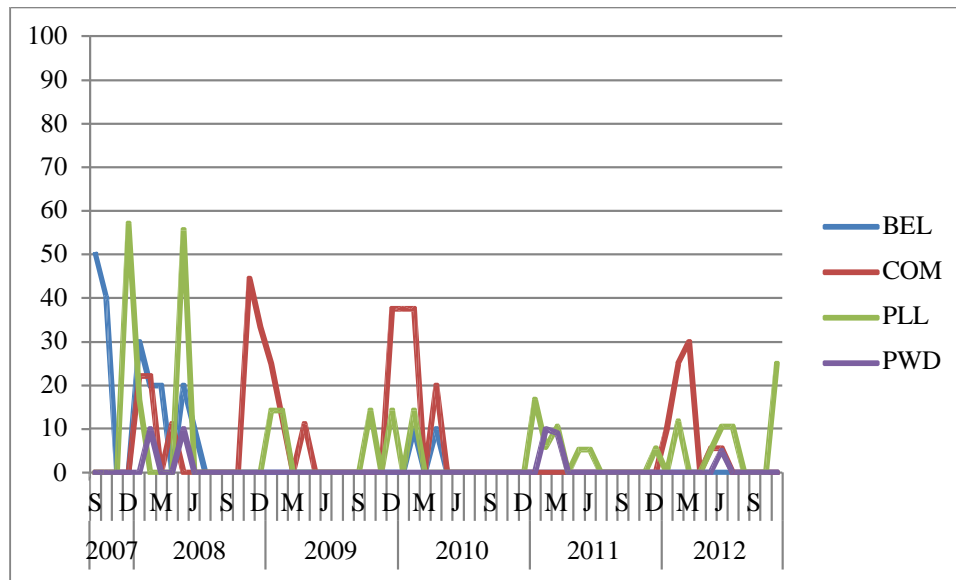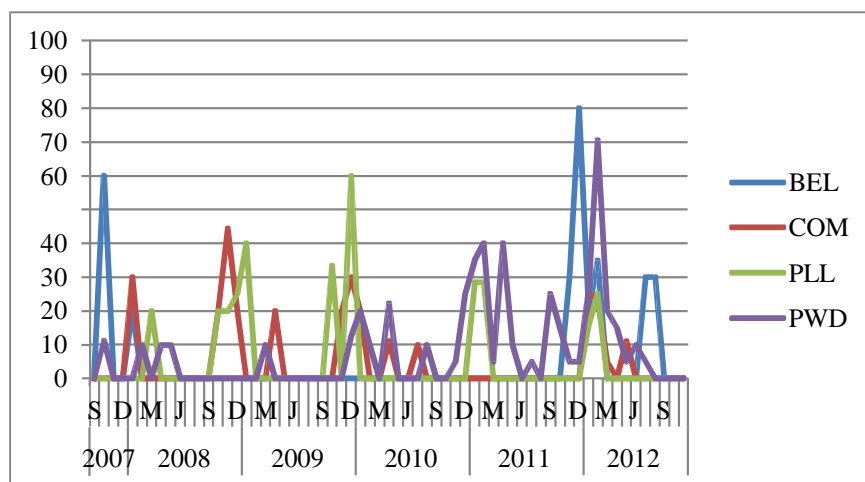

Figure 22.3. Percentage of *Litsea monopetala* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
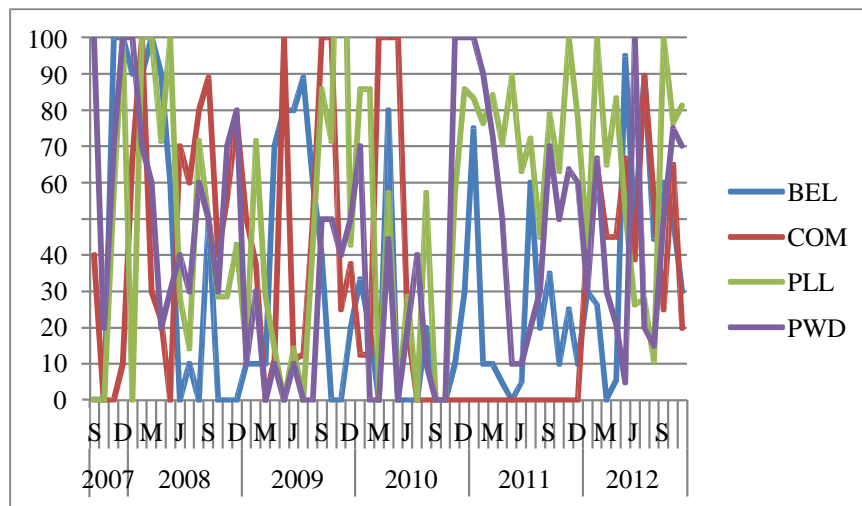
Figure 22.4. Percentage of *Litsea monopetala* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

The proportion of *Litsea monopetala* trees having flower buds varied according to all factors; the month ($F_{11,2796}$=26.33, P<0.0001), the site ($F_{3,2793}$=11.06, P<0.0001) and the individual tree ($F_{1,2767}$=2.66, P<0.0001). For the proportion of trees having flowers, the month ($F_{11,2796}$=18.33, P<0.0001) and site varied ($F_{3,2793}$=4.01, P=0.007) had a strong bearing, but not individual trees ($F_{1,2767}$=1.24, P=0.181).

For the proportion of trees having fruits it varied according to all factors; the month ($F_{11,2796}$=35.04, P<0.0001), the site ($F_{3,2793}$=11.58, P<0.0001) and the individual tree ($F_{1,2767}$=2.77, P<0.0001).

Regarding the proportion of trees having young leaves, it varied according to all factors; the month ($F_{11,2796}$=6.02, P<0.0001), the site ($F_{3,2793}$=32.23, P<0.0001) and the individual tree ($F_{1,2767}$=4.17, P<0.0001).

Mangifera indica **(mangue)**
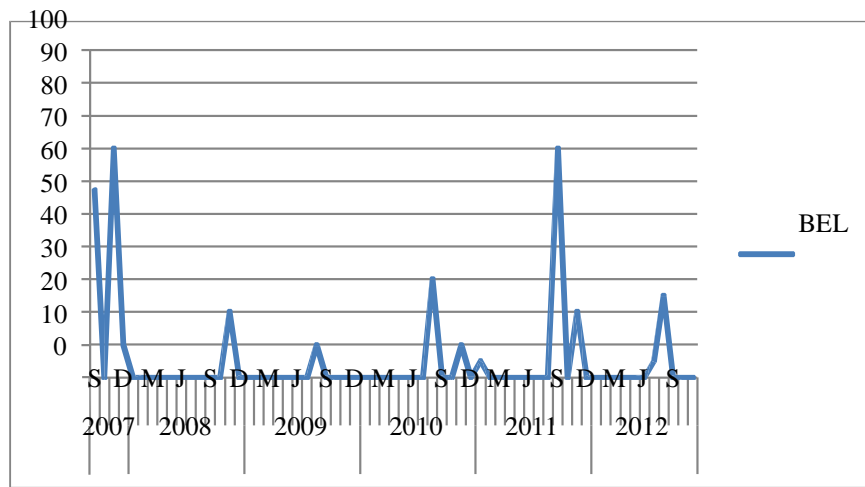
Figure 24.1. Percentage of *Mangifera indica* trees in flower bud at Bel Ombre (BEL) between 2007 and 2012.
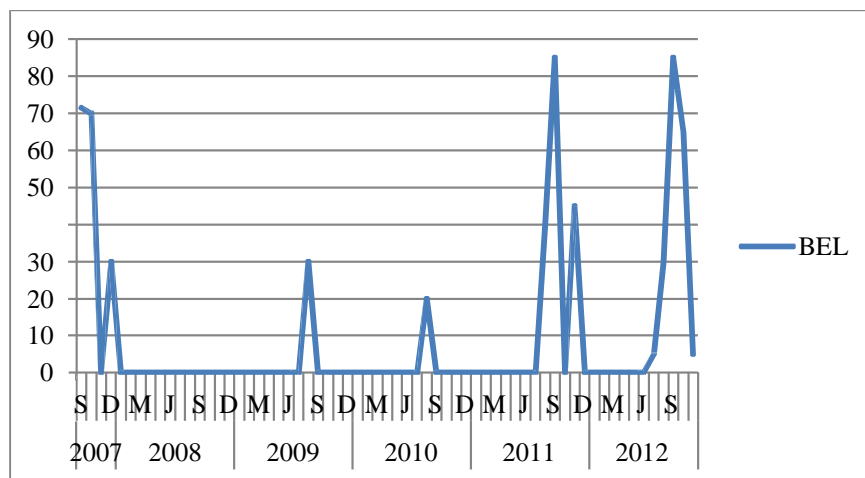
Figure 24.2. Percentage of *Mangifera indica* trees in flower at Bel Ombre (BEL) between 2007 and 2012.
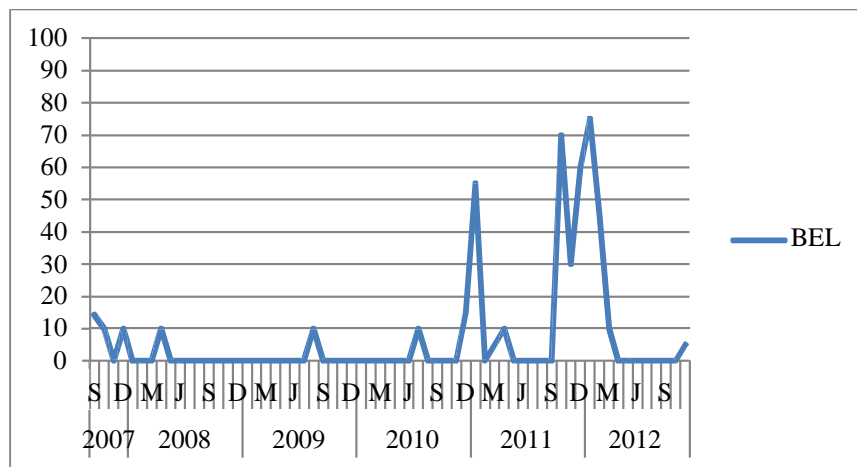
Figure 24.3. Percentage of *Mangifera indica* trees in fruit at Bel Ombre (BEL) between 2007 and 2012.
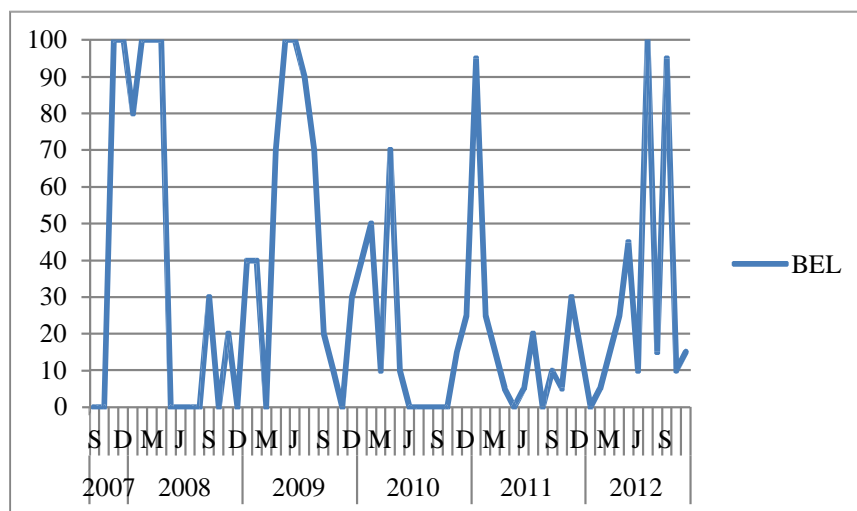
Figure 24.4. Percentage of *Mangifera indica* trees with young leaves at Bel Ombre (BEL) between 2007 and 2012.

The proportion of *Mangifera indica* trees having flower buds varied for the month ($F_{11,488}=6.40$, $P<0.0001$), but not the individual tree ($F_{1,487}=0.04$, $P=0.984$). The proportion of trees having flowers, varied for the month ($F_{11,488}=19.33$, $P<0.0001$), but not the individual tree ($F_{1,487}=0.49$, $P=0.482$).

For the proportion of trees having fruits it varied according to the month ($F_{11,488}=13.32$, $P<0.0001$) and the individual tree ($F_{11,487}=19.12$, $P<0.0001$).

The proportion of trees having young leaves varied for both factors, the month ($F_{11,488}=7.12$, $P<0.0001$) and the individual tree ($F_{11,487}=3.97$, $P=0.046$).

Psidium cattleianum **(goyave de Chine)**
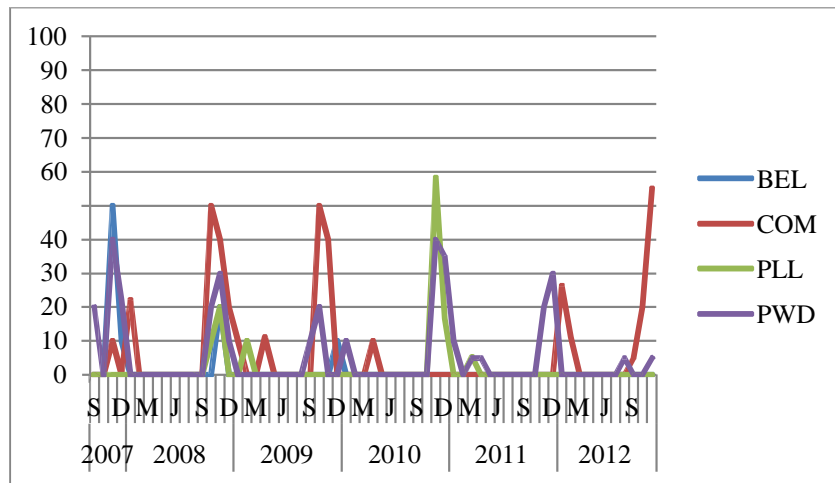
Figure 23.1. Percentage of trees with flower buds at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
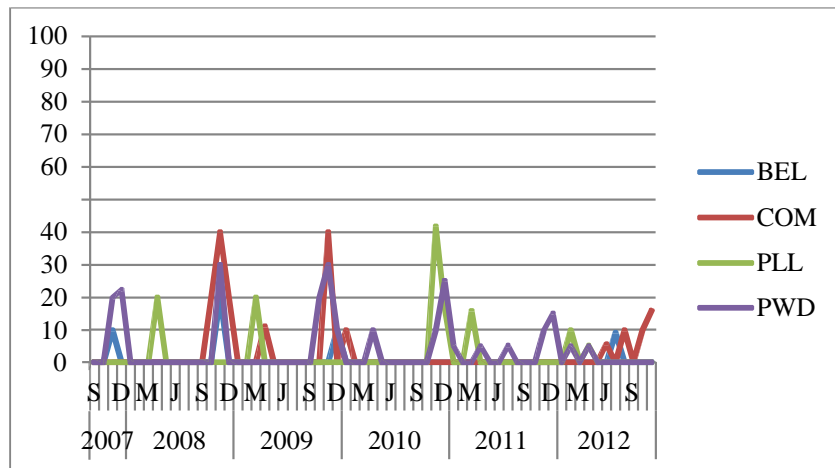
Figure 23.2. Percentage of *Psidium cattleianum* trees in flower at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
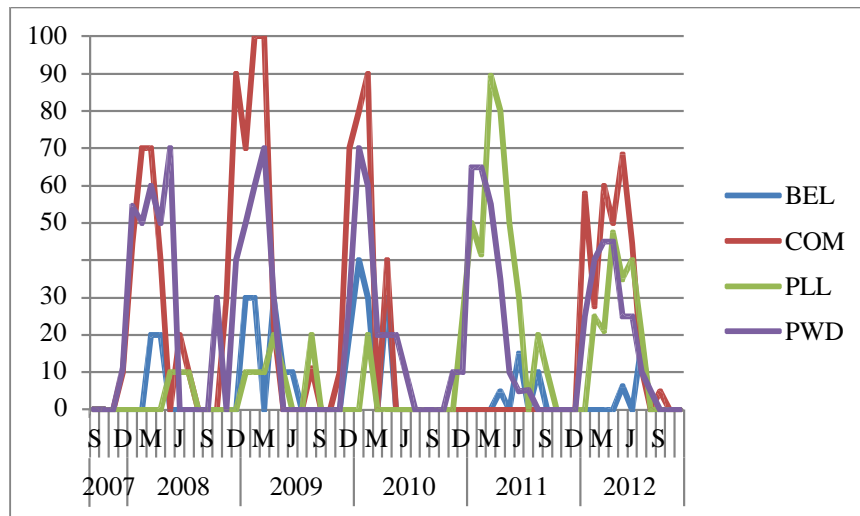
Figure 23.3. Percentage of *Psidium cattleianum* trees in fruit at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.
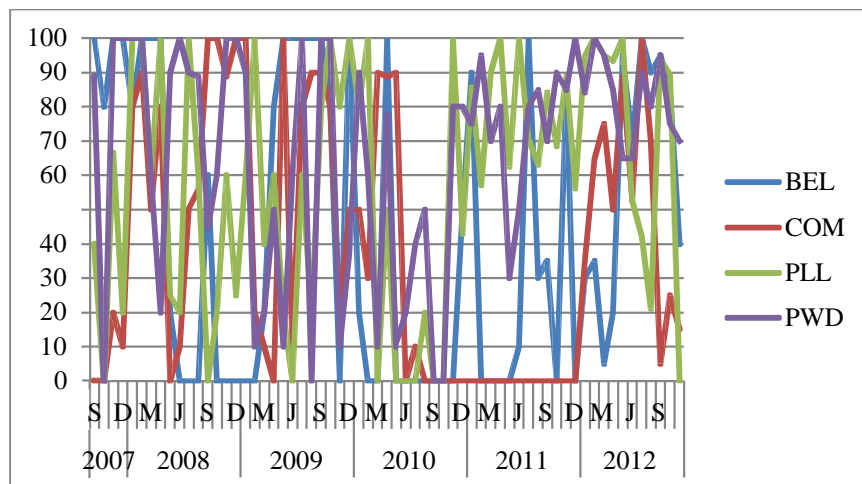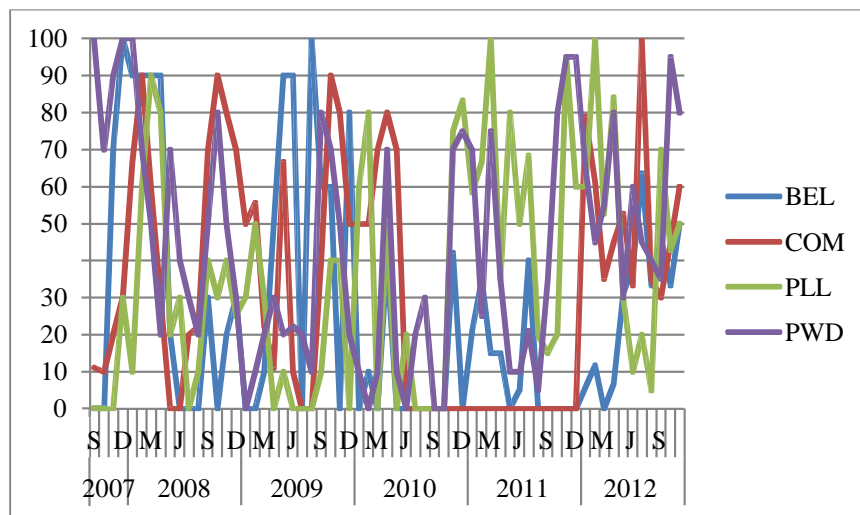

Figure 23.4. Percentage of *Psidium cattleianum* trees with young leaves at Bel Ombre (BEL), Combo (COM), Plaine Lièvre (PLL) and Pigeon Wood (PWD) between 2007 and 2012.

In *Psidium cattleianum*, the proportion of trees having flower buds varied for the month ($F_{11,2972}=20.46$, $P<0.0001$) and the site ($F_{3,2969}=2.39$, $P<0.0001$), but not to the individual tree ($F_{1,2968}=0.13$, $P=0.718$). Similarly, the proportion of trees having flowers, it varied for the month

($F_{11,2972}=9.48$, $P<0.0001$) and the site ($F_{3,2969}=7.57$, $P<0.0001$), but not the individual tree ($F_{1,2968}=0.08$, $P=0.767$).

For the proportion of trees having fruits it varied according to the month ($F_{11,2972}=39.17$, $P<0.0001$) and the site ($F_{3,2969}=63.86$, $P<0.0001$), but not to the individual tree ($F_{1,2968}=7.79$, $P=0.005$).

The proportion of trees having young leaves, varied for the month ($F_{11,2972}=15.10$, $P<0.0001$) and the site ($F_{3,2969}=30.93$, $P<0.0001$), but not to the individual tree ($F_{1,2968}=12.37$, $P=0.001$).

5.3   Influence of Rainfall on Plant Phenology

This section is based on rainfall data collected between June and November 2012 at four mainland sites within the Black River Gorges and one island site, on Ile aux Aigrettes.

5.3.1 Native species

***Diospyros tesseleria* (bois d'ebene noir)**

The proportion of ebony trees having flower buds varied across the month ($F_{4,181}=7.73$, $P<0.0001$) and the individual tree ($F_{1,179}=5.89$, $P=0.015$). The site ($F_{1,180}=2.3$, $P=0.999$) and the total amount of rain received ($F_{1,185}=1.30$, $P=0.254$) did not influence the proportion of trees bearing flower buds. For the proportion of trees having flowers, no factor analysed had any influence (the month ($F_{1,181}=0.38$, $P=0.536$), the site ($F_{1,180}=0.01$, $P=1.00$), the individual tree ($F_{1,179}=0.01$, $P=0.952$) and the total amount of rain received ($F_{1,185}=0.38$, $P=0.535$)).

We found the same trend for the proportion of trees having fruits, no factor had any influence (the month ($F_{1,181}=1.11$, $P=0.347$), the site ($F_{1,180}=0.01$, $P=1.00$), the individual tree ($F_{1,179}=1.02$, $P=0.311$) and the total amount of rain received ($F_{1,185}=0.65$, $P=0.421$)). For the proportion of trees having young leaves, the month ($F_{1,181}=14.66$, $P<0.001$) and the site ($F_{1,180}=9.96$, $P=0.002$) had a significant effect . The individual tree ($F_{1,1798}=0.81$, $P=0.367$) and the total amount of rain received ($F_{1,185}=1.94$, $P=0.163$) had no influence.

Gastonia mauritiana (bois de boeuf)

The proportion of *Gastonia mauritiana* trees having flower buds varied for the individual tree ($F_{1,75}$=5.23, P=0.022), but not the month ($F_{1,78}$=0.12, P=0.887) nor the total amount of rain received ($F_{1,78}$=1.00, P=0.317). The proportion of trees with flowers was strongly correlated with the month ($F_{1,76}$=14.04, P<0.0001) and individual tree ($F_{1,75}$=4.79, P=0.028), whilst the total amount of rain received ($F_{1,78}$=3.63, P=0.057) had no influence.

For the proportion of trees in fruit, the month ($F_{1,76}$=9.56, P<0.0001) and individual trees ($F_{1,75}$=4.23, P=0.034) had a strong influence, but not the total amount of rain received ($F_{1,78}$=0.31, P=0.579).

For the proportion of trees having young leaves, no factor had any influence (the month ($F_{1,76}$=0.28, P=752), the individual tree ($F_{1,75}$=0.9, P=0.767) and the total amount of rain received ($F_{1,78}$=0.79, P=0.373)).

Labourdonnaisia glauca (bois de natte à grandes feuilles)

The proportion of trees having flower buds varied for the month ($F_{4,181}$=7.73, P<0.0001) and the individual tree ($F_{1,179}$=5.89, P=0.015). The site ($F_{1,180}$=2.3, P=0.999) and the total amount of rain received ($F_{1,185}$=1.30, P=0.254) did not influence the proportion of trees having flower buds. For the proportion of trees having flowers, no factor had any influence; the month ($F_{1,181}$=0.38, P=0.536), the site ($F_{1,180}$=0.01, P=1.00), the individual tree ($F_{1,179}$=0.01, P=0.952) and the total amount of rain received ($F_{1,185}$=0.38, P=0.535).

We found the same trend for the proportion of trees having fruits, no factor had any influence: the month ($F_{1,181}$=1.11, P=0.347), the site ($F_{1,180}$=0.01, P=1.00), the individual tree ($F_{1,179}$=1.02, P=0.311) and the total amount of rain received ($F_{1,185}$=0.65, P=0.421). For the young leaves, the month ($F_{1,181}$=14.66, P<0001) and the sites ($F_{1,180}$=9.96, P=0.002) had an effect but the individual tree ($F_{1,179}$=0.81, P=0.367) and the total amount of rain received ($F_{1,185}$=1.94, P=0.163) did not have any influence.

Olea lancea (bois cerf)

The proportion of trees having flower buds varied for the month ($F_{4,181}=7.73$, $P<0.0001$) and the individual tree ($F_{1,179}=5.89$, $P=0.015$). The site ($F_{1,180}=2.3$, $P=0.999$) and the total amount of rain received ($F_{1,185}=1.30$, $P=0.254$) did not influence the proportion of trees having flower buds. For the proportion of trees having flowers, no factor had any influence: the month ($F_{1,181}=0.38$, $P=0.536$), the site ($F_{1,180}=0.01$, $P=1.00$), the individual tree ($F_{1,179}=0.01$, $P=0.952$) and the total amount of rain received ($F_{1,185}=0.38$, $P=0.535$).

We found the same trend for the proportion of trees having fruits, no factor had any influence: the month ($F_{1,181}=1.11$, $P=0.347$), the site ($F_{1,180}=0.01$, $P=1.00$), the individual tree ($F_{1,179}=1.02$, $P=0.311$) and the total amount of rain received ($F_{1,185}=0.65$, $P=0.421$). For the young leaves, the month ($F_{1,181}=14.66$, $P<0.001$) and the sites ($F_{1,180}=9.96$, $P=0.002$) had an effect but not the individual tree ($F_{1,179}=0.81$, $P=0.367$), nor the total amount of rain received ($F_{1,185}=1.94$, $P=0.163$).

Premna serratifolia (bois sureau)

The proportion of *Premna serratifolia* with flower buds varied according to the total amount of rain received ($F_{1,157}=5.94$, $P=0.014$) but the month ($F_{3,154}=2.39$, $P=0.067$), the individual tree ($F_{1,152}=0.0315$, $P=0.8595$) and the site ($F_{1,153}=2.61$, $P=0.106$) did not have a strong influence.

For the proportion of trees bearing flowers, the total amount of rain received ($F_{1,157}=20.85$, $P<0.0001$) had a strong influence but not the month ($F_{3,154}=2.39$, $P=1.00$), the individual tree ($F_{1,152}=0.13$, $P=0.718$) and the site ($F_{1,153}=2.61$, $P=1.00$).

For the proportion of trees having fruits no factor had any influence (the month ($F_{1,1541}=2.11$, $P=0.097$), the site ($F_{1,153}=0.01$, $P=1.00$), the individual tree ($F_{1,152}=2.33$, $P=0.126$) and the total amount of rain received ($F_{1,157}=1.92$, $P=0.165$)).

For the proportion of trees having young leaves, the total amount of rain received ($F_{1,157}=6.39$, $P=0.012$) and the sites ($F_{1,153}=7.40$, $P=0.006$) had an effect but neither the individual tree ($F_{1,152}=0.03$, $P=0.870$) nor the month ($F_{1,154}=0.37$, $P=0.774$) did.

6.0   DISCUSSION

6.1   Phenology Calendars

The user-friendly calendar is well illustrated so as to be a useful tool for conservation scientists locally and beyond. These calendars will enable field biologists to know the timing of flowering, fruiting of the plant species used as food sources by native birds. Information about flowering and fruiting will also be useful for seed collection and propagation in the nurseries. The calendar can also be used as a guide by the general public with an interest in the plants occurring in the Mauritian forests.

The calendars need to be continuously updated as more data is received. In due course, the calendars should cover 'normal years' as well as years with cyclones, excessive rainfall and droughts and years under *El-Nino* and *El-Nina* influence, so that the full response of plants to the range of climatic variables is captured.

6.2   Percentage flower budding, flowering, fruiting and young leaf

6.2.0   General trends in plant phenology:

From statistical analysis of phenology data collected from 2007 to 2012 (Section 5.0 and the summary in Table 3 and Table 4), it appears that:

1. Flower budding and flowering are both strongly correlated to month.
2. The month had a greater influence on phenological traits than site or individuals respectively.
3. Individual trees do not strongly influence phenological traits in the species studied. However, *Chassalia coriacea* showed strong individual tree response to phenological traits, but this was not so for month or site.
4. A high proportion of plants that had month as the significant influence for a phenological trait also had site as a strong influence, but rarely individual trees were important factors.
5. The phenology of exotic species was greatly influenced by month and site in general.

These results are discussed below.

6.2.1   Factors affecting phenological traits:

Preliminary results confirm that the phenology of Mauritian native plants is influenced by more than one factor, probably more than what have been studied so far. Tropical forest ecosystems, located in areas with varying degrees of seasonality, exhibit a large variety of phenological patterns (Wright 1996). Seasonality exposes plants to regular, periodic changes in the quality and abundance of resources (Fretwell 1972). Almost all tropical environments vary seasonally in temperature, humidity, rainfall, wind speed and day length although the amplitude of the variation may be small (Richards 1952). All of these factors are known to play a role, alone or in combination in triggering changes in tropical plants (Longman & Jenik 1974).   Organisms, populations and ecological communities respond to regional changes which are spatially heterogenous and these are more relevant in the context of ecological response to climatic change (Walther *et al.* 2002). In many regions there is an asymmetry in warming that undoubtedly contributes to heterogeneity in ecological dynamics across systems. During this study, month and site were found to have significant influences on phonological traits, in line with observations from other studies.

Some species such as *Antidesma madagascariensis, Cassine orientalis* and *Grangeria borbonica* seem to be strongly affected by particular months i.e. these plants will exhibit phenological events only during those specific months despite other environmental factors. In climates with a distinct seasonality, the vegetation adapts to this seasonality by its phenology (Lieth 1974). If a significant climate change occurs, plant species will be less well adapted to this new climate (Kramer *et al*. 2000). This is especially the case for trees or long-living shrubs as a climate change may be anticipated within the longevity of individuals. An adaptive response, i.e., a change in the genetic composition of the population, is therefore less possible for long-lived trees such as *Cassine orientalis*, whereas this may be possible for much shorter-lived species e.g. *Antidesma madagascariensis*.

The functioning of trees is closely adapted to their local climate. In *Chassalia coriacea* flowering, fruiting budding and young leaf occurrence are all strongly correlated to the individual tree.   Two modes of adaptation can be distinguished: survival adaptation, which considers the tree's ability to survive unfavourable circumstances, and capacity adaptation,

which relates to the features enabling the tree to use available resources effectively (Hänninen 1990). Phenology is an important feature for both types of adaptation as it marks the shift from a dormant, resistant stage to an active, but more vulnerable stage in response to adverse environmental conditions (Kramer *et al.* 2000). If a rapid climate change occurs during the coming century, that is, within the life of currently long-living trees, then these individuals may be less adapted to the prevailing climate. Furthermore, if tree species respond differently to a climate change, then the competitive relationships between species will alter, and hence, in the long run, the species composition of forests and possibly the geographical ranges of species.

6.2.2   The phenophases and their interrelationships:

Most tropical woody plants produce new leaves and flowers in bursts rather than continuously and most tropical forest communities display seasonal variation in the presence of new leaves, flowers, and fruits. This patterning suggests that phenological changes represent adaptations to either biotic or abiotic factors. Biotic factors may select for either a staggering or a clustering of the phenological activity of individual plant species. The idea that plant species can reduce predation by synchronizing their phenological activity has the best support. However, because biotic factors are often arbitrary with respect to the timing of these peaks, it is essential also to consider abiotic influences e.g. a major role for climate.

The three phenophases (leafing, flowering, and fruiting) are not mutually independent in individual plants. Fruiting must obviously follow flowering, and so understanding flowering allows one to understand fruiting. Likewise, flowering and leafing can be interrelated. Axillary, ramiflorous, or cauliflorous flowering may be partly or wholly independent of leafing activity, but terminal flowering preempts the terminal buds of a plant and requires the initiation of a new set of shoots from lateral buds. Terminal flowering thus usually precedes leafing on the same branch. Many deciduous species show flowering and fruiting during the leafless phase (Frankie *et al.* 1974). In other deciduous species and many evergreens flushing and flowering occur on the same new shoots and therefore occur close in time (Bullock *et al.* 1990).

Individuals and populations of tropical plants display nearly every possible phenological behavior from nearly continuous activity to repeated brief bursts, and from complete intraspecific synchrony to complete asynchrony (leafing, flowering, and fruiting). Even in the most uniform tropical climates, however, only a tiny fraction of individuals shows continuous leafing, flowering, or fruiting (Newstrom 1993). This clumping in time and synchrony among individuals provides the basis for considering phenological events as adaptations to biotic or abiotic selective agents.

Plant species may compete to attract pollinators or dispersers (Wheelwright 1985) and thereby evolve behaviour that minimises phenological overlap with other plants dependent on the same animal vectors. On the other hand, the seasonal presence or activity of animal vectors could select for temporally clumped phenological activity.

In the seasonal tropics, the abundance of insect herbivores may be lower during hot, dry seasons (Wolda 1978). Moreover, herbivore damage is greatest on young leaves (Coley 1983). Thus, plants producing new leaves during dry periods may experience reduced herbivory, a result obtained experimentally by Aide (1992) for an understory shrub.

Plants may swamp predators by producing vulnerable organs in concentrated bursts (Augspurger 1981). If different plant species share predator species, selection would favor interspecific synchrony of bursts, and so community-level peaks in phenological activity. Leaves produced during flushing peaks sustain less damage than those produced out of synchrony (Aide 1992).

The control of flowering periodicity in tropical forest communities is not well understood (Bullock 1995) and it is not readily apparent how the observed large differences in flowering periodicity might be related to climatic differences (Borchert *et al.* 2004). Some tropical dry forest species have shown that flowering periods are strongly determined by the timing of vegetative phenology and thus depend at least indirectly on environmental periodicity (Rivera & Borchert 2001; Rivera *et al.* 2002). Seasonal variation in climate should therefore be an important determinant of flowering periodicity at the community level. On the other hand, the timing of synchronous flowering in individual species of tropical trees and, implicitly, the resulting flowering periodicity at the community level, are widely thought to have evolved as a result of biotic interactions between trees and their pollinators or seed dispersers (Wright, 1996).

Species or sets of species vulnerable to generalist seed predators may evolve highly clumped fruiting at supra-annual intervals (masting). Phenological clumping in time can result from selection to attract pollinators, and/or to avoid seed predators or herbivores; such clumping leads to peaks separated by long periods with little or no activity.

Hence, whenever biotic processes favour phenological convergence, the strength of these processes may determine the sharpness of the peak, whereas climatic factors may determine its timing. It is therefore essential to consider the influence of climate on phenology.

Correlations between tropical plant phenologies and rainfall seasonality abound. Drought is manifested in many seasonally dry areas by increasing deciduousness, increased water conservation strategies, diminished tree height, decreased leaf area index, and reduced vertical stratification, among other features (Whitmore 1990). Conditions that plants experience as a drought can vary greatly, depending on temperature, humidity, and the availability of water in the soil, as well as intrinsic factors such as the extent and depth of the root system. Even modest water deficits impair growth and cell expansion, and plants under more severe water stress are unable to produce new organs. Thus, in seasonally dry forests, many plants concentrate leafing and flowering around the start of the rainy season; they also tend to fruit at the same time, probably to minimize seedling mortality during the subsequent dry season.

Young leaves that have just finished expanding are most efficient at photosynthesis and at controlling transpirational water loss (Field 1987). They also have maximum effective leaf area, undiminished by accumulating herbivory, epiphylls, or pathological damage. Hence, in the absence of water limitation, it could be predicted that tropical plants should produce crops of young leaves to coincide with periods of high assimilation potential (Van Schaik 1986), i.e. high insolation. The prediction can also be extended to flowering on the ground that it is energetically most efficient to transfer assimilates directly into growing organs rather than store them for later translocation (Chaplin *et al.* 1990). Thus, we can also predict that flowering coincides with periods of peak insolation in everwet areas, and more generally, that the emergence of young leaves and the onset of flowering should be closely related in time. Peaks in irradiance are accompanied by peaks in flushing and flowering except where water stress makes this impossible. Plants in more severe water stress are unable to produce new organs (Tyree 1982).

For these reasons, it has frequently been inferred that water availability is both the proximate and ultimate factor controlling the phenologies of many tropical forest plants (Bawa 1983).

Plant production is potentially limited by a small set of abiotic factors: water, sunlight, CO_2, and minerals. Significant seasonal variation in any of these factors could provide a selective force on phenological behavior. Plants may maximize production in a seasonal climate by avoiding the production of new leaves before or during unfavorable periods (e.g water stress), or by producing new leaves to coincide with the onset of periods of favorable conditions (e.g. high radiation). Despite early speculation to the contrary, all tropical forests studied to date show pronounced phenological variation between seasons and/or between years.

6.2.3   Effects of invasive plants on phenology of native species:

Plants respond directly to many aspects of climate (e.g. mean temperature, total precipitation), timing (e.g. frost-free period length, temperature regimes during critical life-history stages), and variability (magnitude and duration of climate extremes). Climatic changes will also affect plants indirectly by altering ecosystem processes; plant responses often reflect the indirect effects of climate on soil nutrients and moisture as much as the direct effects on plant physiology itself (Brooker & van der Wal 2003).

The introduced species in this study showed the close relationship between time of the year and site. If phenophases of native and introduced species overlap, competition for resources will be at the detriment of native species. Several lines of reasoning suggest that as a group, invasive plant species could disproportionately benefit from climate change, but these have not been directly tested. This can be attributed to invasive plant species' ability to 'tolerate' new climates better than the average species. Some invasives demonstrate a potential for disproportionately rapid evolutionary change (Maron *et al.* 2004) and or high phenotypic plasticity (Schweitzer & Larson 1999). Several studies suggest that invasive plant species tend to have broad environmental tolerances (Goodwin *et al.* 1999, Qian & Ricklefs 2006). All of these properties could allow them to maintain or even increase their fitness relative to other species in a changing climate. In addition, invasive plants might be better than average at 'keeping up' with climate

change. Many invasive species have traits that facilitate long-range dispersal (Pitelka *et al.* 1997, Dukes and Mooney 1999); it is expected that these species will rapidly establish populations in areas with newly suitable climates. There, they might compete with species that are less well adapted to the new climate.

6.2.4   Effects of disrupted plant phenology on animals:

Phenological variation at the level of the forest community affects primary consumers who respond by dietary switching, seasonal breeding, changes in range use, or migration. During periods of scarcity, certain plant products, keystone resources, act as mainstays of the primary consumer community.

The changes in phenology of plants have been suspected to be affecting breeding in some native birds. There are also certain breeding trends such as time and length of moulting (non-breeding) period and fluctuating earliest breeding date in the Echo Parakeet *Psittacula eques* season, which may be linked to changing phenology activities of their food plant species (Malham 2007).

In tree swallows *Tachycineta bicolor* there is a strong negative relationship between clutch size and laying date, and although laying date has advanced by an average of nine days, there has been no significant change in clutch size (Winkler *et al.* 2002). One possibility is that birds are optimising the combined date of laying, number of eggs laid and days of incubation, so young hatch at the peak of food abundance for nestlings. If climate change is shifting the peak of food abundance earlier, it may be advantageous for females to advance the date of laying in order to maintain synchronization between nestling growth period and food abundance. The researchers also found that variation in laying dates was reduced in years with warmer temperatures, and they suggested that warmer temperatures were primarily causing later-laying individuals to advance their laying dates, while early-laying individuals were constrained from laying earlier.

Over the past 39 years, the mean laying date of great tits *Parus major* in Oxford, England has advanced in response to climate change, but their mean clutch size has not changed (Cresswell and McCleery 2003). Nevertheless, these birds have synchronized their hatch dates with the

peak date of food abundance by adjusting the length of incubation to annual variations in temperature. Another possible explanation is that climate change has made it easier for some individuals to start laying earlier, but not caused any change in how many eggs they can lay.

6.2.6   Length of a phenology study:

It is generally agreed that the global climate is changing, but changes are not uniform across the globe. Whilst climate change has been known to occur in a geological time scale, and indeed reversals have been documented, the rapid industrialization of the global economy since the 1700s, and particularly after the Second World War, has significantly increased the rate of global climate change. The effects of climate change on plant phenology are only starting to emerge and the study is still in its infancy worldwide. The effects of climate change on Mauritian plants are very difficult to predict at this stage, and relies on both long term climatic and plant data. Although some correlations have been made in this report, these have to be taken with extreme caution.   Are these correlations within the normal expected plant behaviours to climatic fluctuations, and not in response to climate change? What are the effects of ecosystems degradation on phenology eg disruption of plant community, loss or decline in pollinators and dispersers, competition from invasive species, and restoration management?

This study will be used as a stepping stone for further analyses and research work on the effect of climate change on the Mauritian biodiversity over the coming decades, since the impacts of climate change on plant phenology may not be fully apprehended in the short or medium term. A phenology study needs to cover seasonal variation and needs to span a period of 10-20 years or more, and ideally should include local weather extremes (e.g. Class 3 or 4 cyclone, severe drought, abnormally hot or cold periods).

6.3   Effect of climate on plant phenology

Problems were encountered with the minimum and maximum thermometers, which provided inaccurate records, despite prior assurances from the supplier. This has caused much wasted effort and loss of data. It also highlights that for phenological and climatic research high quality and reliable equipment, not commonly available on the local market, needs to be sourced.

We have identified the appropriateness of a data logger for recording temperature. However the cost of the data loggers exceeds available funding and we are researching to see if i-buttons would be equally effective and cheaper. We will then search for alternative funding as their cost exceeds funds available. Once the equipment has been obtained we will set them up at the field stations and resume temperature data collection. It may be worth enquiring further in the use of i-buttons, which are increasingly being used for taking weather data.

A request was made to the MMS for additional climate data to be used for statistical analysis of relationship between phenology and climatic variables. It was our expectation to receive this data for free as it was for non-commercial purposes, and it had not been budgeted for. Thus, when requested to pay a substantial sum for the data, for which budget had not been secured, we were compelled to use the limited climatic data in our possession.

With available rainfall data covering period June to November 2012, collected as part of the current funding, some analysis was conducted to understand the types of relationships that could be obtained. It appears that rainfall does not greatly influence the phenology of plants over this period. However, these trends are not to be relied upon, and only underpin the need for long-term climate data in confirming phenological relationship with climate.

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8.0   ACKNOWLEDGEMENTS

9.0   APPENDIX

Table 3: Factors influencing phenological traits of native species (shaded cells indicate strong relationships between phenological traits for the listed species and the factor).

(Shaded cells marked ✓ below: Month = yellow, Site = red, Individual tree = blue)

Native Species	Phenological trait	Influence by:		
		Month	Site	Individual tree
Antidesma madagascariensis	Flower budding	✓	✓	
	Flowering		✓	
	Fruiting	✓	✓	
	Young leaves	✓		✓
Aphloia theiformis	Flower budding	✓	✓	
	Flowering	✓	✓	
	Fruiting			✓
	Young leaves			✓
Calophylum eputamen	Flower budding	✓		
	Flowering			✓
	Fruiting		✓	
	Young leaves	✓	✓	
Cassine orientalis	Flower budding	✓	✓	
	Flowering	✓	✓	
	Fruiting	✓	✓	
	Young leaves	✓	✓	✓
Chassalia coriacea	Flower budding			✓
	Flowering			✓
	Fruiting			✓
	Young leaves			✓
Cordemoya integrifolia	Flower budding	✓	✓	✓
	Flowering	✓		✓
	Fruiting	✓		
	Young leaves		✓	✓
Erythrospermum monticolum	Flower budding	✓	✓	✓
	Flowering	✓	✓	✓
	Fruiting	✓	✓	✓
	Young leaves	✓	✓	✓
Ficus reflexa	Flower budding	✓		✓
	Flowering			
	Fruiting	✓	✓	
	Young leaves	✓	✓	✓
Gaertnera psychotrioides	Flower budding	✓	✓	✓
	Flowering	✓		✓
	Fruiting	✓	✓	✓
	Young leaves			

	86

Native Species	Phenological trait	Influenced by		
		Month	Site	Individual tree
Grangeria borbonica	Flower budding	yellow		
	Flowering	yellow	red	
	Fruiting		red	
	Young leaves	yellow	red	blue
Nuxia verticillata	Flower budding	yellow	red	
	Flowering	yellow	red	
	Fruiting			
	Young leaves	yellow		blue
Ochna mauritiana	Flower budding	yellow	red	blue
	Flowering	yellow		
	Fruiting	yellow		
	Young leaves	yellow	red	blue
Securinega durissima	Flower budding	yellow		blue
	Flowering	yellow		blue
	Fruiting	yellow	red	
	Young leaves	yellow	red	
Syzygium glomeratum	Flower budding	yellow	red	
	Flowering	yellow	red	
	Fruiting	yellow	red	
	Young leaves	yellow	red	blue
Warneckea trinervis	Flower budding	yellow	red	
	Flowering	yellow	red	
	Fruiting	yellow		
	Young leaves	yellow	red	

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Table 4: Factors influencing phenological traits of introduced species (shaded cells indicate strong relationships between phenological traits for the listed species and the factor).

Introduced Species	Phenological trait	Influence by:		
		Month	**Site**	**Individual tree**
Ligustrum robustum	Flower budding			
	Flowering			
	Fruiting			
	Young leaves			
Litsea glutinosa	Flower budding			
	Flowering			
	Fruiting			
	Young leaves			
Litsea monopetala	Flower budding			
	Flowering			
	Fruiting			
	Young leaves			
Mangifera indica	Flower budding		NA	
	Flowering		NA	
	Fruiting		NA	
	Young leaves		NA	
Psidium cattleianum	Flower budding			
	Flowering			
	Fruiting			
	Young leaves			