REPRODUCTIVE PHENOLOGY AND CLIMATE VARIABILITY OF FOUR MANGROVES SPECIES OF ZANZIBAR

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Abstract: The present study aimed at exploring, the reproductive phenological pattern of four major mangroves species of *Rhizophora mucronata, Bruguiera gymnorhiza*, *Ceriops tagal and Avicennia marina* in Nyeke and Michamvi forests in the Southern region of Zanzibar. Our result show that peak periods for budding, flowering, fruitset, fruit abortion and fruiting were different in the two study sites and among different mangrove species. Weather is the major factor found to trigger the production of buds and flowers. Avicennia marina reproductive pattern in Zanzibar slightly differ between the two study sites. Rhizophora mucronata showed similar phenological trends with Bruguiera gymnorrhiza and Ceriops tagal. Temperature variations seem to influence flower buds, flowers and fruit production in the two study sites. This study has added ecological knowledge that could be useful for management and conservation of mangroves biodiversity in Zanzibar and East Africa.

Keywords: buds; flower; fruits; mangroves; phenology; climate; species.

INTRODUCTION

Plant phenology is concerned with all reproductive events from buds' induction to fruiting [1]and is fundamental to a plant species reproductive ecology [2]. Vast studies on mangroves have been based on reproductive biology and breeding mechanism [3,4]. There are more than 35 phenological studies conducted on mangrove species in Australia and other parts of the world [5,6]. However, there is little information on the phenology of mangroves in East Africa except for few studies conducted in Kenya on Avicennia marina [7,8]. Study on phenology of mangroves is useful because the information can be used in predicting the interactions of plants and animals; and climate change on sea water rise [9]. There is no information on reproductive phenology of mangroves community in Zanzibar. In this context, the present study aimed at exploring, the reproductive pattern of four major species of mangroves in Nyeke and Michamvi forests in the Southern region of Zanzibar. This information is vital for developing conservation strategies and will help understanding the ecological distribution of reproductive phenology of mangrove species. The study aimed at addressing the following questions: (1) Are the flowering patterns of the different mangrove species affected by weather and do they differ between sites? (2) Is there any difference in the proportion of buds, flowers, fruit abortion and fruits in different species and in different site? (3) What is the peak period for flower buds, flowers and fruits for different mangroves species and sites?

MATERIALS AND METHODS

Identifying and tagging the branches

At each study sites 80 trees were (20 trees per specie) selected belonging to four mangroves species of *Rhizophora mucronata, Bruguiera gymnorhiza*, *Ceriops tagal and Avicennia marina*. The distance between trees was approximately 25m. From each randomly selected tree, one branch was chosen for observation of the reproductive pattern. The selected branches were tagged with a permanent label that indicated tree species and date it was tagged. All the selected branches were approximately 1.5m high from the ground to prevent sea water interference. After tagging and labeling of the branches, petroleum jelly was smeared on the woody back of the branch to deter invertebrates

getting into the flowers. Selected branches were free from diseases and pests. Yellow flags were placed on top of the tree to easy plots identification during data collection. In case of flowering alternation in the same tree, another branch was selected and observed. Observation was done twice a week in every month for a period of one year in 2013. The number of flower buds, flowers, aborted flowers, fruitset and young fruits were recorded for each branch.

Monitoring buds, flowers and fruits

All buds, flowers and fruits that emerged from selected branches were counted every 10 days except for A. marina which was done every 7 days. A permanent white mark was made with a marker pen and tagged labels were placed in buds, flowers and fruits to avoid double count. The number of aborted flowers was also recorded. Climatic data of the year 2013 was obtained from Zanzibar Meteorological Head Office every month. A bud was defined as swelling of growing tips of between the leaves. Flowering was defined as conversion of buds showing all flower morphology. A fruit set was defined as conversion of flower to fruit initiation showing successful fertilization. Aborted fruit was defined as a young un-matured fruit detached from the tree. Fruit was defined as young and matured fruits attached from the mother tree.

Statistical analysis

The field data were recorded in Microsoft excel sheet include variables of date, site, mangroves species, numbers of flower buds, flowers, fruits set, fruits abort and fruits. Mean for each variable was calculated using Statistical analysis tool (SPSS). The mean of each variable was converted into a percentage to ease results clarification. Graphs contain two Y axis were develop for each mangrove's specie. First y axis shows percentages of flower buds, flowers, fruits set, fruits aborted and fruits. Second y axis shows monthly means of temperature and rainfall. The X axis was included months of 2013 of data collection

RESULTS

Reproductive phenology of Avicennia marina

The flower buds arose at the beginning of the last week of September for Nyeke and second week of October for Michamvi sites and ended in the first and third weeks of January respectively. However, full appearance of buds starts in October for both study sites (Tables 1 and 2). The peak flower bud's production occurred in November (41%) in both site. Relationship between environmental factors of temperature, relative humidity and rainfall and the abundance of buds, flowers, fruits aborted, fruits set and fruits for A. marina is shown in figures 1A to F. Flowering production of this species was initiated during short rainy season and ended in dry season (usually starts in October to February) with total duration of 4 months. However, weekly variations occur between the two sites (Table 1 and 2). The peak flowering periods are January and November- December in Nyeke and Michamvi 37% and 33%. Lowest flower production recorded was 1% in February for both sites (Fig. 1A to F). Temperature showed a positive relationship with flower production. A 1^0C increase in temperature (28 to 29^0C) resulted in increased flowering by 8% (Fig. 1A and 1D). There is no relationship observed between RH and rainfall and flowering of buds (Fig. 1B, C, E, and F). This species exhibited the shortest flowering and fruiting period of all the four species.

Fruitsets of A. marina began in the first week of December, and ended at the last week of February, a total period of 3 months (Table 1 and 2). The peak fruitsets was observed in January, 75% and 73% in Nyeke and Michamvi respectively (Figures 1A to F). Temperature had a positive influence on fruitsets of A. marina. Increasing temperature to 28^0C seen to triggers the fruitset. However, no relationship was observed between RH and rainfall on fruit set (Fig. 1A and 1D).

The higher percentage of fruit abortion was observed during dry season, Nyeke 54% in January and Michamvi 64% in February (Fig. 1A and 1F). The duration of fruit abortion lasted for two months, January to February (Table 1 and 2). Temperature does not only trigger formation of buds and flowering but also increases fruit abortion (Fig. 1A and 1D). Relative Humidity and rainfall show little influence on fruit abortion.

The peak period of fruits produced was observed in February and the records showed that 44% and 49% in Nyeke and in Michamvi respectively (Fig. 1A to 1F). Fruiting starts in dry seasons from first week of January up to the end of the last week of April, during long rainy seasons. There was little fruit production from second week of May to December (Table 1 and 2).

Reproductive phenology of Rhizophora mucronata

Generally R.mucronata showed reproductive structures for entire year. Budding started at the beginning of last week of September at the onset of short rainy season, although, the flower buds were found to be present all year round with exception of the first three week of September in Nyeke and in July in Michamvi (Table1 and 2). Highest bud peaks of 28% and 27% were observed in dry seasons in month of January for Nyeke and Michamvi respectively. Low bud production occurred from April to October with 1% to 4% in Nyeke and Michamvi respectively (Fig. 2A to 2F). Whereas average Temperature recorded ranged between 25^{0}C and 27^{0}C, with minimum and maximum Temperature of 21^{0}C and 31^{0}C (Fig. 2A and 2D). An increase in temperature showed increases in number of flower buds produced in both sites. However, there was little influence of RH and Rainfall on flower buds' production (Fig. 2B, 2C, 2E and 2F).

Flowering occurs all year round with exception of July-August in Michamvi the last three week of June (Table 1 and 2). Highest flowering seasons were observed in January and February in Michamvi 27% and Nyeke with 28%. However, in August 13% and 1% flower production was witnessed in Nyeke and Michamvi sites respectively (Fig. 2A to 2F). The peak flowering periods corresponded with dry season when mean temperature ranged between 28^{0}C to 30^{0}C, and maximum Temperature are 25^{0}C and 34^{0}C (Fig. 2A and 2D), with monthly Rainfall range from 0mm to 62mm and mean RH range is 63% (Fig. 2B, 2C, 2E and 2F). Temperature variation showed a corresponding, relationship with flowering patterns.

Fruitset for R.mucronata occurred from last week of January to May and last week of August to December in Nyeke (Table 1). In Michamvi, fruitset began in second week of February to the first week of July and second week of September to December (Table 2). In general, fruitset occurred during dry and rainy seasons in both sites (Fig. 2C and 2E). Highest fruitset were detected during long rainy season of March 40% and April 34% for Nyeke and Michamvi sites respectively (Fig. 2B and 2E). Fruitset is not strongly associated with Temperature, RH and rainfall, since fruitset is carried out in low and high Temperature, RH and Rainfall.

Higher percentages of fruit abort were observed in April 46% and May 45% in Nyeke and Michamvi sites respectively (Figures 2A and 2F). Abortions begin in last week of February and ended in second week of June in Nyeke site (Table 1), whereas in Michamvi begin in last week of February and ended in second week of July (Table 2). During this period of fruit abortion, the Temperature, RH and rainfall were recorded between 26^{0}C to 30^{0}C, 55% to 73% and 0mm to 390mm respectively

Fruiting of R.mucronatawas observed throughout the year with exception of two weeks in mid-September in Nyeke (Table 1 and 2). In Michamvi highest fruit production occurred between May and June of 21% and 22%, while Nyeke occurred between April and May of 23% and 22% (Table 1 and 2). Peak fruit production seasons were mainly witnessed during heavy rains and high RH, of between 90mm to 390mm and 69% to 73% (Fig. 2b and 2E). Association of rainfall and fruit production was not minimal (Fig. 2C and 2F).

Reproductive phenology of Bruguieragy mnorrhiza

In both sites flower buds' production occurred throughout the year except of few weeks in March and April (Table 1 and 2). Highest buds' production was observed during dry seasons, 27% and 29% in Nyeke and Michamvi, when, temperature, RH and Rainfall were recorded as 29^{0}C, 62% and 63mm (Fig. 3A to 3F). However, the level of monthly buds' initiation varied between sites. Low buds' production was observed in dry and rainy seasons from February to June of 1 to 3% (Fig. 3A to 3F).

Flowering of B.gymnorrhiza occurred throughout the year, except for two weeks of April in Nyeke and four weeks in April and May in Michamvi (Table 1 and 2). Peak flowering seasons were observed during dry season in January of 27% and 22% for Nyake and Michamvi respectively (Fig. 3A to 3F). Low flowering period occurred between

March and June of 1% to 3%, when Temperature, RH and Rainfall were recorded between 26^{0}C to 29^{0}C, 58% to 73% and 30mm to 390mm respectively (Fig. 3A to 3F). Buds and flower production occurred concurrently in both sites. Also overlapping of flower buds and fruits were observed in both sites throughout the year (Table 1 and 2). In summary, overlapping of buds, flowers, fruitset and fruits were observed in this specie. Observation had showed that the peak fruitset occurred during dry seasons. Fruitset found in all year round except in few weeks of May, June and July. Fruits abortion were observed during dry and rainy seasons and lasting between August to December and January to May in both sites.

3.3.4 Reproductive phenology of Ceriops tagal

This specie showed that the flower buds production present in the almost entire year, (Table1 and 2). Whereas the most abundant buds were produced during dry and short rainy seasons from October and January (Fig. 4A to 4F). Peak buds' production occurred in January corresponding to 27% and 28% respectively. Where, the Temperature, RH and Rainfall recorded at 29^{0}C, 62% and 63mm (Fig. 4A to 4F). Lowest buds' production was detected from March to August in both sites. This is the period of long rainy seasons, the Mean Temperature, Mean RH and Rainfall was highest recorded at 29^{0}C, 73%, 390mm and lowest was 25^{0}C, 55% and 0mm. There was no relationship of bud's production with RH and Rainfall but increasing temperature also increases number of buds (Fig. 4A to 4F). PresumablyC. tagal produce flowers throughout the years in both sites, with exception of a few weeks observed in March, April and May (Table 1 and 2). Increasing Temperatures from 27^{0}C to 29^{0}C showed triggered flowering production. Peak flower production was 42% and 43% in Nyeke and Michamvi respectively, occurring during dry season (Fig. 4A and 4D). Details of flower production in relation to RH and rainfall is illustrated (Fig. 4B, 4C, 4Ee and 4F)

Variation of fruitset between months was noticed in both sites. For example, the peak fruitset in Nyeke of 25% occurred during December and January (Fig. 4A to 4F), whereas the lowest was 1% observed between April and June. In Michamvi peak fruitset was 35%, observed in dry season (February), whereas the lowest was 0 to 1% occurred between April and June (Fig. 4D to 4F). Influence of Temperature on fruitset is shown in both experimental sites and shown to increase the number of fruitset in both sites. But there was little relationship of RH and Rainfall on fruitset. For example, when RH at 73% and 390mm rainfall only 4% of fruitset, (Fig. 4B, 4C, 4E and 4F).

High number of aborted fruits occurred at the end of dry season beginning of long rainy season from February to March. A peak abortion month was in February recording 40% and 42% in Nyeke and Michamvi respectively. Lowest fruit abortion was recorded between months of April to October in both sites (Fig. 4A to 4F). There was little association observed between fruit abortion with Temperature, RH and Rainfall respectively. Fruits of C. tagal are occurring all year round (Table 1 and2). Peak fruits production was registered in April, containing 28% and 24% in Nyeke and Michamvi. Lowest fruit production was recorded from June to December with 1% to 2% (Fig. 4A to 4F). There was no association of fruit production with climatic data of Temperature, RH and Rainfall (Fig. 1 and 2).

DISCUSSION

The peak periods for budding, flowering, fruitset, fruit abortion and fruiting were differed in the two study sites and among different species. However, the differences are not very wide. Weather was also found to trigger the production of buds and flowers, but intensive research study is necessary to quantify the variation level. This observation agrees with the view held by other researchers [10,11,12]. Variation of flowering in mangroves varies due to biotic and abiotic factors such as rain, soil, temperature, sun light and Humidity [13] (FAO 2004). However, this is not always the case. It was reported that rainfall can lead to increase in flower production by Rhizophora mangle and Lagunculatria racemosa, but flower production by Avicennia germinans was similar in both rainy and dry seasons in Caribbean Island [14]. On the other hand, the flowering pattern of mangrove specie Avicennia schaueriana was strongly related to rainfall and day length but the flowering pattern of Lumnizera racemosa shows continuous flowering with highest of increasing Rainfall, however it is not correlated with environmental factors [15]. Studies on the phenology of A. marina conducted in many mangroves growing areas of the world have shown that, its reproductive cycle differs between regions [16, 17, 18,19]. Weather is believed to play an important role in triggering phenological patterns in tropical forests [20]. Differences in variations in groundwater salinity and environmental conditions were mentioned and related with phenological patterns of mangroves evergreen and ever-

growing patterns [16]. In addition, phenology of Bruguiera cylindrical, C. tagal, Lumnizera littoreaand A. marinarevealed that the A. marinahad a distinct flowering period than other species, which were found to flower throughout the year.

The study confirmed that A.marina reproductive pattern in Zanzibar slightly differ between the two study sites. The peak flower buds of A. marina was observed from October to December in both sites, this finding was contrary to Gazi bay of Kenya where buds production peak period is December to January [8]. Weather and soil variation is mentioned in many studies [21]to influence reproductive pattern of mangrove and crops. It was reported that clay sandy texture that is rich in organic matter favours the best development of mangroves [22]. The presented findings of A. marina reproductive cycle concur with other studies [7, 19] where flower production pattern lasted for 4 months in both sites. However, at Michamvi flowering period was longer by two weeks.

Mangrove flowers production seasons vary between sites and species [8]. Significant differences in buds, flowers and fruits can result due to differences in temperature [7, 19], salinity, light penetration [16], soil texture and latitude [21, 23,24, 25]. However, Duke [17] found that peaked flowering in A. marina in the dry season is not associated with a localized influence of seasonal rainfall, evaporation, salinity, nutrients, but rather with other factors such as day-length and temperature. Results of this study agree with other findings [19] that temperature influences buds, flowers and fruit production in the four mangroves species. One interesting observation revealed in this study that fruit set of A. marina is significantly higher percentage of fruits aborted (64%) compared to other species.

In this regeneration and pollination takes place throughout the year, while peaks period and duration showed deference between sites and species. Temperature variations seem to influence flower buds, flowers and fruit production in the two study sites. Peak seasons of flower buds, flowers and fruit production in R.mucronata, B.gymnorrhiza and C. tagal occurred during dry season, when average temperatures recorded between 28^0C and 30^0C. There was no relationship between rainfall and RH and flower buds, flowers and fruit production, since peaks periods occurred during high and low rainfall and RH. The findings coincide with those obtained in other studies.[11, 12] Peak fruiting pattern of Ceriopserectus occur in dry season and is positive related to temperature and negatively related to rainfall [4].This is contrary toflowering pattern of family Rhizophoraceae that t significant variation occur in wet and dry zone of low precipitation.[26]On the other hand, flowering pattern of mangroves specie Avicennia schaueriana in Northern Brazil is strongly influenced by variation in rainfall and day length [15].

Many studies on mangroves phenology mentioned continuous flowering pattern and peak seasons [27, 28]. In Orisa state of India continuous flowering period was observed in Xylocarpus species, but flowering duration of the several mangrove species differ in term of month and period [13].

This study revealed existing variation of fruitset between species and sites. The peak fruit set showed differences between species and site. Flower morphology and maturity variation has been found to influence pollination visitation rate and fruit sets in mangroves of family Rhizophoraceae [29]. Air temperature, day length and rainfall were reported to control reproduction of B. gymnorrhiza [30]. Other study reported that the phenology of mangroves was not only affected by weather variation between species but also nutrients study enrichment on growth was believed to play a role in red mangroves [31].

In conclusion, the present study of four mangrove species found that not all flower buds developed into fruits andnot all developed fruits grew and reached maturity, some of fruit drooped down (aborted). Intensive study is required to determine how many of fruits falloff before full maturity, how many fruits consumed by crabs before germination, and how many fruits germinate to seed. Collectively, this study has added knowledge that could be used for management, developing or review of policy and strategic plan for mangroves biodiversity conservation in Zanzibar. Mangroves phonological patterns differed between among species and sites at weekly level. A. marina had the shortest reproductive cycle compared to other species. This study further confirmed that there was reproductive overlapping in Rhizophora mucronata, Bruguiera gymnorhiza and Ceriops tagal. The study agreed with other report that plant reproductive phenology is interdisciplinary, combining history, meteorology, seasonally and plant physiology.

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Table 1. Reproduction phenophases of four mangroves species AM= *Avicennia marina,* RM= *Rhizophora mucronata*, BG= *Bruguiera gymnorrhiza* and CT= *Ceriops tagal* at Nyeke and Mangroves Forest

		J				F				M				A				M				J				J				A				S				O				N				D			
Species	Stages	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
AM	Bd																																															
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Key: (Bd) Buds, (FLw) Flowers, (Fst) Fruitset, (Fa) Fruit abort and (Frt) Fruit

Table 2 Reproduction phenophases of four mangroves species AM= *Avicennia marina*, RM= *Rhizophora mucronata*, BG= *Bruguiera gymnorrhiza* and CT= *Ceriops tagal* at Michamvi Mangroves Forest.—

		J				F				M				A				M				J				J				A				S				O				N				D			
Species	Stages	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
AM	Bd																																															
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Key: (Bd) Buds, (FLw) Flowers, (Fst) Fruitset, (Fa) Fruit abort and (Frt) Fruit

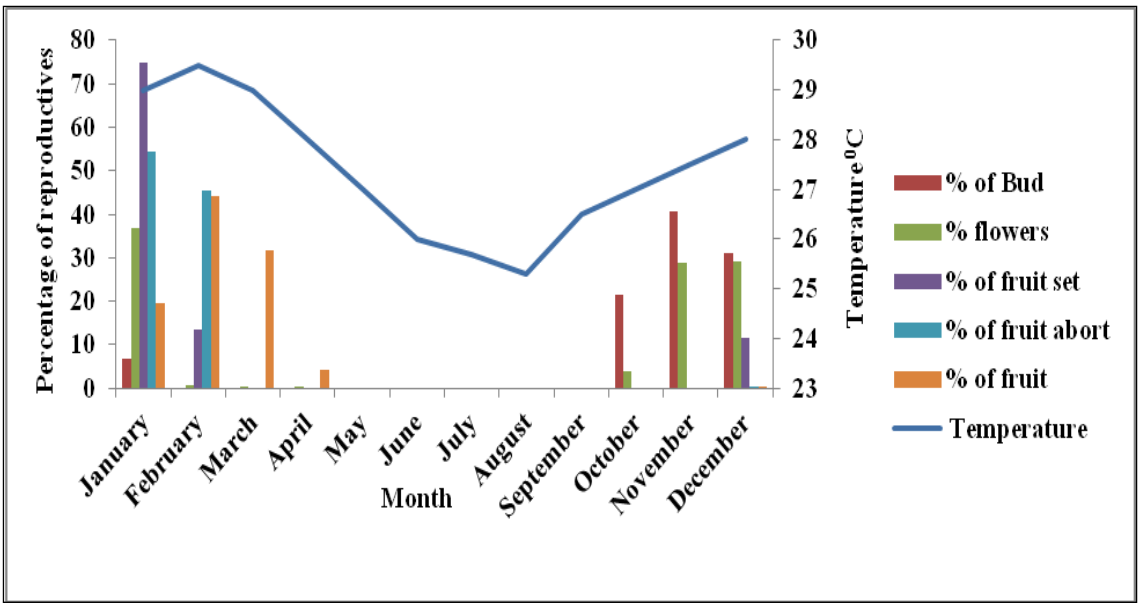

Fig 1A. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Avicennia marina* in Nyeke forest

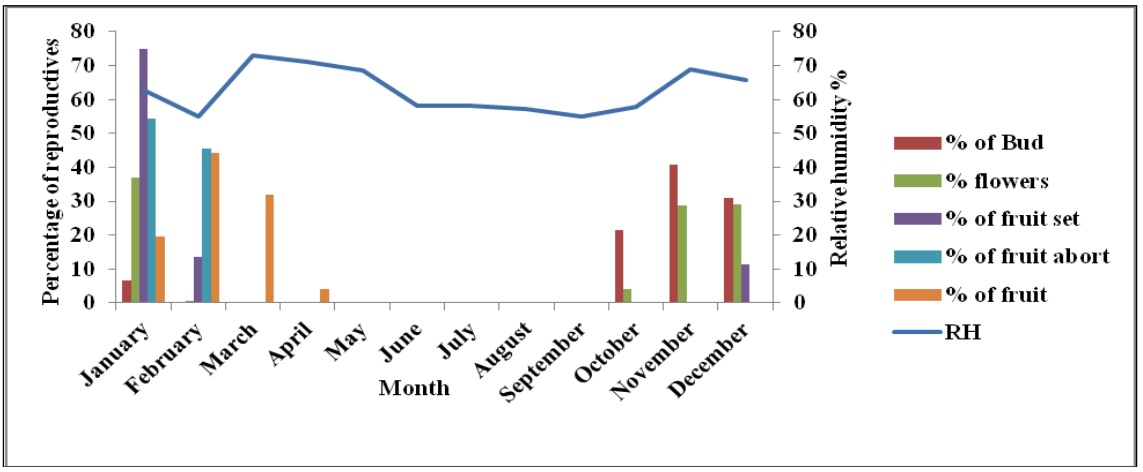

Figure 1B. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Avicennia marina* in Nyeke forest

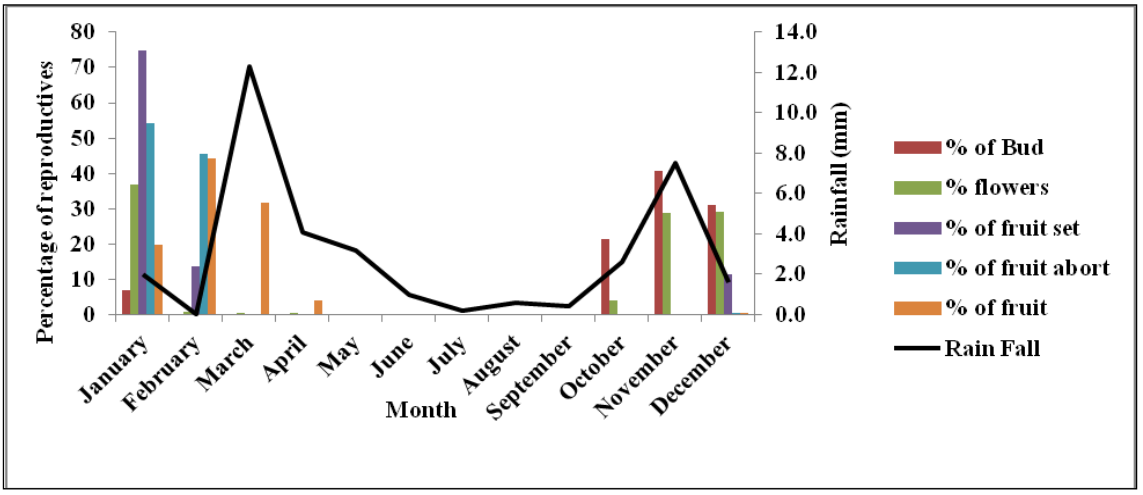

Figure 1C. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Avicennia marina* in Nyeke forest

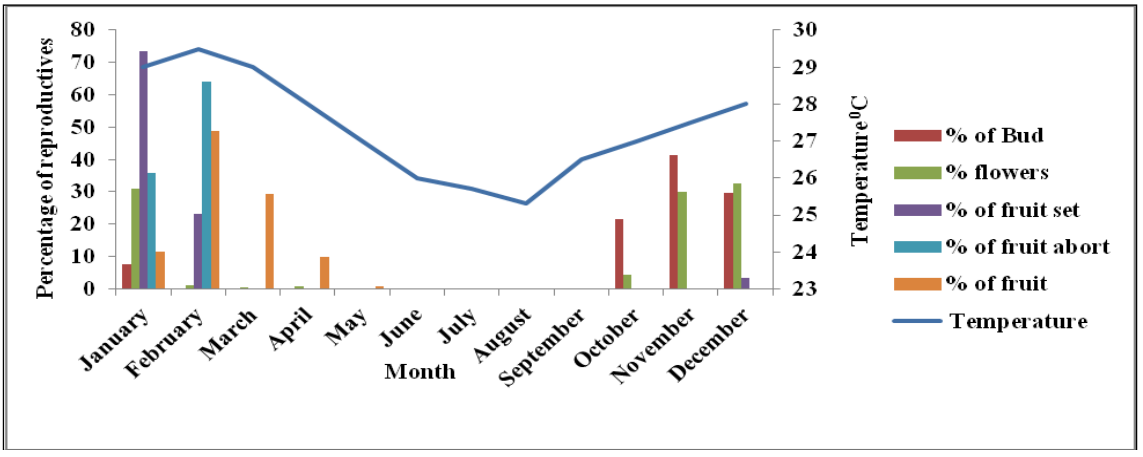

Figure 1D. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Avicennia marina* in Michamvi forest

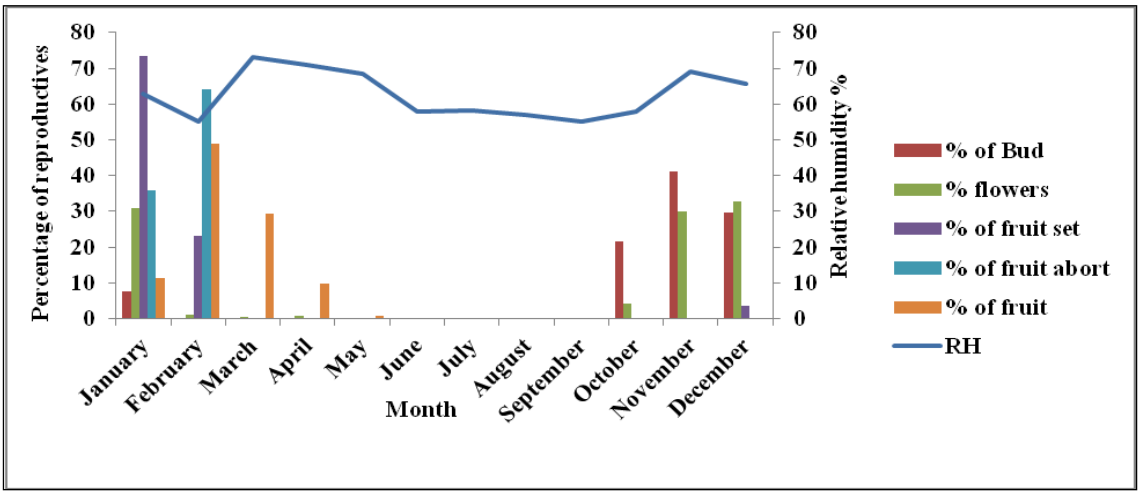

Figure 1E. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Avicennia marina* in Michamvi forest

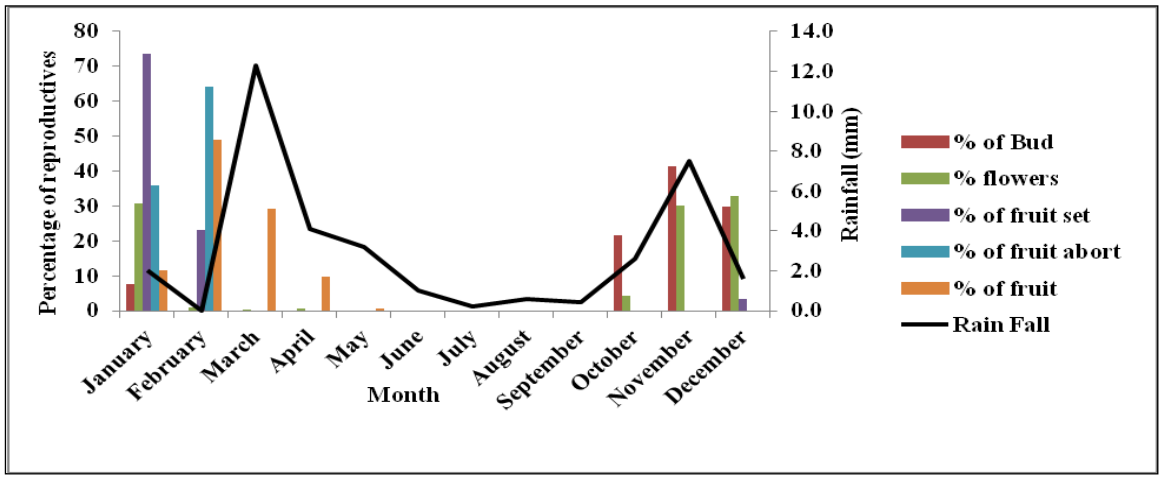

Figure1F. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Avicennia marina* in Michamvi forest 3.3.2

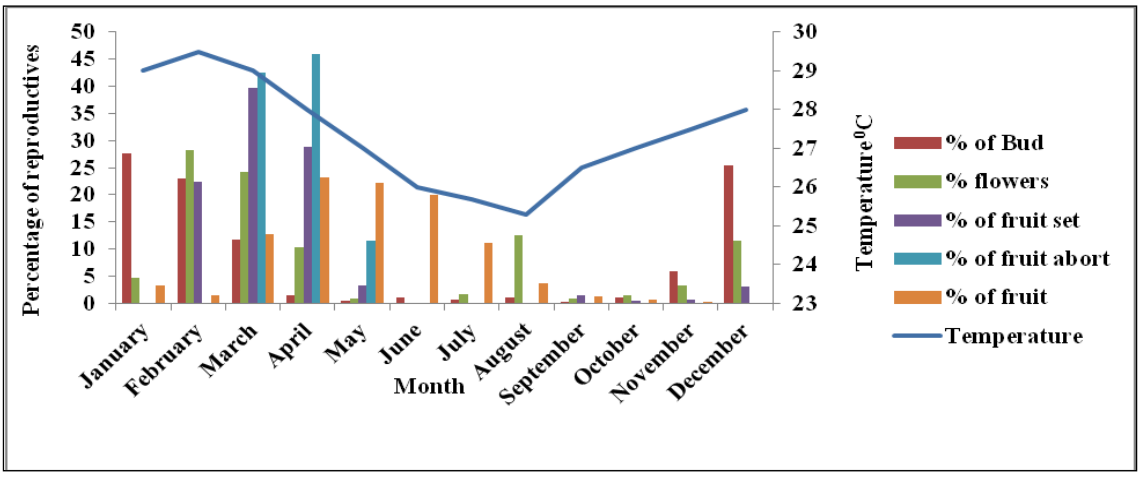

Figure 2A. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Rhizophora mucronata* in Nyeke forest

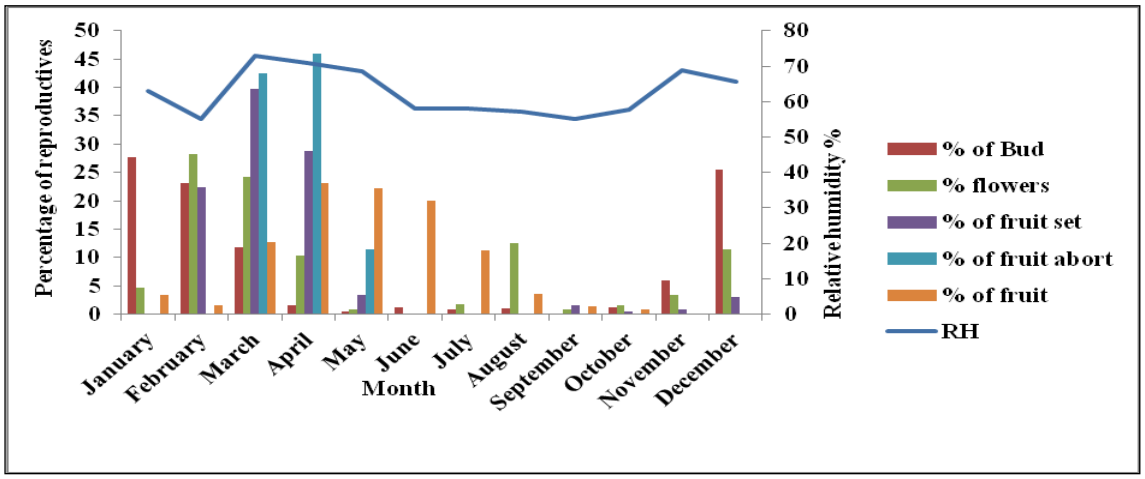

Figure 2B. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits *of Rhizophora mucronata* in Nyeke forest

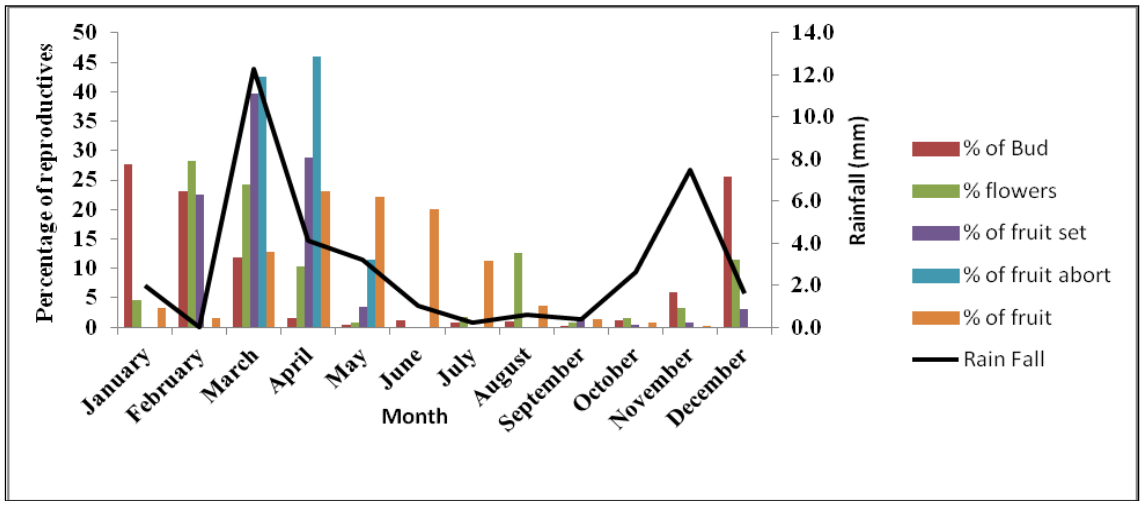

Figure 2C. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Rhizophora mucronata* in Nyeke forest

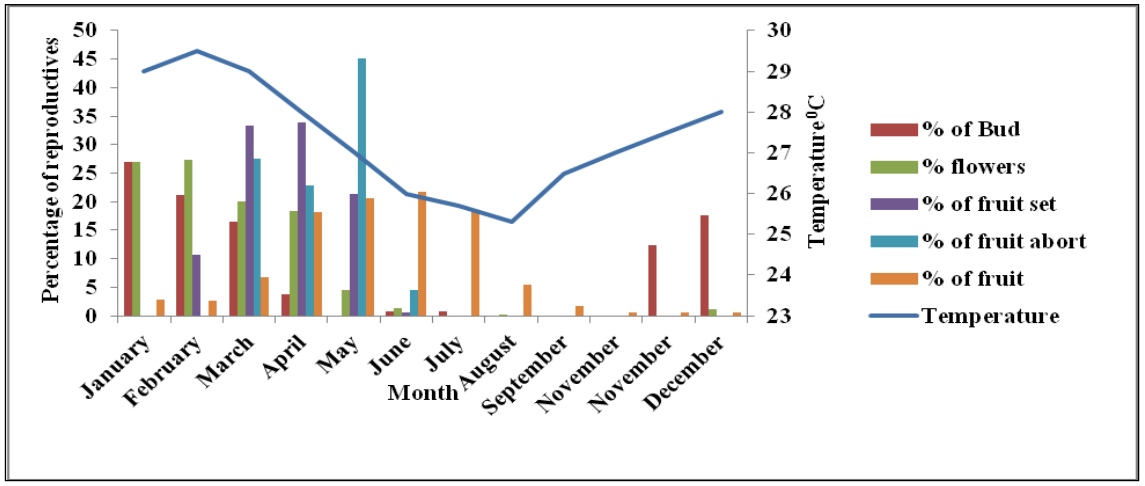

Figure 2D. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Rhizophora mucronata* in Michamvi forest

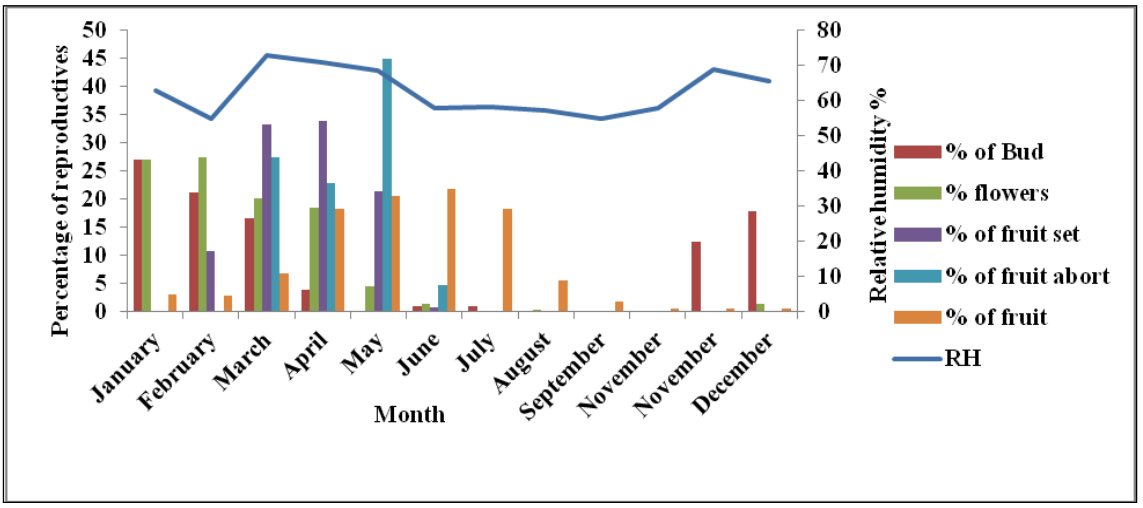

Figure 2E. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Rhizophora mucronata* in Michamvi forest

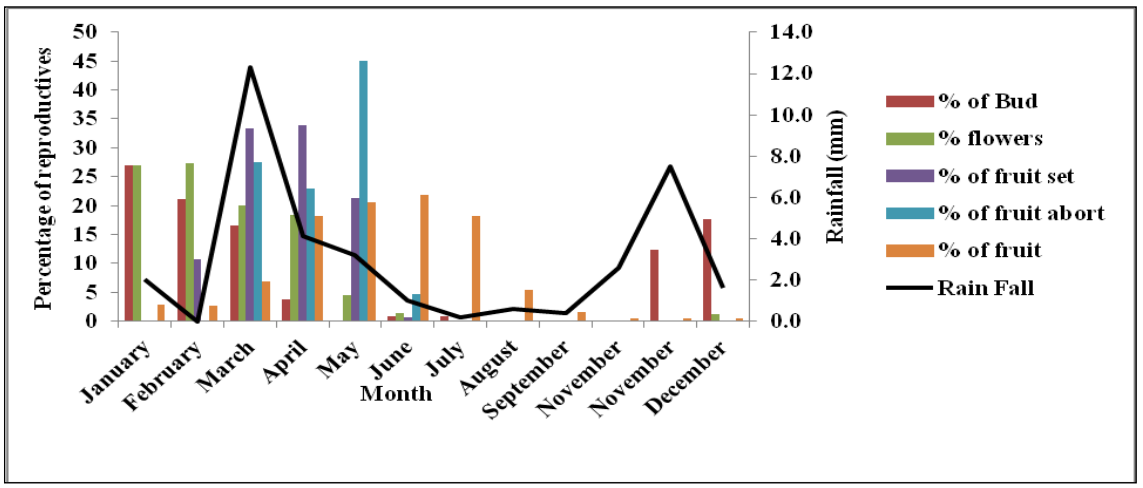

Figure 2F. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Rhizophora mucronata* in Michamvi forest

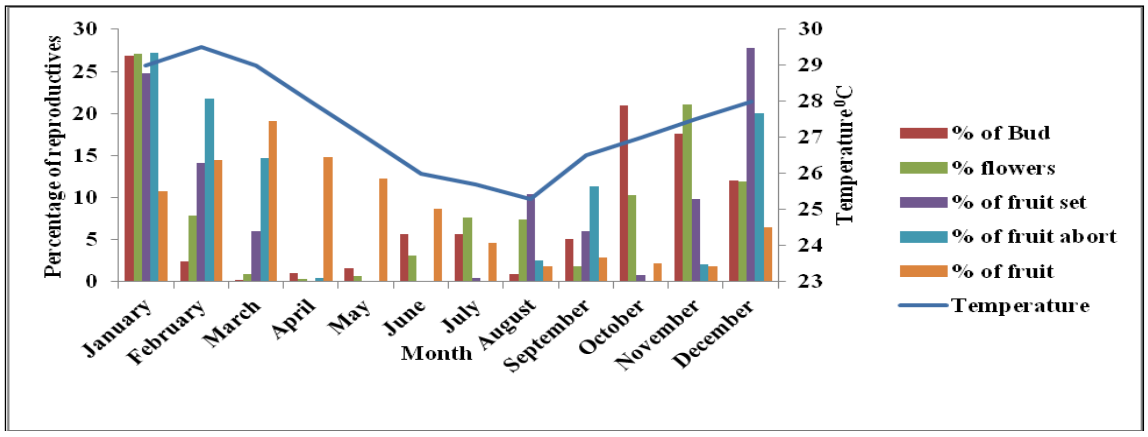

Figure 3A. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Nyeke forest

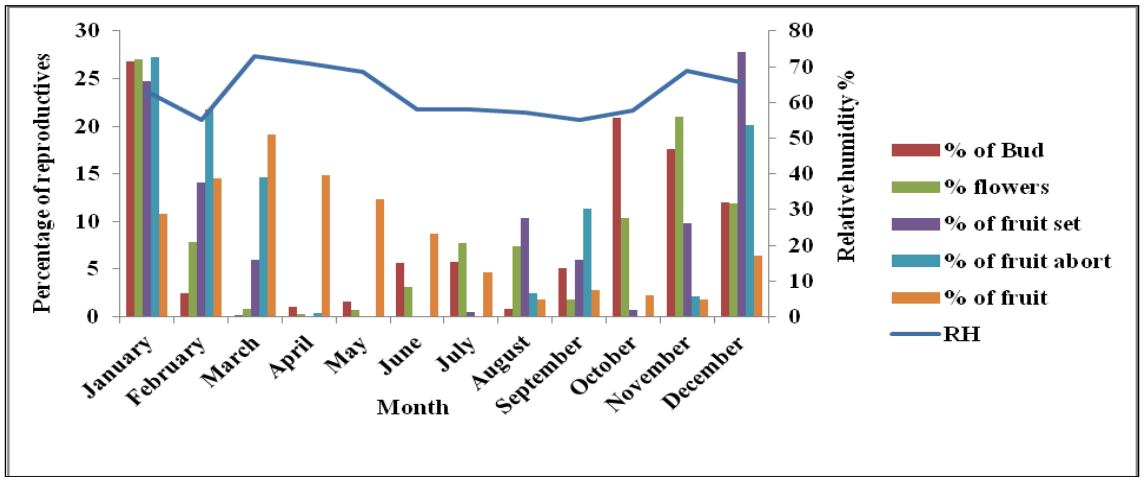

Figure 3B. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Nyeke forest

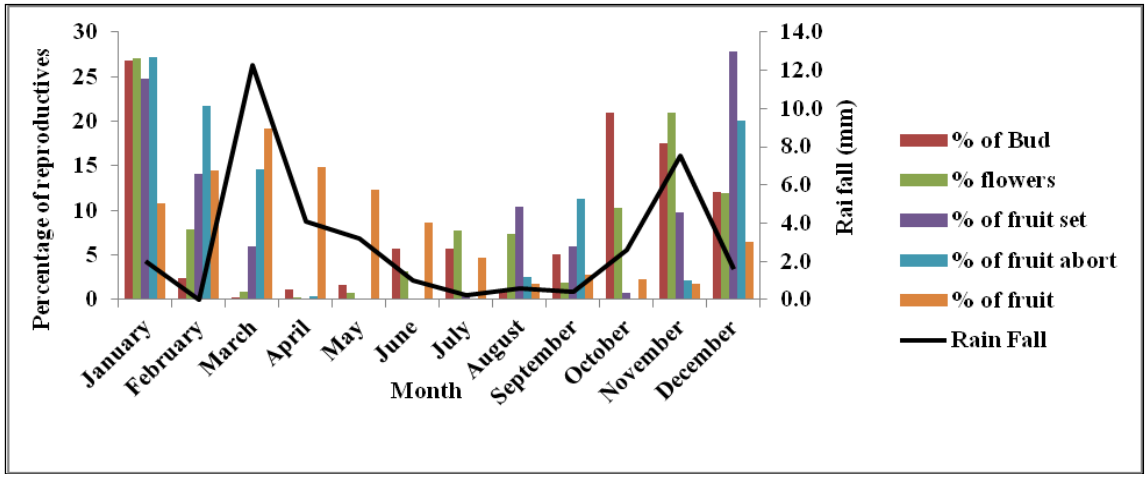

Figure 3C. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Nyeke

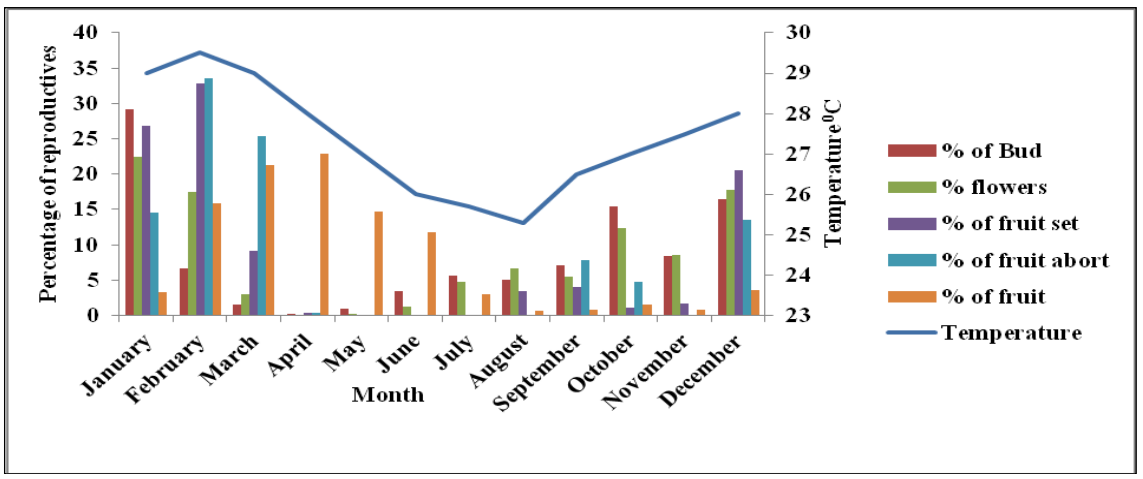

Figure 3D. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Michamvi forest

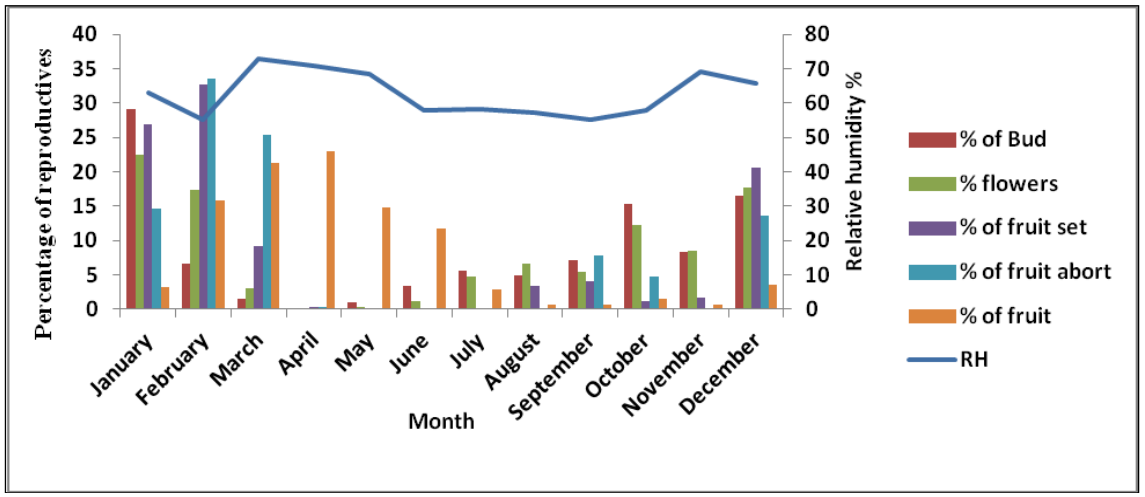

Figure 3E. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Michamvi forest

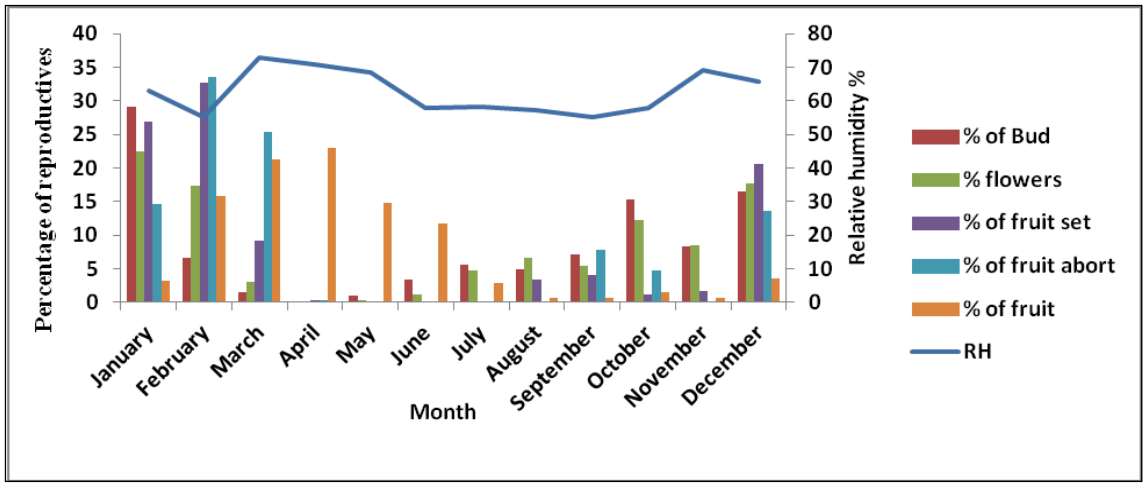

Figure 3F. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Michamvi forest

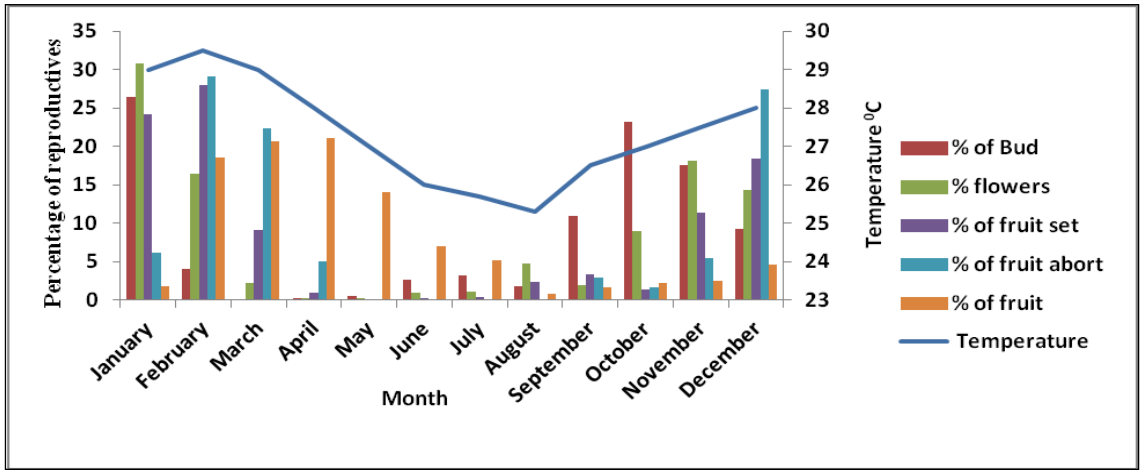

Figure 4A.Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Ceriops tagal* in Nyeke forest

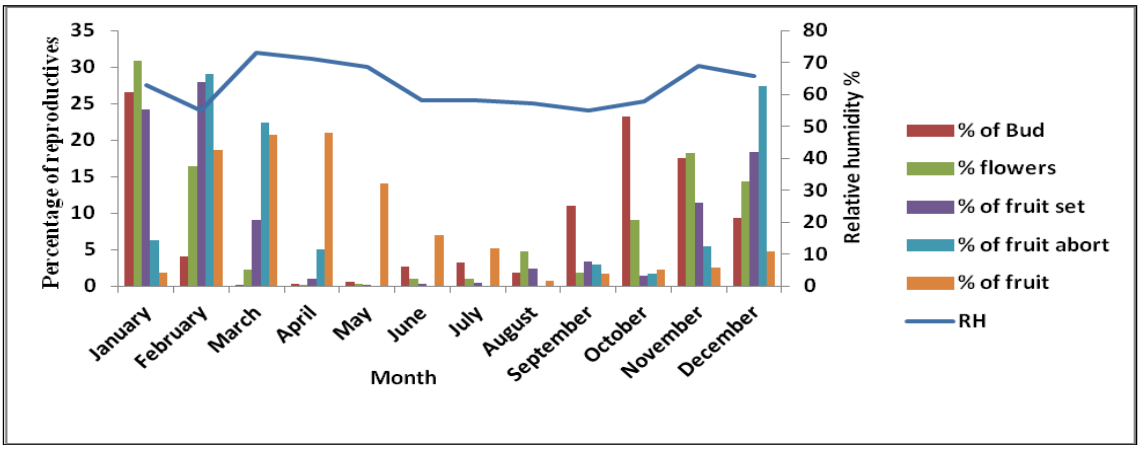

Figure 4B. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Ceriops tagal* in Nyeke forest

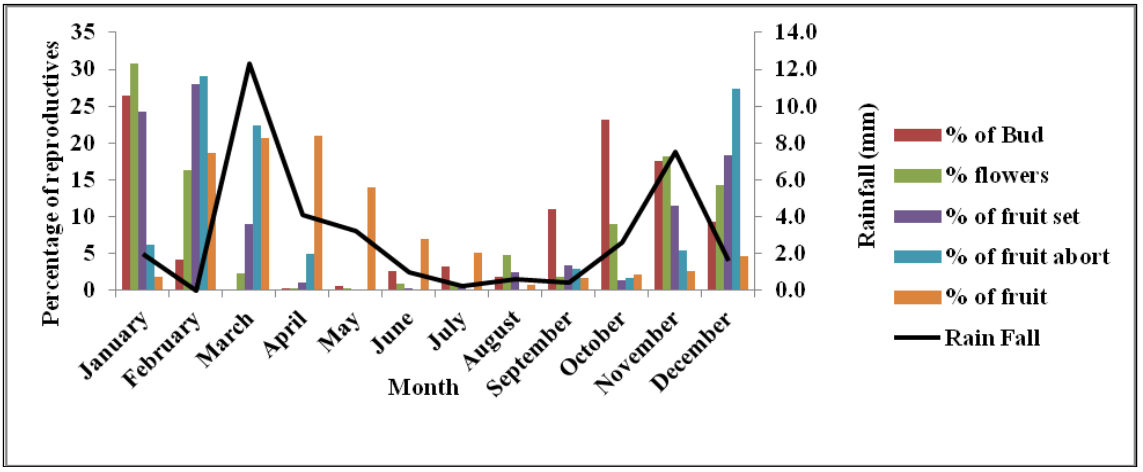

Figure 4C. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Ceriops tagal* in Nyeke forest

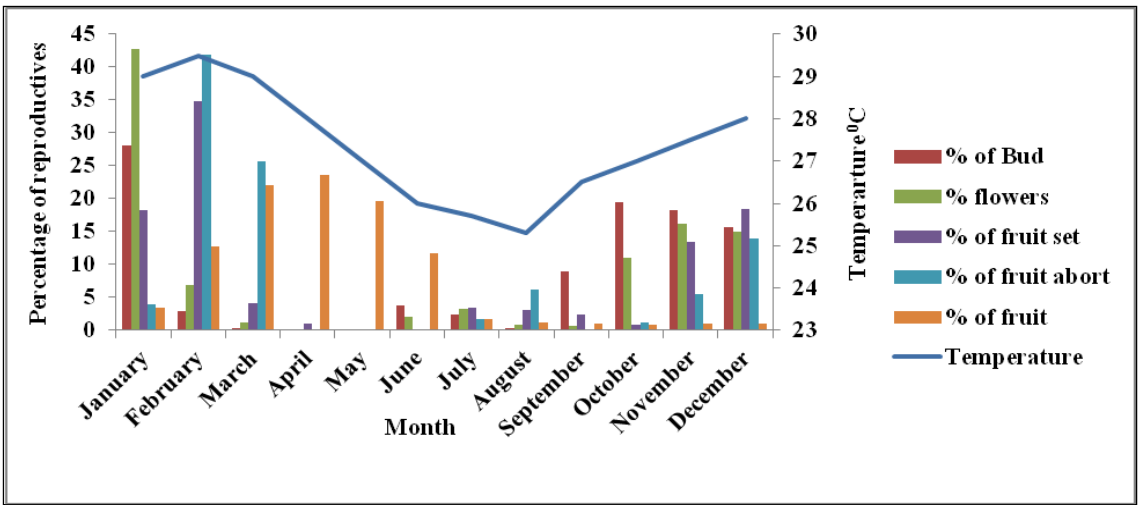

Figure 4D. Mean monthly Temperature and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Ceriops tagal* in Michamvi forest

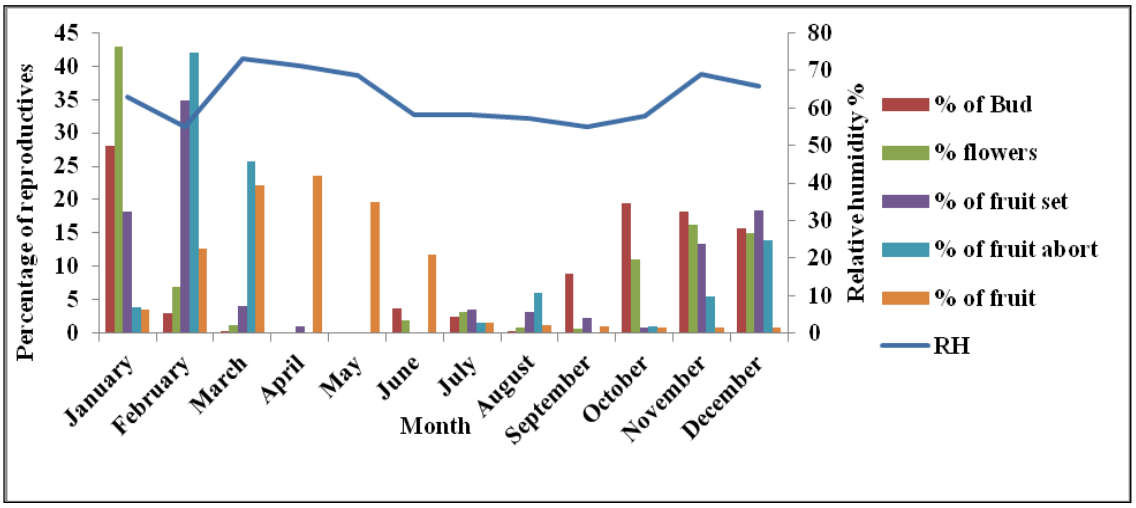

Figure 4E. Mean monthly Relative Humidity (RH) and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Ceriops tagal* in Michamvi forest

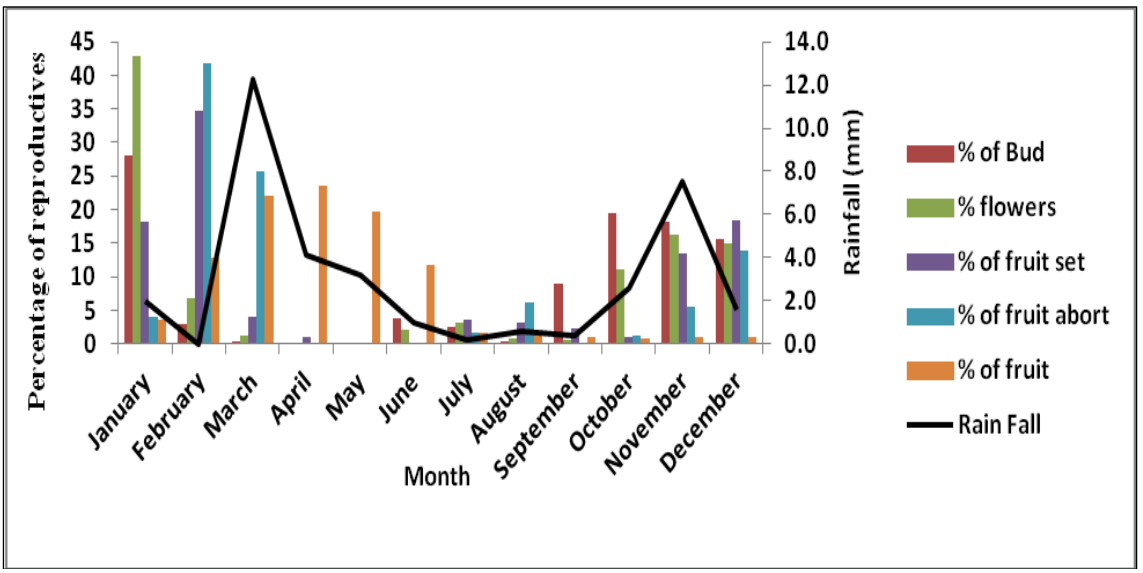

Figure 4F. Mean monthly Rainfall and percent of buds, flowers, fruitsets, fruits aborted and fruits of *Ceriops tagal* in Michamvi forest