ASSESSMENT OF MANGROVE PHENOLOGY AND THE ROLE OF INSECT POLLINATORS IN FRUIT PRODUCTION AT NYEKE AND MICHAMVI MANGROVE FORESTS, ZANZIBAR

BY

ALI, ABDALLA IBRAHIM

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or for any other award.

……………………………... **………………………….**
Signature Date
Abdalla Ibrahim Ali (I84/20407/2012)
Department of Zoological Science

SUPERVISORS

We as supervisors confirm that the work reported in this thesis was carried out by the candidate under our supervision.

………………………………… **………………………….**
Signature Date
Dr. Eunice W Kairu
Department of Zoological Science, Kenyatta University, Nairobi, Kenya

………………………………… **………………………….**
Signature Date
Dr. Zakia M Abubakar
Department of Sciences, The State University of Zanzibar, Zanzibar, Tanzania

………………………………… **………………………….**
Signature Date
Prof. Ørjan Totland
Department of Ecology and Natural Resources Management, The Norwegian University of Life Sciences, Norway

DEDICATION

To my family

This thesis is dedicated to members of my family: Wives Halima and Jamila, My Late Mum Farisha, Father Ibrahim, My daughters, Aisha, Ilham, Zainab, Faika, Khairiya, Zulekha and my son Ali, bothers, Mohammed, Amin, Thabit and Ramadhani and late Ali, my Sisters Amina, Zainab and Khadija, my cousins, Grand fathers and mothers, and my friend Ali Maulid.

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ABBREVIATIONS AND ACRONYMS

AM	*Avicennia marina*
ANOVA	Analysis of Variance
BG	*Bruguiera gymnorhiza*
CCIAM	Climate Change Adaptation and Impact Mitigation
CT	*Ceriops tagal*
FAO	Food and Agriculture Organization
MACEMP	Marine and Coastal Environment Management Project
NMBU	Norwegian University of Life Sciences
RH	Relative Humidity
RM	*Rhizophora mucronata*
SAS	Statistical Analysis Software
SERC	Society for Research and Environmental Conservation
SMZ	Serikali ya Mapunduzi ya Zanzibar (Zanzibar Revolutionary Government)
SNK	Student Newman Keuls
SUA	Morogoro University of Agriculture
SUZA	State University of Zanzibar
SONARECOD	Society for Natural Resources Conservation and Development

ABSTRACT

Mangrove forests are evergreen estuarine and open systems which receive nutrients, fresh water and sediments from terrestrial environments. They vary both in their salinity tolerance and the degree to which salinity may be necessary to maintain their growth and competitive dominance. Mangroves grow throughout the tropics wherever the average monthly minimum temperature is at least 20^0C. The ecological importance of mangroves are due to the ecosystems' ability to maintain marine life, their high productivity and role in supplying organic material to other coastal marine ecosystems as reported by many studies. Mangroves trees have been proven to be very important in the mangroves ecosystem. Anthropogenic activities have been shown to be the primary cause of mangrove depletion worldwide. Rising mangroves forest destruction has negatively impacted on pollinator diversity and fruit set significantly. However, little is known about the magnitudes of these issues in East Africa. This research was therefore designed to assess diversity and abundance of mangrove insect pollinators and their role in fruit set in four mangrove species at Nyeke and Michamvi mangrove forests, Zanzibar. The study was conducted in two mangrove sites in South region of Zanzibar, Nyeke mangrove forest located between 6^0 19' and 6^0 24` S and $39^0$ 25` E, and Michamvi mangrove forest located between 6^0 14' S and 39^0 49' E. The distance between the two sites is approximately 25km. Four mangrove species which are pollinated by insects (*Rhizophora mucronata, Bruguiera gymnorhiza*, *Ceriops tagal and Avicennia marina*) selected from Nyeke and Michamvi mangroves forests were used in the study. The reproductive phenology, reproduction relationships of mangroves, pollinator species diversity and richness, and effect of pollination on fruit set were investigated. The study found that reproductive phenology varied among species and sites. The peak fruit set varied among species and sites. There was a positive relationship between temperature and reproduction but not with rainfall and relative humidity. In both sites the findings showed a weak relationship between fruit set and number of fruits. The study also revealed that increase in number of insect flower visitors and visits did not result in increased fruit sets. However, increase in number of flowers increased the number of insect flower visitors and visits. A total of 18029 insect flower visitors representing 70 species in 7 orders and 40 families were observed visiting flowers of the four mangrove species in both sites. Family Apidae of the order Hymenoptera was the most common and insects of this order were found in all four mangroves species. *Apis mellifera* was the most dominant flower pollinator for *Bruguiera gymnorhiza*, *Ceriops tagal and Avicennia marina*. *Hypotrigona gribodoi* was predominantly found on RM and is potentially the flower pollinator of this species. Higher number of *Apis mellifera* 721 (32.2%) was recorded in *Bruguiera gymnorhiza* at Nyeke site. Bagged experiment that prevented most pollinators accessing the flower, showed a high percentage of flower abortion and lowest fruits produced than other treatments in this study. *A. marina* had confirmed lower fruit set compared to the other species. Pollen Supplement (PS) (hand cross pollination) produce higher percentage of fruits set and fruits in some mangroves species in both sites. This not only shows that additional pollen enhances fertilization but also that pollination is necessary for fruit production. The study concludes that, in depth research on various variables of mangroves including inventory of pollinators, biodiversity, social economic significance, potential threats and phenology for other species and climate alteration are important for strengthen biodiversity conservation and mitigation.

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background

Mangroves have been extensively studied for years by botanists, ecologists, social scientists and marine scientists (Dahdouh-Guebas *et al.*, 2000; Kathiresan and Bingham, 2001; Larcerda *et al.*, 2002; Upadhyay and Mishra, 2008). Some research has been done on mangroves reproductive biology and breeding mechanism (Tomlinson, 1986; Nadia *et al.*, 2012). However, it was not until the 1980's and early 1990's when significant research attention was brought to the human interactions with these unique forested wetlands (Cormier-Salem, 1999; FAO, 2007).

Mangrove forests serve as habitat for a diversity of fauna (Mchenga and Ali, 2013) and flora and are sources and sinks for most of biochemical and energy flows, including trace gas emissions and hydrological cycle, that sustain the biosphere and geosphere (Kathiresan and Bingham, 2001; Kathiresan, 2002). Worldwide, scientists divide mangroves into two major groups: the major and minor species. Tomlinson *et al.* (1979) explains the characteristics that distinguish the two groups. The major species are the strict or true mangroves, and have most or all of the following features: they occur exclusively in mangal, play a major role in the structure of the community and have the ability to form pure stands, have morphological specializations - especially aerial roots and specialized mechanisms of gas exchange, have physiological mechanisms for salt exclusion and/or excretion, have viviparous reproduction, and are taxonomically isolated from terrestrial relatives (Donald *et al.*, 2010). Duke (1992), identified 69 mangrove species belonging to 26 genera in 20 families. Graham (1995) reported of 12 additional species and 27 genera of mangroves and associated plants. The minor mangrove species are less conspicuous elements of the vegetation and rarely form pure stands. The major mangroves belong to 34 species in 5 families and 9 genera. The minor species contribute 20 additional species in 11 families and 11 genera to form a total of 54 mangrove species in 20 genera and 16 families (Donald *et al.*, 2010).

Mangroves grow in areas with humid climate and freshwater inflow that brings in abundant nutrients and silt. They grow luxuriantly in alluvial soils, loose fine-textured mud or silt, rich in humus (Azariah *et al.*, 1992). They are abundant in broad, sheltered, low-lying coastal plains where topographic gradients are small and tidal amplitudes are large. Repeatedly flooded but well-drained soils support good mangrove growth and biodiversity (Azariah *et al.*, 1992). Mangroves do poorly in stagnant water (Gopal and Krishnamurthy, 1993). Flowering mangroves is related to water balance and air vapor pressure deficit and reproduction in the community depends on seasonally contrasting water conditions of low and high tides (David *et al.*, 2010). Mangroves use both self- and cross-pollinating mechanisms that vary with the species (Aluri, 1990). For example, *Aegiceras corniculatum* and *Lumnitzera racemosa* are self-pollinated trees. *Avicennia officinalis* is self-fertile, but can also cross-fertilize (Aluri, 1990).

Mangroves are pollinated by a diverse group of animals including bats, birds, and insects (Noske, 1993, 1995). Pollen is deposited on the animals as they deeply probe the flowers for nectar and subsequently they transfer the pollen to the stigma of another flower (Tomlinson, 1986). The identity of pollinators differs among species. For example, *Lumnitzera littorea* is pollinated primarily by birds while *L. racemosa* and the small-flowered *Bruguiera gymnorhiza* are pollinated by insects (Tomlinson, 1986). Sunbirds visit and may pollinate *Acanthus ilicifolius* (Aluri, 1990) and the large-flowered *Bruguiera hainesii* (Noske, 1993; 1995). Birds are particularly important pollinators in the dry season when absence of flowers in terrestrial habitats causes them to turn to mangroves as a food source. Pollination by insects comprises an important ecosystem service, as reproduction and yields of many wild flowering (Larson and Barrett, 2000) and crop plants (Klein *et al.,* 2007) benefit from faunal pollinating vectors.

Long-term declines in populations of pollinators and related threats to plant reproduction have led to concerns of a widespread loss of pollination services in which pollen-limited plants will suffer reduced yields from declining pollen supply (Kremen *et al.,* 2002; Steffan-Dewenter *et al.,* 2005; Biesmeijer *et al.,* 2006). Veddeler *et al.* (2006) reported large differences in initial fruit set between sites and trees and emphasized the importance of studying coffee’s pollinator limitation at different spatial scales. Roubik (2002) found that, pollinators’ availability improved fruit set and yield of highland coffee (*Coffea arabica* L.) by between 15% and 50%. The capacity of mangroves to convert floral visitation to flower fertilization and fruit set is an important step in the recruitment process and ultimately to the maintenance of existing mangrove communities and their regeneration (Coupland *et al.,* 2006). However, such information is lacking regarding mangroves found in Zanzibar.

Zanzibar is an archipelago made up of Zanzibar (known locally as Unguja) and Pemba islands, and several other islets. The islands are endowed with mangrove vegetation estimated to cover nearly 6.1 % (18000 ha) of the total land area which is about 232,800 ha (Unguja Island cover 6000 ha and Pemba 12,000ha) (MACEMP, 2008). The mangrove forest area is the second largest natural forest vegetation, after the coral rag thicket which is estimated to cover 40% of the Unguja Island total land area. However, inventory information on the mangroves of Zanzibar is still scanty (MACEMP, 2008). At least 1000 ha of natural vegetation are cleared annually for agricultural and other social economic activities, out of which, 40% are estimated to be mangrove forests (MACEMP, 2008, SONARECOD, 2010).

1.2 Statement of the problem

Pollination is a basic ecosystem service with an estimated economic benefit ranging between 90 billion and 160 billion Euros at the global scale (Costanza *et al.*, 1997; Kearns *et al.,* 1998). However, loss of pollinators is big threat to the pollination services and may result in decline in fruit or/and crop yield. The main cause of pollinator decline is fragmentation and destruction of natural or semi-natural habitats resulting in the loss of pollinator diversity and disruption of plant pollinator interactions (Steffan-Dewenter *et al.,* 2002). Further, destruction of natural forests result in increased distance between the latter resulting in decreased pollinator diversity in farm lands far from the source of pollinators and subsequent reduction in fruit set and crop yield (De Marco and Coelho, 2004; Ricketts, 2004).Thus, it is of great interest to understand how future land use changes might affect, ecologically and economically, important functions provided by natural forests (Steffan-Dewenter *et al.,* 2005).

Globally, mangrove forests are exposed to a number of anthropogenic and natural disturbances, including human economic development. Causes of disturbance include construction of new houses and harbours, climate change etc. (Ellison and Farnsworth, 1996; Dahdouh-Guebas *et al.*, 2004). In addition, Mangroves and mangrove ecosystems have been studied extensively but remain poorly understood. With continuing degradation and destruction of mangroves, it is critical to understand these ecosystems worldwide (Kathiresan and Bingham, 2001).

In Zanzibar, mangroves face diverse number of threats that jeopardize their very existence as a result of livelihood activities of the local inhabitants. These activities include salt production, fuel wood extraction and urban development (Hussein, 1995; Kombo and Makame, unpublished report). Mangroves of Zanzibar are threatened by destruction intimately linked with human activities such as harvesting for timber and fuel-wood. Unless this issue is addressed, continued destruction of mangrove forests will results in biodiversity decline and loss, and lack of coastal protection against sea wave erosion and tsunamis. Also, numerous marine organisms (flora and fauna) will slowly get deprived of natural shelter and sources of food. One worrying trend is that some mangroves tree species are aging without much regeneration as is the case of*Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal,* and *Rizophora mucranata* in the Minai Conservation Marine Ecosystem (Uzi Mangroves Conservation Organization, unpublished report). If these ecosystems have to be conserved, it is important to understand the factors that are responsible for this worrying trend.

It is for this reason that the current study was conducted. This is an in depth study on various variables of mangroves including inventory of pollinators, phenology, reproduction and, regeneration of four common species of mangroves in two of

Zanzibar's important mangrove forests, Nyeke and Mchmvi. No similar studies have been conducted in Zanzibar. Thus the aim of this study was to assess the diversity and abundance of mangrove insect pollinators and their role in fruit set in four mangrove species at Nyeke and Michamvi mangrove forests, Zanzibar.

1.3 Justification of the study

In Zanzibar, mangroves forests create unique ecological environments that host rich assemblages of species of epibenthic, infaunal, and meiofaunal invertebrates. Mangrove forests are also important in disaster management, marine conservation and offer social and economic benefits to local people. However, heavy deforestation through human encroachment has been the primary cause of mangrove loss and its biodiversity in many areas in Zanzibar. In the past three decades, numerous tracts of mangrove forests have been converted into salt farming sites, development of tourism facilities like hotels, aquaculture and agriculture areas (Shunula, 1996;; Shunula and Whittick, 1999; Akil and Jidawi, 2000). This has led to fundamental alteration of the nature of the habitat. To avoid irreversible loss of mangrove forests and associated biodiversity, it is important for the government and conservation agents to have a comprehensive conservation and management strategy for these ecosystems. In order to be able to do so, detailed understanding of the ecology of mangroves and the variables that affect their existence is urgently needed.

It is for this reason that the current study was conceived and aimed to assess the phenology of diversity of mangrove, insect pollinators, relationship on reproductive variables and reproduction based on fruit set and abortion in Nyeke and Michamvi mangrove forests. The species of mangroves chosen for detailed study are:

Rhizophora mucronata, *Bruguiera gymnorhiza*, *Ceriops tagal and Avicennia marina*. These are the most commonly exploited species in Zanzibar (Mchenga and Juma, 2011; Mchenga and Ali, 2013; 2014; Hamad *et al.*, 2014).

1.4 Research questions

a) What are the phenological pattern and variations of four mangroves species in Nyeke and Michamvi forests, Zanzibar?

b) What is the relationship between the numbers of flower buds, flowers, fruits set, fruits produced, insect flower visitors and visits in four mangroves species?

c) What is the diversity and abundance of insect pollinators visiting four mangrove species in Nyeke and Michamvi forests, Zanzibar?

d) What are the effects of pollinator exclusion on flower abortion, fruit set, fruit abortion and fruit production in four mangroves species in Nyeke and Michamvi forests, Zanzibar?

1.5 Hypotheses

a) The spatial and temporal variation of the phenological pattern of mangrove species in the two study sites is the same.

b) The relationship between insect visitors, visits, buds, flowers, fruit set, and fruits produced is the same in the four mangrove species and in the two study sites.

c) The diversity of pollinators, species richness and abundance is the same in the four mangrove species and in the two study sites.

d) Exclusion of pollinators has no effects on flower abortion, fruit set, fruit abortion and fruit production in the for mangroves species and in the two study sites.

1.6 Objectives of the study

1.6.1 General objective

To assess and document floral phenological pattern and the role of insect pollinators on the reproduction of four mangrove species in Nyeke and Michamvi forests, Zanzibar.

1.6.2 Specific objectives

a) To assess the spatial and temporal floral phenological patterns of four mangroves species.

b) To investigate the relationship between insect visitors, visits, buds, flowers, fruit set, and fruit in four mangrove species, in Nyeke and Michamvi forests.

c) To document insect pollinators, species richness and abundance in four mangrove species in Nyeke and Michamvi mangrove forests.

d) To determine the effects of pollinators on fruit production in four species of mangroves in the two study sites.

CHAPTER TWO: LITERATURE REVIEW

2.1 Distribution of mangroves

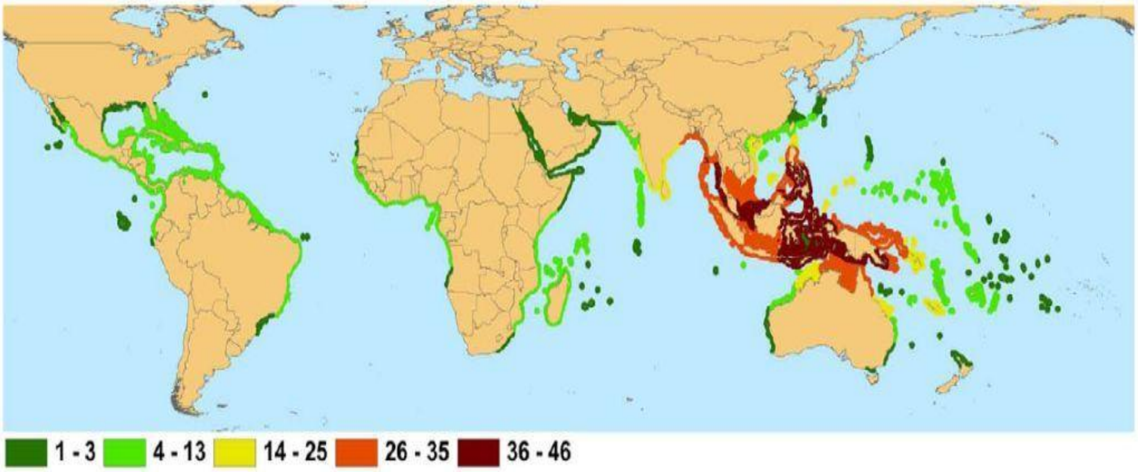
Mangroves are woody plants that grow at the interface between land and sea in tropical and sub-tropical latitudes. They are largely restricted to latitudes between 30° north and 30° south. Northern extensions of this limit occur in Japan (31°22’N) and Bermuda (32°20’N); southern extensions are in New Zealand (38°03’S), Australia (38°45’S) and on the east coast of South Africa (32°59’S); (Yang *et al.*, 1997, Donald *et al.*, 2010). They occur in 112 to 118 countries and territories (Fig 2.1). Globally, they occupied a total area of 137,760 km^2 in the year 2000. Worldwide coverage has been variously been estimated at 10 million hectares and only 6.9 million hectares are protected (Bunt, 1995; Hogarth, 1997; Aizpuru *et al.*, 2000; FAO, 2004; 2007; Giri *et al.*, 2010). Other researchers have estimated them to cover 14-15 million hectares (Schwamborn and Saint-Paul, 1996). Other researchers have given an even higher estimate of 24 million hectares (Twilley *et al.*, 1992) and 18 million hectares (Spalding, 1997) respectively. Indonesia has the largest area of mangroves in the world, followed by Brazil. Within Australia, there is an estimated 11,000-12,000km of mangroves, which constitute around 18-22% of the entire Australian coastline (Aizpuru *et al.*, 2000; Giri *et al.*, 2010).Table 2.1 shows the worldwide distribution of mangroves.

The distribution of mangroves within area of occurance is strongly affected by temperature and moisture conditions (Duke *et al.*, 2007). Other publicized studies conducted in the La Mancha lagoon revealed that, the structure and diversity of mangroves forests are directly attributed to the hydrology and ground water salinity condition (Moreno-Casasola *et al.*, 2009; Portillo and Ezcurra, 2002).

1Table 2.1: Worldwide distribution of mangroves by Regional, Area size and Percentage

Regional	**Area sq/km**	**Percentage**
South and Southern Asia	75,170	41.4
The Americans	49,096	27.1
West Africa	27,995	15.4
Australasia	18,788	10.4
East Africa and Middle East	10,348	5.7

Source Global Mangroves Distribution, 2004. FAO



1Figure 2.1: Worldwide distribution of mangroves forests and species

2.2 Biology of mangroves

2.2.1 Structure and morphology

Mangroves are woody plants that grow at the interface between land and sea in tropical and sub-tropical latitudes. They exist in conditions of high salinity, extreme tides, strong winds, high temperatures and muddy, anaerobic soils (Kathiresan and Bingham, 2001). Most mangrove trees are tolerant to high levels of salt and have mechanisms to take up water regardless of strong osmotic potentials. They also take up salts, but excrete them through specialized glands in the leaves. Others transfer salts into senescent leaves or store them in the bark or the wood (Kathiresan and Bingham, 2001).

The general structure of mangrove roots is similar to that of most other vascular plants. They have a root cap, lateral roots arising endogenously, exarch protoxylem, and alternating strands of primary phloem and xylem (Tomlinson, 1986). Most mangroves have four types of roots and show remarkable adaptations among the species. Tomlinson (1986) found that, the adventitious or stilt roots of *Rhizophora*, pneumatophores of *Avicennia*, *Sonneratia* and *Lumnitzera*, the root knees of *Bruguiera*, *Ceriops* and *Xylocarpus* and the buttress roots of *Xylocarpus and Heritiera*. The roots of these mangroves do not penetrate far into the anaerobic substrata. Instead, the trees produce profuse lateral roots for support.

Mangroves adaptations vary among taxa and with the physico-chemical nature of the habitat (Duke, 1992). Mangrove wood has distinct features that support the trees to overcome the high osmotic potential of seawater and the transpiration caused by high temperatures. The roots of many mangroves do not penetrate far into the anaerobic substrata. Instead, the trees produce profuse lateral roots for support (Duke, 1992). Tomlinson (1986) found that, the specialized roots are important sites of gas exchange for mangroves living in anaerobic substrata. Ish-Shalom and Dubinsky (1992) discovered that, mangroves species of the genus *Avicennia* possesses lenticel-equipped with pneumatophores (upward directed roots) through which oxygen passively diffuses. The lenticels may be closed, partially opened or fully opened, depending on the prevailing environmental conditions. The above-ground mangroves roots come in various forms: *Avicenna* spp have pneumatophores that are pencil-like.), those of *Xylocarpus moluccensis* are stiff and conical, those of *Sonneratia alba* are flexible conical while those of *Sonneratia caseolaris* and *Sonneratia lanceolata* are elongate conical. Knee roots are thick and knobbly (*Bruguiera spp*.), thin and wiry (*Lumnitzera littorea*); stilt roots (Rhizophora spp.); and buttresses as sinuous planks (*Xylocarpus granatum, Heritiera littoralis, Ceriops spp*.), and erect 'fins' (*Bruguiera Xrhynchopetala, Xylocarpus moluccensis*) (Tomlinson, 1986). Mangrove leaves are leathery with obscure leaf veins (there are no vein sheaths) (Tomlinson, 1986). The cuticle is thick and smooth with small hairs, giving the plant a glossy appearance. The leaves are of moderate size and are arranged in a modified decussate (bijugate) pattern with each pair at an angle less than 180 ° to the preceding pair (Tomlinson, 1986). There are about six types of stomata found in mangrove leaves, which differ in the arrangement of guard and subsidiary cells (Das and Ghose, 1993). Mangrove leaves have specialized idioblast cells that include tannin s (*Rhizophoraceae*), mucous (*Rhizophora, Sonneratia*), crystalliferous (*Rhizophoraceae*), oil (Osbornia) and laticifers (*Excoecaria*) cells (Tomlinson, 1986).

Mangrove flowers morphometric have been studied and variations have been found among species and geographical locations (Tomlinson *et al.,* 1976; 1986). All species of *Rhizophoraceae* family have a basic floral structure, however variation of features such as size and orientation of flowers, number of flowers and stamens have been shown to be directly related to pollination. For example, in *Rhizophoraceae* family, the floral parts are uniformly protected within comparatively fleshy calyx lobes, a number of filiform appendages found in the apex of the petals, while the number of stamens is two folds of petals. In the case of *Avicennia marina*, the flower are small, have four stamen filaments that are short. They have very small hairs in the style and have unilocular superior ovary (Tomlinson, 1986; Ghosh *et al.*, 2008).

Mangroves show characteristic C3 photosynthesis. Basak *et al.* (1996) found significant intra- and interspecific variation in photosynthetic activity of 14 mangrove species, suggesting that the rates of photosynthesis may have an underlying genetic basis. In contrast, other researchers have shown that photosynthetic rates of some species are strongly affected by environmental conditions. For example, low salinity conditions reduce carbon losses in *Avicennia germinans* and *Aegialitis annulata* and lead to greater CO_2 assimilation (Naidoo and Von-Willert, 1995). Strong sunlight can also reduce mangrove photosynthesis through inhibition of Photosystem II (Cheeseman *et al.*, 1991).

The timing of mangrove reproduction depends on local environmental conditions and may differ broadly over the range of a species. Duke, (1990) found that flowering in *Avicennia marina* occurred 6 months earlier in Papua New Guinea than in Southern Australia and New Zealand. The period from flowering to fruiting was 2-3 months in the former but stretched to 10 months in the latter. Flowering appeared to be controlled by day length while air temperature set the period for fruit maturation. Phytohormones are essential in development, growth, and dispersal of mangrove seeds, which may undergo no maturation drying, and remain metabolically active throughout development (Farrant *et al.*, 1992; 1993).

2.2.2 Reproductive biology

2.2.2.1 Flowering phenology

Mangroves have been studied for decades by botanists, ecologists, social scientists and marine scientists worldwide (Dahdouh-Guebas, 2000; Kathiresan and Bingham, 2001; Larcerda, 2002; Upadhyay and Mishra, 2008). Most research has concentrated on reproductive biology and breeding mechanism (Tomlinson, 1986; Nadia *et al.,* 2012). Flowering periods in mangroves varies due to biotic and abiotic factors such as rainfall, soil, temperature, sun light and Humidity (FAO, 2004). Fernandes (1999) found that the flowering pattern of *Avicennia schaueriana* was strongly related to rainfall and day length while that of *Lumnizera racemosa* is continuous and it is not correlated with environmental factors. The mangrove species of Bhitarkanika province in India*, viz. Sonneratia apetala*, *Heritiera fomes*, *Avicennia ilicifolius* and *Ceriops decandra* initiate their flowering activities in winter between December and January and complete the fruiting stage between March and April. Some study reported that, the flowering seasons of tropical trees has been interconnected to irradiance, rainfall and temperature (Bendix *et al.,* 2006).

In tropical areas where there is low climatic seasonality, day length and light radiation are the key climatic factors (Morellato *et al.*, 2000), defining seasonal rhythms and reproduction of mangroves (Rivera and Borchert, 2001; Borchert *et al.*, 2005). Variation in phenology in mangroves between species is not only affected by weather variation but also nutrients enrichment especially on the growth of red mangroves (Feller, 1995). Mineral deficiency varies ecologically and environmentally and this affects plants productivity and growth rates (Lambers and

Pooter, 1992). Other studies have revealed that the biological processes of mangroves are influenced by various abiotic factors such as tide amplitude and amount of precipitation (Gilman *et al.,* 2008; Hogarth, 2007). Additionally, mangroves species are adapted to grow in low nutrient condition due to oligotrophic ecosystem (Hutching and Saenger, 1987; Lugo *et al.,* 1988). In Orissa Province in India have been reported the there is a variation in the flowering and fruiting of different mangroves species growing in the area (Banerjee *et al.,* 1989; Banerjee and Rao, 1990).

Plant phenology has useful information in predicting the interactions of plants and animals; and climate change on sea water rise (Bhat and Murali, 2001). There is little information on the flowering phenology of mangroves especially in East Africa. There are a few studies conducted in Kenya on *Avicennia marina* (Ochieng and Erftemeijer, 2002; Wang'ondu *et al.,* 2013). Most studies on phenology have been based on biotic and abiotic factors with the purpose of describing specific or general phenological trends (Seghieri *et al.,* 1995; Morellato and Leitão-Filho, 1996; Brooke *et al.,* 1996; Mehlig, 2006). Overlapping flowering phenologies between two mangrove species have also been observed in Florida, the flowering of *Laguncularia racemosa* tend to increase significantly when flowering in other mangroves specie of *Avicennia germinans* stop (Landry, 2013). The aspect of flowering overlap and synchrony was mentioned by Nadia *et al.* (2012) in northeast Brazil, the flowering period observed were found to differ between *Avicennia schaueriana, Ceriops erectus* and *Laguncularia racemosa* that overlap exist between the end of one species and beginning of flowering of another. It has been reported that variations in salinity level of water affect species richness, productivity and reproduction in *Avicennia germinans* and *Lumnizera racemosa* (Hernández *et al.*, 2005).

The effect of day length, rainfall and temperature on the reproductive structure of mangrove community was influenced by rainfall and temperature in northeast Brazil mangrove community Nadia *et al.* (2012). It was reported that rain fall led to an increase in flower production by *Rhizophora mangle* and *Laguncularia racemosa*, but flower production by *Avicennia germinans* was similar in both rainy and dry seasons in Caribbean island (Sånchez-Nůńez and Pineda, 2011). On the other hand, the flowering pattern of *Avicennia schaueriana* was strongly related to rainfall and day length but the flowering pattern of *Lumnizera racemosa* was continuous to flower as threre was a rainfall, and was not correlated with ant other environmental factors (Fernandes, 1999).

Variation of flowering in mangroves varies due to biotic and abiotic factors such as rainfall, soil, temperature, sun light and Humidity (FAO, 2004). In Bhitarkanika province in India, the mangrove species of *S. apetala*, *H. fomes*, *A. ilicifolius* and *C. decandra* initiate their flowering activities in winter in December-January and complete the fruiting stage by March-April. A study conducted by Bendix *et al.* (2006) reported that, the flowering seasons of tropical trees is influenced by irradiance, rainfall and temperature. Borchert (1994) revealed that, species specific combinations between environment endogenous regulators like day length, rainfall and meristematic activity were also mentioned. In tropical vegetation areas with low climatic seasonality, day length and light radiation observed are reported as the key climatic factors defining seasonal rhythms and reproduction (Morellato *et al.*, 2000;

Rivera and Borchert, 2001; Borchert, 2005b). Flowering phenology affects seed size, seed number, seed dispersal and abundance of pollinators (Du and Qi, 2010), abiotic and biotic factors reported to influenced flowering phenology of many plant and trees (Rathcke and Lacey, 1985).

The mangrove phenology is not only affected by weather variation, but also by nutrient enrichment (Feller, 1995). This affects the productivity of plant species and their growth rates (Lambers and Pooter, 1992). Other studies revealed that the biological processes in mangroves are influenced by various abiotic factors such as tide amplitude and amount of precipitation (Hogarth, 2007; Gilman *et al.*, 2008). Mangroves are adapted to grow in low nutrient condition due to oligotrophic ecosystem (Hutching and Saenger, 1987; Lugo, 1988). In Orissa Provinces in India reported the existing of variation of flowering and fruiting in different mangroves species growing in the area (Banerjee *et al.*, 1989; Banerjee and Rao, 1990). On the other hand, phenology variation of four mangroves species were recorded in Thailand, whereby *Avicennia marina* had showed to have dinstinct flowering period annually compared with *Lumnizera Littorea, Bruguiera cylindrical* and *Ceriops tagal*, that were found to produce flowers all year round with maximum flower production (Wium-Andersen and Christensen, 1978).

Studies by Lieberman (1982), revealed that the development of flowers to mature fruits was observed as follows; 11 months for *Lumnizera littorea,* 3-4 months for *Bruguiera cylindrical*, 4-5 months for *Ceriops tagal* and 3-4 months for *Avicennia marina*. Weather is believed to be an important player in triggering phenological patterns in mangroves. Scientists explained mangroves phenophases varied according to the species, example Rabinowitz (1978) pointed out that *Rhizophora mangle, Laguncularia recemosa* and *Avicennia schaueriana* are viviparous, while Tomlinson (1994) stated that, *Laguncularia recemosa* and *Avicennia schaueriana* are crypto-viviparous, because their germination occurs when the fruit is still attached to the mother tree. In Zanzibar about ten mangroves species have been identified, however, mangroves species of *Avicennia marina, Rhizophora mucronata, Bruguiera gymnorrhiza* and *Ceriops tagal* are dominant and common throughout the Islands, but their phenology is not studied yet (Ngoile and Shunula, 1992; Mchenga and Ali, 2014; Hamad *et al.*, 2014).

2.2.2.2 Pollination of mangroves

Mangroves have both self-pollinating and cross-pollinating mechanisms that vary with the species. For example, *Aegiceras corniculatum* and *Lumnitzera racemosa* are self-pollinated trees. *Avicennia officinalis* is self-fertilized, but can also be cross-fertilized (Aluri, 1990). Mangroves are pollinated by a diverse group of animals including bats, birds, and insects. Some mangrove species have developed specialized mechanisms related to a particular type of pollinator (Juncosa andTomlinson, 1987; Noske1993). In cross-pollination, pollen is deposited on the animals as they deeply probe the flowers for nectar; and subsequently they transfer the pollen to the stigma of another flower. The identity of pollinators differs among species. *Lumnitzera littorea*, for example, is pollinated primarily by birds while *L. racemosa* and the small-flowered *Bruguiera gymnorhiza* are pollinated by insects. *Aegiceras corniculatum* and *Lumnitzera racemosa* are self-pollinated, while *Avicennia officinalis* is self-fertilized, but can also be cross-fertilized (Tomlinson, 1986; Aluri, 1990). Majority of mangrove species are pollinated by animals, with the exception of *Rhizophora species* in which is also wind pollinated (Juncosa and Tomlinson, 1987; Noske 1993; Tomlinson, 1994). Insect pollinators are the lagest important faunal group in agriculture and horticulture production (Klein *et al*., 2007). Sunbirds visit and may pollinate *Acanthus ilicifolius* (Aluri, 1990) and large-flowered *Bruguiera hainesii* (Noske, 1993, 1995). Birds are particularly important pollinators in the dry season when absence of flowers in terrestrial habitats causes them to turn to mangroves as a food source.

Pollinators provide an important ecosystem service as reproduction and yields of many flowering wild (Larson and Barrett, 2000) and crop plants benefit from faunal pollination (Klein *et al.,* 2007). It is estimated that the pollination services in agriculture production reached 208$ billion USD per annum in 2005, or 9.5 percent of the total value of the world’s trade (Gallai *et al.,* 2009). Moreover, animal pollination is being increasingly recognised as an essential ecosystem service, whose sufficient provisioning leads to overall increased and stabilized crop production globaly (Garibaldi *et al*., 2011). In Ghana, the overall contribution of pollination services to agricultural production is estimated at 11.1 % of the national agricultural production per annum of circa US$ 7 million (Gallai and Vaissière, 2009a and b). In addition to the overall economic importance of pollination services, the production value per unit farming area of insect pollinated crops is four times that of crops that do not need insect pollination (Gallai *et al.,* 2009). This economic benefit from pollinators is under threat as long-term declines in pollinator populations and related threats to plant reproduction. This has led to concerns of a widespread loss of pollination services in which pollen-limited plants will suffer reduced yields from declining pollen supply (Kremen *et al.,* 2002; Steffan-Dewenter *et al.,* 2005;

Biesmeijer *et al.,* 2006). A global survey of several studies demonstrated a severe decline of pollinators and provision of pollination services in a wide range of intensively managed temperate and tropical agro-ecosystems (Anonymous, 2012). In Africa, there is no solid documentation of the status and trends of pollinator populatios (Gemmill-Herren *et al.,* 2014). However, the overall global trends of demands for pollination against anticipated supply is relevant in an African context. The current unregulated harvesting of mangroves in Zanzibar may reduce the mangrove pollinators' population which in turn creates slowness of availability of mangroves seedlings for regeneration and restoration (Personal observation). However, no studies have been conducted to determine the role of pollinators in in the regeneration of mangroves. This is the gap that the current study sought to fill.

Worldwide researchers are concerned about biodiversity decline and even species losses (Tilman *et al.,* 2006). For example Klein *et al.* (2003a); DeGrandi-Hoffman and Chambers, (2006) reported that pollinators' community might differ on behaviorally partitioning niches. It is undisputed that many crops human use for food and majority of wild plant species depend on pollination by insects. The effect of pollination decline was reported in Sichuan province in China where the farmers have to use hand pollination in apple flowers (Goulson, 2003; Kevan, 2004; Allsopp *et al.,* 2008; Anonymous, 2012). In East African, little information is available on the effects of reduced pollinators yet overuse of pesticides; habitat destruction, agricultural innovation and climate change continue unabated though believed to reduce biodiversity species and richness.

2.3 Economic benefits of mangroves

Mangrove forests are extremely important coastal resources, which are vital to the socio-economic development of local people. Majority of human populations that live in coastal areas depend on local resources for their livelihood including house constructions. The mangroves are sources of highly valued commercial products and fishery resources and also as sites for developing a burgeoni eco-tourism (Kathiresan and Bingham, 2001). Mangrove forests have been shown to sustain more than 70 direct human activities, ranging from fuel-wood collection to fisheries (Lucy, 2006). Mangroves supply many forestry products which include firewood, charcoal, timber, honey, fishery products such as fish, prawn, crab, mollusk *etc*. (Turner, 1991). Due to high calorific values, mangrove twigs are used for making charcoal and firewood. One ton of mangrove firewood is equivalent to 5 tons of Indian coal, and it burns producing high heat without generating smoke (Kathiresan and Rajendran, 2005). The mangrove wood with high content of tannin is used as timber for its durability. The pneumatophores are used to make bottle stoppers and floats. *Nypa* leaves are used to thatch roofs, make mats and baskets. Shells of mangrove molluscs are used to manufacture lime (Ish-Shalom and Dubinsky, 1992).

Mangrove extracts are used in indigenous medicine; for example, leaves of *Bruguiera* species are used for reducing blood pressure. Roots and stems of *Derris trifoliata* are used for narcotizing fishes, whereas *Acanthus ilicifolius* is used in the treatment of rheumatic disorders. Seeds of *Xylocarpus* species have antidiarrhoeal properties and *Avicennia* species have tonic effect, whereas *Ceriops species* produce hemostatic activity (Kathiresan, 2000). The bark of *Rhizophora* species has astringent, antidiarrhoea and antemetic activities. Tender leaves of *Acrostichum* are used as a vegetable and a beverage is prepared from the fruits of *Sonneratia* spp. Extracts of *Bruguiera* species and *Excoecaria agallocha* are used for the treatment of leprosy and epilepsy (Kathiresan, 2000).

Mangrove swamps act as traps for the sediments, and sink for the nutrients, offering protection to other associated flora and fauna, remove CO_2 from the atmosphere through photosynthesis and mitigating tsunami (Kathiresan and Rajendran, 2005). They also attract honey bees and facilitate apiculture activities for people living along the coastal zones (Siddiqi, l997).Mangroves apiculture activities accounts for about 90% of honey production among the mangrove community of India (Krishnamurthy, l990). In Bangladesh, an estimated 185 tons of honey and 44.4 tons of wax are harvested each year in the western part of the mangrove forest (Siddiqi, l997). The best quality honey is produced from *Aegialitis rotundifolia* and *Cynometra ramiflora.* The bulk of honey seems to come from *Ceriops species.*

The mangroves litter fall has direct relationship with marine biodiversity and are commercially very important (Tovilla-Hernandez *et al.,* 2004; Khan *et al.,* 2007; Bouillon *et al.,* 2008; Granek *et al.,* 2009;). Mangroves and especially *Avicennia* form cheap and nutritive feed for buffaloes, sheep, goats and camels. These animals are allowed to graze in mangrove areas and camels are periodically taken to uninhabited islands with a good mangrove cover for grazing. This is very common in India, Pakistan, Persian Gulf region and Indonesia (Qasim, l998).

2.4 Important of forest conservation on pollination

Conservation of flora and fauna become important because any human habitat fragmentation activities dramatically reduce species richness (Mchenga and Ali, 2013). Generally all living organisms are interconnected through food webs and hence research and conservation are necessary to ensure their existence. The importance of conservation of insect's pollinators and flowering plants is due to their interactions ecologically and economically. Nearly 88% of angiosperms rely on animals as major pollination service providers (Ollerton *et al.,* 2011), and any interference with this interaction may cause effects that could be felt throughout ecological communities, affecting frugivory, seed dispersal, and plant recruitment (Kearns and Inouye, 1997). Reduction in plant and seed production are believed to be major threats to plant life history development and might accelerate the probability of extinction of populations and species (Olesen and Jain 1994). Pollination represents a basic ecosystem service with an estimated economic benefit between 90 and 160 billion Euros at the global scale (Costanza *et al.*, 1997; Kearns *et al.*, 1998). It has been estimated that in the mangroves ecosystems pollinators contribute $200 billion annually (Gallai *et al.,* 2009).

Despite this huge economic contribution, pollinators especially insects are declining globally due to disruption of interacting factors (Potts *et al.,* 2010a). It has been reported that over the last 25 years, there has been a significant decline in the diversity pollinators' globally but in particular of butterflies and bumblebees (Potts *et al.,* 2010b). Furthermore, Brittain *et al.* (2010) reported that the over use of pesticides, agricultural intensification and destruction of the natural habitats are major contributing factors to this declines. There is little information on the role of pollinators in the East African mangrove ecosystems. Further, the current destructions of these ecosystems may cause loss of diversity of pollinators. The current study sought to investigate the role of pollinators in fruit set, abortion and production two mangrove forests in Zanzibar. Also the diversity and abundance of insect pollinators was investigated. . This information is useful to the conservationists and the government when making policies regarding the conservation of the mangroves.

CHAPTER THREE: STUDY SITES AND GENERAL METHODOLOGY

3.1 Study sites

Zanzibar is a tropical island located in the Indian ocean between latitude 04° 50” and 06° 30” South, and longitude 39°10” and 39° 50” East. The local climate is characterized by four distinct seasons; hot season “Kaskazi” between December and February with little or no rain, the long rain “Masika” occur from March to May. The relatively cool dry season “Kipupwe” occurs between June and September, while Vuli is short rainy season from October to November. The average rainfall varies from 1000mm to 2500mm per year while temperature ranges between 17^{o}C and 40^{o}C. The island is surrounded by the coral reefs, sandy beaches, lagoons, mangrove swamps which are rich in marine life. This study was carried out in two mangrove sites with different degree of degradation and management status.

Site 1 is Michamvi Chwaka Bay located about 60 km south-east of Zanzibar township in the South Region (Fig 3.1). The site situated at latitude 6°14’ S and longitude 39° 49’ E in Chwaka bay marine conservation area, the distance to Nyeke sites are approximately 25km. Michamvi site is relatively remote peninsular which forms the upper part of the southeast coast of Zanzibar. To the east the land continues to be lined by the same broad coral lagoon of the adjacent Bwejuu area to the south. Seven species of mangroves are common in this areas, *Avicenia marina, Rhizophora mucronata, Bruguiera gymnorrhiza, Ceriops tagal, Pemphis acidula, Xylocarpus sp and Sonneratia alba (*personal observation). Michamvi mangrove forest is not under any management program at the moment, thus the site is useful to elucidate the impact of human pressure on regeneration of mangroves.

Site 2 is Nyeke mangroves forest located between Uzi Island and Unguja Ukuu village in the southern part of Zanzibar in the Indian Ocean between latitude 6° 19’ and 6° 24` S and longitude 39° 25` E. Uzi is Small Island with an area of about 15.6 km2 and a population of 3200 peoples.

The mangrove forest is found both in sandy and rocky shore in the northern tip and the southern part of the island. Eight species are reported to grow in this site include *Avicenia marina*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza* , *Ceriops tagal*, *Pemphis acidula*, *Xylocarpus sp*, *Lumnitzera racemosa* and *Sonneratia* alba (Mchega and Juma, 2011). The mangrove forests lie within Menai Bay Conservation area and nearby Jozani Chwaka Bay National Park (Plate 3.1). The Nyeke mangrove stand serves as a feeding ground and a nursery ground for some import commercial species of fish (Mchega and Ali, 2013). The mangroves forests also interact with the terrestrial habitats, as Red Colobus and other small mammals from the nearby Jozani Forest visit the Uzi mangroves in search for food. These two sites were selected because of ongoing anthropogenic activities such as constructions of new hotels, expansion of human settlements, deforestation and exploitation of mangroves tree forest.

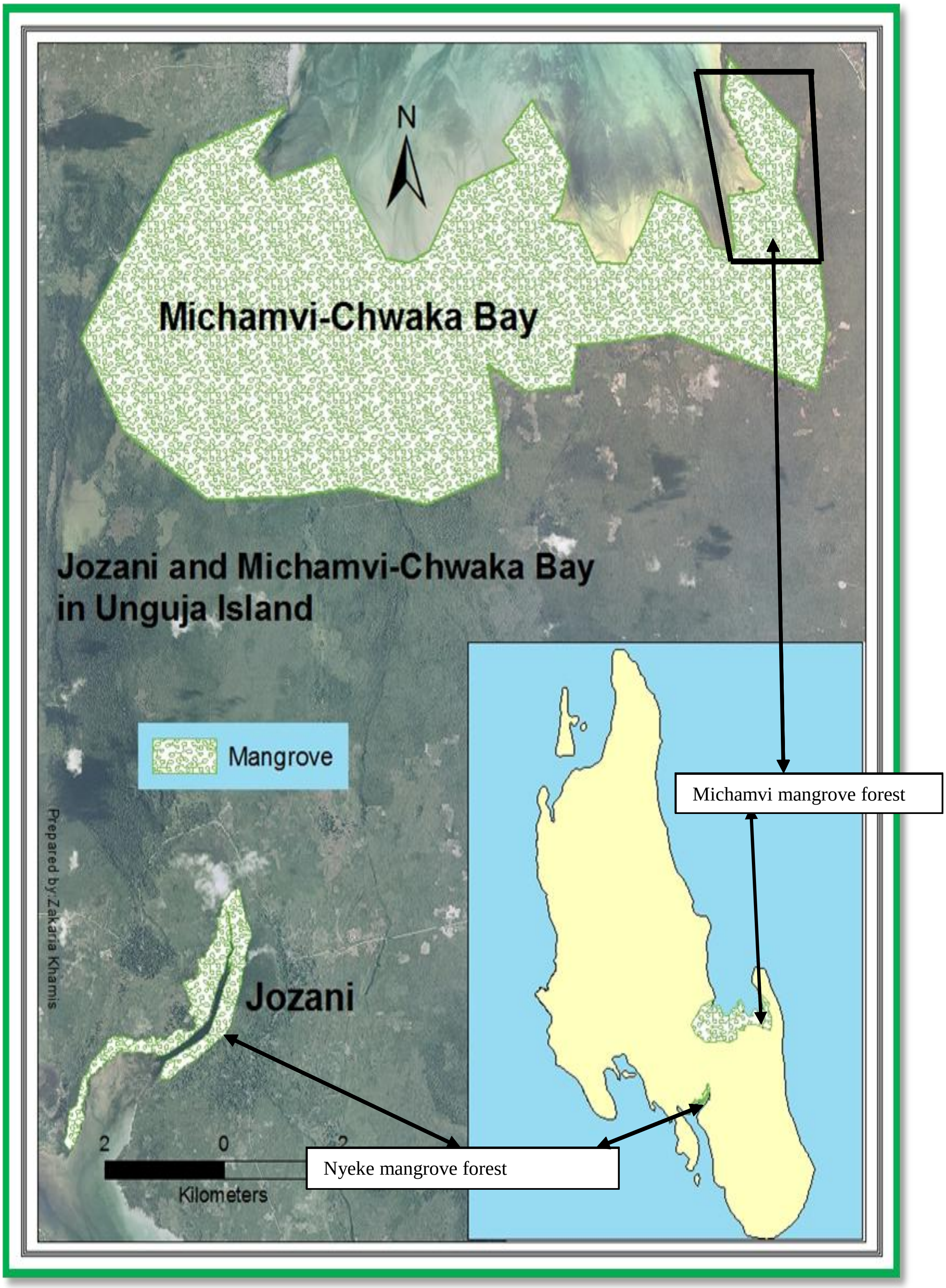


Figure 3.1 Michamvi and Nyeke mangrove forests sites

Source, Author and Zakaria Khamis, 2013

Plates 3.1 Arial view of Nyeke mangroves forest

Source, Author 2013

Plates 3.2 View of Michamvi mangrove forest

Source, Author 2013

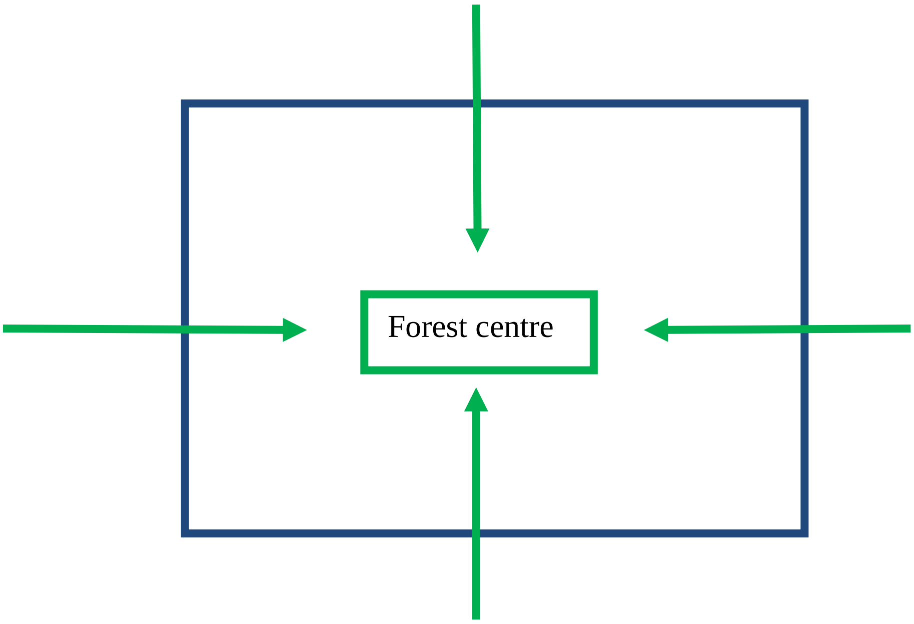


Figure 3.2 Direction transect toward the centre of the study site

3.2 General Methodology

Four species mangroves (*Avicenia marina, Rhizophora mucronata, Bruguiera gymnorrhiza* and *Ceriops tagal*) were chosen for this study. These were chosen because they are the most commonly usedby humans in Zanzibar. For each mangroves species study, twenty trees were randomly selected in each site, and one branch for each was tagged for identification. The four species were monitored for one year (from January 2013 to December 2013) to determine flower phenology. The number of flower buds, flowers, aborted flowers, fruitset and fruits production was recorded weekly.

A similar set up was done for the study on the role of pollinators in the reproductive of the four mangrove species. Another 80 mangroves tree was identified and selected branches were monitored twice a week from July 2013 to March 2014. The number of insect flower visitors, visitation frequency, and number of buds, flowers, fruits set and fruits produced were recorded. In the study of insects pollinator identification, their abundance, diversity and species richness. Sampling of insect pollination was done in all year of 2013 from all four campus direction transect toward the centre of the study site (Fig. 3.2). Each transect was sampled once a week. At each sampling date, the distance was approximately thirty metre long and within was ten metre on either side. Insect flower pollinators in each transect was collected by used of sweeping net and kept into vials with 70% ethanol for identification to species level.

The study of effect of pollination on fruits production in a four species, this was study by bagging a selected branch and control treatments. The monitored of insect pollinators, visitors and number of flowers, fruits set, fruit aborted and fruits produced were observed twice a week from September 2013 to February 2014. Selection of the study trees and setup was the same as for phenology study.

3.3 General description of four mangroves species

3.3.1 *Avicennia marina*

Avicennia marina, (Forssk.) is commonly known as grey mangrove or white mangrove (Aluri, 1990). This species of mangrove belongs to Family Acanthaceae (formerly in the Verbenaceae or Avicenniaceae). As with other mangroves species, it occurs in the intertidal zones of estuarine areas. The species is a shrub or tree that can grow up to 3-10 meters high but in some tropical regions it can be up to 14 meters. It has smooth light-grey bark made up of thin, stiff, brittle flakes (Aluri, 1990; Spalding *et al,* 2010; Duke *et al,* 2010). The bark may be whitish hence its common name. The leaves are thick, 5-8 cm long, a bright, glossy green on the upper surface, with very small matted hairs on the surface below (Plate 3.3). The flowers measure less than a centimeter across, range from white to a golden yellow in colour, and occur in clusters of three to five. The fruit contains large cotyledons that surround the new stem of a seedling. This produces a large fleshy seed, often germinating on the tree and falling as a seedling (Kathiresan and Bingham 2001).

The root system of mangroves is divided as in other plants in to three main groups, flat root system, heart root system and top root system. *Avicennia* species develop flat root systems and therefore have an advantage compared to other mangrove species as they can easily establish in sandy, stony and rocky coastlines. *Avicennia* and *Bruguiera* species can develop additional stilt roots in a few cases, especially when they are in danger to lose their location. These stilt roots prevent the tree from being uprooted. This happens often when the tree is out washed by rising sea level, tides.

3.3.2 *Rhizophora mucronata*

Rhizophora mucronata (L.) Lamk "Orange mangrove" – (*Rhizophoraceae* – Dicotyledon loop-root mangrove, red mangrove or Asiatic mangrove Afrikaans) is a small to medium size evergreen tree that grows to a height of about 20 to 25 metres (66 to 82 ft) on the banks of rivers. On the fringes of the sea 10 or 15 meters (33 or 49 ft) is a more typical height. The tallest trees are those closest to the water and shorter trees are further inland. The tree has a large number of aerial stilt roots buttressing the trunk (Kathiresan and Bingham, 2001; Spalding *et al.,* 2010; Duke *et al.*, 2010). The leaves are elliptical and usually about 12 centimetres (4.7 in) long and 6 centimetres (2.4 in) wide. They have elongated tips but these often break off. There are corky warts on the pale undersides of the leaves. The flowers develop in auxiliary clusters on the twigs. Each has a hard cream-coloured calyx with four sepals and four white, hairy petals (Plate 3.4). The seeds are viviparous and start to develop whilst still attached to the tree. The root begins to elongate and may reach a length of a metre (yard) or more. The propagule then becomes detached from the branch when sufficiently well developed to root in the mud (Kathiresan and Bingham 2001).

3.3.3 *Ceriops tagal*

Ceriops tagal (Perr.) Yellow mangrove - *Rhizophoraceae* –Dicotyledon Evergreen tree 5-25m high and 20-40 cm in diameter, often with unbranched stilt roots and thin knees 20–30 cm high. Bark light grey or reddish-brown, smooth or irregularly fissured; inner bark orange or reddish (Spalding *et al.*, 2010; Duke *et al.*, 2010). Leaves opposite, clustered at end of twigs, obovate to elliptical, 5-10 cm long, 2-6 cm wide, rounded and emarginate at tip, acute at base, entire, thick, leathery, glabrous, without visible veins. Petiole 1-3.5 cm long, stipules paired, narrow and calyx 2 cm long. Cymes are single and short-stalked in leaf axils. Flowers are 4-10cm, short stalked calyx with 6mm long. Calyx yellow-green with 5-6 narrow pointed lobes turned back on fruit; petals 5-6, white, united at base, 2-lobed and ending in 2-4 bristles, stamens 10-12; pistil with conical, partly inferior 3-celled ovary and short style. Berry drooping, ovoid, 1.5-2.5 cm long and leathery (Plate 3.5). Seed, viviparous, becoming cigar-shaped or club-shaped, sharply angled, 15-25(-35) cm long (Little, 1983).

3.3.4 *Bruguiera gymnorrhiza*

Bruguiera gymnorrhiza (L.) Lamk. “Black mangrove” Large-Leafed Orange/ Oriental Mangrove. This is a tree that grows up to 10m high and belongs to Family Rhizophoraceae. It is found on the seaward side of mangrove swamps, often together with *Rhizophora*. Its bark is rough and reddish-brown. The tree develops short prop-roots rather than long stilt-roots. Flowers are creamy-white initially but turn brown soon. The sepals are persistent, narrow and slightly tapered (Spalding *et al.*, 2010; Duke *et al.*, 2010) (Plate 3.6). When mature, the spindle-shaped fruits drop and become embedded in the mud in an upright position, where they rapidly de develop roots.

Plate 3.3 *Avicennia marina*, Leaves, flowers and buds

Plate 3.4 *Rhizophora mucronata*, flowers and buds

Plate 3.5 *Ceriops tagal*, leaves, flowers and buds

Plate 3.6 *Bruguiera gymnorrhiza*, flowers and leaves

CHAPTER FOUR: REPRODUCTIVE PHENOLOGY OF FOUR MANGROVES SPECIES IN NYEKE AND MICHAMVI FORESTS

4.1 Introduction

Plant phenology is concerned with all the reproductive events from induction of buds to production of fruit (Sun and Frelich, 2011) and is fundamental to a plant species reproductive ecology (Ollerton and Lack, 1998). Vast studies on mangroves have been based on reproductive biology and breeding mechanism (Tomlinson, 1986; Nadia *et al.,* 2012). There are more than 35 phenological studies conducted on mangrove species in Australia and other parts of the world (Duke *et al.,* 1984; Duke, 2007; Duke *et al.*, 2010). However, there is little information on the phenology of mangroves in East Africa except for a few studies conducted in Kenya on *Avicennia marina* (Ochieng and Erftemeijer, 2002; Wang'ondu *et al.*, 2013). There is no information on reproductive phenology of mangroves community in Zanzibar. It is in this context, the present study aimed at exploring, the reproductive pattern of four major mangroves species abundant in Nyeke and Michamvi forests in the Southern region of Zanzibar.

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 (Bhat and Murali, 2001). Information obtained in this study is vital for developing conservation strategies and will help in understanding the ecological distribution of reproductive phenology of mangrove species in Zanzibar. The study aimed at answering the following questions: (a) Are the flowering pattern of the different mangrove species affected by weather and do they differ between sites? (b) Is there any difference in the proportion of buds, flowers, fruit abortion and fruits produced in different species and in different sites? (c) What is the peak period for flower buds, flowers and fruits for different mangroves species and sites?

4.2 Materials and Methods

4.2.1 Identifying and tagging the branches

At each study sites a total of 80 trees, 20 trees per each species of mangrove were selected. The species were *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 the date it was tagged. All the selected branches were approximately 1.5m from the ground to prevent sea water interference. After tagging and labeling, petroleum jelly was smeared on the woody part 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 ease identification of the plots during data collection. In case the selected branch did not produce flowers another branch of the same tree was selected and observed. Observations were done twice a week in every month for a period of one year in 2013. The number of flower buds, flowers, aborted flowers, fruits set and a young fruit was recorded for each branch.

4.2.2 Monitoring buds, flowers and fruits

All buds, flowers and fruits that emerged from selected branches were counted every 10 days except for *Avicennia marina* which was done every 7 days. A permanent white mark was made with a marker pen and tagged labels were placed on 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 (Figure 3.1 and 3.2).

A bud was defined as swelling of growing tip between the leaves. Flowering was defined as conversion of buds to show all flower morphology. Fruits set were defined as conversion of flower to fruit initiation showing successful fertilization. Aborted fruit was defined as a young un-mature fruit detached from the tree. Fruit was defined as young and mature fruits attached to the mother tree. Data were were entered into Microsoft excel. The variables recorded were: date, site, mangroves species, and numbers of flower buds, flowers, fruits set, fruits aborted and fruits.

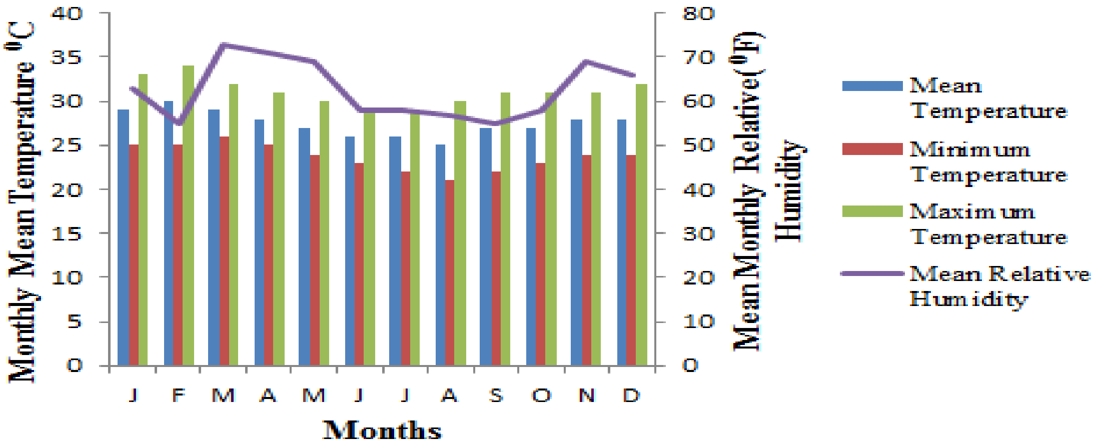


Figure 4.1Monthly Temperatures and Relative Humidity 2013

Source: Zanzibar Meteorological Head Office, 2013

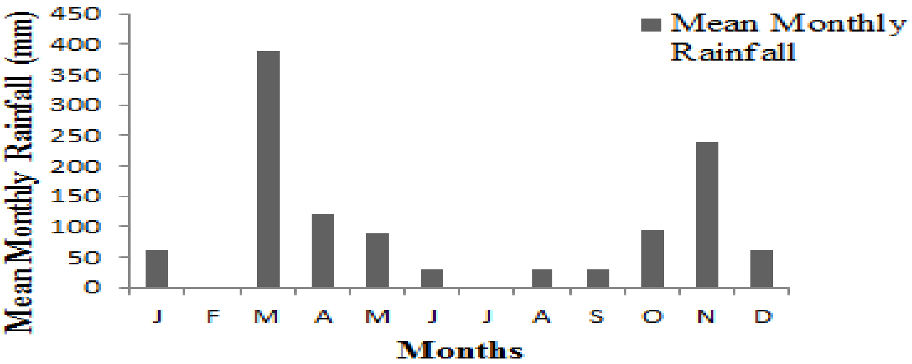


Figure 4.2 Monthly Rainfall; South Region, Zanzibar 2013

Source: Zanzibar Meteorological Head Office, 2013

4.2.3 Data analysis

Mean for each variable was calculated using Statistical analysis tool is SPSS. The mean of each variable was converted into a percentage to ease interpretation of the results. Graphs containing two variables on the Y-axis were developed for each mangroves species. First y axis shows percentages of flower buds, flowers, fruits set, fruits aborted and fruits. The second y axis shows monthly means of temperature and rainfall. The X axis was included months in the year 2013. Reproduction phenophases tables of four mangroves species were developed (AM= *Avicennia marina*, RM= *Rhizophora mucronata*, BG= *Bruguiera gymnorrhiza and CT= Ceriops tagal*).

4.4 Results

4.4.1 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, appearance of buds started in October for both study sites (Tables 4.1 and 4.2). The peak flower buds production occurred in November

(41%) in both sites (Fig. 4.3a to 4.3f). 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 4.3a to 4.3f. Flowering in this species started during the short rainy season and ended in dry season (usually starts in October to February) for a total duration of 4 months. However, weekly variations occurred between the two sites (Table 4.1 and 4.2). The peak flowering periods were January and November- December in Nyeke (37% of the flowers) and Michamvi (33% of the flowers) respectively. Lowest flower production was recorded in February, 1% of the flowers for each site (Fig. 4.3a to 4.3f). 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. 4.3a and 4.3d). There is no relationship observed between RH and rainfall and formation of buds (Fig. 4.3b, 4.3c, 4.3e, 4.3f). This species exhibited the shortest flowering and fruiting period of all the four species.

Fruits set in *Avicennia marina* began in the first week of December, and ended at the last week of February, a total period of 3 months (Table 4.1 and 4.2). The peak fruits sets were observed in January, in Nyeke (75%) and Michamvi (73%) of the flowers produced recorded to set fruits respectively (Figures 4.3a to 4.3f). Temperature had a positive influence on fruits sets 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. 4.3a and 4.3d).

The highest percentage of fruit abortion was observed during dry season, Nyeke 54% in January and Michamvi 64% in February (Fig. 4.3a and 4.3f). The duration of fruit abortion lasted for two months, January to February (Tables, 4.1 and 4.2). Temperature does not only trigger formation of buds and flowering but also increases fruit abortion (Fig. 4.3a and 4.3d). Relative Humidity and rainfall shows little influence on fruit abortion.

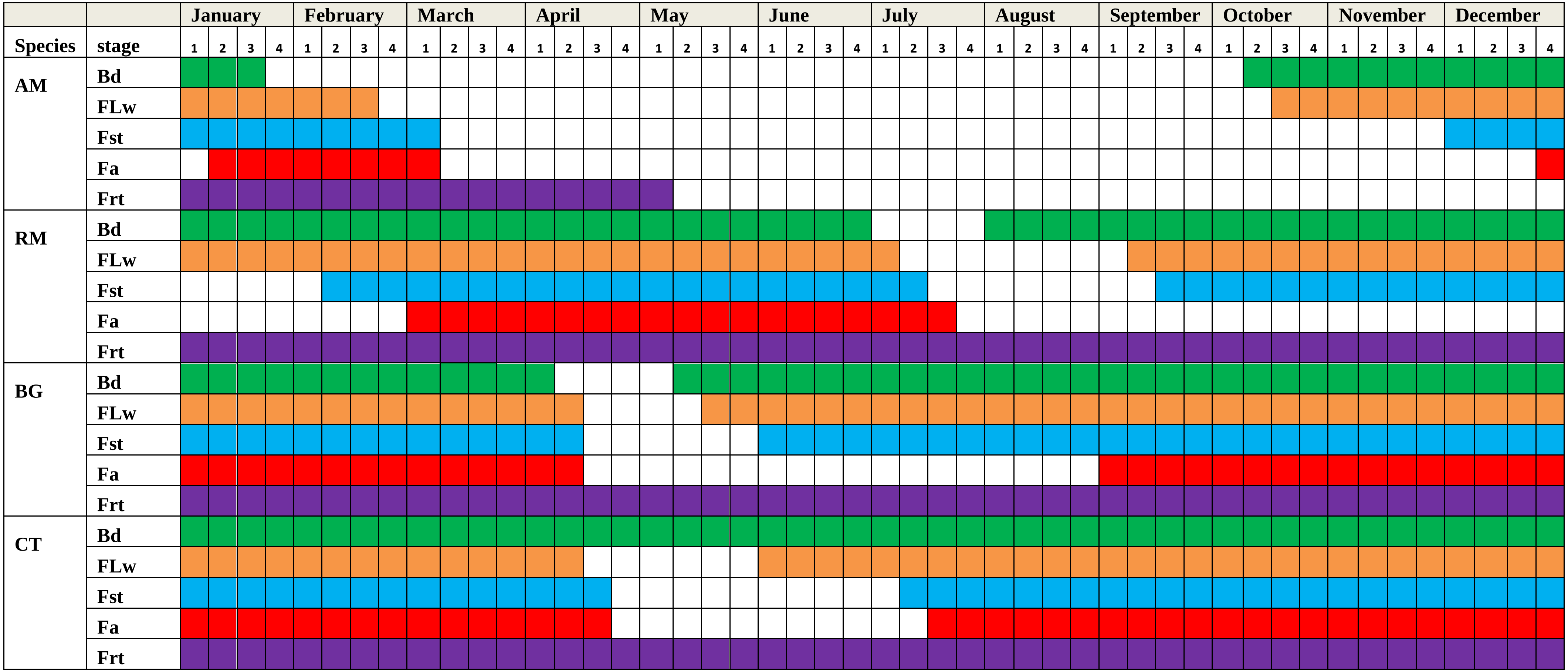
The peak period of fruits produced was observed in February and the records showed that 44% and 49% in Nyeke and in Michamvi respectively (Fig. 4.3a to 4.3f). Fruiting starts in dry seasons from first week of January up to the end of the last week of April, during long rainy seasons (Table 4.1 and 4.2). There was little fruit production from second week of May to December (Table 4.1 and 4.2)

Table 4.1Reproduction phenophases of four mangrove species AM= *Avicennia marina*, RM= *Rhizophora mucronata*, BG= *Bruguiera gymnorrhiza* and CT= *Ceriops tagal* at Nyeke Mangrove Forest

		January				**February**				**March**				**April**				**May**				**June**				**July**				**August**				**September**				**October**				**November**				**December**			
Species	**stage**	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**	🟩																																			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧																																	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																																					🟦	🟦	🟦	🟦
	Fa	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																																								🟥
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪																																				
RM	**Bd**	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦												🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Fa								🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																														
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪			🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
BG	**Bd**	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦						🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Fa	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
CT	**Bd**	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧							🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Fa	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥														🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪

Key: (Bd) Buds, (FLw) Flowers, (Fst) Fruitset, (Fa) Fruit abort and (Frt) Fruit

Table 4.2 Reproduction phenophases of four mangrove species AM= *Avicennia marina*, RM= *Rhizophora mucronata*, BG= *Bruguiera gymnorrhiza* and CT= *Ceriops tagal* at Michamvi Mangroves Forest.



		January				February				March				April				May				June				July				August				September				October				November				December			
Species	stage	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	🟩	🟩	🟩																																			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧																																🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																																				🟦	🟦	🟦	🟦
	Fa		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																																							🟥
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪																															
RM	Bd	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧									🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst						🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦									🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Fa									🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																					
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
BG	Bd	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧					🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Fa	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
CT	Bd	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	FLw	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧							🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
	Fst	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦											🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Fa	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥												🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	Frt	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪

Key: (Bd) Buds, (FLw) Flowers, (Fst) Fruitset, (Fa) Fruit abort and (Frt) Fruit

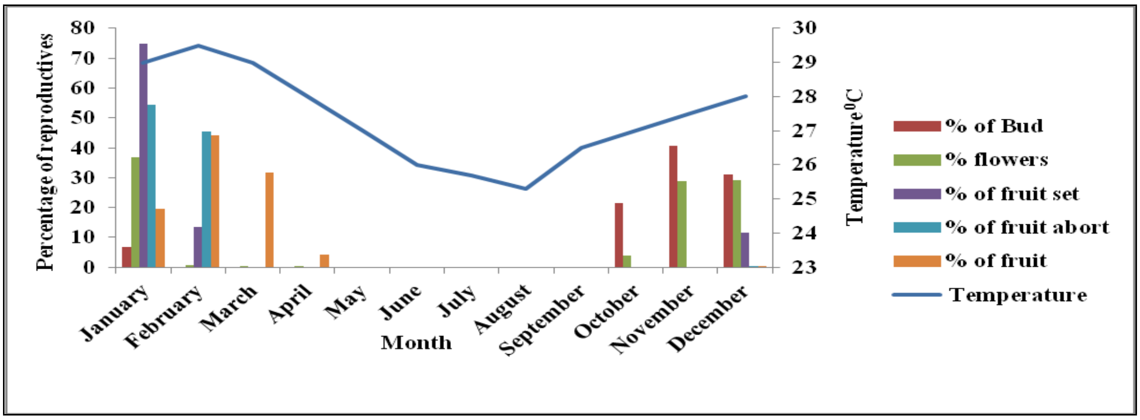


Figure 4.3a Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Avicennia marina* in Nyeke fores

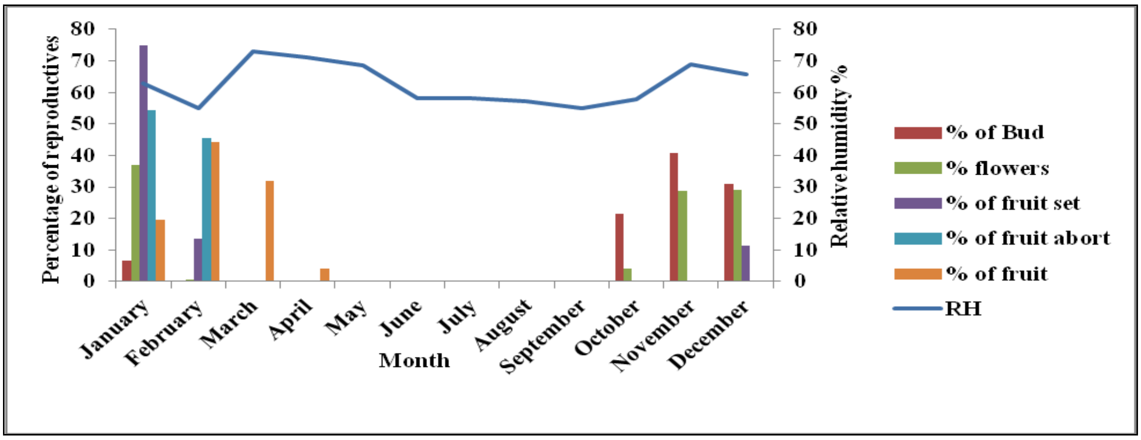


Figure 4.3b Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Avicennia marina* in Nyeke forest

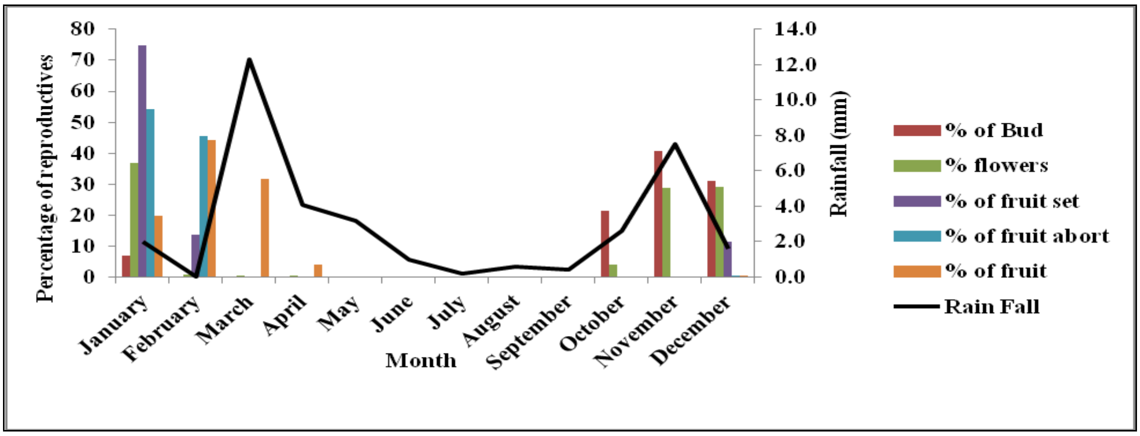


Figure 4.3c Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Avicennia marina* in Nyeke forest

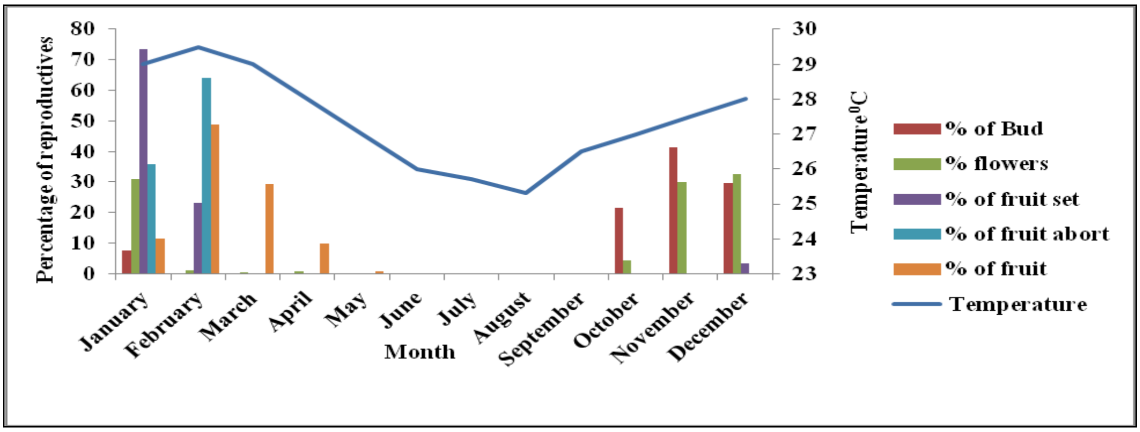


Figure 4.3d Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Avicennia marina* in Michamvi forest

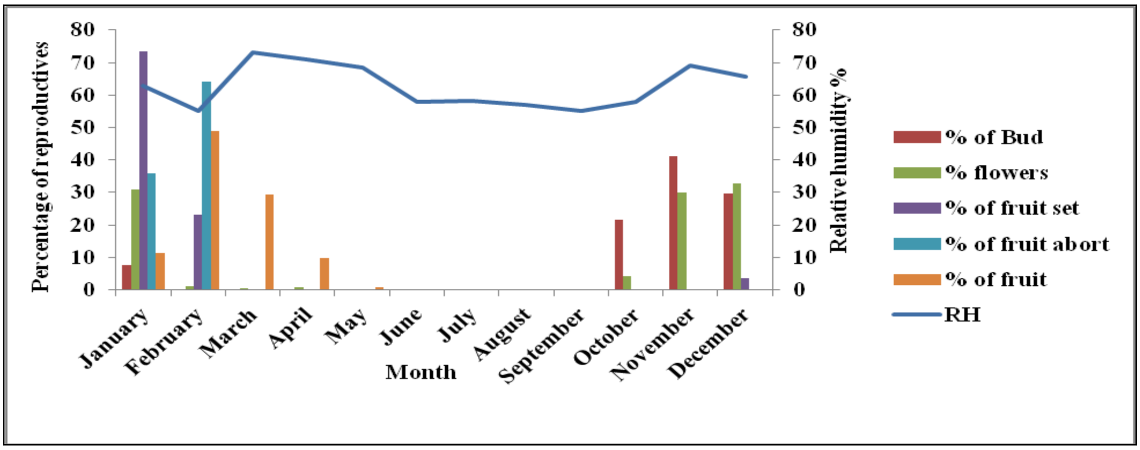


Figure 4.3e Mean monthly Relative Humidity and percent of buds, flowers,fruits set, fruits aborted and fruits formed by *Avicennia marina* in Michamvi forest

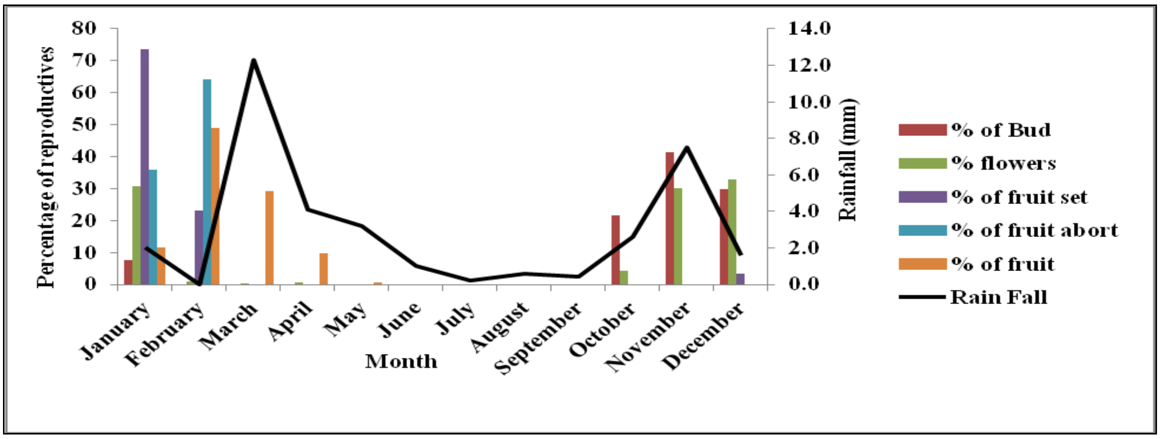


Figure 4.3f Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Avicennia marina* in Michamvi forest

4.4.2 Reproductive phenology of *Rhizophora mucronata*

Rhizophora 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 (Table 4.1 and 4.2). 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% and 4% in nyeke and Michamvi respectively (Fig. 4.4a to 4.4f). Whereas average temperature recorded ranged between 25^0C and 27^0C, with minimum and maximum Temperature of 21^0C and 31^0C (Fig. 4.4a and 4.4d). 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. 4.4b, 4.4c, 4.4e and 4.4f).

Flowering occurs all year round with exception of July-August in Michamvi the last three week of June (Table 4.1 and 4.2). Highest flowering seasons were observed in January and February in Michamvi 27% and Nyeke with 28% of the buds produced were recorded to set flowers respectively (Fig. 4.4a to 4.4f). However, in August 13% and 1% flower production was witnessed in Nyeke and Michamvi sites respectively (Fig. 4.4a to 4.4f). The peak flowering periods corresponded with dry season when mean temperature ranged between 28^0C to 30^0C, and maximum Temperature are 25^0C and 34^0C (Fig. 4.4a and 4.4d), with monthly Rainfall ranging from 0mm to 62mm and mean RH range was 63% (Fig. 4.4b, 4.4c, 4.4e and 4.4f). Temperature variation showed a corresponding, relationship with flowering patterns.

Fruits set for *Rhizophora mucronata* occurred from last week of January to May and last week of August to December in Nyeke (Table 4.1). In Michamvi, fruitset began in second week of February to the first week of July and second week of September to December (Table 4.2). In general, fruitset occured during dry and rainy seasons in both sites (Fig. 4.4c and 4.4e). Highest fruitset were detected during long rainy season of March 40% and April 34% for Nyeke and Michamvi sites respectively (Fig. 4.4b and 4.4e). Fruitset is not 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 (Fig. 4.4a and 4.4f). Abortions begin during last week of February and ended in second week of June in Nyeke site (Table 4.1), whereas in Michamvi begin during last week of February and ended in second week of July (Table 3.2). During this period of fruit abortion, the temperature, RH and rainfall were between 26^{0}C to 30^{0}C, 55% to 73% and 0mm to 390mm respectively.

Fruiting of *Rhizophora mucronata* was observed throughout the year with exception of two weeks in mid September in Nyeke (Table 4.1 and 4.2). In Michamvi highest fruit produced occurred between May and June of 21% and 22%, while Nyeke occurred between April and May of 23% and 22% (Table 4.1 and 4.2). Peak fruit production seasons were mainly witnessed during heavy rains and high RH, of between 90mm to 390mm and 69$^{\%}$ to 73$^{\%}$ (Fig. 4.4b and 4.4e). Association of rainfall and fruit production was not minimal (Fig. 4.4c and 4.4f).

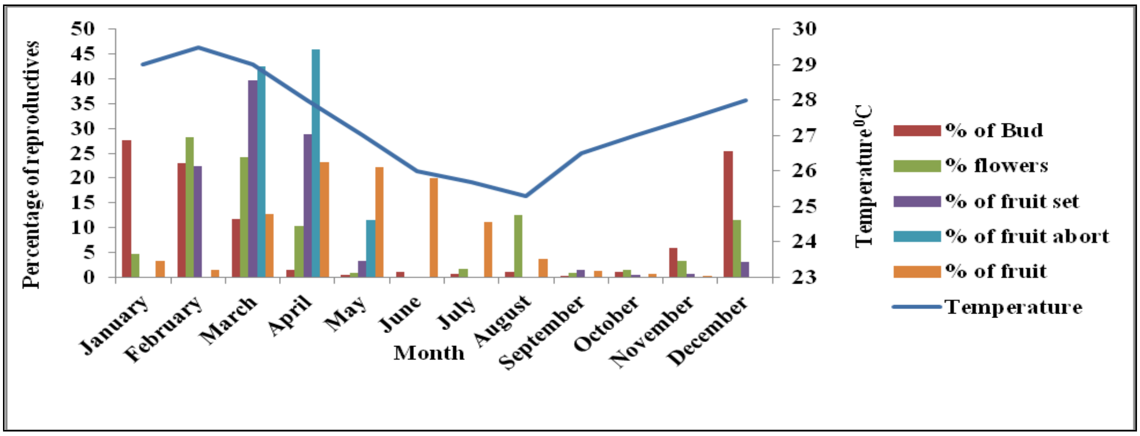


Figure 4.4a Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Rhizophora mucronata* in Nyeke forest

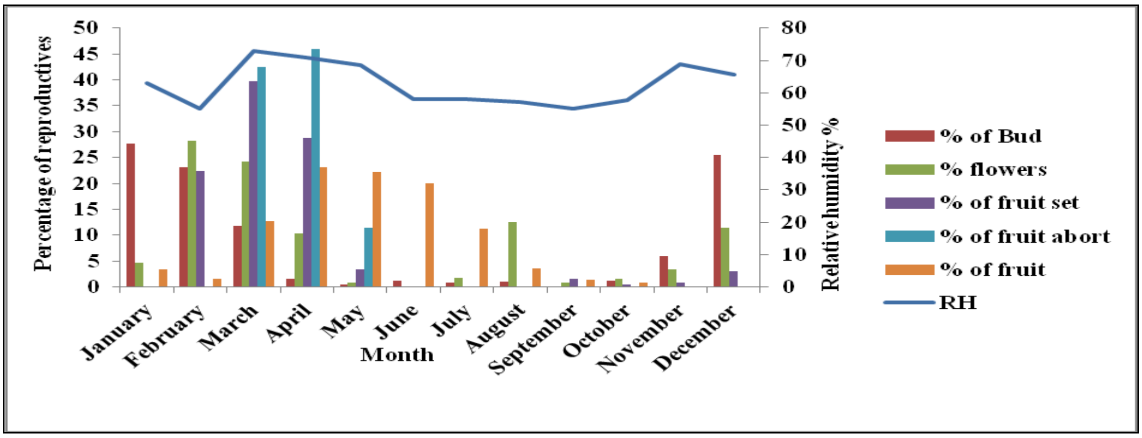


Figure 4.4b Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Rhizophora mucronata* in Nyeke forest

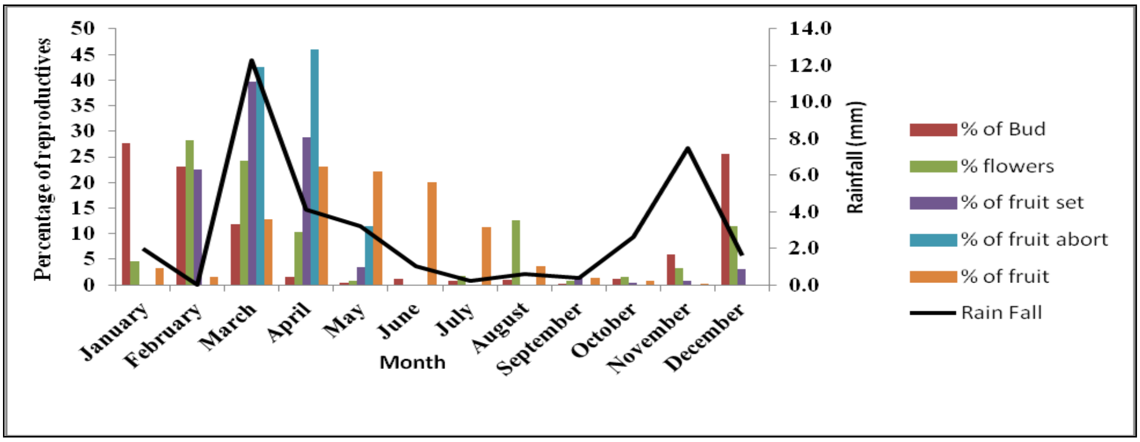


Figure 4.4c Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Rhizophora mucronata* in Nyeke forest

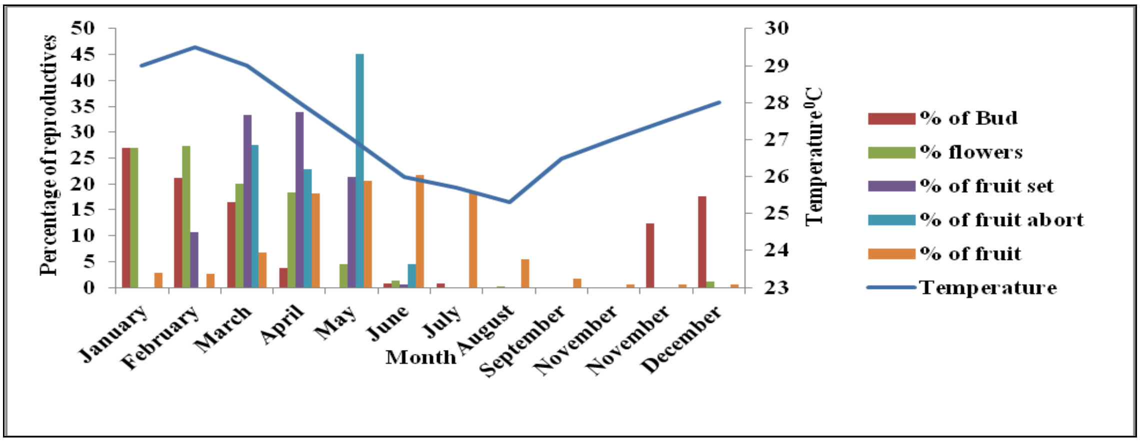


Figure 4.4d Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Rhizophora mucronata* in Michamvi forest

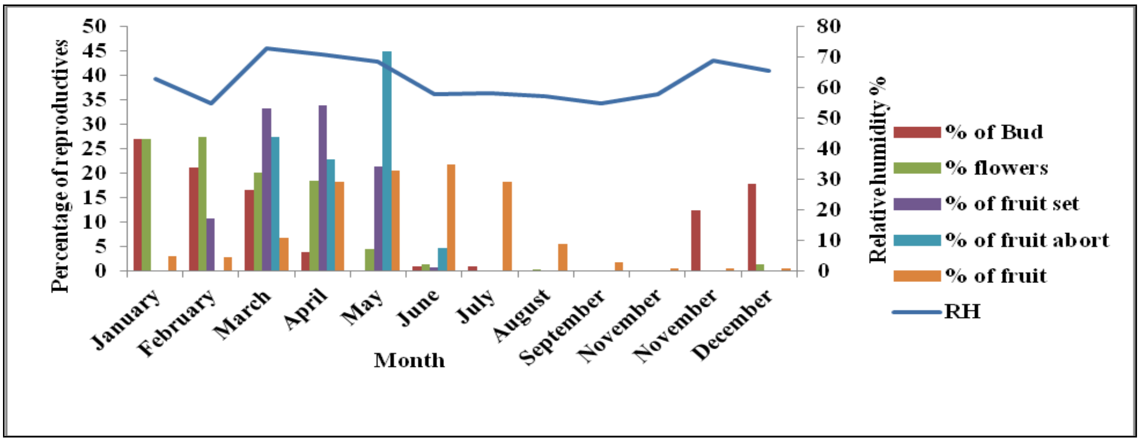


Figure 4.4e Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Rhizophora mucronata* in Michamvi forest

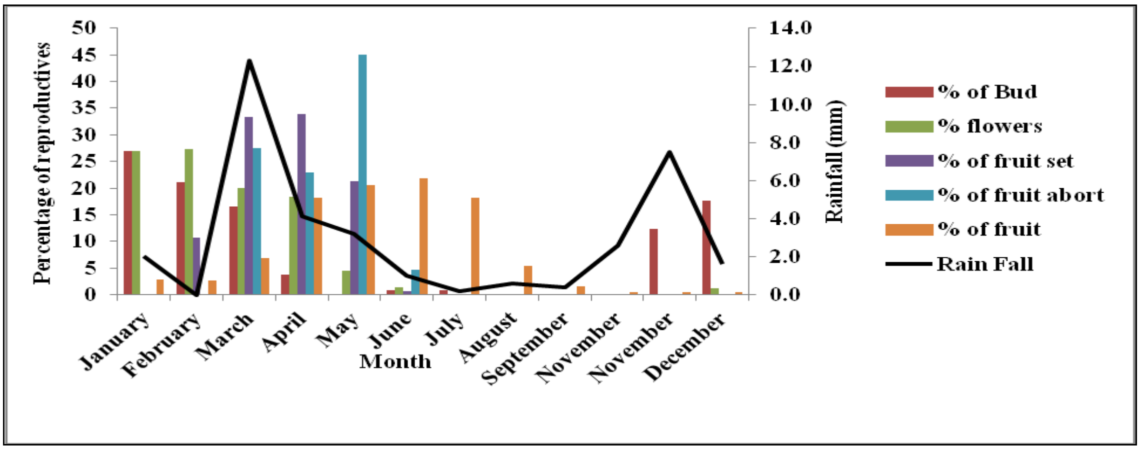


Figure 4.4f Mean monthly Rainfall and percent of buds, flowers, fruits set,fruits aborted and fruits formed by *Rhizophora mucronata* in Michamvi forest

4.4.3 Reproductive phenology of *Bruguiera gymnorrhiza*

In both sites flower buds production occurred throughout the year except during a few weeks in March andApril (Table 4.1 and 4.2). 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 respectively (Fig 4.5a to 4.5f). 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. 4.5a to 4.5f).

Flowering of *Bruguiera gymnorrhiza* occurred throughout the year, except for two weeks of April in Nyeke and four weeks in April and May in Michamvi (Table 4.1 and 4.2). Peak flowering seasons were observed during dry season in January of 27% and 22% for Nyake and Michamvi respectively (Fig. 4.5a to 4.5f). 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. 4.5a to 4.5f). 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 4.1 and 4.2). In summary, overlapping of buds, flowers, fruitset and fruits were observed in this species. 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 (Table 4.1 and 4.2). Fruits abortion were observed during dry and rainy seasons and lasting between August to December and January to May in both sites

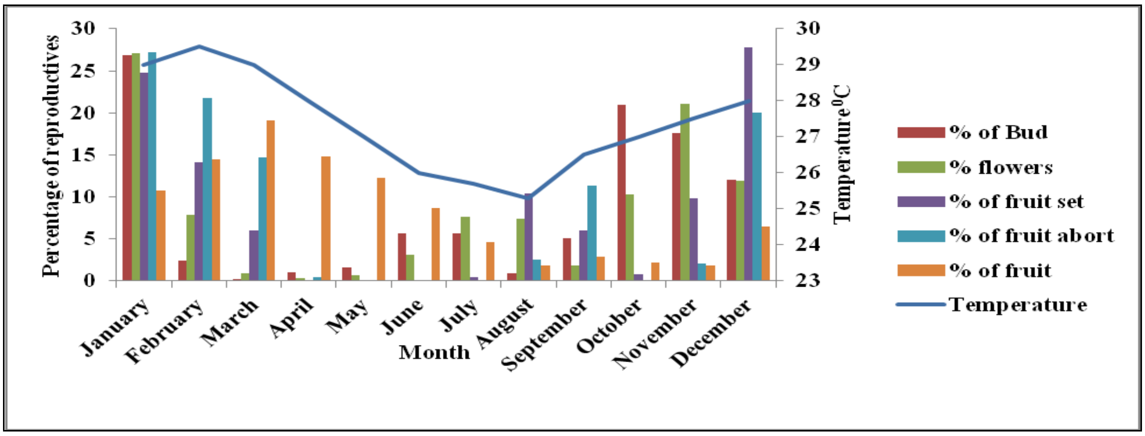


Figure 4.5a Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Bruguiera gymnorrhiza* in Nyeke forest

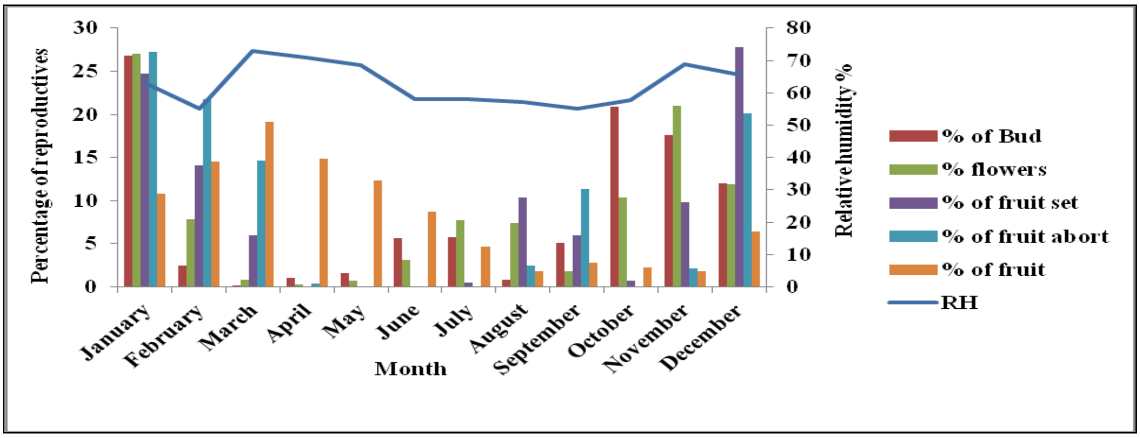


Figure 4.5b Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Bruguiera gymnorrhiza* in Nyeke forest

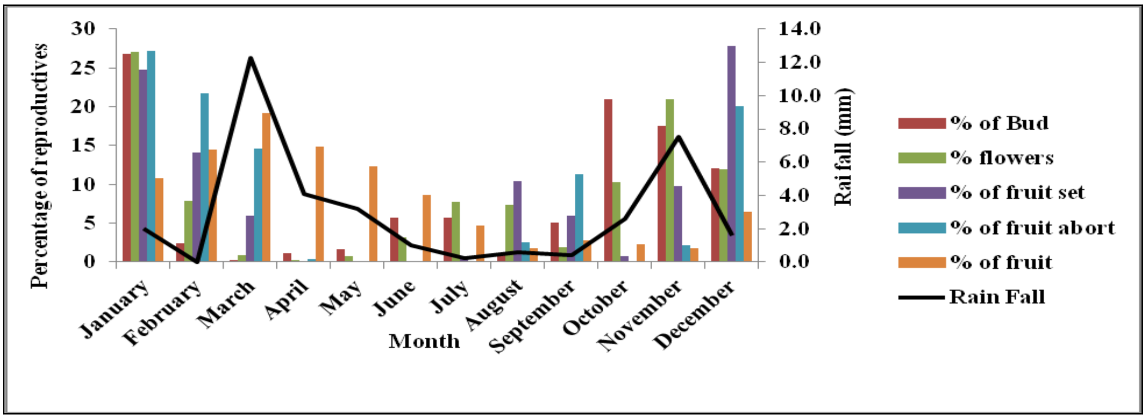


Figure 4.5c Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits of *Bruguiera gymnorrhiza* in Nyeke

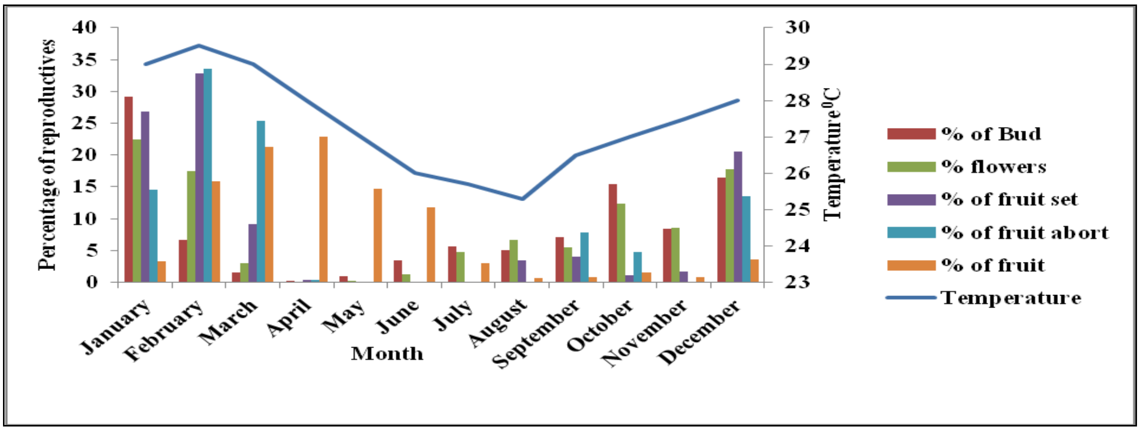


Figure 4.5d Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Bruguiera gymnorrhiza* in Michamvi forest

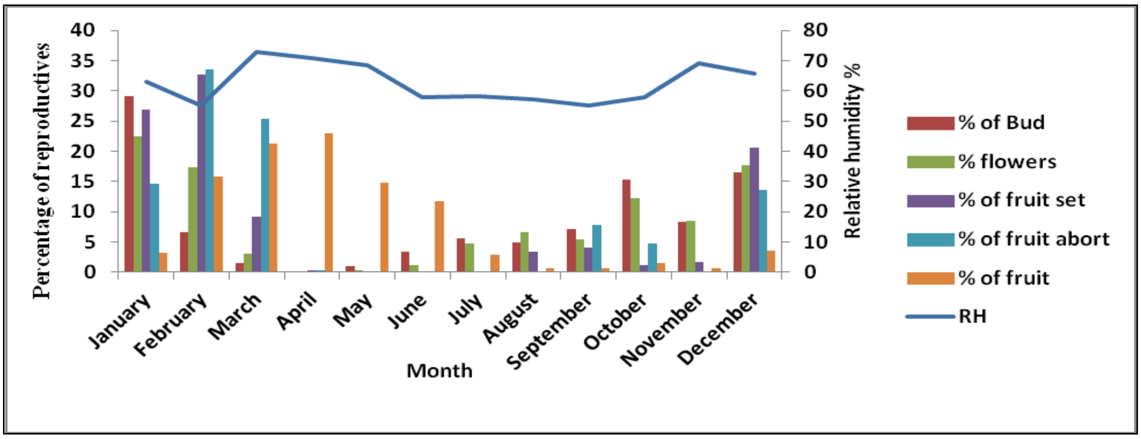


Figure 4.5e Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Bruguiera gymnorrhiza* in Michamvi forest

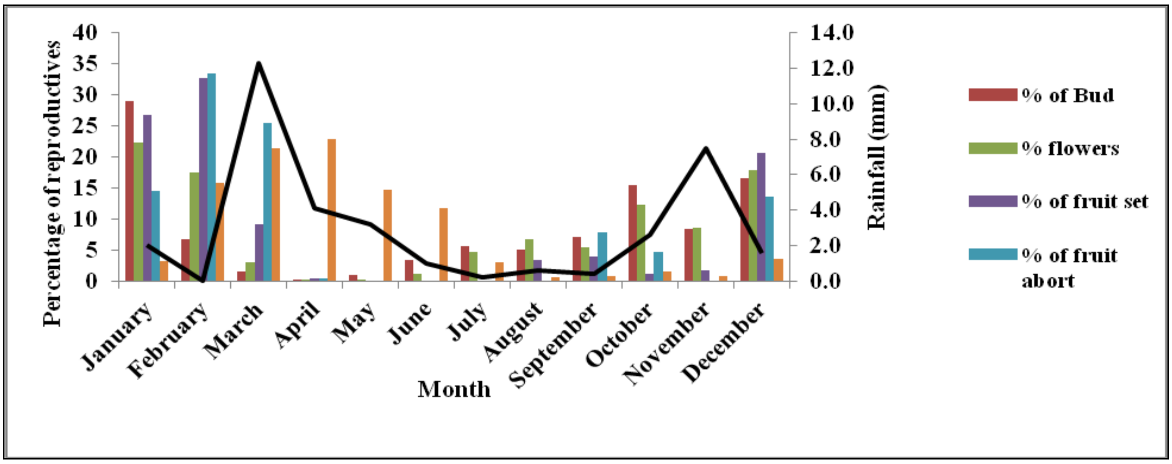


Figure 4.5f Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Bruguiera gymnorrhiza* in Michamvi forest

4.4.4 Reproductive phenology of *Ceriops tagal*

This specie showed that the flower buds production present in almost the entire year, (Table 4.1 and 4.2). Whereas the most abundant buds were produce during dry and short rainy seasons from October and January (Fig. 4.6a to 4.6f). Peak buds production occurred in January corresponding to 27% and 28% respectively. Where, the temperature, RH and rainfall recorded at 29^0C, 62% and 63mm (Fig. 4.6a to 4.6f). 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 29^0C, 73%, 390mm and lowest was 25^0C, $55^{\%}$ and 0mm. There was no relationship of buds production with RH and Rainfall but increasing temperature also increases number of buds (Fig. 4.6a to 4.6f).

Presumably *Ceriops tagal* produce flowers throughout the years in both sites, with exception of a few weeks observed in March, April and May (Table 4.1 and 4.2). Increasing Temperatures from 27^0C to 29^0C showed triggered flowering production. Peak flower production was 42% and 43% in Nyeke and Michamvi respectively, occurring during dry season (Fig. 4.6a and 4.6d). A detail of flower production in relation to RH and rainfall is illustrated (Fig. 4.6b, 4.6c, 4.6e and 4.6f).

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. 4.6a to 4.6f), 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. 4.6d to 4.6f). 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 association of RH and rainfall on fruitset. For example when RH at 73$^{\%}$ and 390mm rainfall only 4% of fruitset, (Fig. 4.6b, 4.6c, 4.6e and 4.6f).

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. 4.6a to 4.6f). There was little association observed between fruit abortion with temperature, RH and rainfall respectively. Fruits of *Ceriops tagal* are found occurring all year round (Table 4.1 and 4.2). 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. 4.6a to 4.6f). There was no association of fruit production with climatic data of temperature, RH and rainfall (Fig. 3.1 and 3.2).

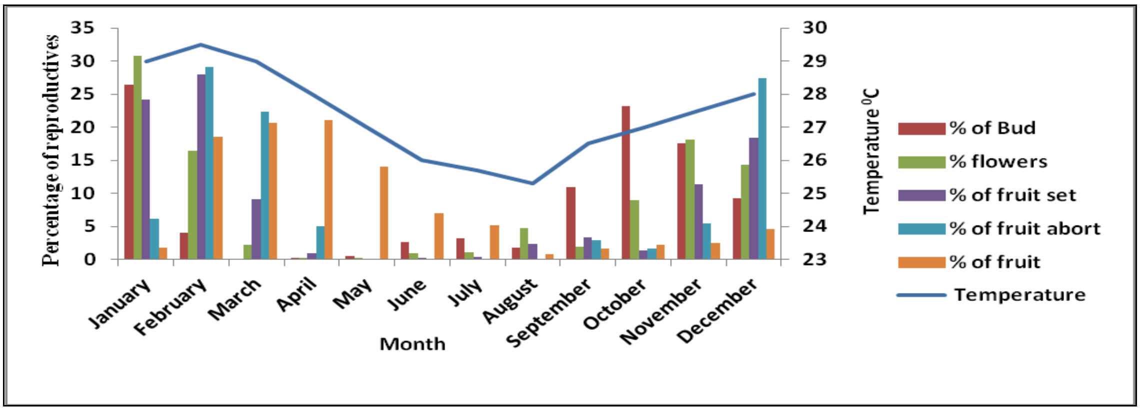


Figure 4.6a Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Ceriops tagal* in Nyeke forest

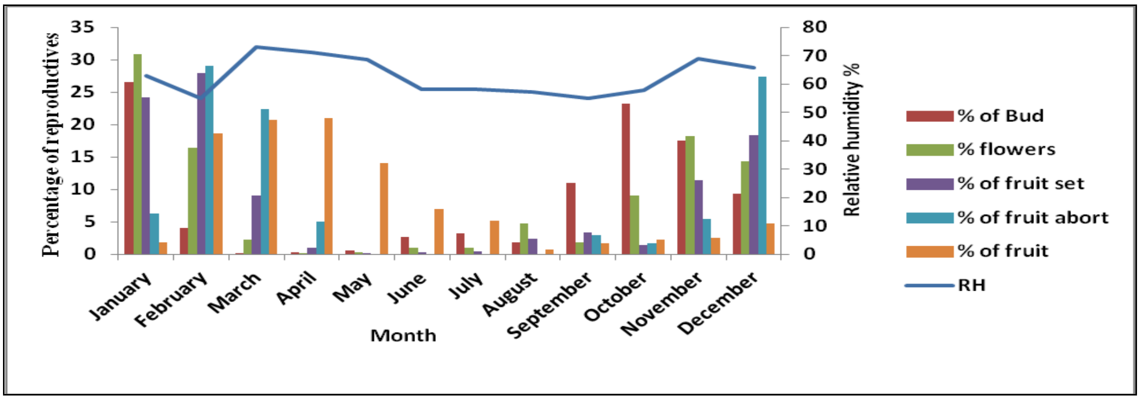


Figure 4.6b Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Ceriops tagal* in Nyeke forest

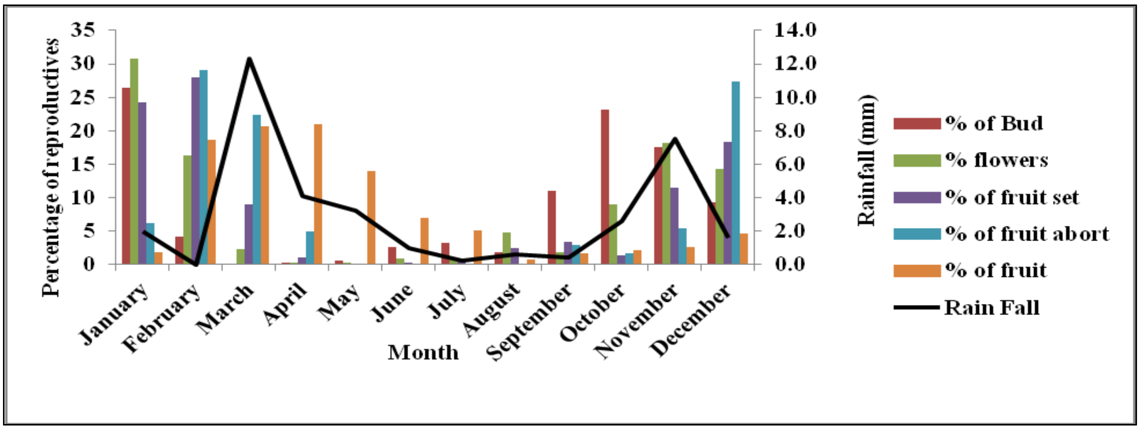


Figure 4.6c Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Ceriops tagal* in Nyeke forest

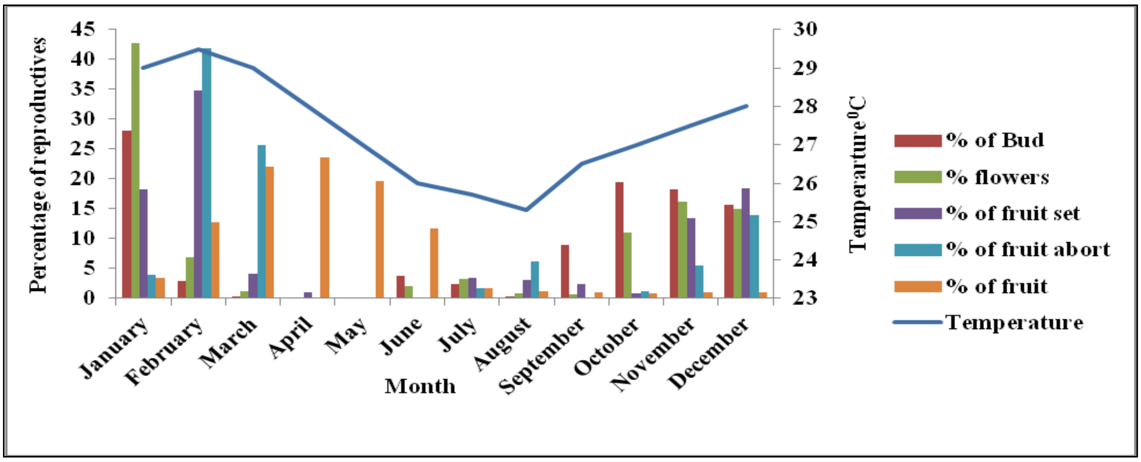


Figure 4.6d Mean monthly Temperature and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Ceriops tagal* in Michamvi forest

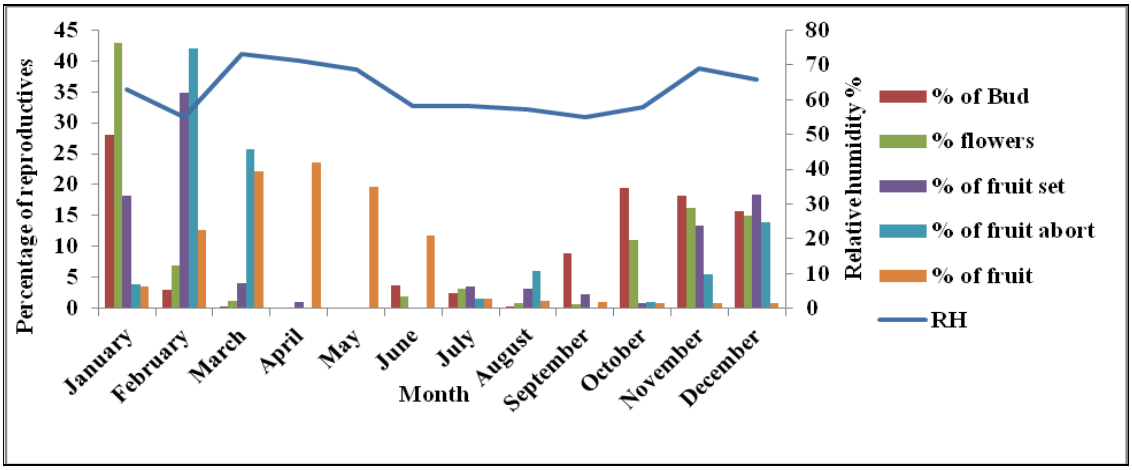


Figure 4.6e Mean monthly Relative Humidity and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Ceriops tagal* in Michamvi forest

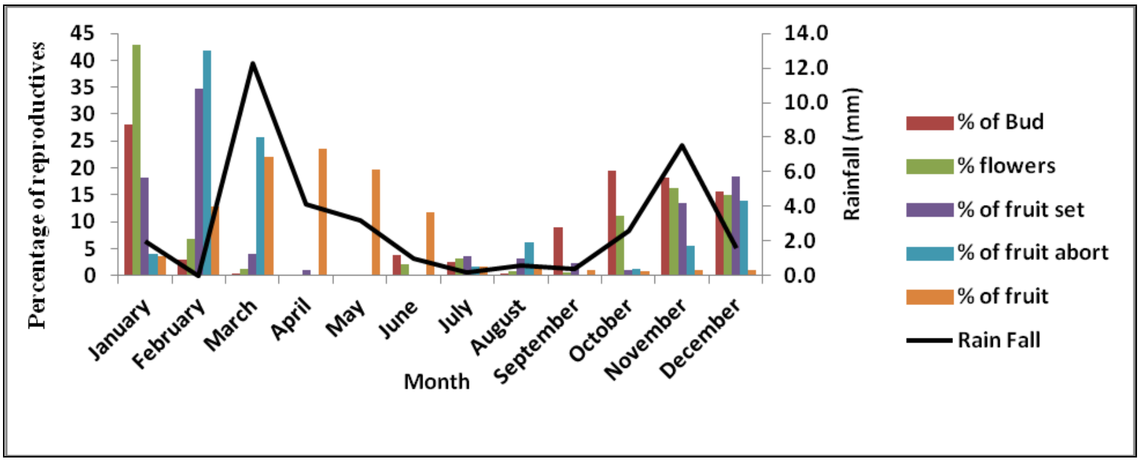


Figure 4.6f Mean monthly Rainfall and percent of buds, flowers, fruits set, fruits aborted and fruits formed by *Ceriops tagal* in Michamvi forest

4.5 Discussion

The peak periods for budding, flowering, fruitset, fruit abortion and fruiting was not the same in the two study sites and among mangroves species. Temperature was observed 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 (Rivera and Borchert, 2001; Borchert *et al.*, 2005; Bendix *et al.*, 2006). Variation of flowering in mangroves could be due to biotic and abiotic factors such as rain, soil, temperature, sun light and Humidity (FAO, 2004). However, this is not always the case. It has been 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 (Sånchez-Nůńez and Mancera-Pineda, 2011). 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 during high rainfall, however it is not correlated with environmental factors (Fernandes, 1999). Studies on the phenology of *Avicennia marina* conducted in many mangroves growing areas of the world have shown that, its reproductive cycle differs between regions (Wium-Andersen and Christensen, 1978; Duke, 1990; Hegazy, 1998; Coupland *et al.*, 2005). Weather is believed to play an important role in triggering phenological patterns in tropical forests (Lieberman, 1982). According to Wium-Andersen and Christensen, (1978) phenological patterns of mangroves are also affected by groundwater salinity and environmental conditions. They further found that , phenology of *Bruguiera cylindrical*, *Ceriops tagal*, *Lumnizera littorea* and *A. marina*, the *A. marina* have been found to have a distinct flowering periods than other species, which were found to flower throughout the year.

Results of this study show that *Avicennia marina* reproductive pattern in Zanzibar differed slightly between the two study sites. Peak flower buds of *Avicennia marina* was observed from October to December in both sites. This observation does not agree with that of Wang'ondu *et al.* (2013) who reported that the peak period for buds production in the Gazi bay of Kenya is December to January. Weather and soil variation is mentioned in many studies to influence reproductive pattern of mangrove and crops (Wilson and Saintilan 2012). Hernández-Trejo *et al.* (2006) insists that clay sandy texture that is rich in organic matter favours the best development of mangroves. It has been observed that *Avicennia marina* reproductive cycle, from buds to mature fruits take 6 months. This result concurs with the results of Ochieng and Erftemeijer, (2002) and Coupland *et al.*, (2005). Flower production pattern of *A. marina* lasted for 4 months in both Nyeke and Michamvi. However, at Michamvi flowering period was longer by two weeks (Table 3 and 4).

Mangrove flowers production seasons varied between sites and species (Wang'ondu *et al.,* 2013). Significant differences in buds, flowers and fruits can result due to differences in temperature (Ochieng and Erftemeijer, 2002; Coupland *et al.*, 2005), salinity, light penetration (Wium-Andersen and Christensen, 1978), soil texture and latitude (Hernández *et al.*, 2011; Dahdouh-Guebas *et al.*, 2004, 2007). However, Duke (1990) found that the peaked flowering in *A. marina* was recorded in the dry season and is not associated with a localized influence of seasonal rainfall, evaporation, salinity, nutrients, but rather with other factors such as day-length and temperature. The study have shows that, temperature influences buds, flowers and fruit production in the four mangroves species, this findings agree with those of Coupland *et al.* (2005). One interesting observation in the current study is that fruit set of *A. marina* was found higher percentage of fruits aborted (64%) compared to other species.

Rhizophora mucronata showed similar phonological trends with *Bruguiera gymnorrhiza* and *Ceriops tagal*. All the three species were found to produce flower buds, flowers and fruits throughout the year. Further, buds, flowers and fruit productions period overlapped within the year. This indicated that, regeneration and pollination takes place throughout the year; however the peaks periods and duration showed defference between sites and species. Temperature variations seemed to influence flower buds, flowers and fruit production in the two study sites. Peak seasons of flower buds, flowers and fruit production in *Rhizophora mucronata Bruguiera gymnorrhiza* and *Ceriops tagal* occurred during dry season, when average temperatures recorded was between 28^0C and 30^0C. There was no association between rainfall and Relative Humidity on one hand and flower buds, flowers and fruit production on the other, since peaks periods occured during high and low rainfall and RH. The findings concur with those obtained in other studies. It has been reported that the peak fruiting pattern of *Ceriops erectus* occur in dry season and is positively related to temperature and negatively related to rainfall (Nadia *et al.*, 2012). However, the study by Tyagi (2004), on family *Rhizophoraceae* reported that there is significant variation on flowering pattern in the wet and dry seasone of low precipitation. The findings of this study have been observed that, rainfall and RH did not influenced phenology of four mangroves. On the other hand, flowering pattern of *Avicennia schaueriana* in Northern Brazil is strongly influenced by variation in rainfall and day length (Fernandes, 1999).

Many studies on mangroves phenology reported that the there is continuous flowering pattern and peak seasons (Mehlig, 2006; Gill and Tomlinson, 1971). 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 (FAO, 2004).

This study revealed existing variation of fruit set between species and sites. The peak fruit set showed differences between species and sites. Flower morphology and maturity variation has been found to influence pollination visitation rate and fruit sets in mangroves of family *Rhizophoraceae* (Tomlionson, 1979). Air temperature, day length and rainfall were reported to control reproduction of *B. gymnorrhiza* (Kamruzzaman *et al.*, 2013). The study conducted by Feller (1995), 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. In the current study, it was observed that, the influence of temperatures affected buds, flowers and fruit production in the four mangroves.

The present study found that not all flower buds developed into fruits in four mangroves species studied. In *A.marina* about 26% developed into fruitset but half of these aborted, *R.mucronata* only 40% of flower buds set fruit and half reached fruit stage, *B. gymnorrhiza* estimated 30% of flower buds set fruits and *C. tagal* estimated 30% flower buds set fruits. Not all developed fruits grew and reached maturity, some of fruit drooped down (aborted). Intensive study this area required to determine how many of fruits falloff before full maturity. It is important to estimate the number of fruits consumed by crabs and how many germinate to seedlings. Collectively, this research study has added knowledge that could be used for management, developing or review of policy and strategic plan in mangroves biodiversity conservation in Zanzibar.

CHAPTER FIVE: POLLINATION AND REPRODUCTIVE RELATIONSHIP OF FOUR MANGROVES SPECIES

5.1 Introduction

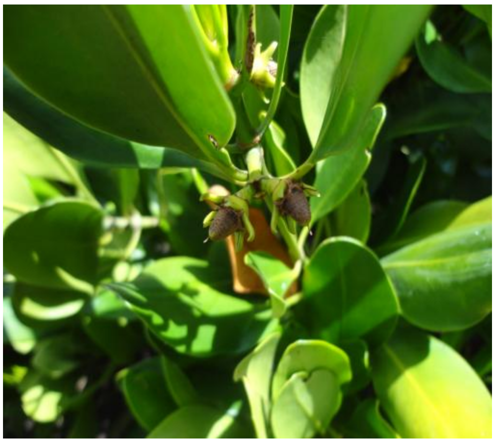
The importance of pollination and pollinators in fruit and seed production in many plants and trees has been reported in many studies. However, some studies have indicated that pollinators may actually lower reproduction by the plant due to removal of large amounts of pollen from flowers or even by depositing very little pollen (Thomson and Thomson, 1992; Franzen and Larsson, 2009; Harggreaves *et al.,* 2009). A study by Aluri (2013), found that in *Ceriops tagal*, the stigma attains receptivity on the second day and remains receptive up to 6 days but, peak receptivity occurs in 3rd -5th day. The study also reported that there was increased insect flower foraging during the peak receptivity period, when nectar sugar concentration was 35-50%. The common sugars include fructose, sucrose and dextrose with the first being relatively more dominant.

Flowers are generally visited by pollinators repeatedly over the course of a day. The visitors belong to various species of insects that seem to be effective pollinators and that are generalist floral foragers (Holt *et al.,* 2014). The success of pollination is primarily determined by visitation rates (Totland, 1993; Sahli and Conner, 2007). However, pollinators have considerable spatial and temporal variation in their visitation rates to a single plant species (Traveset and Saez, 1997; Fenster and Dudash, 2001; Ivey *et al.,* 2003). Thus, pollinator communities differ in their visitation rate and in the effectiveness of each taxon at transferring pollen (Armbruster *et al.,* 1989; Fishbein and Venable, 1996).

Further, trees may control the behavior of pollinators by adjusting floral design and exhibit flowering to maximize pollination efficiency. The foregoing dynamics may influence the net fruit production for a given plant species. This study was designed to investigate relationship between the number of pollinators and the number of flowers, fruits set and fruits produced of four mangroves species in Nyeke and Michamvi mangrove forests.

Plates 5.1 Flag showed selected tree

Plates 5.2 Flower buds of *Rhizophora mucronata*



Plates 5.4 Fruits on *Avicennia marina* tree Plates

5.3 Fruit set on *Ceriops tagal* tree

Plates 5.6 Apis melifera visit on flower of *Bruguiera*

Plate 5.5 Flowers and buds of *Ceriops tagal*

5.2 Materials and Methods

The study was conducted in two mangroves forests, Nyeke and Michamvi, located in the southern region of Zanzibar. At each study site, 80 trees belonging to four mangroves species namely *Rhizophora mucronata, Bruguiera gymnorhiza, Ceriops tagal* and *Avicennia marina* were selected. The distance between the trees was approximately 25m. Red flags were placed on top of all selected trees for ease identification of the selected plots during data collection (Plate 5.1). A branch free from pest and diseases was randomly selected from each tree. The selected branches were tagged with permanent labels that indicated the plant species and date the tree was tagged. All selected branches were 1.5m from the ground to avoid being destroyed by sea water during high tides. Petroleum jelly was smeared on the woody part to deter invertebrates from walking or crawling into the flowers and fruits.

To take care of the flowering alternation within the same tree, another branch was selected and observed. Observations were carried out twice a week in every month for a period of 9 months (July 2013 to March 2014). The data collected included the numbers of buds, flowers, insect flower visitors, visits, fruits set and fruits (Plate 5.2-5.6). To avoid double count permanent white marker and tagged labels were placed on buds, flowers and fruits. For each treatment flower visitors and visitation frequency were counted from 30 selected flowers for 30 minute period on selected branches of mangrove trees. Thereafter, all insect visitors and visit frequency for the four mangroves spp were recorded. This exercise was carried out during peak flowering period (from the day a bud was produced to the time fruit was produced) for each mangrove species. Observation of insect visitors was done between 06.00 and10.00am. Visitation rates of insect pollinator were determined by counting the number of insect visits to flowers. A visit was defined as the landing of flying insects on the selected flowers. All visits were counted, regardless of whether they were by the same insect or by different insects. A visitor was defined as an individual insect that visited a flower. Even if an insect visited many flowers it was recorded as one visitor. Fruit set was defined as the conversion of a flower to a fruit initiation which indicates successful fertilization. Observations were done by three trained technicians.

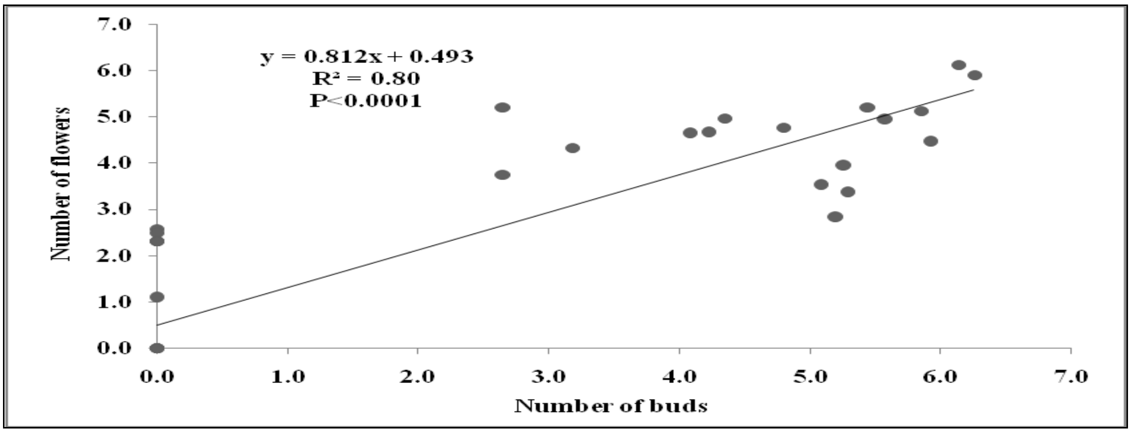
5.3 Data analysis

All study parameters (the numbers buds, flowers, insect visitors, visits, fruits set and fruits formed) were compared with each other using Linear Regression Analysis. Significance of the Regression Coefficient was done using F-Statistics. Coefficient of determination, R^2, was used to determine the strength of the linear association between x and y (explanatory and response variables respectively). The data was log transformed ($1 + \log_{10} x$ (LN)) for because the y-variables were not normaly distributed. Regression categories for the Regression for R^2 are: (a) 0.6 to 1 is very strong relationship, (b) 0.3 to 0.59 is strong relationship, (c) 0.1 to 0.29 is very weak relationship, (d) if R^2 is zero (nonlinear) shows no relationship between two variables. All data were analyzed using the statistical software R version 2014 Mac OS X 10.5 (pr. March 2014 this is version 3.0.3), R Commander of library ('RcmdrPlugin.NMBU') of University of Life Sciences, Norway. Significant difference was tested at P< 0.05.

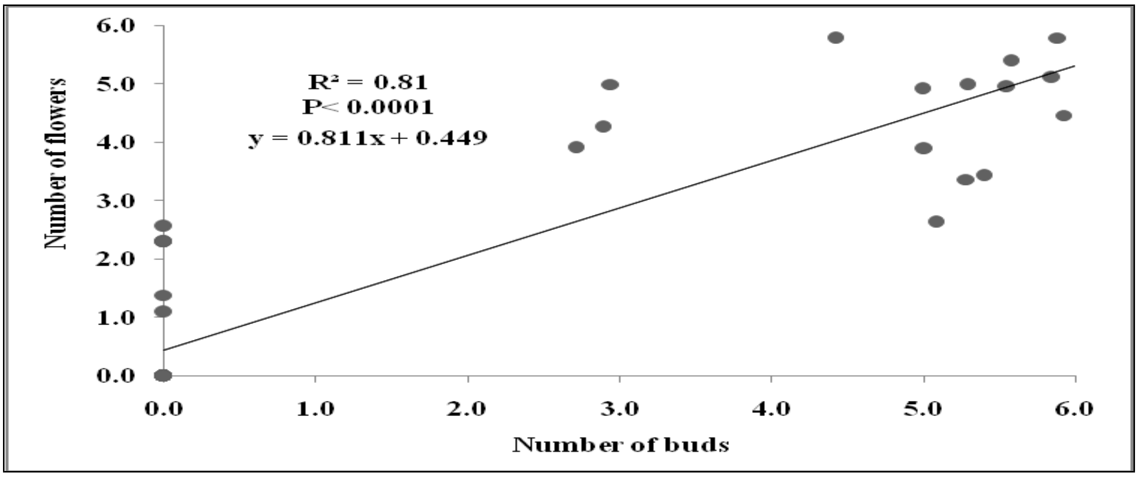
5.4 Results

5.4.1 Relationship between number of buds and number of flowers

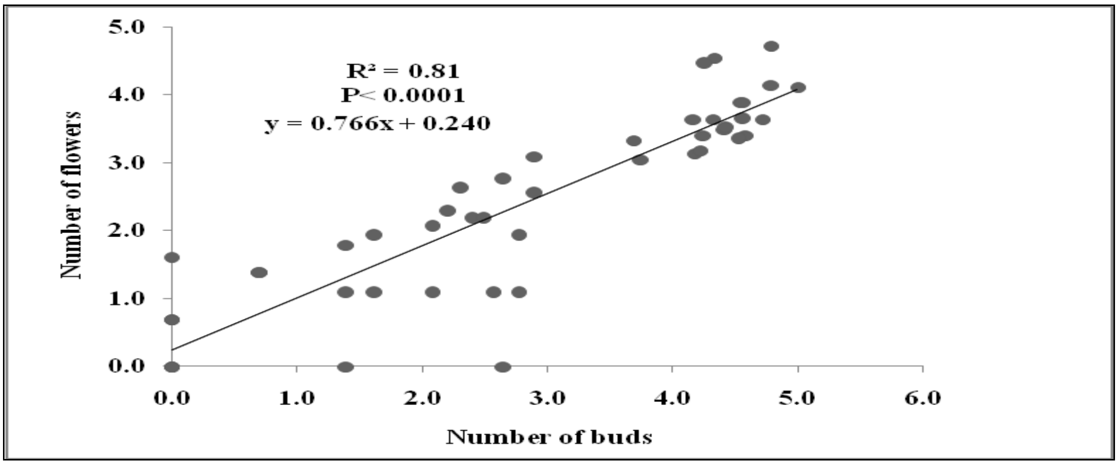
Results on the regression of number of flowers against the number of buds are shown in Figures 5.1a-5.1h. Generally, there was a positive relationship between number of bud and number of flowers. The least relationship was recorded in *Rhizophora mucranata*., Generally, the relationship was less strong in Nyeke than in Michamvi.



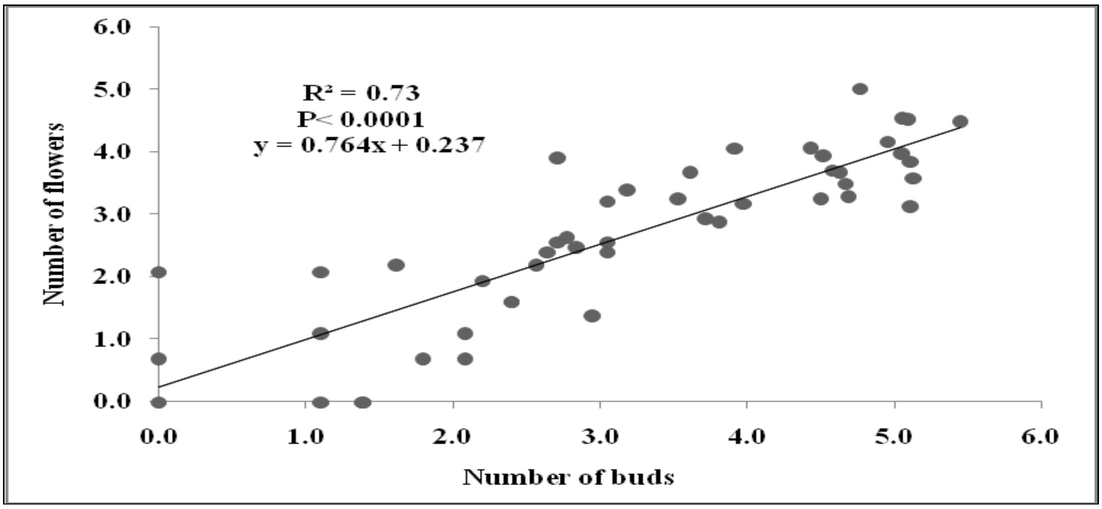
Avicennia marina, Michamvi.



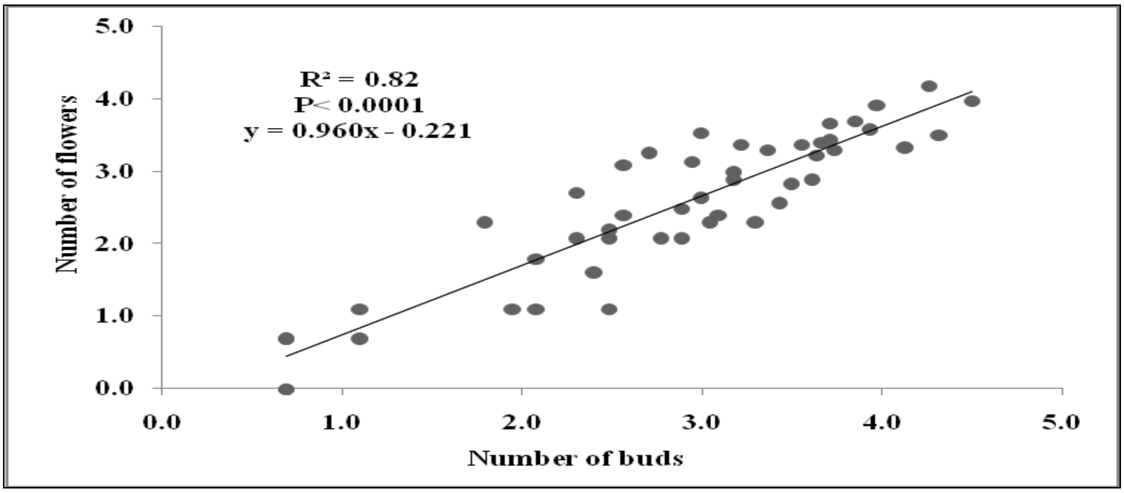
(b) *Avicennia marina*, Nyeke



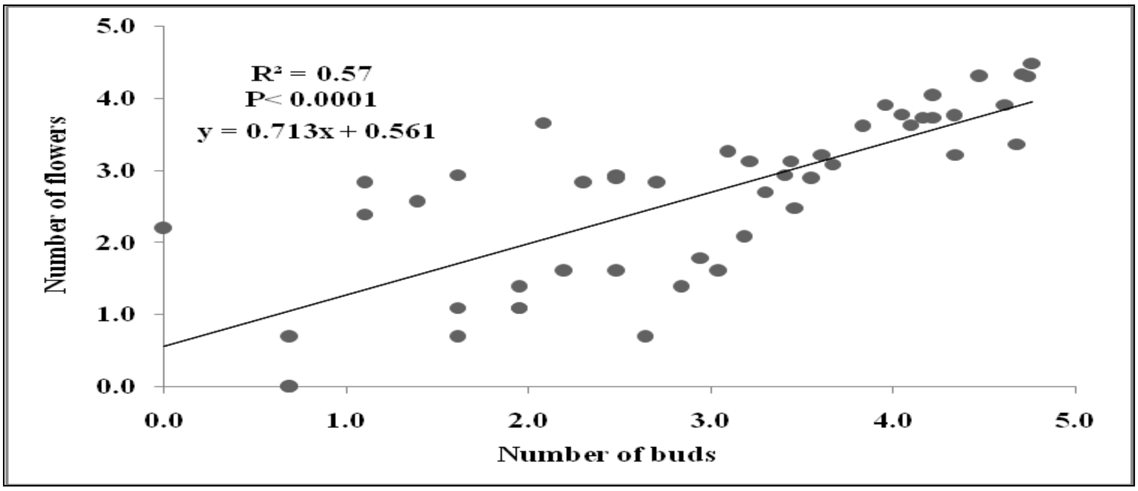
(c) *Ceriops tagal*, Michamvi



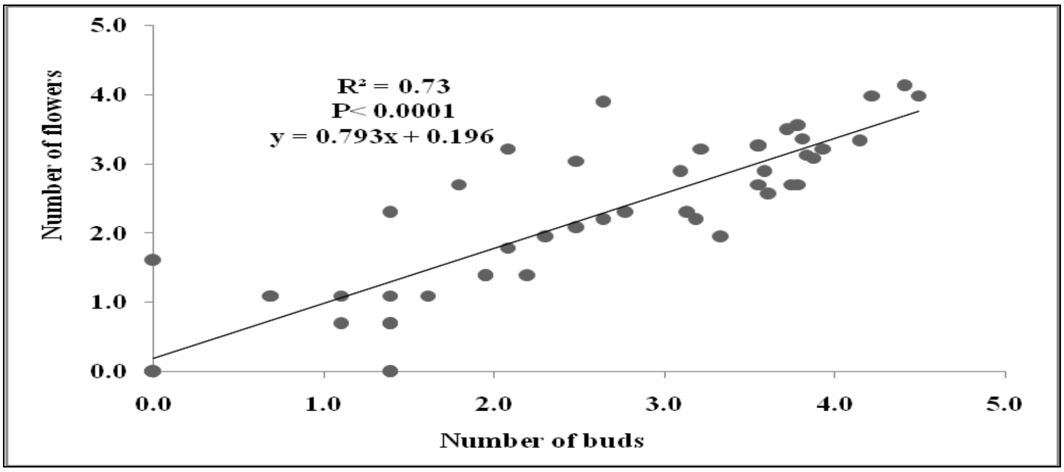
(d) *Ceriops tagal*, Nyeke



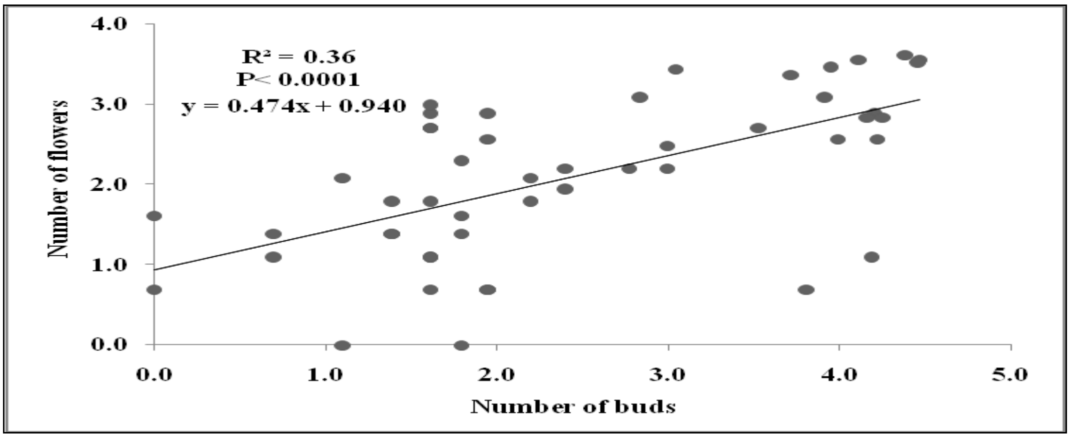
(e) *Bruguiera gymnorrhiza*, Michamvi



(f) *Bruguiera gymnorrhiza*, Nyeke



(g) *Rhizophora mucranata*, Michamvi

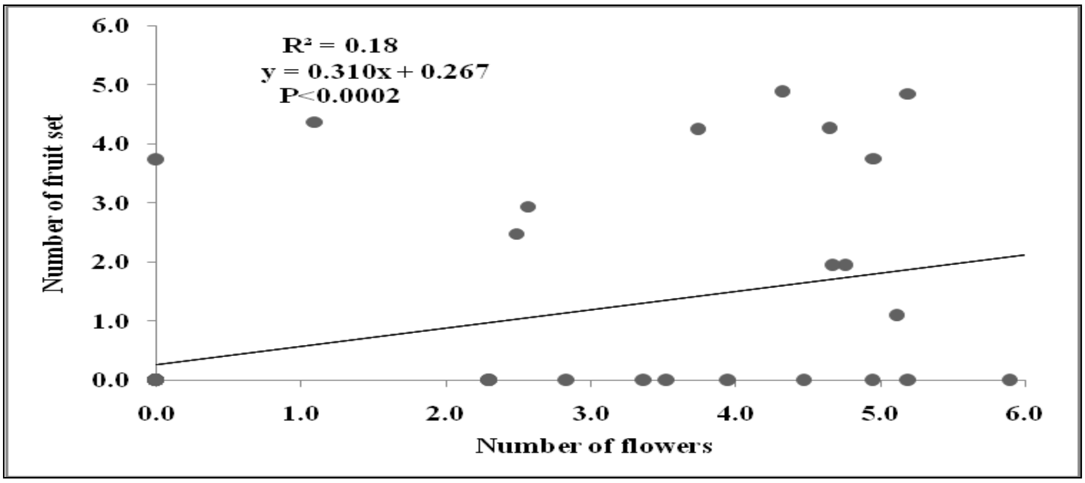


(h) *Rhizophora mucranata*, Nyeke

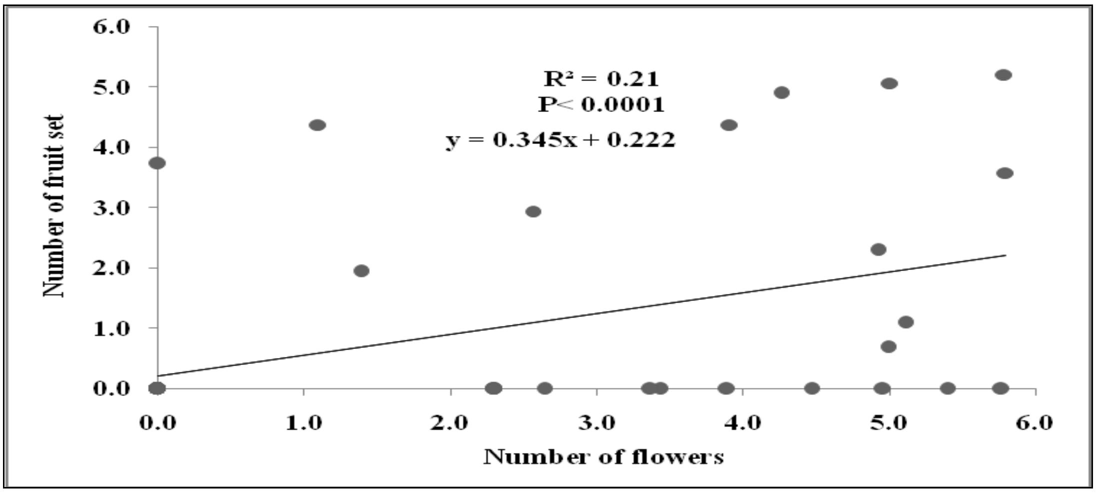
2 Figure 5.1 (a-h): Relationship between number of buds and number of flowers at Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.4.2 Relationship between number of flowers and number of fruit set

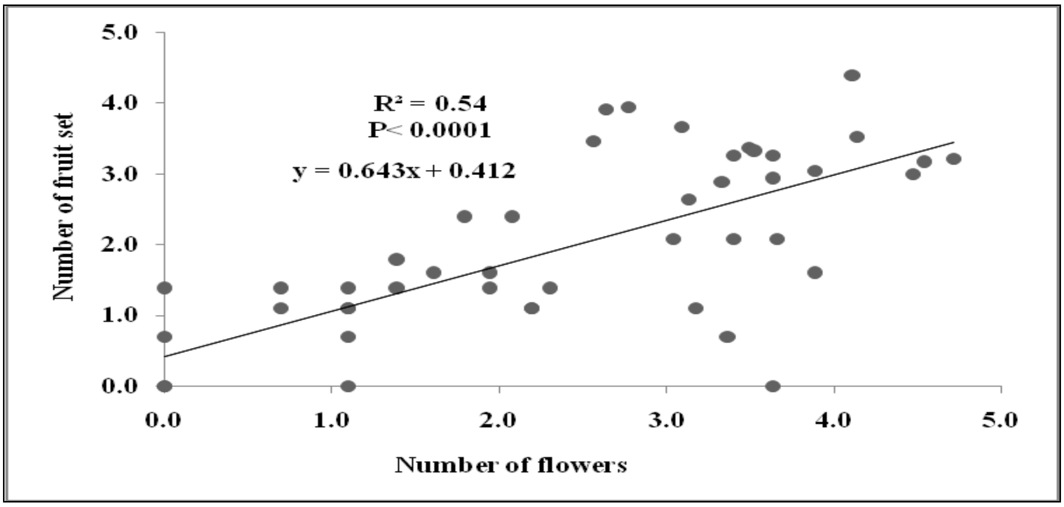
The relationship between number of flowers and fruits is shown in Figures 5.2a-5.2h. In general there was a positive relationship between number of flowers and number of fruits set. However, the relationship between the two variables was very weak in *A. marina* in both study sites: at Michamvi (df =47, R^2=0.18, P= 0.0002,F=10.52) (Fig. 4.2a); Nyeke (df=46, R^2 = 0.21, P< 0.0001, F=12.28)(Fig. 5.2b).



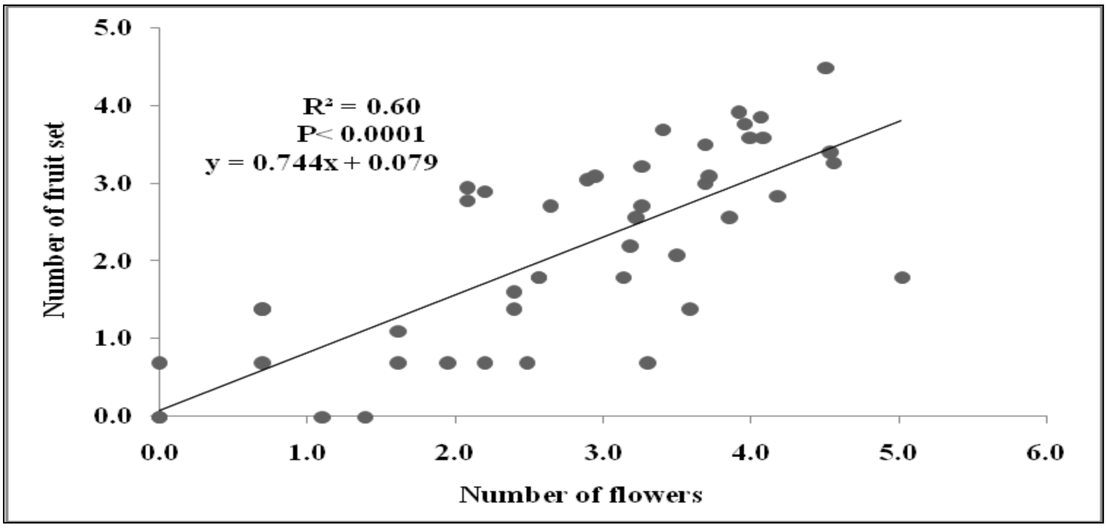
(a)*Avicennia marina*, Michamvi



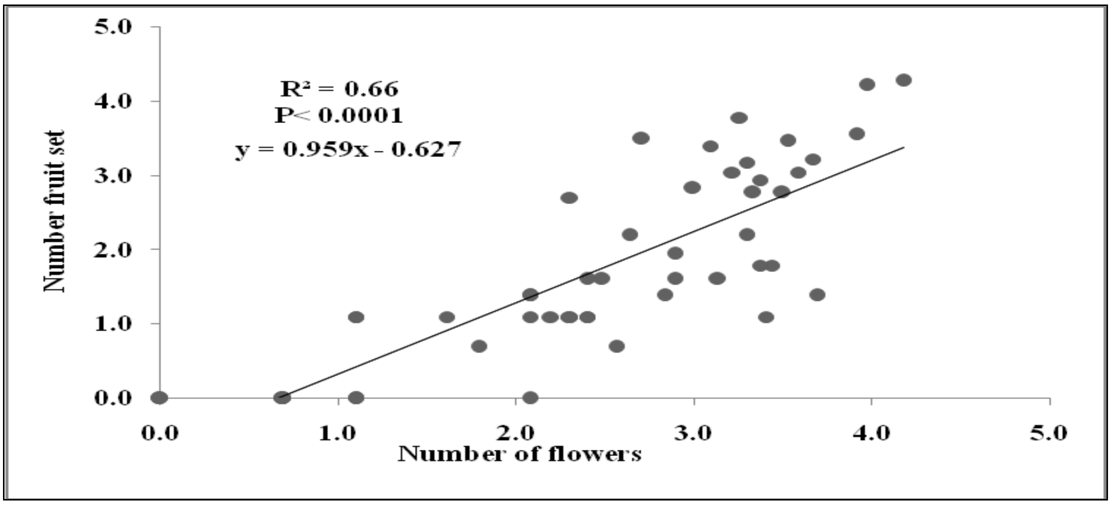
(b) *Avicennia marina*, Nyeke



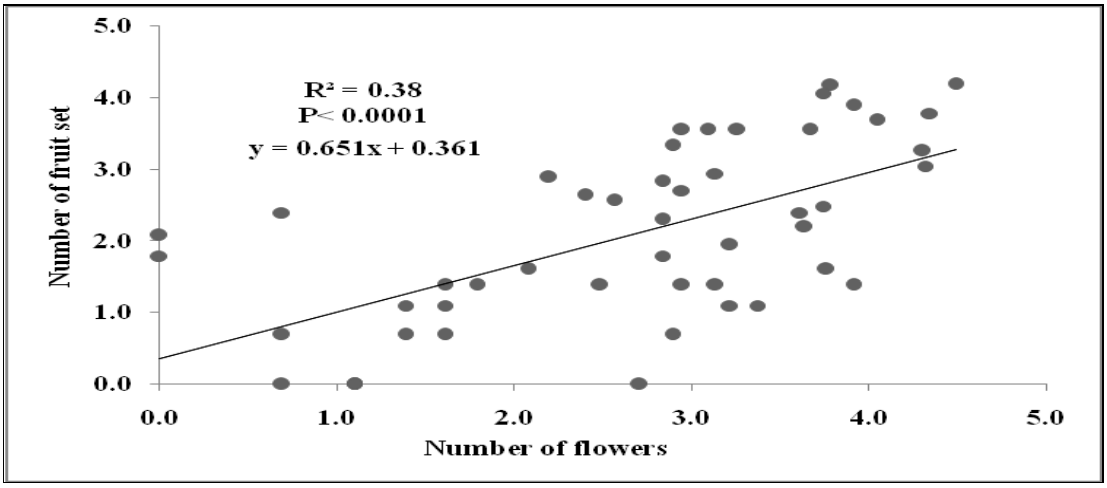
(c) *Ceriops tagal*, Michamvi



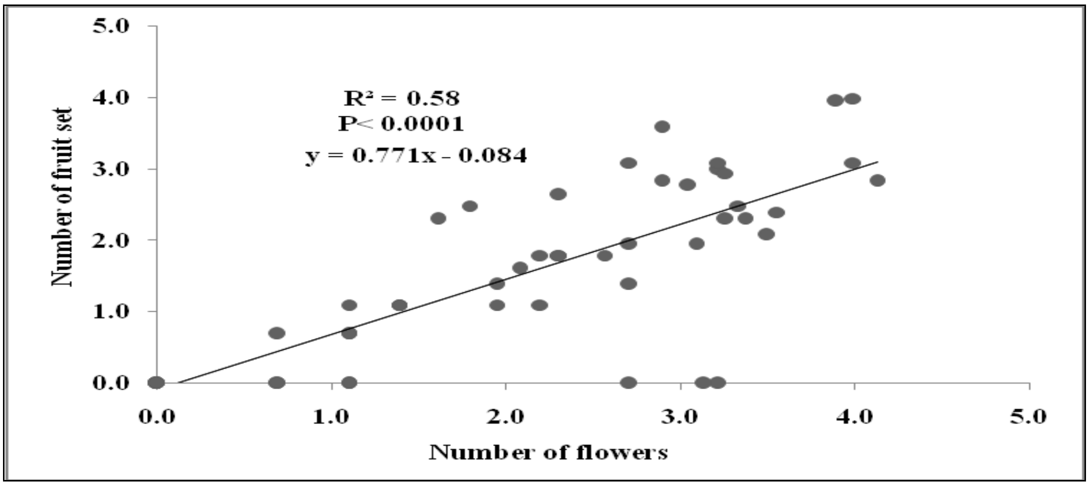
(d)*Ceriops tagal*, Nyeke



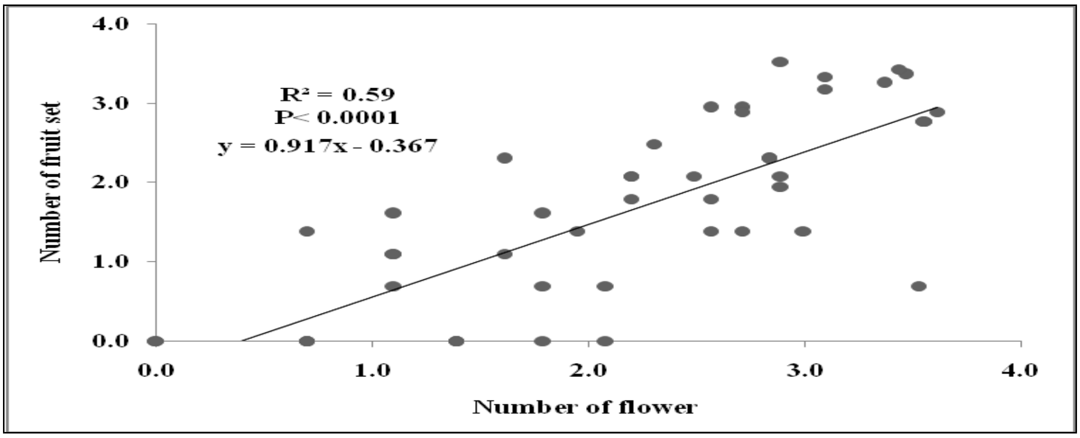
(e)*Bruguiera gymnorrhiza*, Michamvi



(f) *Bruguiera gymnorrhiza*, Nyeke



(g) *Rhizophora mucranata*, Michamvi

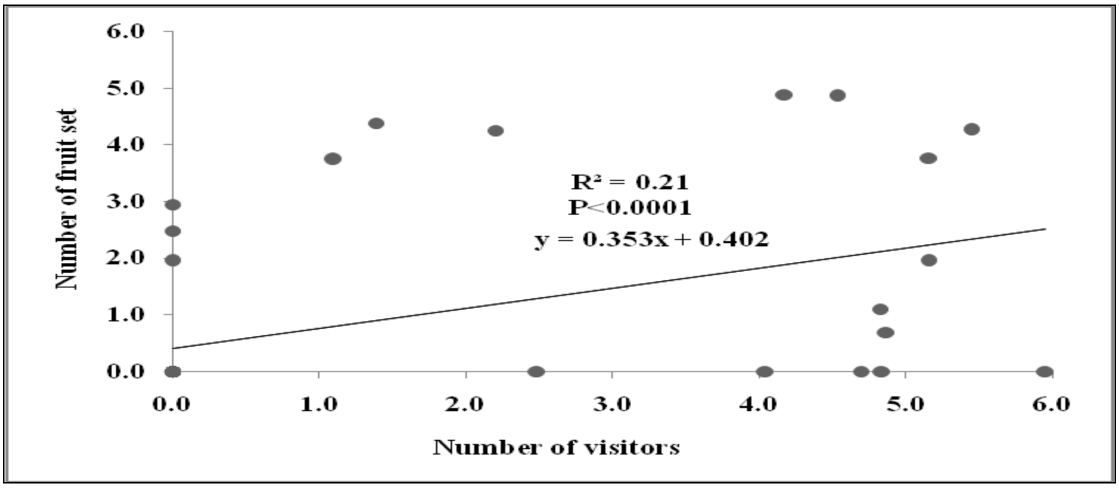


(h) *Rhizophora mucranata*, Nyeke

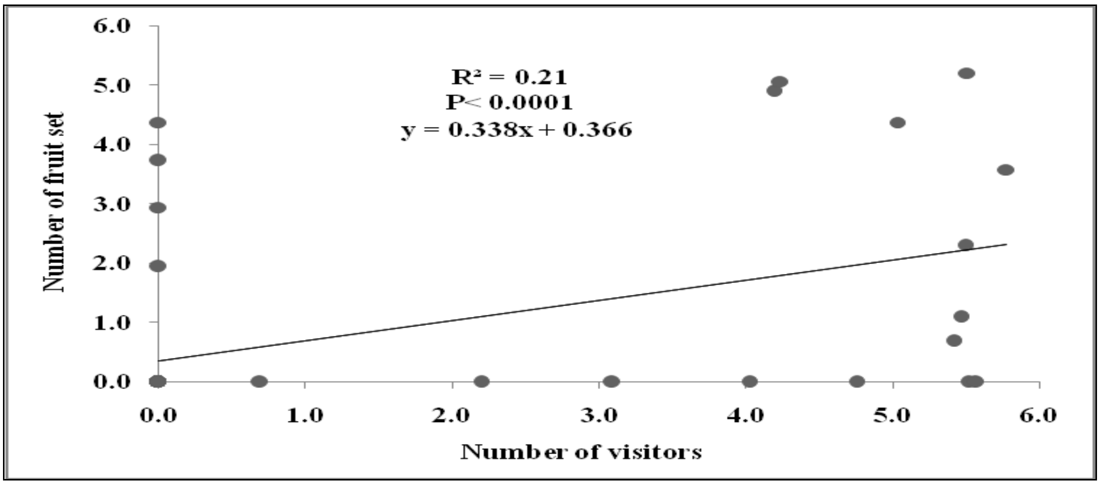
Figures 5.2 (a – h): Relationship between number of flowers and number of fruits set, at Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.4.3 Relationship between number of flower visitors and number of fruit set

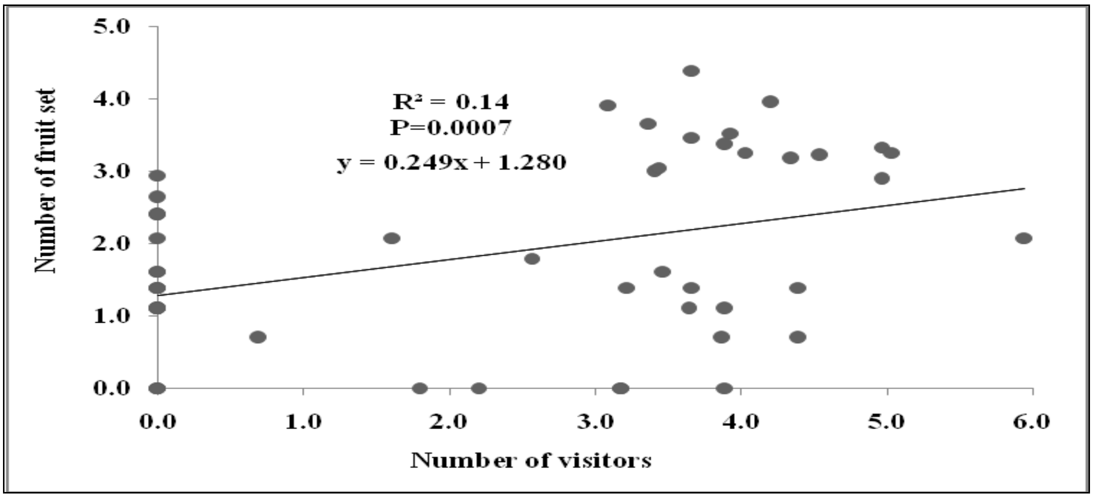
Relationship between number of fruits set and number of visitors was generally very weak with R^2 ranging from 0.11 to 0.28 (Fig. 5.3a-5.3h). Further, the relationship between the number of flower visitors and number of fruits set varied among mangrove species.



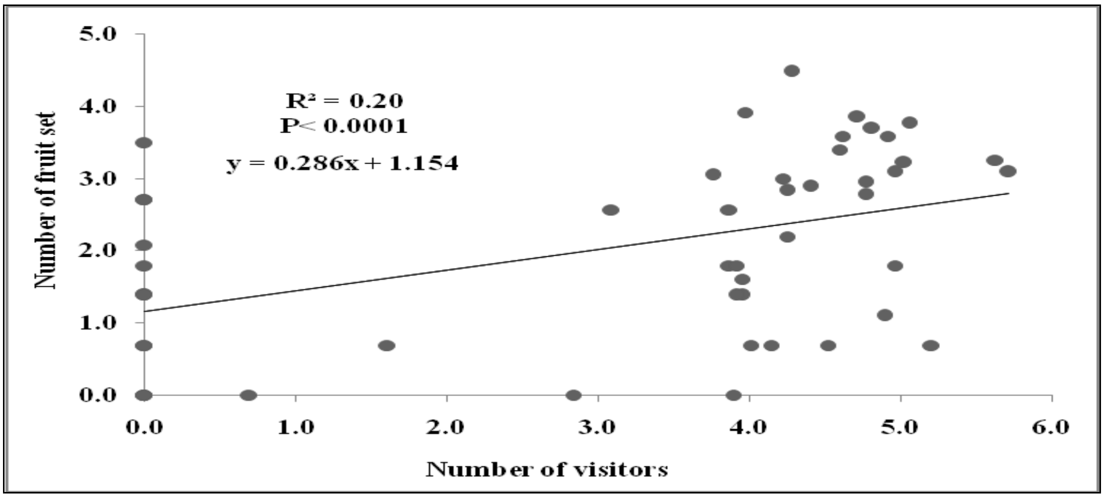
(a) *Avicennia marina*, Michamvi



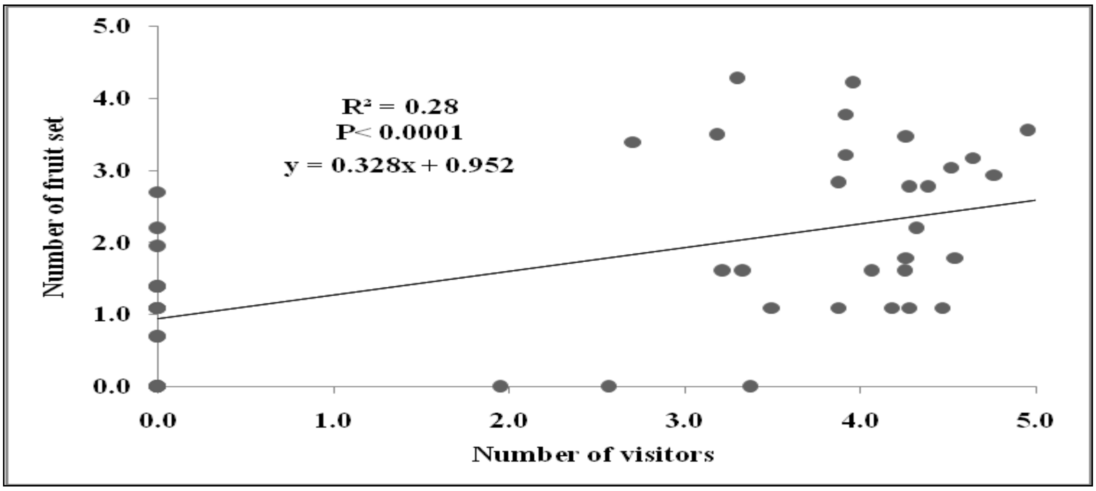
(b) *Avicennia marina*, Nyeke



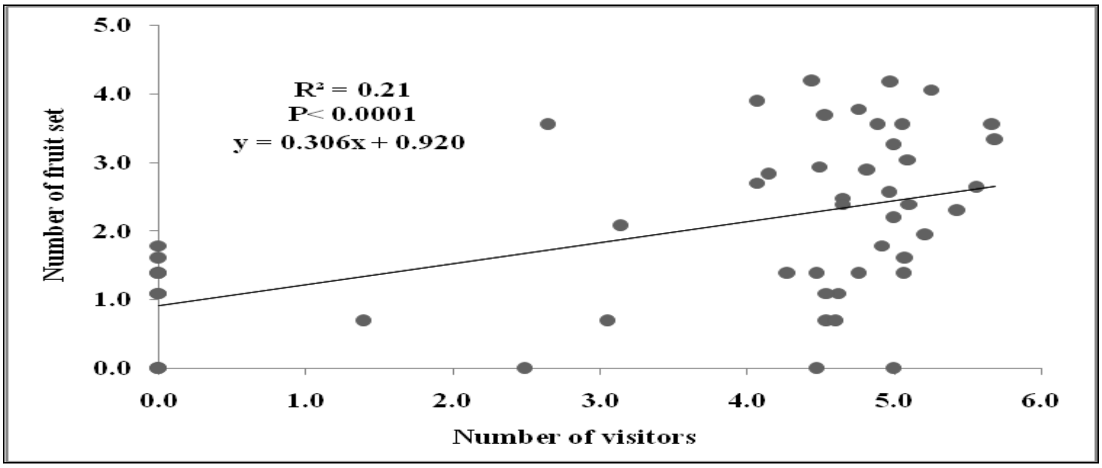
(c) *Ceriops tagal*, Michamvi



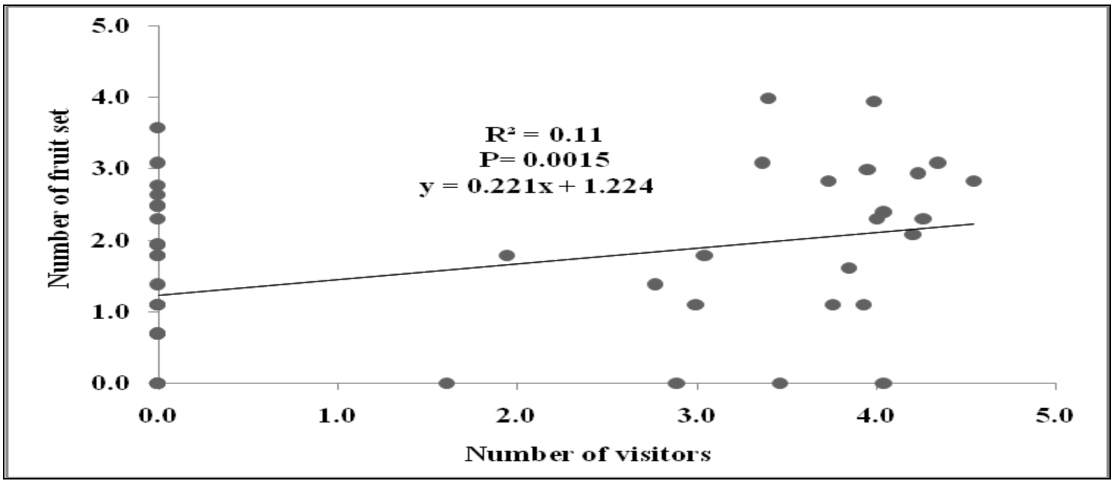
(d) *Ceriops tagal*, Nyeke



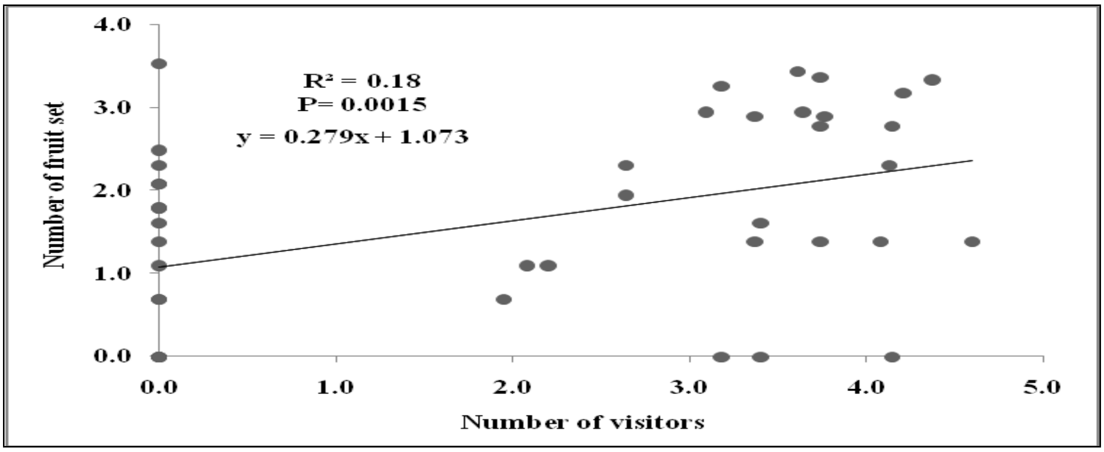
(e) *Bruguiera gymnorrhiza*, Michamvi



(f) *Bruguiera gymnorrhiza*, Nyeke



(g) *Rhizophora mucranata*, Michamvi

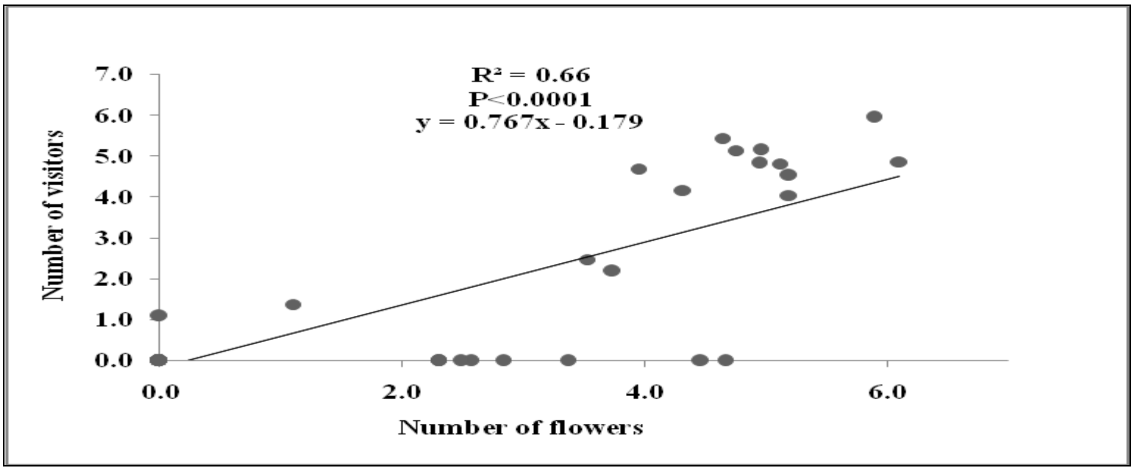


(h) *Rhizophora mucranata*, Nyeke

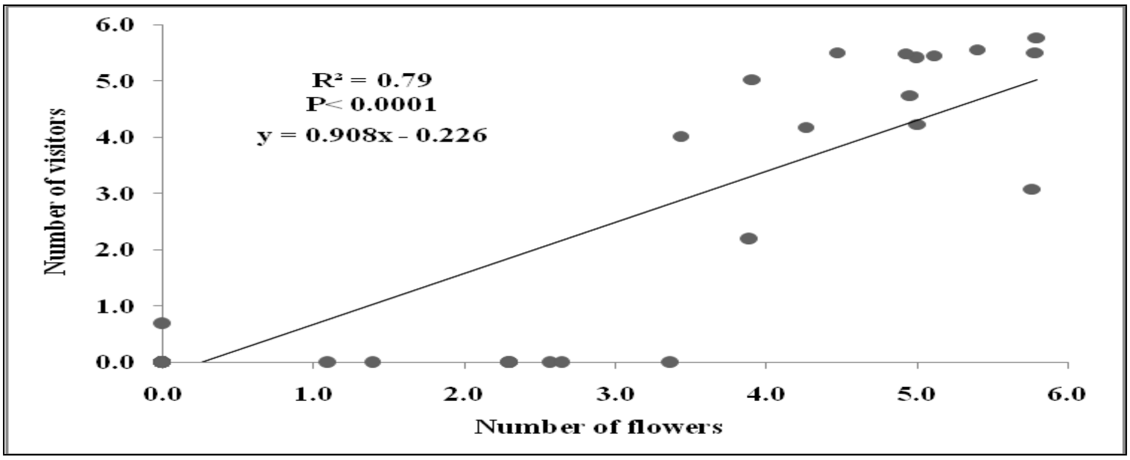
Figures 5.3 (a-h): Relatinship between number of fruit set and number of visitors at Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.4.4 Relationship between number of flower visitors and number of flowers

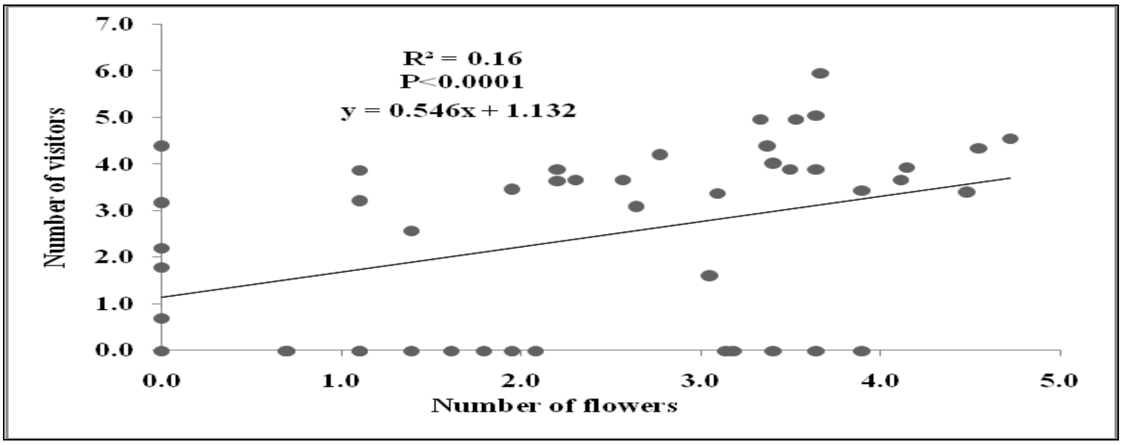
There was a positive relationship between the number of flowers and the number of visitors. However, the relationship was very weak in *Ceriops tagal*, in both study sites: Michamvi (df = 47, R^2 = 0.16, P< 0.0001, F= 9.57) and in Nyeke (df=46, R^2 = 0.29, P< 0.0001, F= 19.61) (Fig. 5.4c and d). Similarly, a very weak relationship was observed in *Rizophora mucranata* at in both sites (Fig. 5.4g and 5.4h).



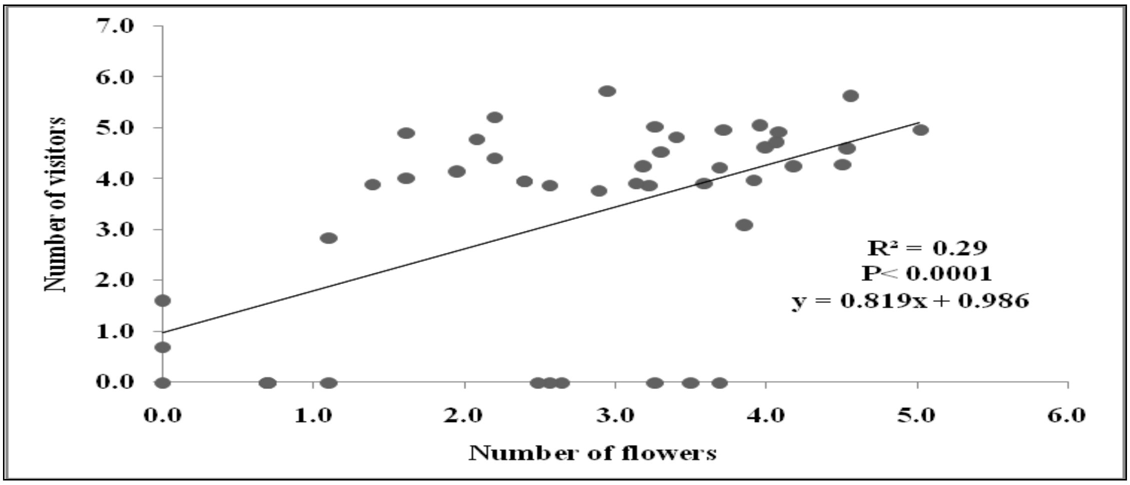
(a) Avicennia marina, Michamvi



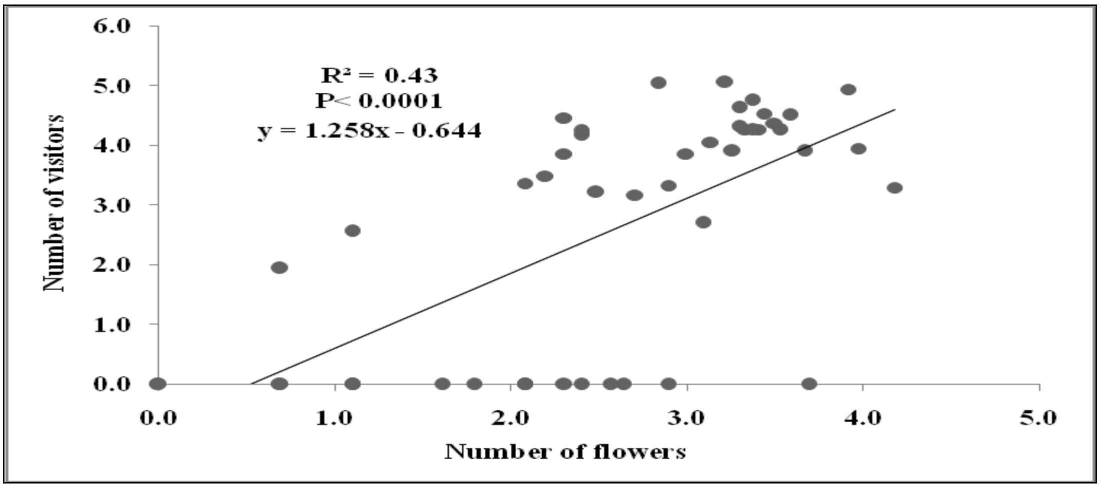
(b) *Avicennia marina*, Nyeke



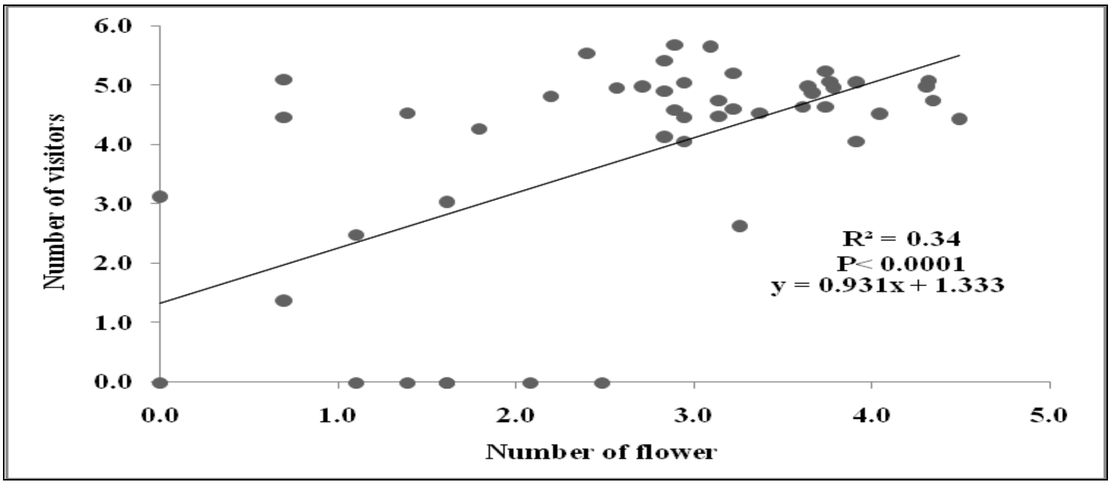
(c). *Ceriops tagal*, Michamvi



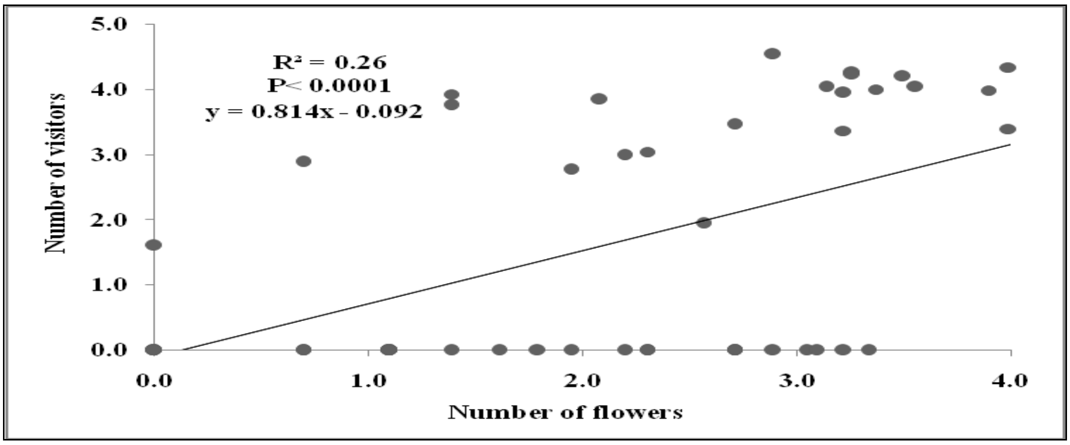
(d) *Ceriops tagal*, Nyeke



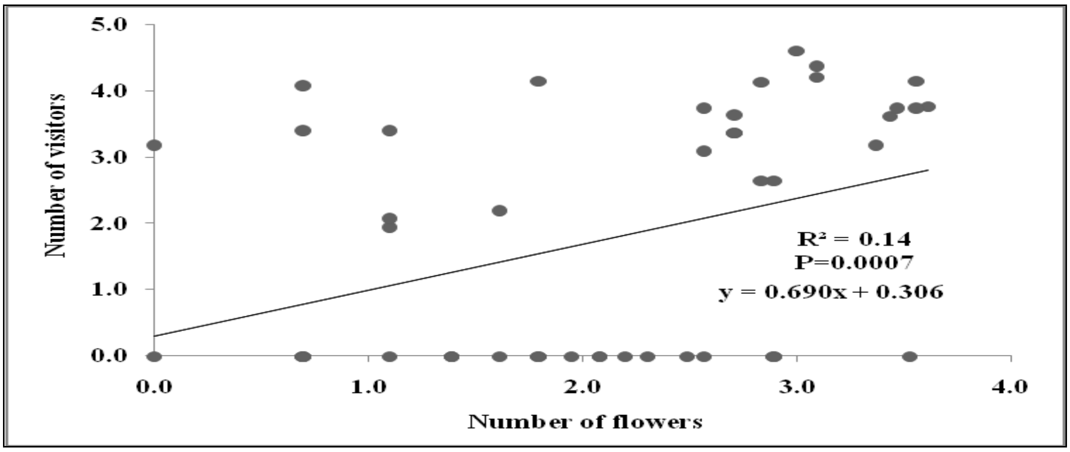
(e) *Bruguiera gymnorrhiza*, Michamvi



(f) *Bruguiera gymnorrhiza,* Nyeke



(g) *Rhizophora mucranata*, Michamvi

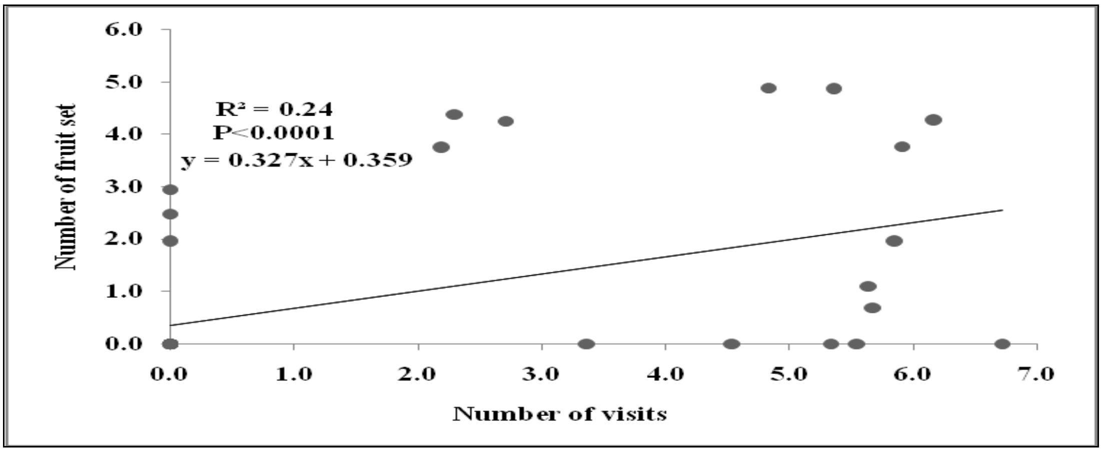


(h) *Rhizophora mucranata*, Nyeke

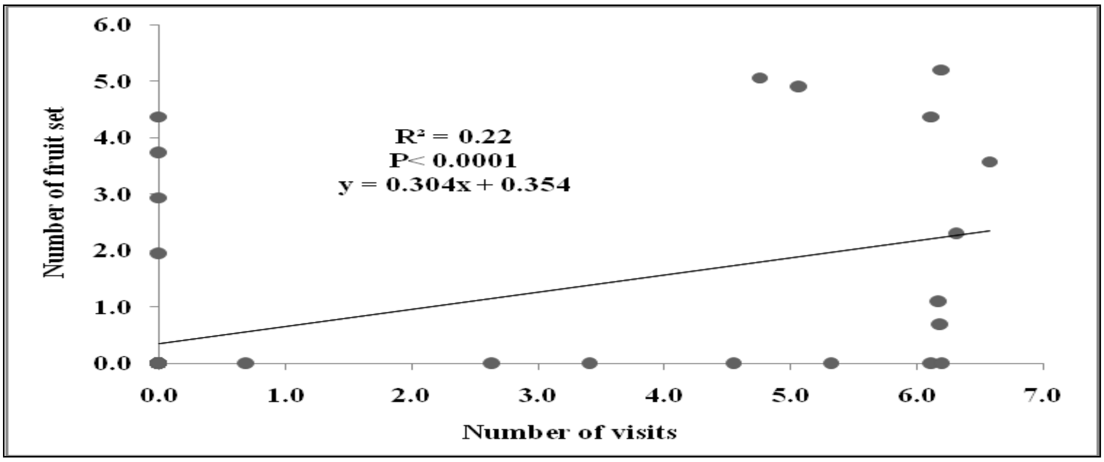
Figures 5.4 (a-h). Relatioship between number of flower and number of visitors at Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.4.5 Relationship between number of the flower visits and number of fruits set

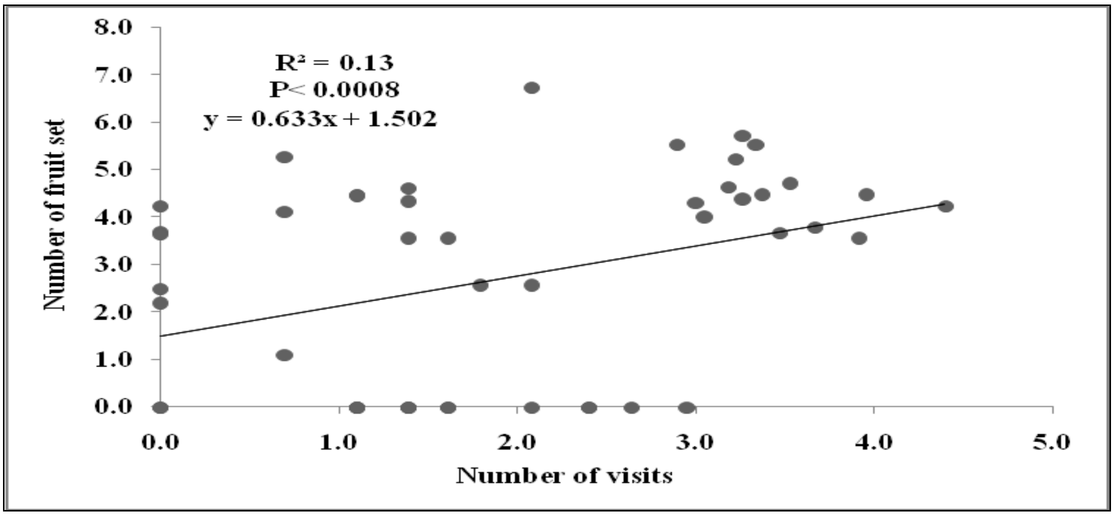
The relationship between number of visits and fruit set was weak for all mangrove species in both sites with R^2 ranging from 0.12 to 0.26 (Fig. 5.5a-5.5h). Number of visits and the number fruits set differed significantly among the four mangroves species.



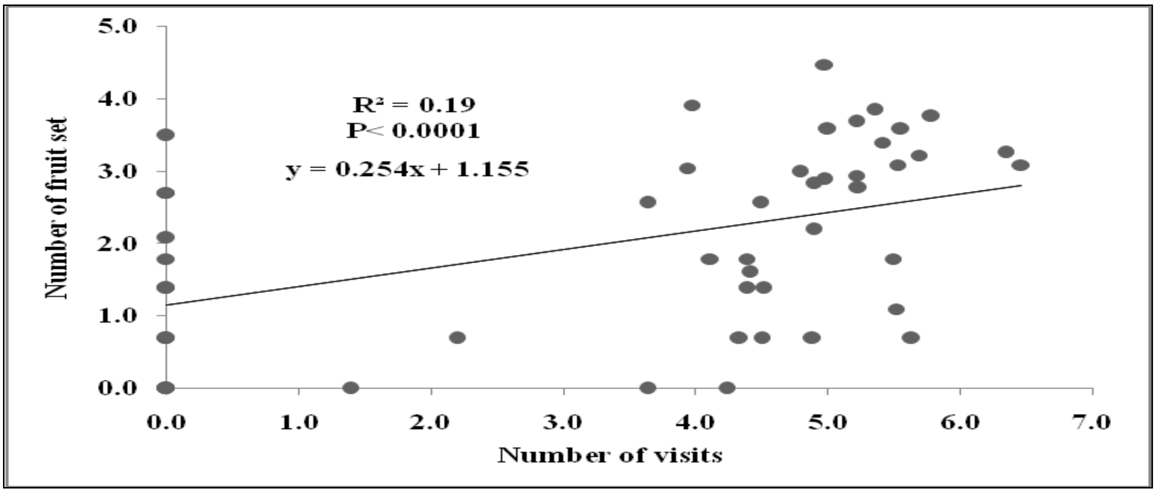
(a) *Avicennia marina*, Michamvi



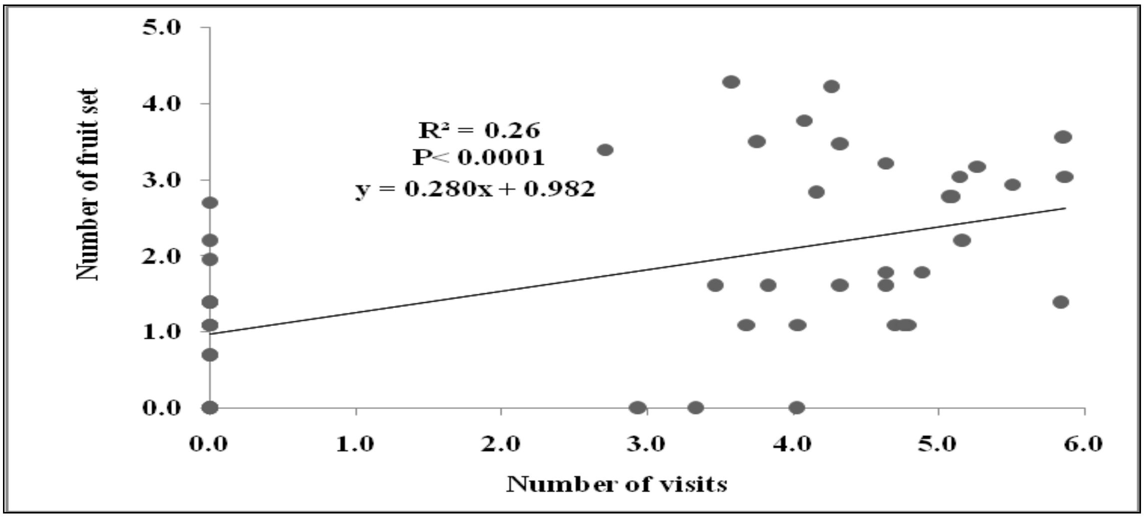
(b) *Avicennia marina*, Nyeke



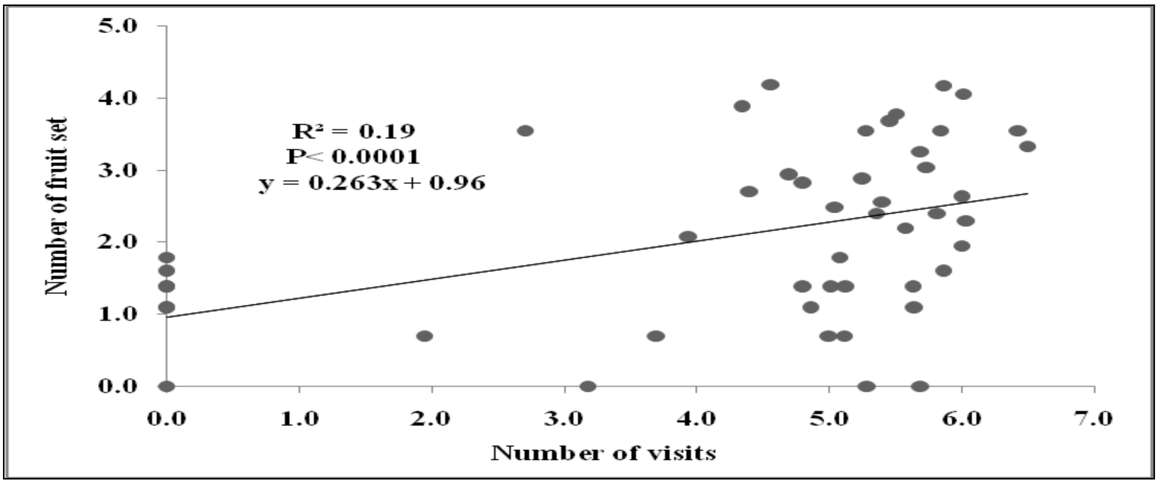
(c) *Ceriops tagal*, Michamvi



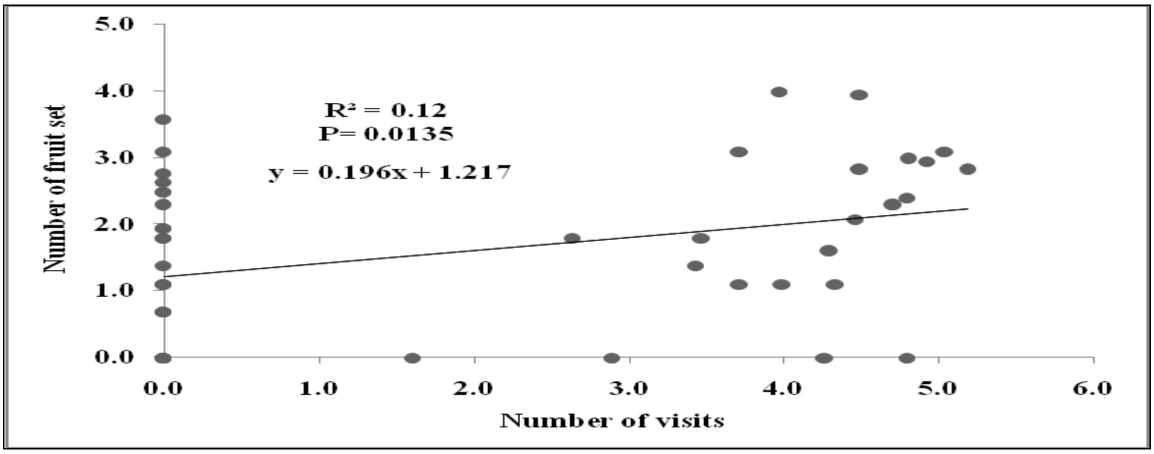
(d) *Ceriops tagal*, Nyeke



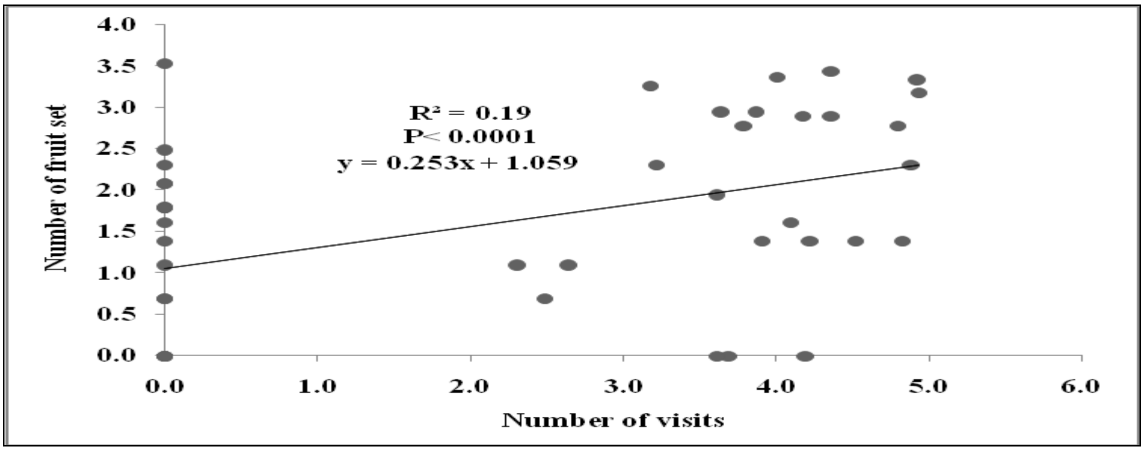
(e) *Bruguiera gymnorrhiza*, Michamvi



(f) *Bruguiera gymnorrhiza*, Nyeke



(g) *Rhizophora mucranata*, Michamvi

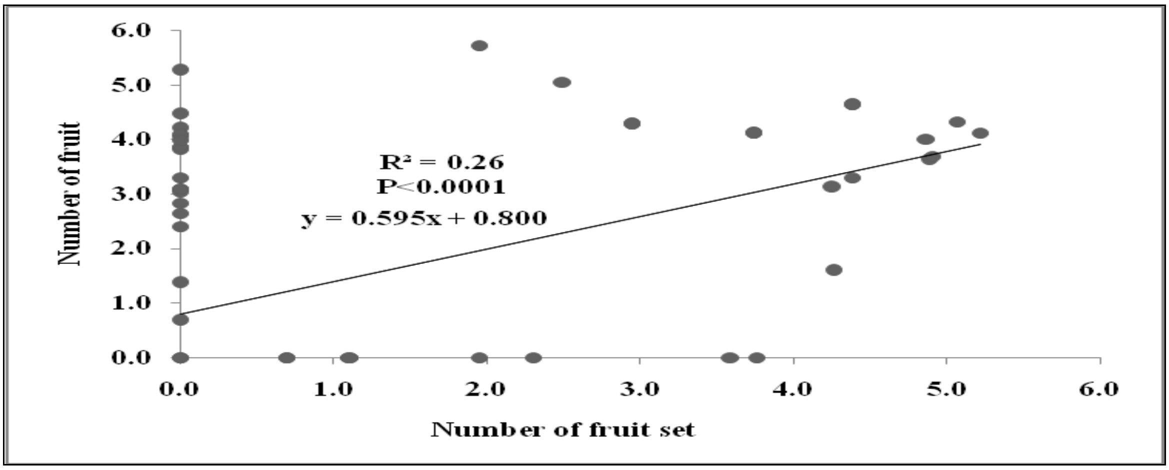


(h) *Rhizophora mucranata*, Nyeke

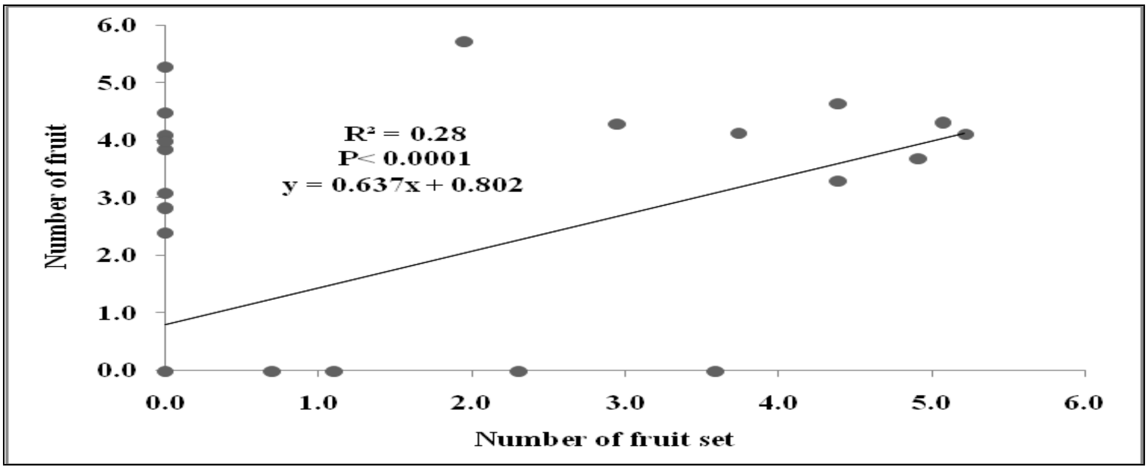
Figures 5.5 (a-h): Relationship between number of visits and number of fruits set at, Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.4.6 Relationship between number of fruits proced and number of fruits set

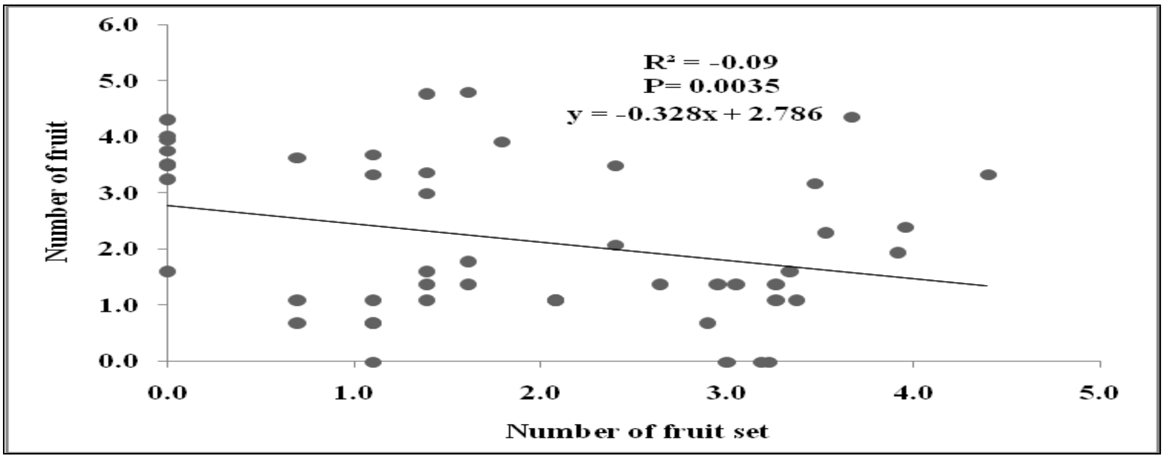
The relationship between number of fruits set and number of fruits produced is shown in Figures 5.6a-5.6h. For *A. marina*, there was a positive relationship between number of fruits set and number of fruits produced. The relationship was stronger in Nyeke than in Michamvi. For *Ceriops tagal*, there was an inverse relationship in Michamvi. The more the fruits set, the lower the number of fruits produced. However, in Nyeke there was no relationship between fruit set and number of fruits for *C. tagal*. The remaining two species of mangroves showed no relationship between number of fruits set and number of fruits produced.



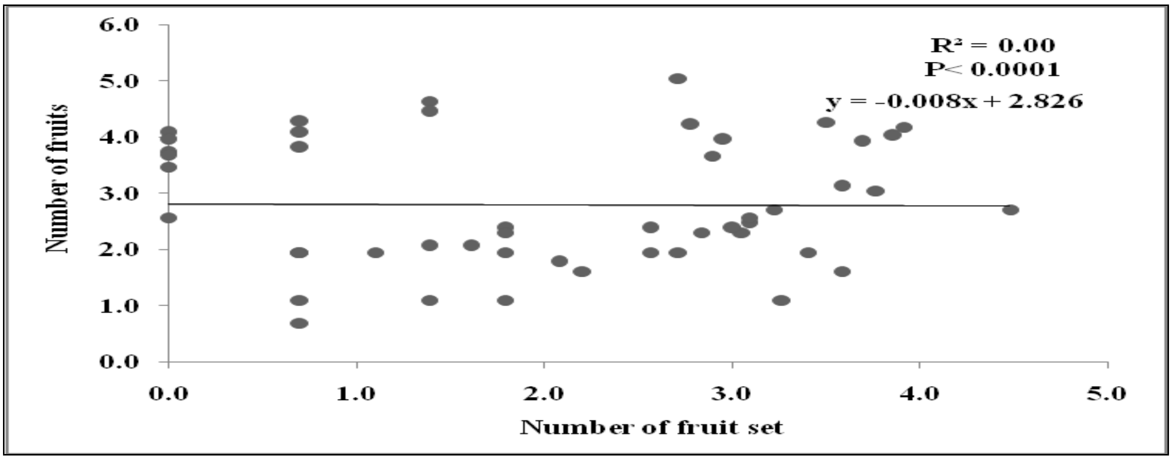
(a) *Avicennia marina*, Michamvi



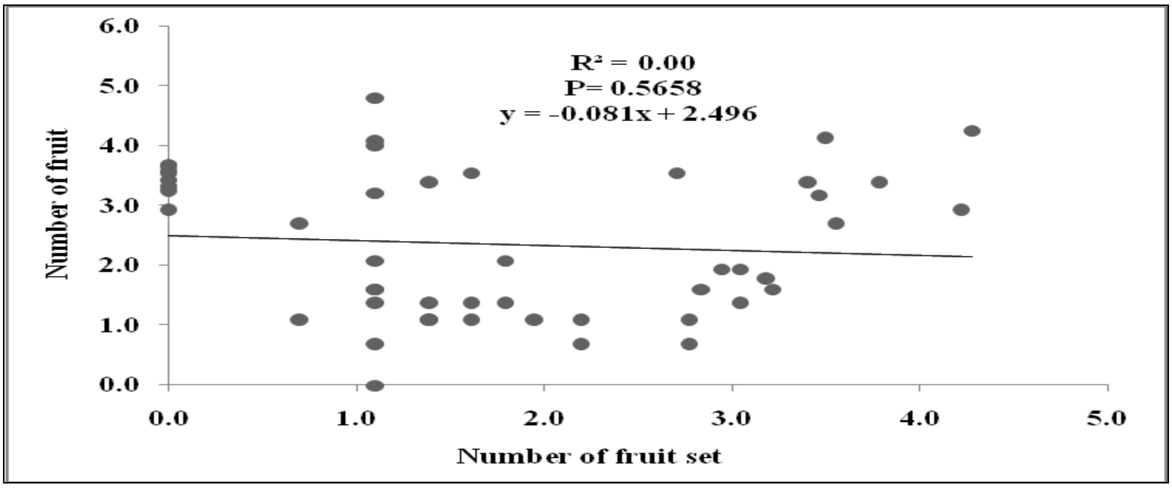
(b) *Avicennia marina*, Nyeke



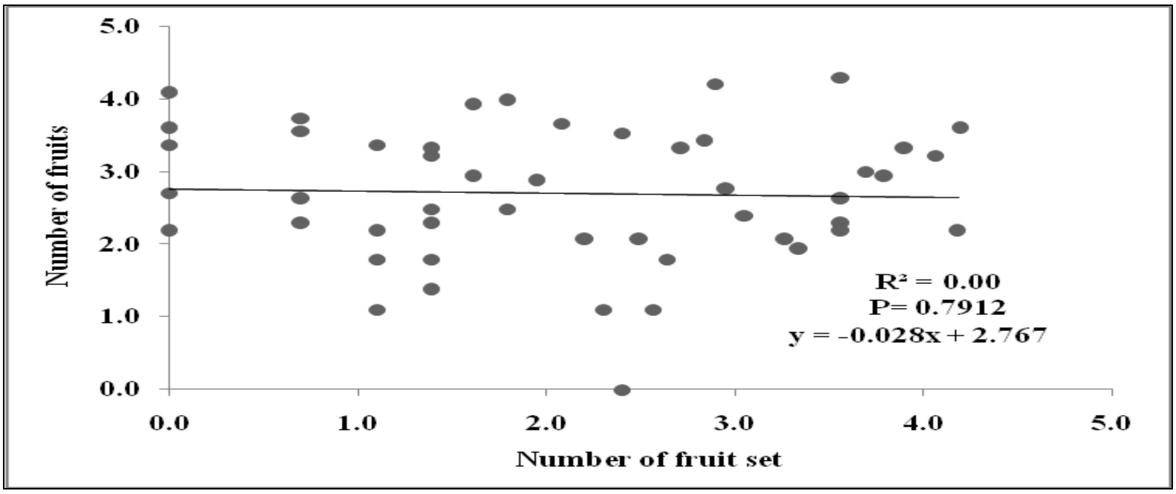
(c)*Ceriops tagal*, Michamvi



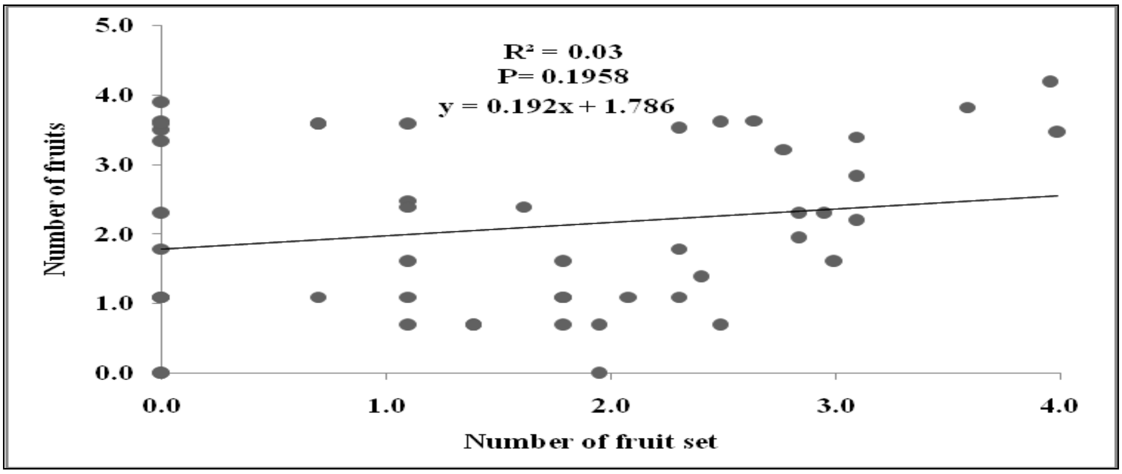
(d) *Ceriops tagal*, Nyeke



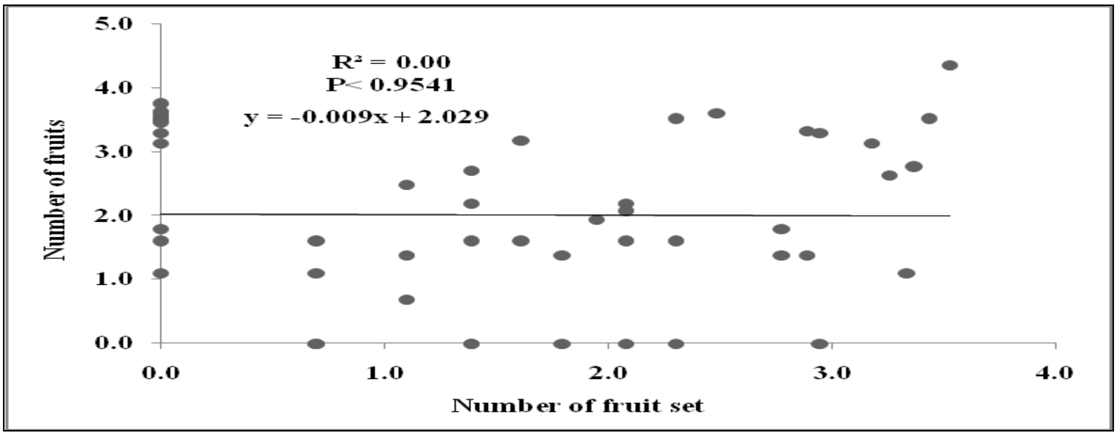
(e)*Bruguiera gymnorrhiza*, Michamvi



(f) *Bruguiera gymnorrhiza*, Nyeke



(g) *Rhizophora mucranata*, Michamvi

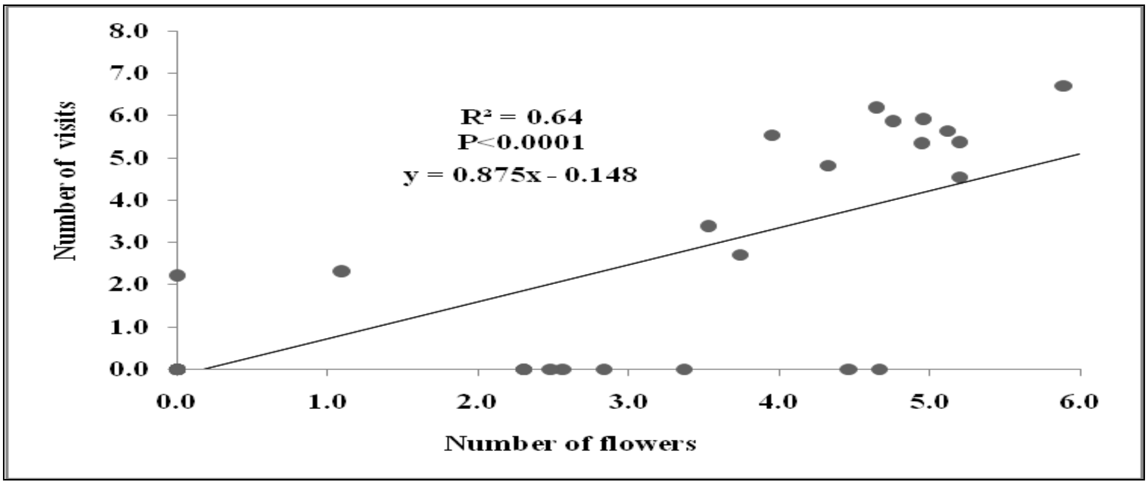


(h) *Rhizophora mucranata*, Nyeke

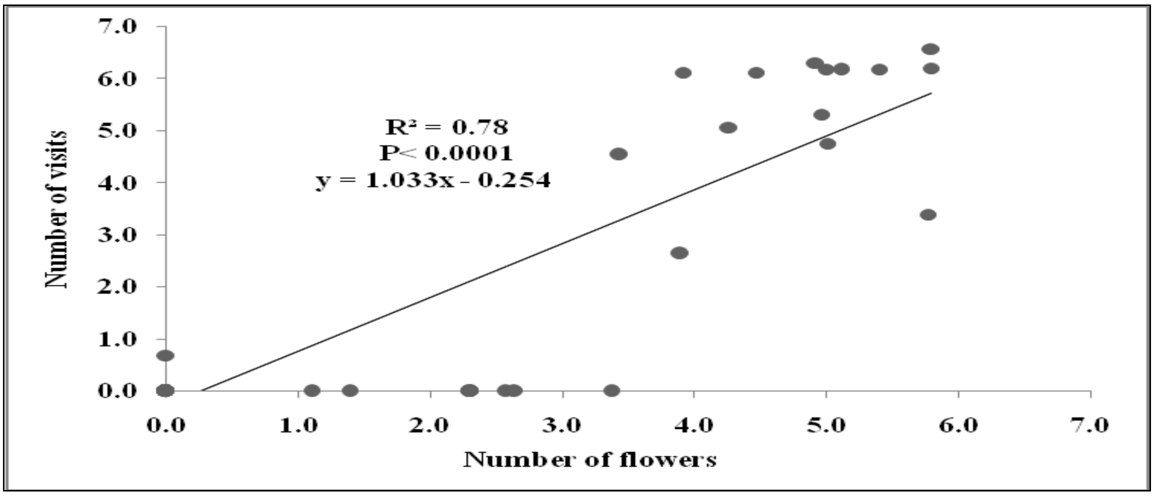
Figures 5.6 (a-h): Relationship between number of fruits set and number of fruits produced at Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.4.7 Relationship between number of flowers and number of visits

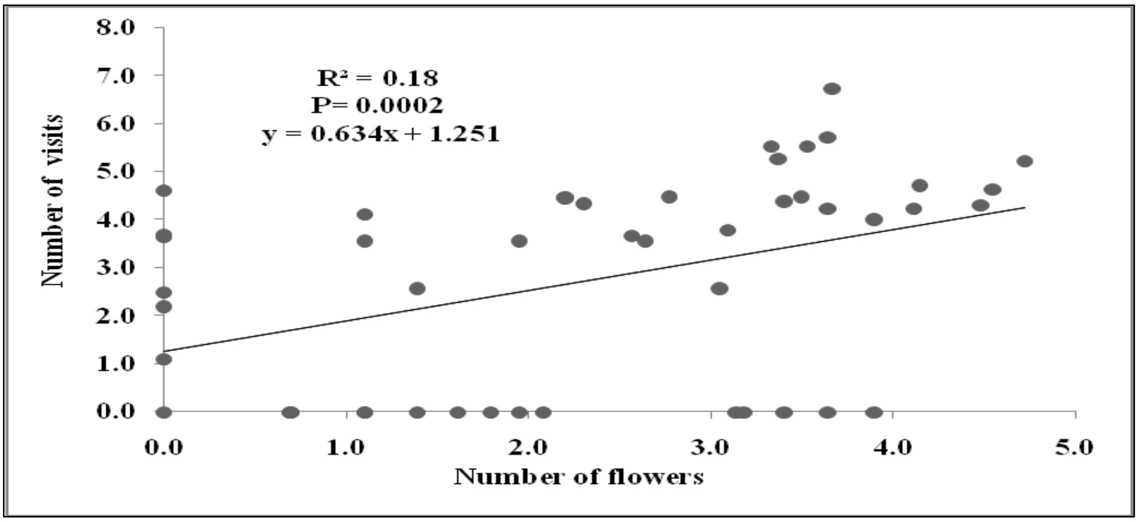
The relationship between number of flowers and number of visits for the four mangrove species is shown in figures 5.7a-5.7h. There was a positive relationship between number of flowers and number of fruits in both study sites for all the four mangrove species. The higher the number of flowers the higher the number of visits. However, the relationship was strongest in *Avicennia marina* in both sites.



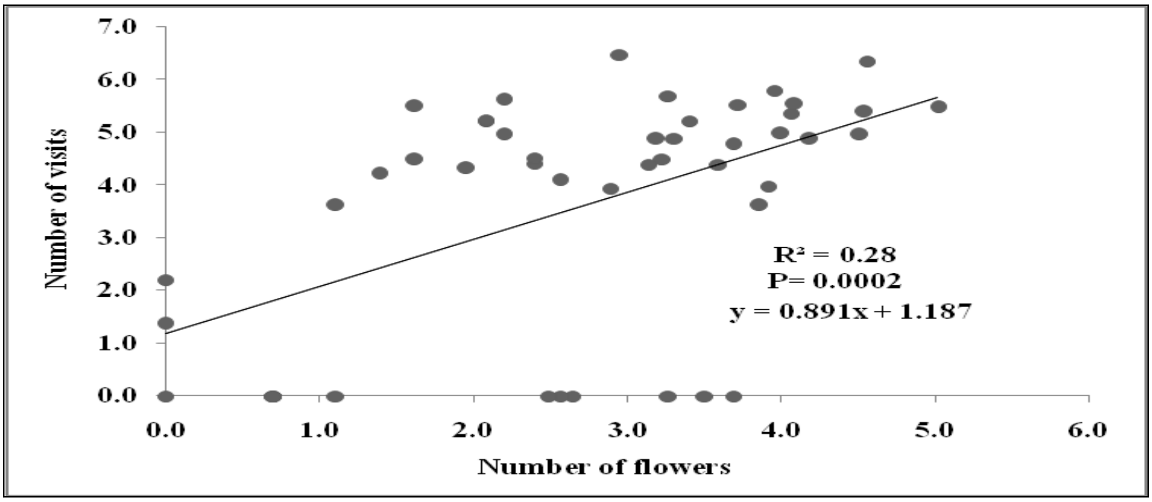
(a) *Avicennia marina*, Michamvi



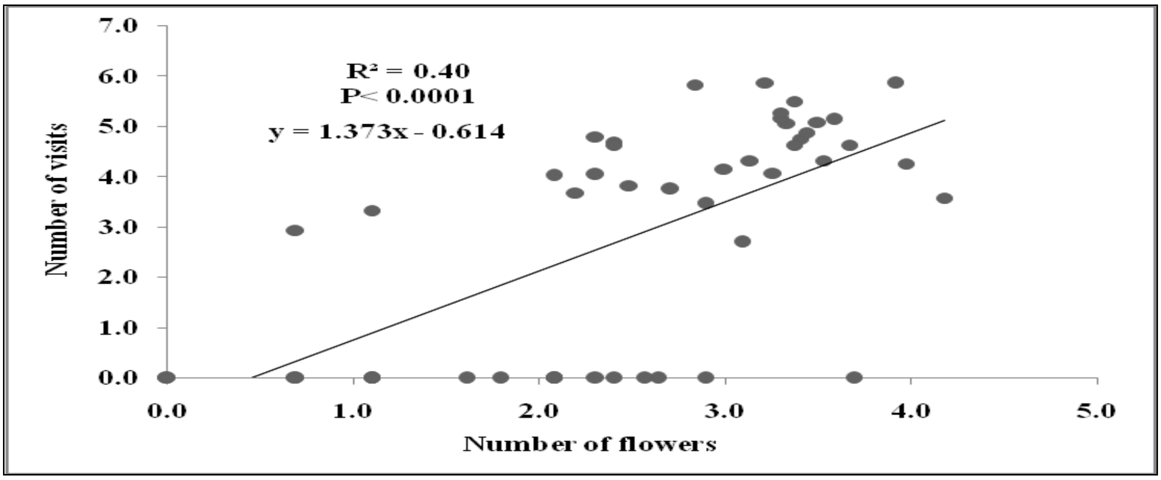
(b) *Avicennia marina*, Nyeke



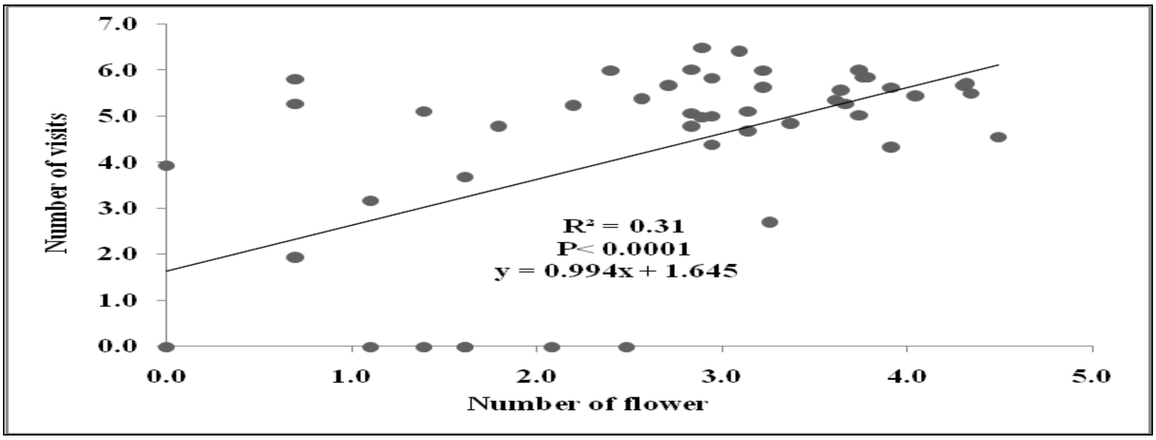
(c)*Ceriops tagal*, Michamvi



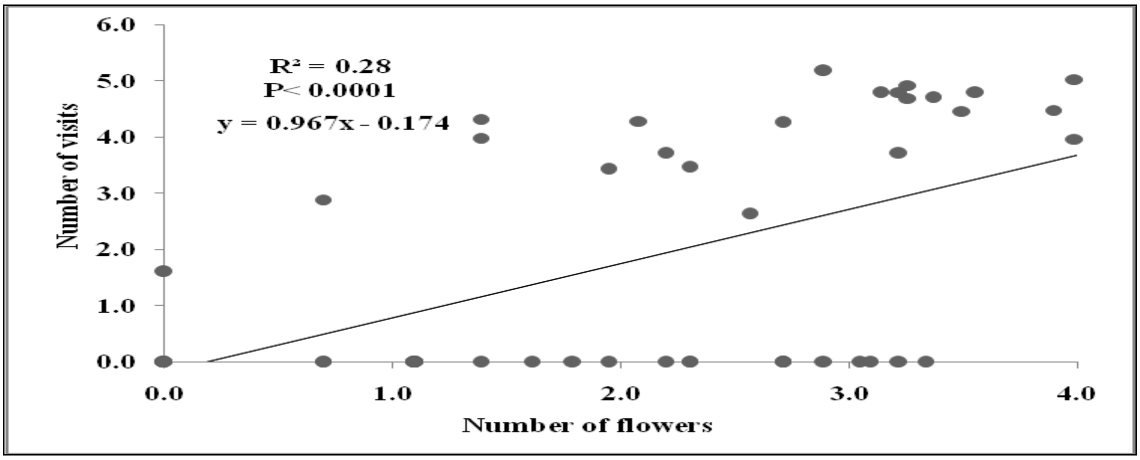
(d) *Ceriops tagal*, Nyeke



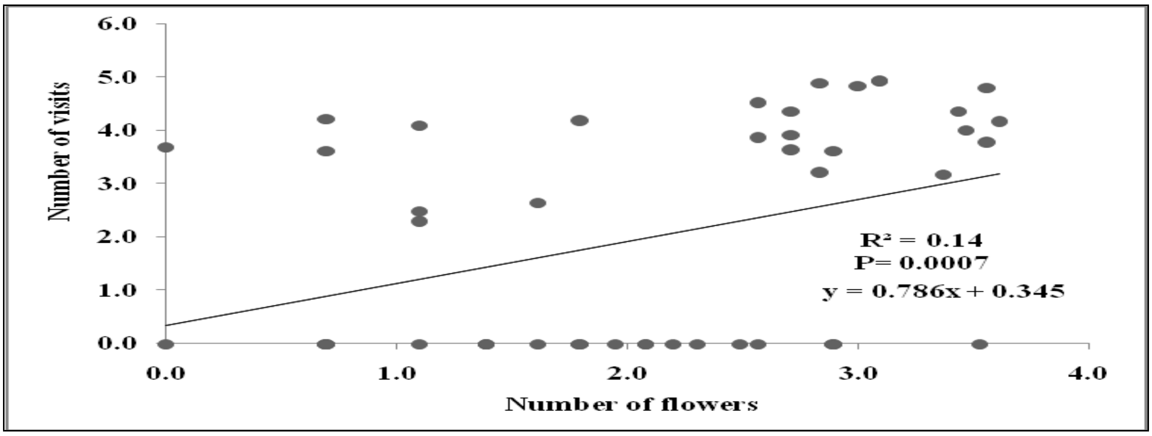
(e) *Bruguiera gymnorrhiza,* Michamvi



(f) *Bruguiera gymnorrhiza*, Nyeke



(g) *Rhizophora mucranata*, Michamvi



(h) *Rhizophora mucranata*, Nyeke

Figures 5.7 (a-h): Relationship between number of flowers and numbers of visits at Michamvi (n= 48) and Nyeke mangrove forests (n= 47) for *Avicennia marina* (a and b), *Ceriops tagal* (c and d), *Bruguiera gymnorrhiza* (e and f), *Rhizophora mucranata* (g and h)

5.5 Discussion

Results on all mangroves species in both Michamvi and Nyeke revealed significant positive relationship between the number of flower buds and the number of flowers produced. This suggests that reduction of flower buds could lead to lower flower production. The two study sites differed in the number of flower visitors. The two study sites are different in landscape and natural vegetation. Nyeke site is situated about one kilometer from Jozani National Park and surrounded by fruit trees such as mango, jack fruit, papaya, avocado, banana, citrus and many vegetables farms while Michamvi study is more than 20 kilometers from Jozani National Park. The site is surrounded by coral land with few fruit trees. This difference could explain why generally the relationship between number of flowers and insect flower visitors was stronger in Nyeke than in Michamvi. The visitors could be coming from the surrounding areas. The availability of pollinators may be affected not only by population size itself but also by the landscape that surrounds a focal population. Even if two population of a plant species are the same size and have the same extent of floral display, pollinator availability necessarily will be different depending on the potential pollinator's abundance, which may be related to the amount of available resources for pollinator species (Tomimatsu and Ohara, 2002).

It was noticed that increase of number of flowers in *Avicennia marina* increased insect flower visitors and visiting frequency in both study sites than other mangroves species. However, increase of number of insect flower visitors and visiting frequency did not have a big effect on fruit sets. This could be because not all visitors are pollinators or there could be other factors responsible. Kearns and Inouye (1997) reported that changes in pollinator's communities during flowering affects composition of pollen load taken by pollinators. Differences in flower visit duration among pollinators have been implicated in influencing pollinator effectiveness. Visit duration has been shown to be positively related to pollinators' effectiveness (Fishbein and Venable, 1996; Ivey *et al.,* 2003; Boyd, 2004).

The relationship between the number of flowers and number of fruits set was positive but weak. This implies that proportionately there many flowers that did not result in fruit setting due to other factors probably nutrient availability and the rate of absorption from the soil to reproductive area. Variations of nutrients and salinity have been reported to affect plant species productivity requirement and growth rates (Lambers and Pooter, 1992).

In both mangrove sites, the findings revealed a weak relationship between number of fruits set and number of fruits produced. Many of immature fruits were observed to fall down. *Avicennia marina* fruits showed slight increase in the number of fruits formed when the number of fruits set increased. Though the reason for this scenario is beyond the scope of this study, it is probably related to availability of resources to support a large number of offspring. Studies conducted by Pestana *et al.* (2005) and Jones and Comita (2008) reported that, plant resources play a major role in increasing or reducing fruit set and fruit production in many tropical tree populations.Increases in the concentrations of N, Mg and Fe in orange trees grown in calcareous soil led to a greater fruit set and maturation index Besides soil plant nutrients, Andrew (2008) point out that temperature and pollen-pistil interaction plays an important role on fertilization, fruit set in fruit production.

Ceriops tagal, showed negative relationship between number of fruits set and number of fruits produced in Michamvi and no relationship in in Nyeke. The number of fruits produced declined with increasing number of fruits set in this species in Michamvi Probably indicates that plant resources cannot support the large number of fruits set. The presence of a developing fruit can inhibit subsequent set and growth of a young fruit and may be caused by competition for available assimilates or dueto dominance or due to a combination of competition and dominance (Tamas *et al.*, 1979; Stephenson *et al.*, 1988; Bangerth, 1989). It is believed that in many plants fruit that develop earlier produce auxin and export it to other parts and it serves to inhibit auxin export of the later-developed fruits (Bangerth, 1989).

In conclusion, it can be said that number of fruits produced by mangroves will depend on numbers of viable buds, flower, fruits set, visitors and visits. It is also possible that abiotic factors play a significant role.

CHAPTER SIX: INSECT POLLINATORS ABUNDANCE, DIVERSITY AND SPECIES RICHNESS OF FOUR TROPICAL MANGROVES SPECIES

6.1 Introduction

Pollination by insects comprises an important ecosystem service, as reproduction and yields of many flowering wild (Larson and Barrett, 2000) and crop plants (Klein *et al.,* 2007) benefit from faunal pollinators. Long-term declines in pollinator populations and related threats to plant reproduction have led to concerns of a widespread loss of pollination services in which pollen-limited plants will suffer reduced yields due to declining pollen supply (Kremen *et al.,* 2002; Steffan-Dewenter *et al.,* 2005; Biesmeijer *et al.,* 2006).

Pollination services in agricultural production reached 208$ billion USD per annum in 2005, or 9.5 percent of the total value of the world's trade (Gallai *et al.,* 2009). In Ghana, the overall contribution of pollination services to agricultural production was estimated at 11.1 % of the national agricultural production. In Uganda, the annual value of pollination services delivered by wild bees oscillated between US$67.18 and US$1431.36. Central Uganda produces in total 0.401 million tons of coffee beans for an approximate economic value of US$214 million from which US$149.42 million are attributable to pollination services. In addition to the overall economic importance of pollination services, the production value per unit farming area of insect pollinated crops is four times that of crops that do not need insect pollination (Gallai *et al.,* 2009). Worldwide pollnators are treatened due anthropogenic activiyies. For example, flower dependent animals, including insects, may be vulnerable to changes in flower supply caused by deforestation and the influence of climatic change (Corlett and LaFrankie, 1998). A study by Steffan-Dewenter *et al.* (2005) revealed that the overall diversity and density of flower-visiting bees linearly declined with decreasing proportion of semi natural habitats. The ultimate effects of reduced pollinators are reduced crops production for those crops that depend on pollinators.

Mangroves are tropical ecosystems highly utilized to support coastal economic activities. The rate at which trees are being removed exceeds the rate of regeneration and there is fear that unless something is done these ecosystems may be damaged irreparably. Insects constitute a significant portion of the fauna found in many mangrove communities (Mchenga and Ali, 2013). They may be permanent residents of the mangal or only transient visitors (Coupland *et al.*, 2006) but they play an important role in the ecology of the mangrove ecosystem and contribute to the unique character of these mangroves habitats (Banerjee and Rao, 1990). Many mangrove species are pollinated by insects thus they are crucial in the regeneration of the former. Despite the important role played by pollinators, little solid documentation on the status and trends of pollinators in Africa including Zanzibar exist (Gemmill-Herren *et al.*, 2014). Zanzibar has mangrove forests but very little is known about the, abundance, diversity and species richness of insect pollinators within these ecosystems. Thus, this study was initiated to establish baseline information on insect pollinator's abundance, diversity and species richness in four tropical mangroves species in Zanzibar. Information obtained from this study will be useful in formulating conservation strategies for Zanzibar mangrove forests.

6.2 Materials and Methods

F**o**ur mangroves species: *Rhizophora mucronata* (RM), *Bruguiera gymnorhiza* (BG), *Ceriops* tagal (CT) *and Avicennia marina (*AM) were randomly selected from Nyeke and Michamvi mangroves forests. For each site, 20 mature trees of each of the four species were chosen for observation. For each treatment flower visitors and visitation frequency were counted for 30 minute period on selected branches of mangrove trees. Thereafter, all insect pollinators visiting flowers of the four mangroves species were collected for a period 30 minutes (Plate 6.1 to 6.3). This exercise was carried out during peak flowering period (from day one of flowering to day one of fruit setting/fruit) for each mangrove species. Observation and collection of insect pollinators was done between 06.00 to 10.00 am. Visitation rates of insect's pollinators were determined by counting the number of insect visits to flowers on one to several umbels under observation. During the first 10 minutes insects were not collected, but allowed to forage freely on flowers. This ensured that counting was done at highest visitation rate. However, pollinators trying to leave the tree after foraging were captured and recorded.

In order to examine the species identity of flower visitors to each of the four mangrove species, individual insects were observed outside and inside the flower and caught with a sweepnet or plastic bottles containing a mixture of water and detergent at a concentration of 20ml of distilled water and 5gm of detergent. All collected insects were identified and classified by family, order and species. All insects collected from each site and treatment was kept in sterile glass vials measuring 8.5 x 2.7cm and labeled. Information on the label included the site, date, time, tree number, insect number and mangrove tree species (Plate 6.4). Some insects were identified upon collection and immediately released into the forests to maintain their population. Preliminary identification of the collected insects according to the order, family, genus and species was prepared in Zanzibar at Kizimbani Entomology Research Laboratory on each day of collection (Plate 6.6). Identified specimen of insects of Plant Protection Insectary Museum were used as a backup references. After that, the insects were kept in glass vials containing 70% ethanol (Plate 6.5). Confirmation and further identification up to species level was done at The National Museums of Kenya (Nairobi). The inventory of identified pollinators is kept in Kenya and Kizimbani for future reference (Plate 6.8). The data record sheet included number of insects per plot, mangroves species and site, period and time of insect collection, GPS coordinates of site, insect common name, scientific name, order, family and species. Abiotic factors including temperature, relative humidity, rainfall and wind speed were also recorded. Photographs of each insect species was taken by a digital camera of 16 megapixels and use Digital stereo zoom microscope at The State University of Zanzibar for editing and used as reference.

6.3 Statistical analysis

For all statistical analysis Proc GLM SAS version 9.3 (SAS Institute 2012, Cary, NC) was used. F- test was used to determine whether the observation differed significantly among pollination variation, orders, months and sites. Significant variation were compared at 95% ($\alpha = 0.05$). Post-hoc test SNK ($p < 0.05$) was used whenever there were significant differences among observed variables (t-test used for sites and whereas F-test for months and insect orders). SIMPLER analysis of count was used to recorded data on abundance and species richness. The number pollinators' species were converted into percentages to observe the variations.

Plates 6.1 Camponotus sp ants on *B. gymnorhiza*

1Plate 6.2: Bees foraging on *R mucronata*

Plate 6.3: Recording number of visitors and visits

Plate 6.4: Labeling pollinators on vials

2Plate 6.5: Pollinators kept in 70% ethanol

Plate 6.6:Preliminary insect identification, Zanzibar

Plate 6.7: Insect taxonomy, Nairobi Museum

Plate 6.8: Identified mangroves pollinators

6.4 Results

6.4.1 Abundance of mangrove pollinators by orders at Nyeke and Michamvi sites.

Results on number of visitors, visits and pollinators recorded in the two study sites are shown in Figure 6.1. For all the three parameters, Nyeke had significantly higher values compared to Michamvi (t=22.27, d.f =1, P< 0.0001) (Fig. 6.1). Analysis of the pollinators by order showed that the sites differed significantly in the number of Hymenopterans (t=22.19, d.f =1, P< 0.0001) and Coleopterans (t=4.19, d.f =1, P= 0.0415) visitors but not in the number of other orders (Fig. 6.2).

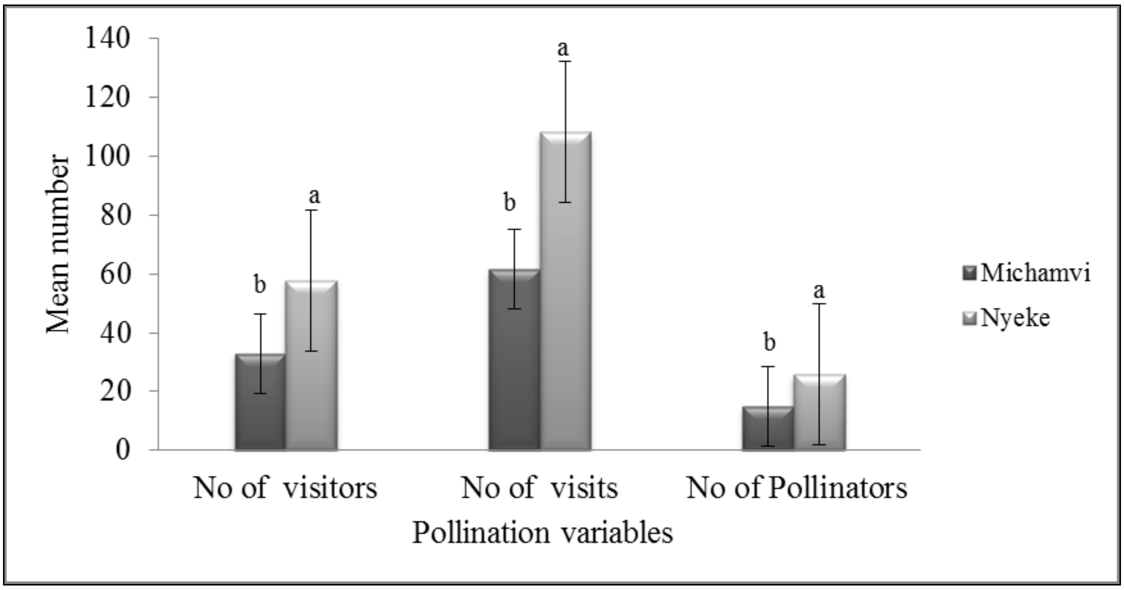


Figure 6.1: Mean numbers (± SE) of insect visitors, visits and pollinators in Nyeke and Michamvi mangroves forests. Different letters on top of bars indicate that the values differ significantly (p < 0.05) (n= 392).

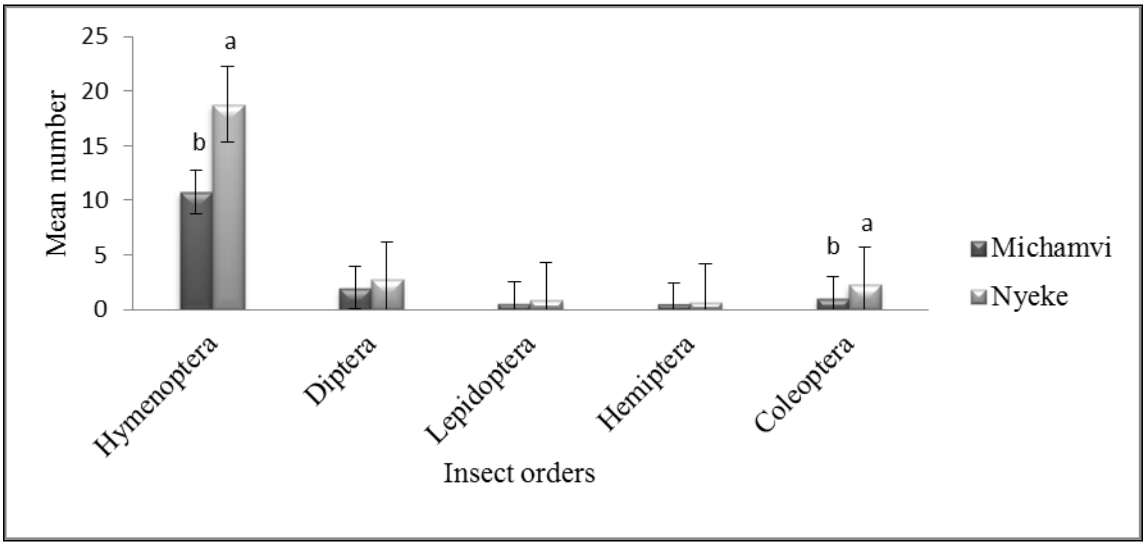


Figure 6.2: Mean number (± SE) of individuals of various orders observed in Nyeke and Michamvi forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 392).

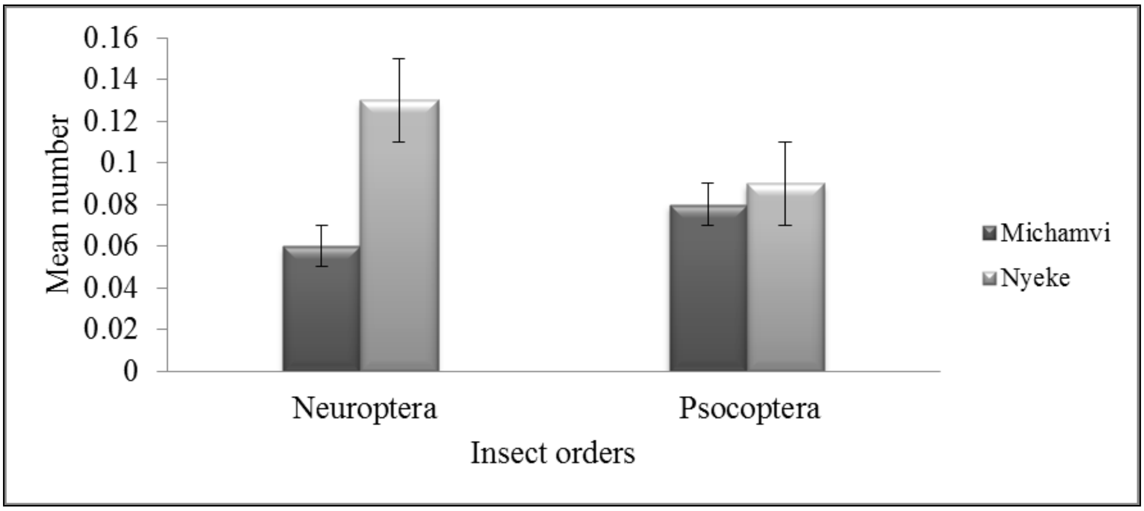
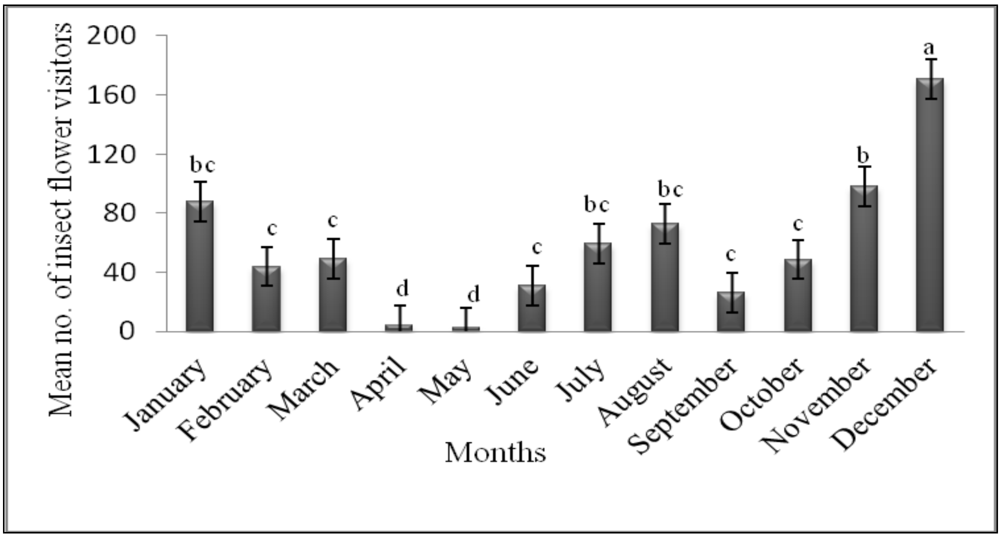


Figure 6.3: Mean number (± SE) of individual of orders Neuroptera and Psocoptera observed in Nyeke and Michamvi forests. Bars without letter above indicate that the values did not differ significantly (p > 0.05) (n= 392).

6.4.2 Temporal abundance of the number of visits, visitors and pollinators in Nyeke mangroves forest

The mean number of flower visitors of the four mangrove species in Nyeke mangroves forest differed significantly among months of the 2013 (Fig. 6.4a) (F= 11.11, d.f =11, P< 0.0001). The highest insect number was recorded in December of 2013, whereas the lowest was recorded in April and May respectively. Similarly, the highest number of flower visits differed significantly among months (F= 12.92, d.f =11, P< 0.0001) with the highest numbers being recorded in December (Fig. 5.4b). Similar pattern was observed in the mean number of insect flower pollinators (F= 8.77, d.f= 11, P< 0.0001) (Fig. 6.4c). The highest mean was recorded in December; and the lowest was observed in April and May respectively (Fig. 6.4c). Temporal variation in abundance of specific insect orders also varied significantly among months (Fig. 6.5). For example, the mean number of order Hymenoptera differed significant between month (F= 9.55, d.f =11, P< 0.0001) (Fig. 6.6) with a peak in December.



3 Figure 6.4a: The mean number (± SE) of insect flower visitors observed in Nyeke forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

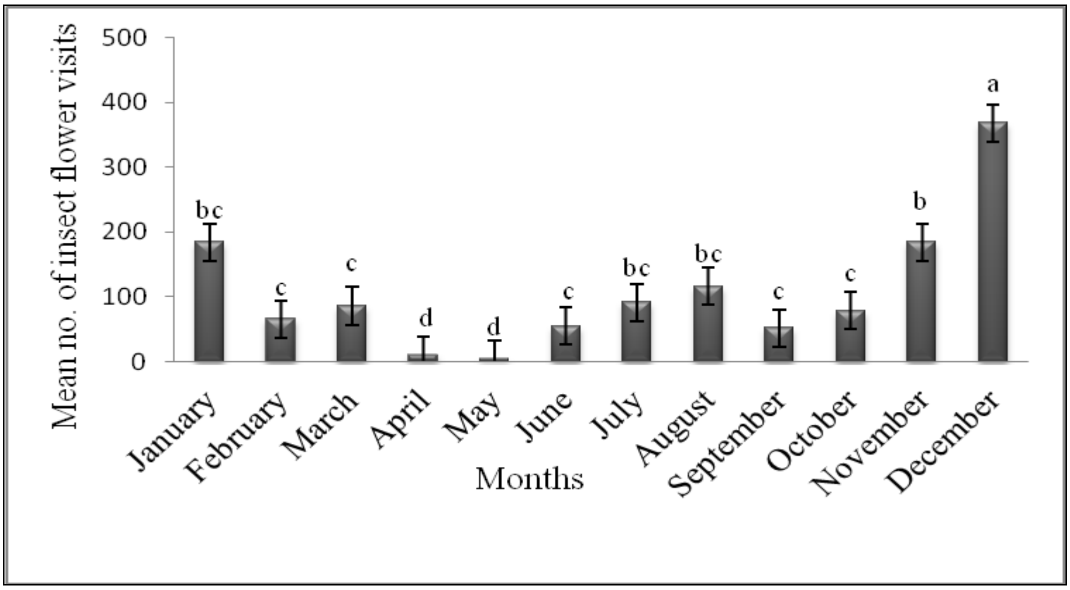


Figure 6.4b: The mean number (± SE) of insect flower visits observed in Nyeke forests. Same letter above the bars indicate that the values did not differ significantly ($p > 0.05$) (n= 196).

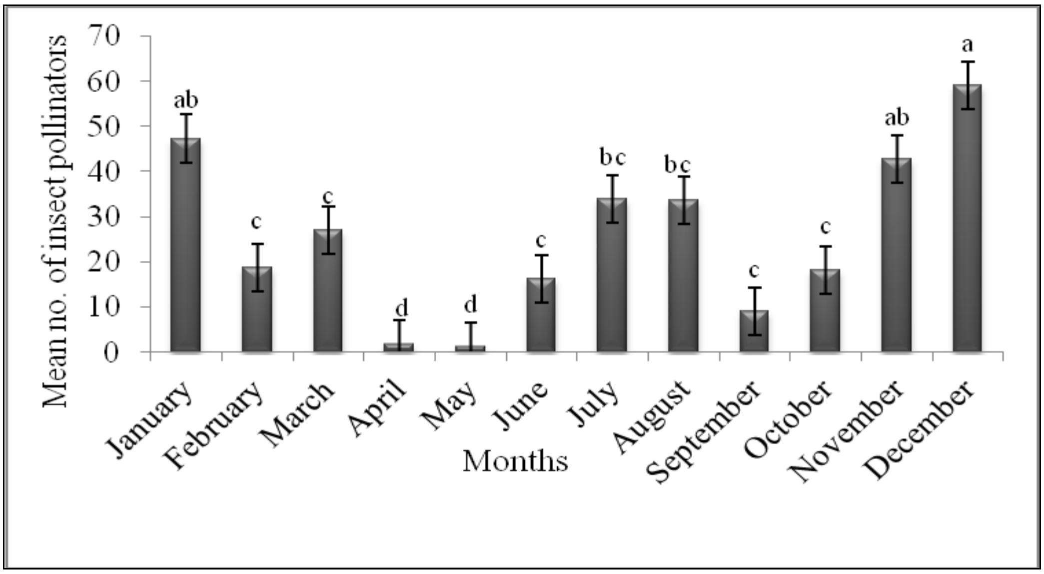


Figure 6.4c: The mean number (± SE) of insect flower pollinators observed in Nyeke forests. Same letter above the bars indicate that the values did not differ significantly ($p > 0.05$) (n= 196).

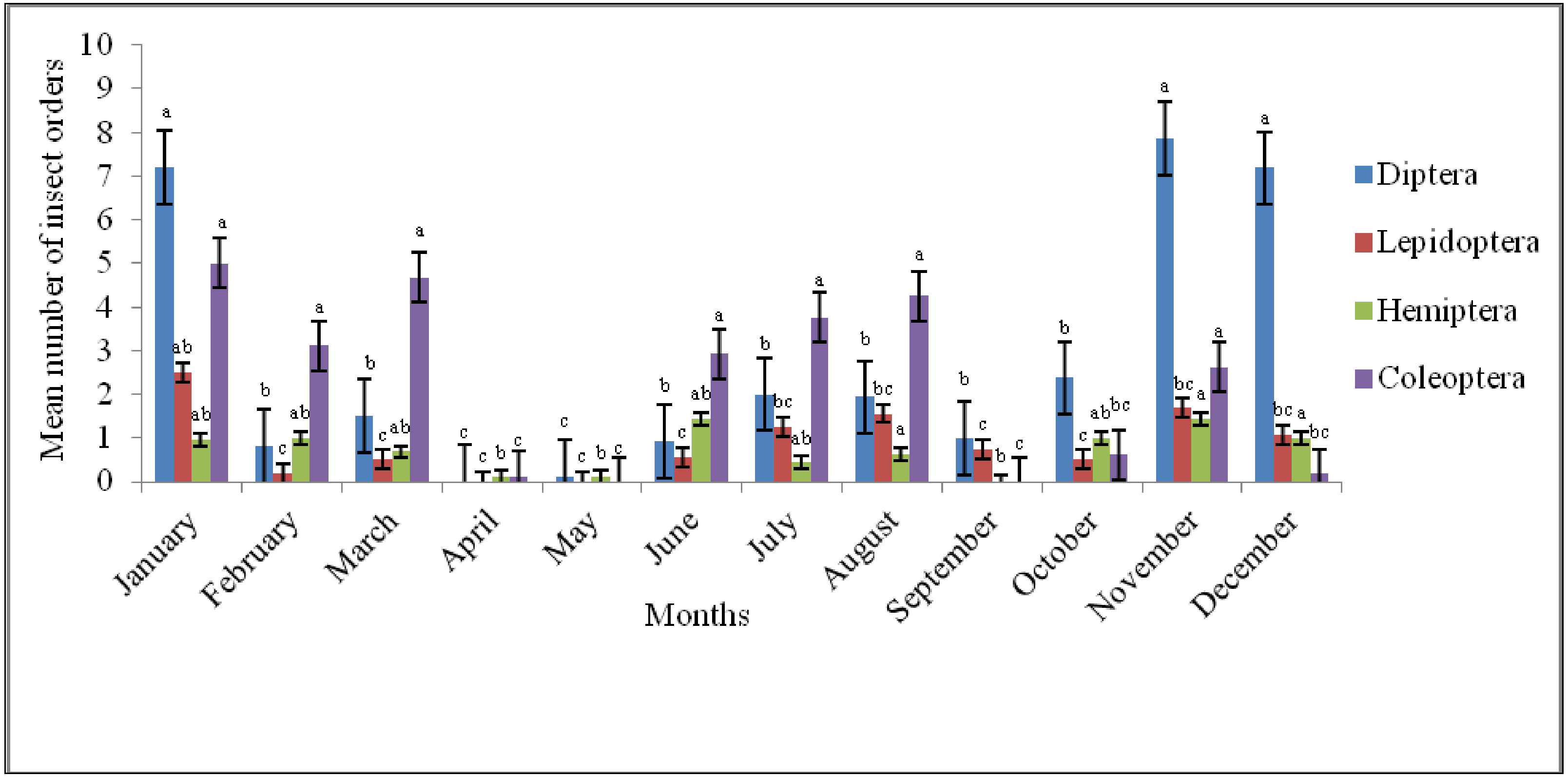


Figure 6.5: The mean number (± SE) of insect orders: Diptera, Lepidoptera, Hemiptera and Coleoptera observed in Nyeke forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

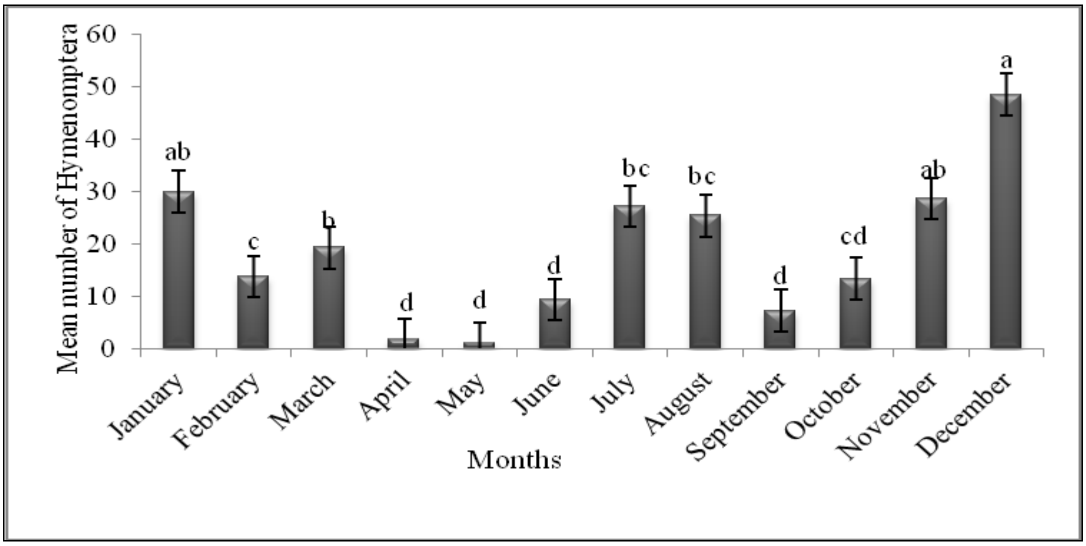


Figure 6.6: The mean number (± SE) of insect order Hymenoptera observed in Nyeke forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

6.4.3 Temporal variation in the abundance and distribution of pollinators in Michamvi mangroves forest

The mean number of flower visitors of the four mangroves species in Michamvi mangroves forest differed significantly among months in 2013 (F= 8.96, d.f = 11, P< 0.0001) (Fig. 6.7a). The highest mean number was recorded in the month of November to January and peak was recorded in August 2013. . The same pattern was observed in number of visits and pollinators (F= 8.95, d.f= 11, P< 0.0001) (Fig. 6.7b) and (F= 6.41, d.f = 11, P< 0.0001) (Fig. 6.7c) respectively. Temporal variation in abundance of specific insect orders also varied significantly among months (Fig. 6.8). For example, the mean number of order Hymenoptera differed significant between month (F= 7.31, d.f =11, P< 0.0001) (Fig. 6.9) with a peak in December.

Similar pattern was observed in Dipterans (F= 3.34, d.f = 11, P= 0.0003) and coleopterans Coleoptera (F= 1.37, d.f = 11, P= 0.1909). There was no significant variation in the numbers of insects of other orders among months (Fig. 6.8).

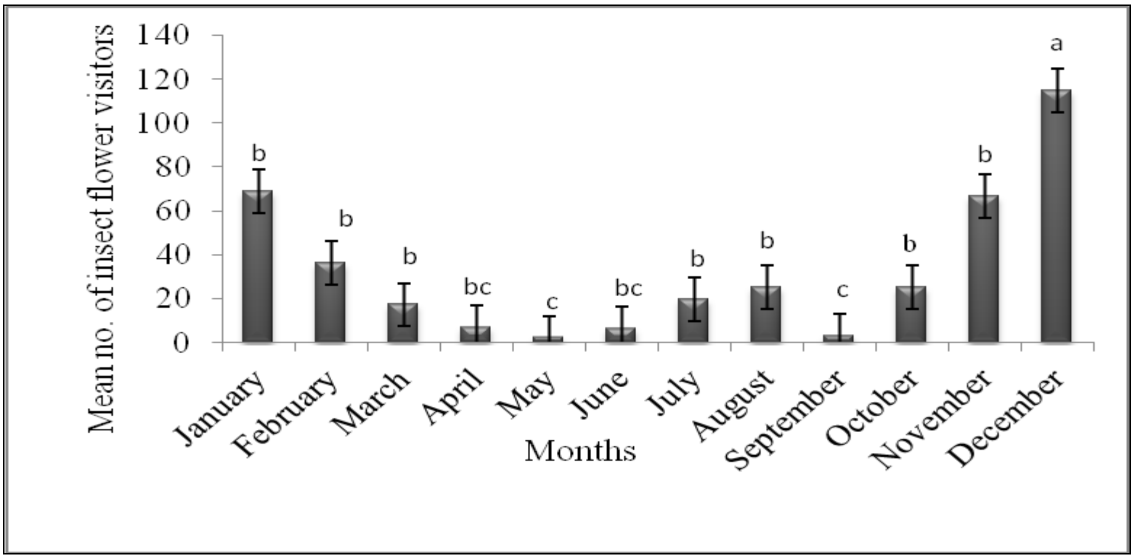


Figure 6.7a: The mean number (± SE) of insect flower visitors observed in Michamvi forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

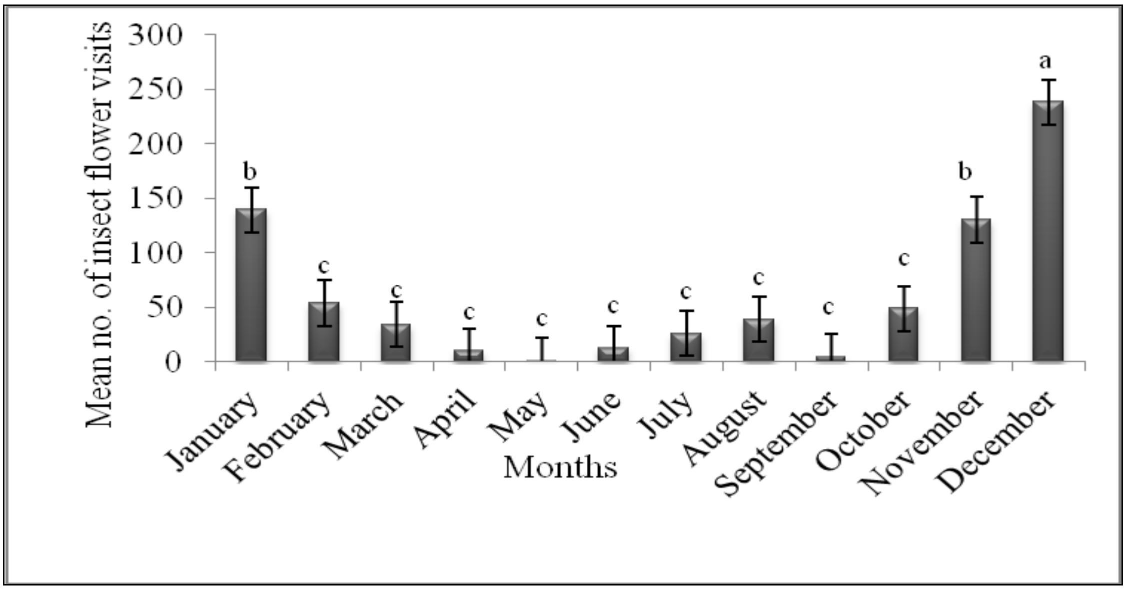


Figure 6.7b: The mean number (± SE) of insect flower visits observed in Michamvi forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

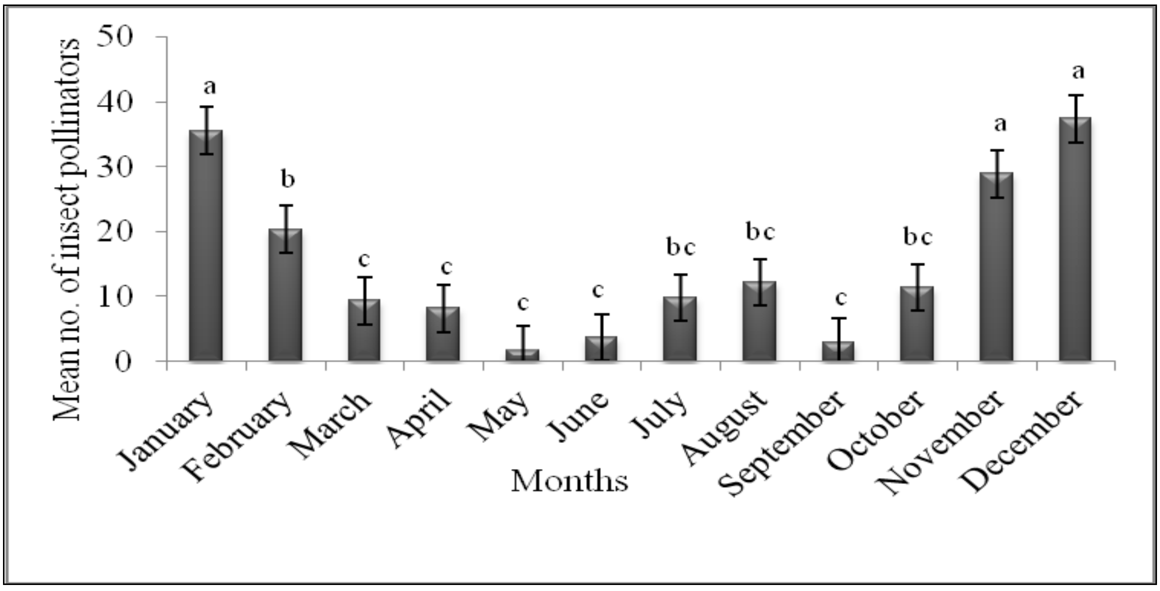


Figure 6.7c: The mean number (± SE) of insect pollinators observed in Michamvi forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

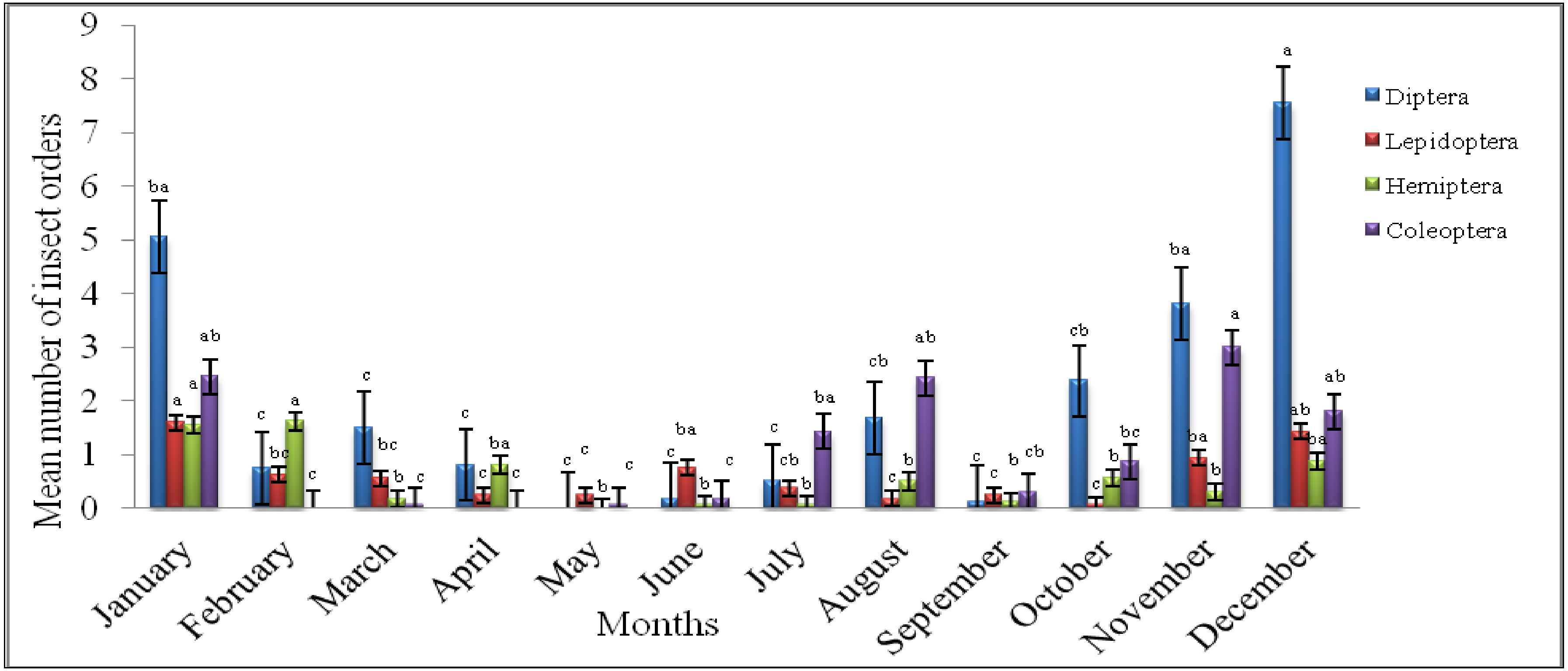


Figure 6.8: The mean number (± SE) of insect orders, Diptera, Lepidoptera, Hemiptera and Coleoptera observed inMichamvi forests.

Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

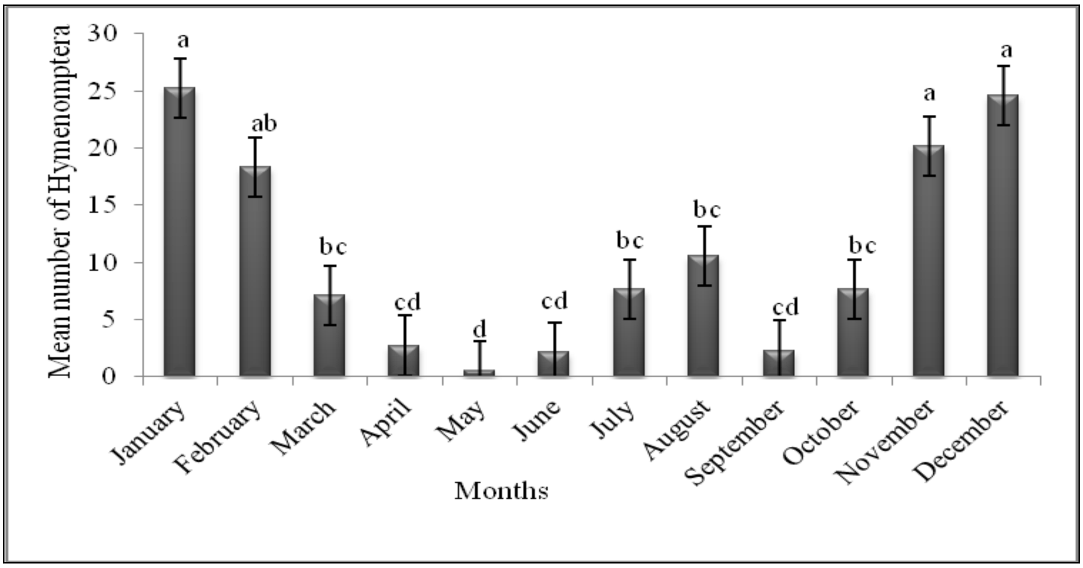


Figure 6.9: The mean number (± SE) of insect order Hymenoptera observed in Michamvi forests. Same letter above the bars indicate that the values did not differ significantly (p > 0.05) (n= 196).

6.4.4 Abdundance of insect pollinators variations and orders at Nyeke and Michamvi mangrove forest

Results of two factors (species, site) ANOVA are shown in Table 6.1. The four mangrove species differed significantly in terms of insect orders and abundance of pollinators, visitors and visits in Nyeke (F= 16.37, d.f= 3, P< 0.0001) (Table 6.1). However, in Michamivi, differences tended not to be significant. The highest mean number of insect flower pollinators, visitors and visits were recorded at Nyeke in *Bruguiera gymnorhiza* compared with other mangroves species in both sites.

2Table 6.1. The mean number of pollination variation between sites and insect Orders observed on four mangrove species.

Mangrove sites and species	**Pollination variation**			**Insect orders**						
	Mean pollinators	Mean visitors	Mean visits	Hymenoptera	Diptera	Lepidoptera	Hemiptera	Coleoptera	Neuroptera	Psocoptera
Michamvi*AM	13.93c	33.63c	70.71de	8.06c	4.74a	0.58bc	0.35bc	0.20c	0.07	0.04b
Michamvi*BG	19.46c	40.10c	72.58de	17.75b	1.02c	0.58bc	0.98ba	0.28c	0.01	0.00b
Michamvi*CT	15.91c	38.05c	68.52de	8.73c	1.33c	0.93ba	0.41b	3.67b	0.07	0.31a
Michamvi*RM	11.02c	19.54dc	34.69ef	8.62c	0.96c	0.29bc	0.29cb	0.00c	0.05	0.02b
Nyeke*AM	17.69c	45.46c	94.73cd	10.73c	5.02a	0.85ba	0.39bc	0.40c	0.24	0.00b
Nyeke*BG	44.67a	99.73a	187.71a	35.51a	2.55c	1.29a	1.08a	1.32c	0.00	0.04b
Nyeke*CT	30.69b	67.26b	119.28bc	17.30b	2.84bc	1.25a	1.10a	7.18a	0.30	0.33a
Nyeke*RM	9.89c	18.73dc	30.46f	8.51c	0.61d	0.13c	0.23c	0.24c	0.01	0.00b
SE	3.28	7.32	14.91	2.32	0.77	0.25	0.20	0.86	0.08	0.10
P value	P< 0.0001	P< 0.0001	P< 0.0001	P< 0.0001	P< 0.0001	P= 0.0033	P< 0.0005	P< 0.0001	P< 0.0658	P< 0.0074

Means within a column followed by different letters are significantly different at P < 0.05) according to SNK (Student Newman Keuls) test (n= 392). AM= *Avicennia marina*, RM= *Rhizophora mucronata*, BG= *Bruguiera gymnorrhiza and CT= Ceriops tagal*

6.4.5 Relative abundance and species richness of insect pollinators in Nyeke and Michamvi forests

Table 6.2 shows the list of potential pollinators recorded during this study. A total of 18,029 insects' flower visitors belonging to seven orders, 40 families and 70 species were recorded visiting mangrove flowers of the four common mangroves species at Nyeke and Michamvi mangroves forests. Family Apidae of the Order Hymenoptera was the most common and its insects were found in all four mangroves species in both sites. *Apis mellifera* was the leading flower pollinator of BG, CT and AM, whereas *Hypotrigona gribodoi* was dominant and potential insect flower pollinators of RM (Table 6.2). Higher number of *Apis mellifera* 721 (32.2%) was recorded in BG at Nyeke mangroves forest during the survey periods, while higher abundance of *Hypotrigona gribodoi* 262 (53.8%) was recorded in RM (Table 6.2). Insect flower pollinator *Egybolis vaillantina* of the family Noctuidae of Order Lepidoptera was common representing 52(2.3%) in Nyeke than Michamvi 13(1.3%).

The results showed that the genus *Patellapia* of family Halictidae was more abundant than *Pseudapis* and *Sphecodes* species in mangroves BG in both studied sites (Table 6.2). However, it was more abundant in Nyeke 362(16.2%) than in Michamvi 104(10.2%). Likewise, *Bembecinus sp* of Family *Sphecidae* was more abundant and potential insect pollinator on BG and recorded 120 (5.4%) and on CT 89(5.8%) in Nyeke. Order Diptera, Family Syrphidae species *Eristalis* had a total number of 119 (17.3%) are very potential pollinators of *Avicennia marina* in Michamvi mangrove forest. Two species of Family Bombyllidae; *Exoprosopa rubescens* and *Bombylius* species recorded total number of 69 (8.6%) and 63 (7.8%)

respectively and are potential pollinators of AM. An insect of *Luciola* sp of the order Coleoptera in the family Lampyridae was the most common insect flower visitors of CT in both sites, however higher population of *Luciola* sp 330 (21.6%) was found in CT Nyeke mangroves forest than 156 (20.3) in Michamvi in this study. Abundance details for orders, family and species are in (Table 6.2).

Table 6.2 shows the insect flowers pollinators present and absent of four mangroves specie in Nyeke and Michamvi mangroves forest. In this study the insect species; *Iphiaulax sp* (Braconidae) BG, *Andrena sp* (Andrenidae) BG and CT, *Eldana sp* (Pyralidae) BG and CT, Wild silkmoth (Saturnnidae) BG and CT, Plume moth (Pterophoridae) found in BG CT and AM, in Nyeke and AM in Michamvi mangroves forests. Whereas, *Aspidimorpha sp* (Chrysomilidae) were found on BG and CT in Michamvi site.

The results of insect’s pollination abundance and species richness on four mangrove species studied shows that, mangroves specie CT had the highest recorded 64 of insect in Nyeke than 58 species diversity of CT in Michamvi site (Table 6.3). Similar results observed on BG, recorded 60 insect species in Nyeke than 55 in Michamvi. However, the lowest number 31 of insect species was recorded in mangrove RM of Nyeke than 41 of Michamvi. The findings indicated that the insect family Sphecidae had higher number of insect pollinator’s species in both site, whereas BG and CT flowers had showed to be pollinated by all seven insect species from this family (Table 6.3). In this study not only family Apidae species (*A. mellifera, Macrogalea candida, Xylocopa scioensis, Braunsapis sp, Hypotrigona gribodoi* and *Ceratina sp*) seen in all four mangrove specie in both sites, but also *Xanthopimpla stemmator*, *Pseudapis sp*, *Patellapia sp*, *Polistes sp*, *Dirrhinus sp*, *Paranotus sp*, *Euscelis sp*, *Exoprosopa rubescens*, *Sarcophaga sp* and *Musca domestica* were identified (Table 6.2 and 6.3).

Table 6.2: Relative abundance of insect taxon in the four mangrove species: *Rhizophora mucronata* (RM), *Bruguiera gymnorhiza* (BG), *Ceriops tagal* (CT) and *Avicennia marina* (AM)

			Nyeke site (%)				Michamvi site (%)			
Order	**Family**	**Genus/specie/name**	**BG**	**CT**	**AM**	**RM**	**BG**	**CT**	**AM**	**RM**
Hymenopteran	Apidae	*Apis mellifera*	721(32.2)	333(21.8)	119(14.8)	64(13.1)	443(43.4)	195(25.4)	169(24.6)	92(18.5)
		Macrogalea candida	35(1.6)	22(1.4)	11(1.4)	11(2.3)	16(1.6)	8(1.0)	24 (3.5)	20(4.0)
		Xylocopa scioensis	9(0.4)	20(1.3)	7(0.9)	2(0.4)	4(0.4)	9(1.2)	6 (0.9)	4(0.8)
		Braunsapis sp	69(3.1)	55(3.6)	25(3.1)	18(3.7)	38(3.7)	20(2.6)	18(2.6)	6(1.2)
		Ceratina sp	22(1.0)	13(0.9)	2(0.2)	4(0.8)	8(0.8)	1(0.1)	4(0.6)	3(0.6)
		Hypotrigona gribodoi	79(3.5)	6(0.4)	39(4.9)	262(53.8)	32(3.1)	4(0.5)	11(1.6)	180(36.3)
	Mengachilidae	*Mengachille sp*	23(1.0)	7(0.5)	6(0.7)	0(0.0)	6(0.6)	1(0.1)	2(0.3)	1(0.2)
	Halictidae	*Pseudapis sp*	60(2.7)	33(2.2)	7(0.9)	7(1.4)	19(1.9)	20(2.6)	14(2.0)	9(1.8)
		patellapia sp	362(16.2)	85(5.6)	40(5.0)	22(4.5)	104(10.2)	25(3.3)	40(5.8)	40(8.1)
		Sphecodes sp	22(1.0)	4(0.3)	6(0.7)	0(0.0)	1(0.1)	2(0.3)	0(0.0)	0(0.0)
	Vespidae	*Ropalidia nobilis*	14(0.6)	1(0.1)	5(0.6)	1(0.2)	2(0.2)	3(0.4)	0(0.0)	5(1.0)
		Ropalidia sp 1	3(0.1)	3(0.2)	0(0.0)	0(0.0)	1(0.1)	2(0.3)	0(0.0)	3(0.6)
		Ropalidia sp 2	0(0.0)	1(0.1)	0(0.0)	0(0.0)	0(0.0)	0(0)	0(0.0)	1(0.2)
		Polistes marginalis	25(1.1)	11(0.7)	18(2.2)	8(1.6)	13(1.3)	9(1.2)	8(1.2)	5(1.0)
		Polistes sp	12(0.5)	7(0.5)	2(0.2)	1(0.2)	11(1.1)	4(0.5)	9(1.3)	2(0.4)
		labus nobilis	7(0.3)	5(0.3)	5(1)	0(0.0)	6(0.6)	3(0.4)	0(0.0)	2(0.4)
	Ichneumonidae	*Xanthopimpla stemmator*	15(0.7)	8(0.5)	3(0.4)	2(0.4)	1(0.1)	1(0.1)	3(0.4)	1(0.2)
	Scoliidae	*Megameris sp*	13(0.6)	10(0.7)	7(0.9)	0(0.0)	0(0.0)	3(0.4)	1(0.1)	0(0.0)
		Cathimeris hymenaea	22(1.0)	4(0.3)	7(0.9)	0(0.0)	3(0.3)	0(0.0)	1(0.1)	1(0.2)
	Eumenidae	*Synagris sp*	10(0.4)	1(0.1)	1(0.1)	0(0)	5(0.5)	1(0.1)	2(0.3)	0(0)
		Odynerus cyanopterum	16(0.7)	0(0.0)	2(0.2)	0(0.0)	1(0.1)	1(0.1)	0(0.0)	0(0.0)
		Eumenes tinctor	18(0.8)	8(0.5)	9(1.1)	0(0.0)	4(0.4)	8(1.0)	10(1.5)	0(0.0)
	Sphecidae	*Trypoxylon sp*	14(0.6)	12(0.8)	0(0.0)	0(0.0)	5(0.5)	0(0.0)	0(0.0)	0(0.0)
		Bembecinus sp	120(5.4)	89(5.8)	74(9.2)	11(2.3)	52(5.1)	34(4.4)	35(5.1)	14(2.8)
		Philanthus triangulum	10(0.4)	5(0.3)	5(0.6)	0(0.0)	2(0.2)	1(0.1)	0(0.0)	1(0.2)
		sphex sp	10(0.4)	2(0.1)	2(0.2)	0(0)	2(0.2)	1(0.1)	0(0.0)	0(0.0)
		Liris sp	28(1.3)	5(0.3)	5(0.6)	1(0.2)	8(0.8)	8(1.0)	8(1.2)	7(1.4)
		Cerceris sp	37(1.7)	4(0.3)	6(0.7)	3(0.6)	31(3.0)	2(0.3)	3(0.4)	5(1.0)
		Tachysphex sp	8(0.4)	4(0.3)	2(0.2)	3(0.6)	3(0.3)	4(0.5)	8(1.2)	4(0.8)
	Braconidae	*Iphiaulax varipalpis*	15(0.7)	0(0)	2(0.2)	0(0.0)	14(1.4)	5(0.7)	2(0.3)	0(0.0)
		Iphiaulax sp	3(0.1)	0(0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
		Cotesia sp	10(0.4)	3(0.3)	2(0.2)	10(2.1)	1(0.1)	11(1.4)	0(0.0)	2(0.4)
	Formicidae	*Camponotus sp ants*	7(0.3)	3(0.3)	5(0.6)	0(0.0)	1(0.1)	3(0.4)	3(0.4)	0(0.0)
	Andrenidae	*Andrena sp*	9(0.4)	5(0.3)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
	Chrysididae	*Hedychridium sp*	10(0.4)	9(0.6)	4(0.5)	0(0.0)	10(1.0)	9(1.2)	0(0.0)	1(0.2)

	Chalcididae	*Dirrhinus sp*	37(1.7)	35(2.3)	27(3.4)	3(0.6)	21(2.1)	10(1.3)	11(1.6)	10(2.0)
	Pieridae	*Catopsilia florella*	11(0.5)	21(1.4)	6(0.7)	0(0.0)	7(0.7)	14(1.8)	8(1.2)	5(1.0)
		Eurema lecabe	5(0.2)	2(0.1)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Lepidoptera	Nymphalidae	*Acraea eponina*	0(0.0)	9(0.6)	1(0.1)	0(0.0)	1(0.1)	4(0.5)	0(0.0)	0(0.0)
		Phalanta phalantha	5(0.2)	1(0.1)	0(0.0)	0(0.0)	2(0.2)	6(0.8)	4(0.6)	0(0.0)
		Amauris niAMius	0(0.0)	8(0.5)	6(0.7)	0(0.0)	1(0.1)	1(0.1)	4(0.6)	0(0.0)
	Lycaenidae	*Anthene amarah*	0(0.0)	0(0)	0(0.0)	0(0.0)	2(0.2)	1(0.1)	3(0.4)	0(0.0)
		Lolaus bolissus	1(0.1)	1(0.1)	0(0.0)	1(0.2)	2(0.2)	12(1.6)	2(0.3)	3(0.6)
	Noctuidae	*Egybolis Vaillantina*	52(2.3)	3(0.2)	20(2.5)	1(0.2)	13(1.3)	4(0.5)	3(0.4)	0(0.0)
	Pterophoridae	Plume moth	4(0.2)	10(0.7)	2(0.2)	0(0.0)	0(0.0)	0(0.0)	4(0.6)	0(0.0)
	Ethmiidae	*Ethmia sp*	9(0.4)	20(1.3)	2(0.2)	3(0.6)	0(0.0)	12(1.6)	7(1.0)	10(2.0)
	Pyralidae	*Eldana sp*	7(0.3)	2(0.1)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
	Saturnnidae	Wild silkmoth	6(0.3)	4(0.3)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Hemiptera	Pentatomidae	Assassin bug	6(0.3)	11(0.7)	4(0.5)	0(0.0)	5(0.5)	1(0.1)	2(0.3)	0(0.0)
	Flatidae	*Paranotus sp*	19(0.8)	24(1.6)	9(1.1)	0(0.0)	26(2.5)	17(2.2)	13(1.9)	8(1.6)
		Paranotus rufigineus	23(1.0)	12(0.8)	2(0.2)	4(0.8)	13(1.3)	1(0.1)	2(0.3)	3(0.6)
	Cicadellidae	*Euscelis sp*	2(0.1)	9(0.6)	5(0.6)	4(0.8)	4(0.4)	1(0.1)	1(0.1)	1(0.2)
Diptera	Syrphidae	*Senaspis sp*	15(0.7)	15(1.0)	38(4.7)	0(0.0)	1(0.1)	6(0.8)	37(5.4)	5(1.0)
		Eristalis sp	12(0.5)	17(1.1)	26(3.2)	0(0.0)	6(0.6)	4(0.5)	119(17.3)	2(0.4)
	Bombyliidae	*Exoprosopa rubescens*	4(0.2)	16(1.0)	69(8.6)	3(0.6)	1(0.1)	11(1.4)	14(2.0)	5(1.0)
		Bombylius sp	30(1.3)	38(2.5)	63(7.8)	2(0.4)	0(0.0)	3(0.4)	34(5.0)	8(1.6)
	Sarcophagidae	*Sarcophaga sp*	21(0.9)	8(0.5)	9(1.1)	8(1.6)	20(2)	9(1.2)	1(0.1)	9(1.8)
	Muscidae	*Musca domestica*	16(0.7)	30(2.0)	14(1.7)	8(1.6)	7(0.7)	26(3.4)	14(2.0)	6(1.2)
	Tachinidae	*Tachnids sp*	23(1.0)	14(0.9)	6(0.7)	5(1.0)	0(0.0)	0(0.0)	1(0.1)	1(0.2)
	Rhagionidae	*Rhagio sp*	0(0.0)	3(0.2)	10(1.2)	5(1.0)	0(0.0)	0(0.0)	1(0.1)	0(0.0)
	Calliphoridae	*Stomorhina sp*	7(0.3)	17(1.1)	15(1.9)	0(0.0)	9(0.9)	6(0.8)	8(1.2)	4(0.8)
Psocoptera	Psocidae	*Trichadenotecnum sp*	0(0.0)	0(0.0)	8(1.0)	1(0.2)	0(0.0)	0(0.0)	0(0.0)	0(0.0)
Coleoptera	Chrysomelidae	*Aspidimorpha sp*	0(0.0)	0(0.0)	0(0.0)	0(0.0)	4(0.4)	6(0.8)	0(0.0)	0(0.0)
		Leaf beetles	8(0.4)	8(0.5)	0(0.0)	0(0.0)	5(0.5)	19(2.5)	0(0.0)	5(1.0)
	Anobiidae	*Stegobium sp*	0(0.0)	11(0.7)	0(0.0)	0(0.0)	0(0.0)	8(1.0)	0(0.0)	0(0.0)
	Carabidae	*Calosoma sp*	15(0.7)	35(2.3)	0(0.0)	0(0.0)	0(0.0)	9(1.2)	0(0.0)	0(0.0)
	Staphylinidae	Rove beetles	10(0.4)	25(1.6)	5(0.6)	0(0.0)	5(0.5)	15(2.0)	2(0.3)	0(0.0)
	Lampyridae	*Luciola sp*	54(2.4)	330(21.6)	16(2.0)	6(1.2)	13(1.3)	156(20.3)	9(1.3)	0(0.0)
Neuroptera	Chrysopidae	*Italochrysa sp*	0(0.0)	8(0.5)	8(1.0)	0(0.0)	1(0.1)	1(0.1)	1(0.1)	2(0.4)
	Myrmeleontidae	*Myrmeleon sp*	0(0.0)	4(0.3)	4(0.5)	0(0.0)	5(0.5)	8(1.0)	0(0.0)	0(0.0)

Summary of the relative abundance in number and percentage, species richness and species dominance of insect taxon within and between each site, based on SIMPLER analysis of count data recorded during the survey period (2013-2014) in mangroves forest of Nyeke and Michamvi sites, four mangroves tree species was observed, BG, CT, AM and RM. **Note** : The value without bracket are the number of insect taxa and with breacket are percentage

Table 6.3 Number of orders, families and species (taxon) by site and mangroves sp.

Order	**Family**	**Number of insect taxon in Nyeke site**				**Number of insect taxon in Michamvi site**			
		BG	**CT**	**AM**	**RM**	**BG**	**CT**	**AM**	**RM**
Hymenopteran	Apidae	6	6	6	6	6	6	6	6
	Mengachilidae	1	1	1	0	1	1	1	1
	Halictidae	3	3	3	2	3	3	2	2
	Vespidae	5	6	4	3	5	5	2	6
	Ichneumonidae	1	1	1	1	1	1	1	1
	Scoliidae	2	2	2	0	1	1	2	1
	Eumenidae	3	2	3	0	3	3	2	0
	Sphecidae	7	7	6	4	7	6	4	5
	Braconidae	3	1	2	1	2	2	1	1
	Formicidae	1	1	1	0	1	1	1	0
	Andrenidae	1	1	0	0	0	0	0	0
	Chrysididae	1	1	1	0	1	1	0	1
	Chalcididae	1	1	1	1	1	1	1	1
Lepidoptera	Pieridae	2	2	1	0	1	1	1	1
	Nymphalidae	1	3	2	0	3	3	2	0
	Lycaenidae	1	1	0	1	2	2	2	1
	Noctuidae	1	1	1	1	1	1	1	0
	Pterophoridae	1	1	1	0	0	0	1	0
	Ethmiidae	1	1	1	1	0	1	1	1
	Pyralidae	1	1	0	0	0	0	0	0
	Saturnnidae	1	1	0	0	0	0	0	0
Hemiptera	Pentatomidae	1	1	1	0	1	1	1	0
	Flatidae	2	2	2	1	2	2	2	2
	Cicadellidae	1	1	1	1	1	1	1	1
Diptera	Syrphidae	2	2	2	0	2	2	2	2
	Bombyliidae	2	2	2	2	1	2	2	2
	Sarcophagidae	1	1	1	1	1	1	1	1
	Muscidae	1	1	1	1	1	1	1	1
	Tachinidae	1	1	1	1	0	0	1	1
	Rhagionidae	0	1	1	1	0	0	1	0
	Calliphoridae	1	1	1	0	1	1	1	1
Psocoptera	Psocidae	0	0	1	1	0	0	0	0
Coleoptera	Chrysomelidae	1	1	0	0	2	2	0	1
	Anobiidae	0	1	0	0	0	1	0	0
	Carabidae	1	1	0	0	0	1	0	0
	Staphylinidae	1	1	1	0	1	1	1	0
	Lampyridae	1	1	1	1	1	1	1	0
Neuroptera	Chrysopidae	0	1	1	0	1	1	1	1
	Myrmeleontidae	0	1	1	0	1	1	0	0
Total number of taxon		**60**	**64**	**55**	**31**	**55**	**58**	**47**	**41**

Key= *Rhizophora mucronata* (RM), *Bruguiera gymnorhiza* (BG), *Ceriops* tagal (CT) *and Avicennia marina (*AM)

6.5 Discussion

Results obtained in this study show that the abundance of pollinators was higher in Nyeke compared to Michamvi forest (Table 6.1). A possible explanation for this observation could be the distance of these forests from the source of pollinators. Nyeke is just a few kilometers from a conservation area, Jozani National Park, and it is surrounded by fruit trees. Michamvi forest on the other hand is more than 20 kilometers from Jozani National Park and is surrounded by an area with few fruit trees. A research study conducted by Klein *et al.* (2007) revealed that, pollinator abundance and species richness depends on the distance from the forest. Their finding concurs with those of this findings study and is in agreement with the island biogeography theory. Nyeke mangroves forest was likely to receive more pollinators from Jozani conservation area than Michamvi which is further away from the latter. Therefore distance to forest might increase or decreases pollinator abundance and species richness. Additionally, Nyeke forest is close to farms where vegetables and fruit trees like mango, citrus, Avocado, sweet soap, Dorian, guava are grown. Michamvi on the other hand is surrounded by very few fruit trees. Scriven *et al.* (2013) found that, improving the diversity of flowering plants within certain pre-existing habitats has a significant effect on the number of pollinators.

This study found that Orders Diptera and Hymenoptera were the most abundant in both sites. However Nyeke study site showed relative high abundance of wasp's, ants and bees but many dipterans were found in *Avicennia marina* at Michamvi. These results agree with those of Corlett (2004) who found that hymenopterans (wasps, ants and bees) comprise the largest and most diverse group of pollinators. Other factors may determine the composition of pollinators visiting a plant species. These include amount of food resources, competition, flower morphology and flowering time. A study by Willmer (2011) reported that, flower colour effect plant pollinators, and many dipterans either prefer to visit yellow or white flowers (Menzel and Shmida

1993; Kevan and Backhaus 1998). In the present study, the colour of *Avicennia marina* which is bright yellow may have attracted the many dipterans.

The study found that the months of November, December and January recorded highest number of insect flower visitors and visiting frequency. Also species richness varied from month to month. Month and weather affects insect assemblages, nectarine and breeding (McCall and Primack, 1992; Brown and Schmitt, 2001). Results obtained in this study are similar to those obtained by Scriven *et al.* (2013) who found that different taxa of pollinators were present at different times of the year. Large numbers of fly species *Senaspis* sp, *Eristalis sp*, *Exoprosopa rubescens* and *Bombylius sp* were observed in *Avicennia marina*; the assumption is that the flower morphology of *Avicennia marina* and access of flies' mouth parts to nectar is compatible.

Abundance and diversity of pollinators were signficantly different in the two study sites. In Nyeke *Bruguiera gymnorhiza* had the highest mean abundance compared to *Avicennia marina*, *Ceriops* tagal and *Rhizophora mucronata*. On the other hand, in Michamvi, the species of mangroves did not differ signficantly in mean numbers of pollinators, flower visits and visitors.

CHAPTER SEVEN: EFFECT OF POLLINATION ON FLOWER ABORTION, FRUIT SET AND FRUIT PRODUCTION IN FOUR MANGROVES SPECIES

7.1 Introduction

Although it is generally accepted that pollinators are important in fruit formation it is important to understand exactly how this happens. The effectiveness of pollinators can be determined by the number of fruits set and fruit produced. There is no information on the role of pollinator in fruit set and fruit production in mangroves of Zanzibar. Therefore, this study investigated the effect of pollination on flowers and fruit set in four species of tropical mangroves in Zanzibar. These findings will provide baseline information for further research and make desirable additional information on the biology of pollination in mangroves ecosystem in East Africa and globally**.**

7.2 Materials and methods

7.2.1 Field experiments

Mangroves trees of *Rhizophora mucronata, Bruguiera gymnorhiza, Ceriops tagal and Avicennia marina* were selected randomly in Nyeke and Michamvi forests. Precaution was taken to ensure that all selected tree branches were of about the same size. Plants with dry branches or those which showed symptoms of diseases or pest attack were excluded. The height of selected trees was approximately 3.5m. In of the two sites 80 trees (20 trees per specie) were randomly selected and on each tree four reproductive branches were selected and tagged. Mature flowers free from diseases, pest and malformation were selected for use in this experiment. Four treatments were established on flowers of the selected branches. The treatments were: open pollination (control), open plus hand cross pollination (pollen supplement), closed self-pollination (bagged), and closed plus hand cross pollination (bagged supplement). The experiment was carried out during peak period of flowering for each of the mangrove species. Sterile camel brush was used to transfer mature sticky pollen grains to the stigma. Hand cross pollination was carried out between flowers (pollen) from the same tree mixed with flowers of separate trees without emasculation. In all treatments an odourless jelly or grease was applied to the tagged branches to prevent and deter ants, spiders, snakes and crustaceans from disturbing the experiments.

Bagged and open treatments were regularly (checked twice a week) and the number of flowers formed, number of flowers aborted was recorded. The time for monitoring was dependent on low and high tides of sea. Generally, observation for this experiment was done in the morning, from 6.00 am to 10.00 am, because most flowers were found open at this time. Observations were carried out throughout peak periods of six months from September 2013 to February 2014 depending on mangroves species. After the flowering period, the number of fruits set was monitored. The number of fruits aborted was also recorded. The extent of flower and fruit abortion was determined by observing and recording wilting and subsequent falling of flowers and fruits. For *Rhizophora mucronata, Bruguiera gymnorhiza*, *Ceriops tagal* observations period was 6 months and *Avicennia marina* was 5 months. The data collection sheet included: date, sites, mangroves species, treatments, percentage number of buds, number of flowers, number of flowers aborted, number of fruits aborted and number of fruits set:

i. Open pollination (control): open natural pollination was conducted by leaving inflorescences open for free access by all vertebrate pollinators, invertebrate pollinators, and self- and wind pollination. In each treatment, the selected branches were tagged when still in their bud stage.

ii. Open and hand cross pollination (pollen supplement): In this treatment the inflorescences were left open for free access by pollinators. Thus pollination included self, cross (autogamous and geitonogamy) and wind pollination. In addition, pollen grain from three trees at least 5 m away (cross fertilization/allogamy), was used to supplement pollination, by brushing anthers gently across stigmas of experimental flowers during peak flowering period. The selected branches were tagged when flower were still in their bud stage.

iii. Closed self-pollination (bagged): In this treatment selected branches were enclosed in bags of fine nylon mesh gauze (10 µm) to exclude pollination by insects, bats, and birds with little wind influence (Plate 7.1). The selected branches were tagged when the flowers were still in their bud stage.

iv. Hand closed cross pollination (bagged supplement): The selected reproductive branches of mangroves were enclosed in a plastic bag with mesh pores measuring 10 µm sizes in order to prevent small insects, birds and bats from entering, and limiting penetration of wind borne pollen (Plate 7.2). This experiment was conducted to investigate how cross pollination could be used to supplement self-fertilization. Manual cross pollination was done by collecting pollen from donor flowers with fine sterilized forceps and rubbing the pollen grains across the stigmas of receiving flowers using camel brushes.

Plate 7.1: Bagging *on A. marina*

Plate 7.2: Bagged supplement front and bagged on *C. tagal*

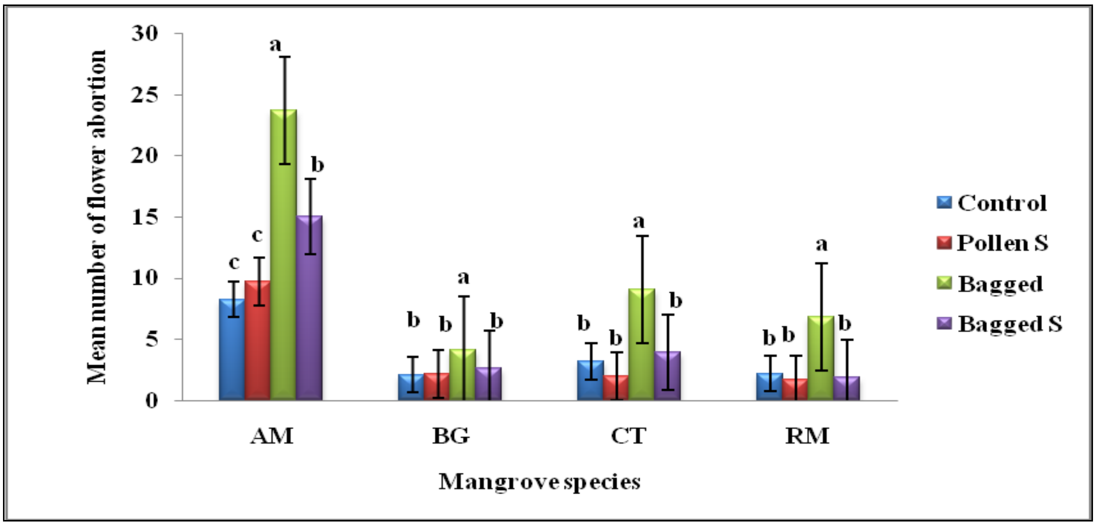
7.2.2 Statistical analysis

For all statistical analysis Proc GLM SAS version 9.3 (SAS Institute 2012, Cary, NC) was used. ANOVA test was used to compare different treatments, species and sites. Significant variation were compared at 95% (α= 0.05). Post-hoc test SNK (Student Newman Keuls) ($p < 0.05$) was to separate the means.

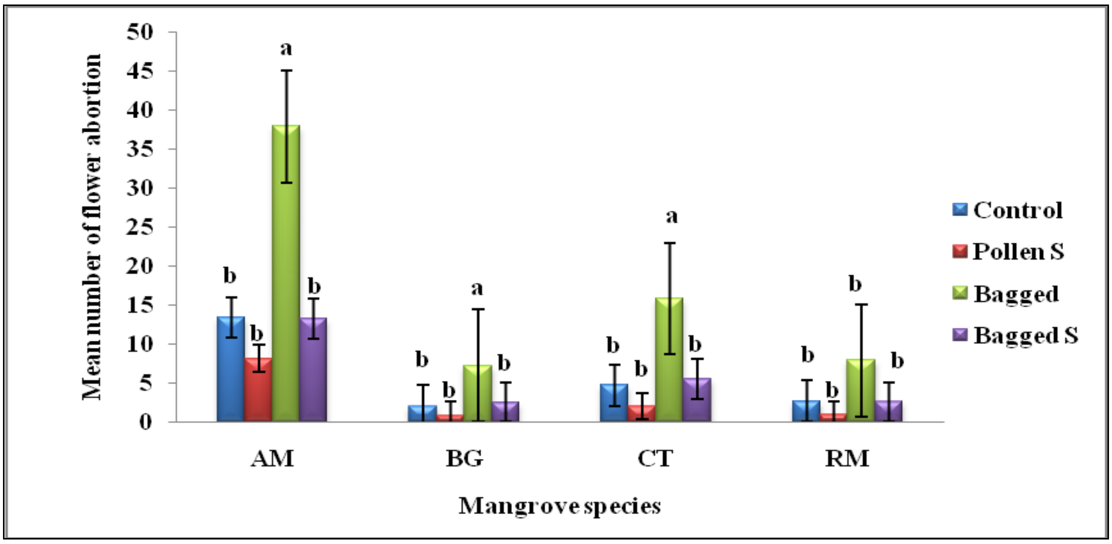
7.3 Results

7.3.1 Flower abortion

Results showed that the mean number of aborted flowers differed significantly among the four mangroves species and treatments (d.f = 15, F=10.45, $P < 0.0001$) (Fig. 7.1a and b). Results of effects of treatment on flower abortion are shown in Figure 7.1. Regardless of site or species, bagged (without pollen supplement) experiment had the highest flower abortion.



4 **Figure 7.1a. Mean number (± SE) of aborted flower in Nyeke forest.** Means with different letters within a species are significant different ($P \leq 0.05$) (n= 196).



5 Figure 7.1b. Mean number (± SE) of aborted flower in Michamvi forest. Means with different letters within a species are significant different (P ≤ 0.05) (n= 196).

7.3.2 Fruit set

The results show that the number of fruits set differed significantly among mangrove species and treatments (d.f = 15, F=9.48, P< 0.0001) (Fig. 7.2a). Generally fruit set in Nyeke was the highest in the control experiment followed by open pollination with supplement, bagged with supplement and bagged treatments respectively (Fig. 7.2a). In Michamvi forest, fruit set was highest in open pollination with supplement (Fig. 7.2b).

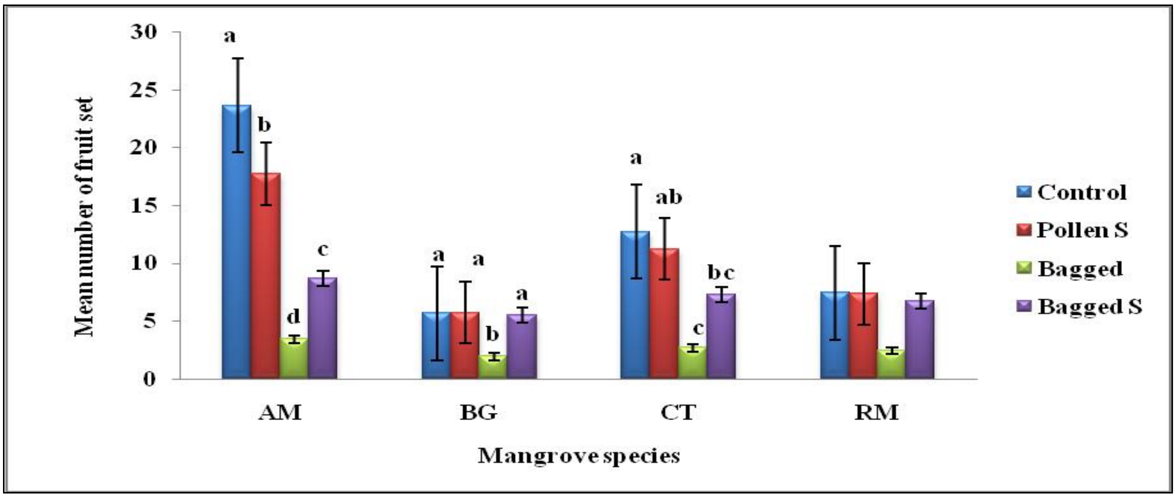


Figure 7.2a. Mean number (± SE.) of fruits set in Nyeke forest. Means with different letters within a species are significant different (P ≤ 0.05) (n= 196).

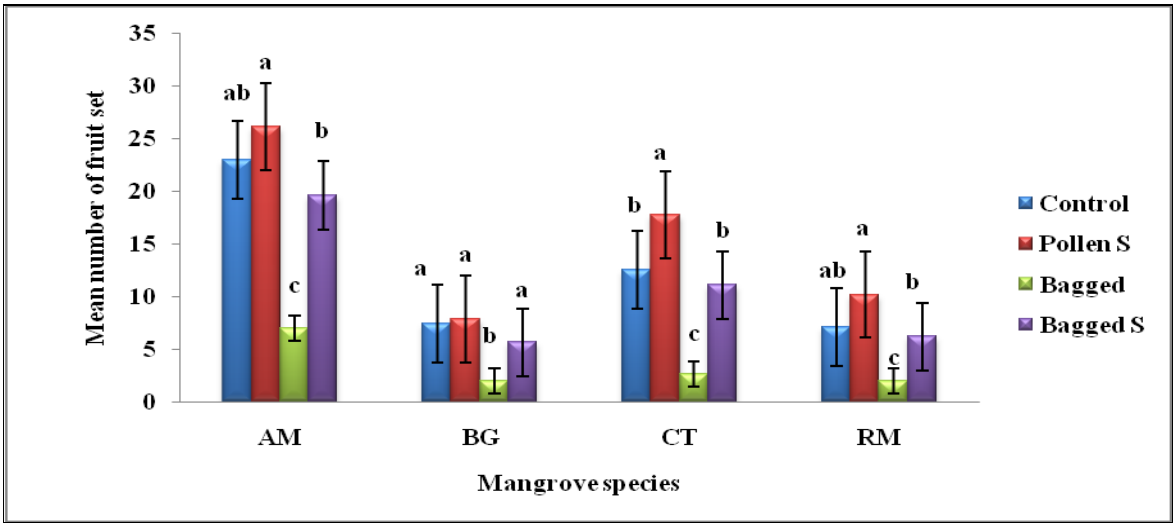


Figure 7.2b. Mean number (± SE.) of fruist set in Michamvi forest. Means with different letters within a species are significant different (P ≤ 0.05) (n= 196)

7.3.3 Fruit abortion

There were significant differences in the mean number of fruits aborted among mangroves species and treatments (d.f = 15, F= 5.85, P< 0.0001) (Fig 7.3). The mean numbers of fruit abortion in Nyeke did not differ among treatments except in *A. marina* where it was significantly less in bagged treatment (Fig. 7.3a). On the other hand open pollinated flowers with pollen supplement had the highest fruit abortion in Michamvi forest (Fig. 7.3b).

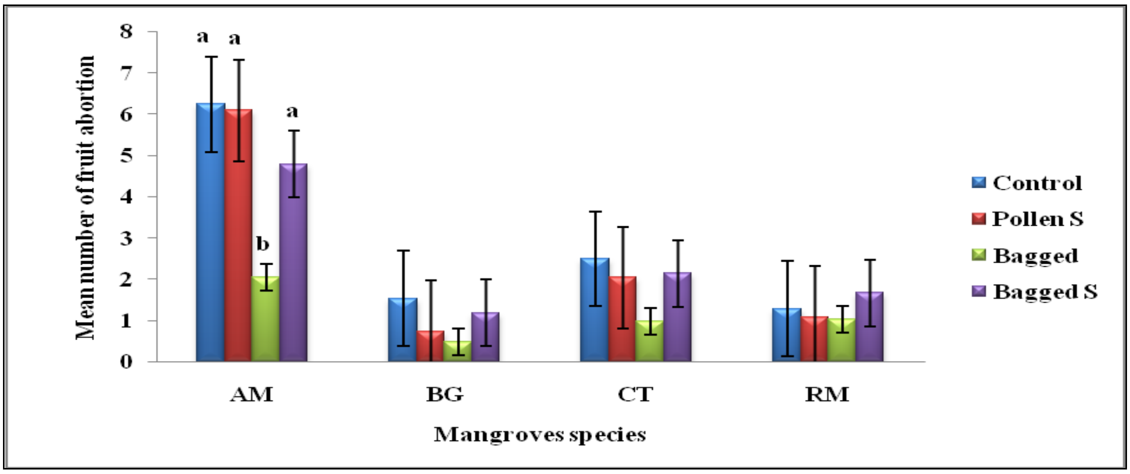


Figure 7.3a Mean number (± SE) of fruits aborted in Nyeke forest. Means with different letters within a species are significant different (P ≤ 0.05) (n= 196).

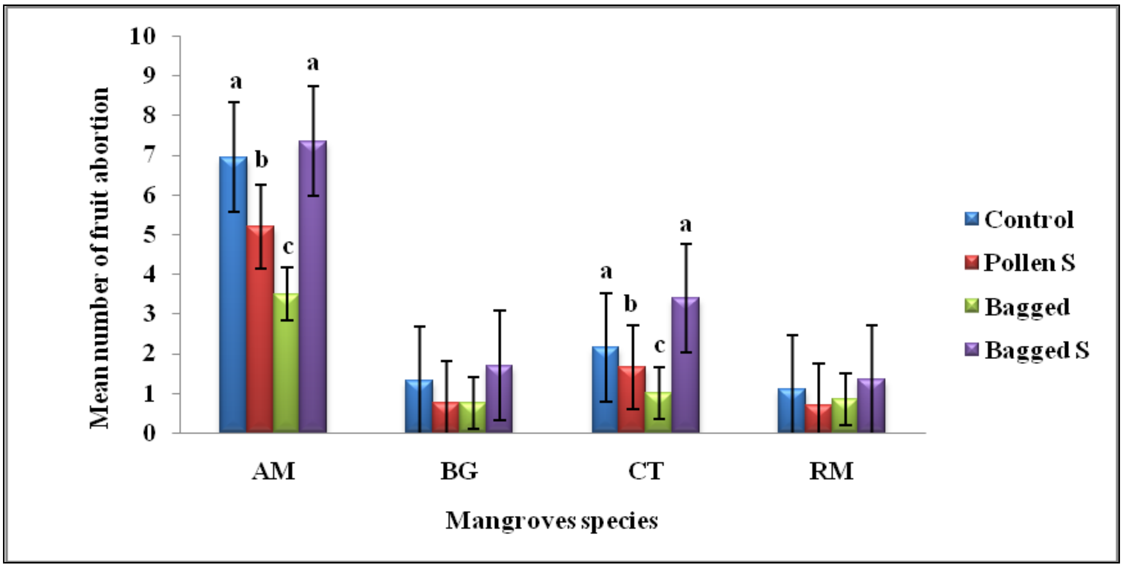


Figure 7.3b Mean number (±SE) of fruits aborted in Michamvi forest. Means with different letters within a species are significant different (P ≤ 0.05) (n= 196).

7.3.4 Fruit production

In Nyeke forest the highest number of fruit set was recorded in control and pollen supplement treatments (Table 7.1, Fig. 7.4a). The least number of fruit set was recorded in the bagged treatment. In Michamvi forest the highest fruit production was in the control and pollen supplement treatments (Table 7.1, Fig. 7.4b).

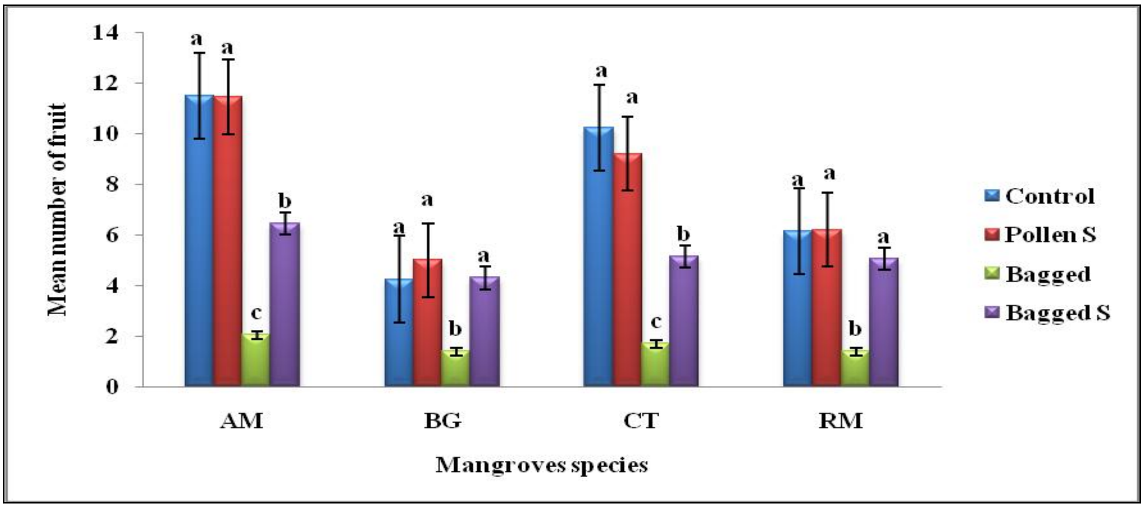


Figure 7.4a.The mean (±SE) number of fruits produced in Nyeke forest. Means letters within a species are significant different (P ≤ 0.05) (n= 196).

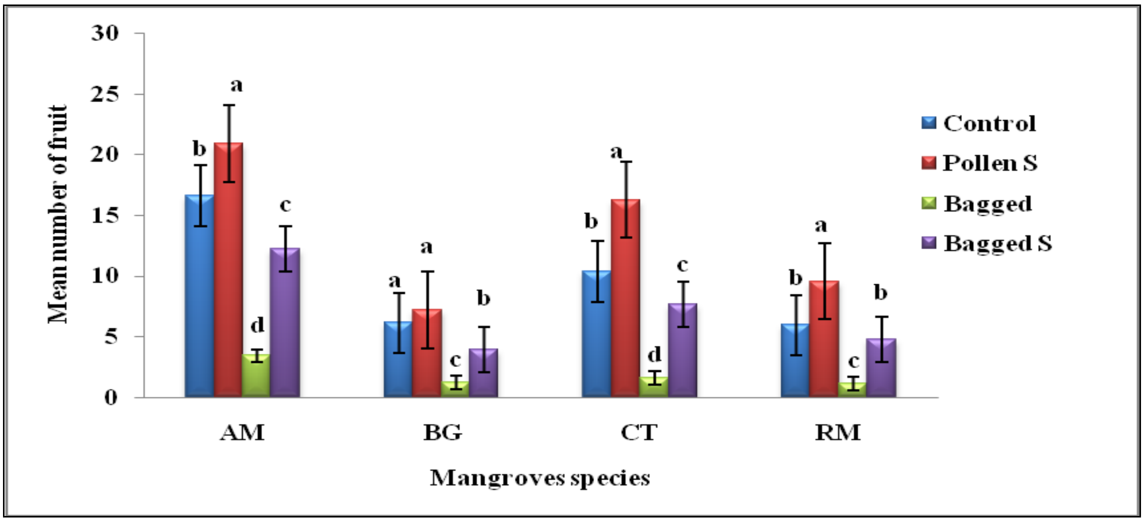


Figure 7.4b. The mean (±SE) number of fruits produced in Michamvi forest. Means with different letters within a species are significant different (P ≤ 0.05) (n= 196).

Table 7.1. Percentages of flowers aborted, fruits set, fruits abort and fruits procuded by site

Mangroves	Treatments	Forest sites

		Nyeke mangrove forest				Michamvi mangrove forest			
		Flowers aborted (%)	Fruits set(%)	Fruits aborted(%)	Fruits produced(%)	Flower aborted(%)	Fruits set (%)	Fruits aborted(%)	Fruit produced (%)
Avicennia marina	Control	20	63	19	28	35	56	17	41
	Pollen S	28	60	17	33	31	67	13	53
	Bagged	64	9	6	6	78	14	7	7
	Bagged S	45	26	14	19	37	55	20	34
Bruguiera gymnorrhiza	Control	28	62	17	46	21	76	13	62
	Pollen S	23	76	10	66	10	88	8	80
	Bagged	56	28	7	10	75	20	8	10
	Bagged S	30	64	14	50	30	67	23	47
Ceriops tagal	Control	18	76	17	62	27	71	12	57
	Pollen S	13	73	14	59	10	89	8	77
	Bagged	71	25	8	6	83	14	5	8
	Bagged S	32	59	14	42	32	65	18	45
Rhizophora mucronata	Control	22	75	13	62	26	69	11	57
	Pollen S	18	77	12	65	9	89	6	84
	Bagged	66	24	10	4	76	15	9	6
	Bagged S	21	74	18	55	29	69	15	54

7.3.5. Interaction between flower abortions, fruit set, fruit abortion and fruit production of four mangrove species and sites.

Summary of interaction of flower abortion, fruit set, fruit abortion and fruit production is shown in Table 7.2. There were variation on interaction between flower abortion, fruit set, fruit abortion and fruit on four mangrove species and sites ($P < 0.0001$) (Table 7.2). The treatments showed that the mean number of aborted flowers were significant different. In *A. marina* it was observed that high number of flowers aborted in bagged treatment in both sites compared to other species. Michamvi recorded the highest abortion of 29% than Nyeke of 18%. The least number of flower abortions were recorded 6% in pollen supplement in Michamvi and control treatment in Nyeke. In contrast, in *B. gymnorrhiza*, the bagged treatment recorded highest abortions and are significantly different from other species. Likewise, high number of fruit abortion in *C. tagal* were found in bagged in Michamvi (34%) and was significantly different from other species. Correspondingly, the *R. mucronata* in bagged experiment have shown to produced high number of fruit abortion, while pollen supplement was observed the least than other species.

Table 7.2. Summary of interaction between flower abortion, fruit set, fruit abortion and fruit production for four mangrove species and sites.

Interaction effects		**The mean values**			
Mangrove species	**Sites and Treatments**	**flower abortion**	**fruit set**	**fruit abortion**	**fruit**
A. marina	Michamvi Bagged	37.95a (29)	6.95cd (5)	3.50cd (8)	3.45e (4)
	Michamvi Bagged S	13.30c (10)	19.60b(15)	7.35a (17)	12.25c(14)
	Michamvi Control	13.45c (10)	22.95ab18	6.95a (16)	16.60b(20)
	Michamvi Pollen S	8.15d (6)	26.15a(20)	5.20bc(12)	20.90a(25)
	Nyeke Bagged	23.70b (18)	3.45d (3)	2.05d (5)	2.05e (2)
	Nyeke Bagged S	15.00c (12)	8.70c(7)	4.80bc(11)	6.45d (8)
	Nyeke Control	8.25d (6)	23.65ab(18)	6.25ab(15)	11.50c(14)
	Nyeke Pollen S	9.75dc (8)	17.75b (14)	6.10ab(14)	11.45c(14)
B. gymnorrhiza	Michamvi Bagged	7.25a (31)	1.95b (5)	0.75 (9)	1.25c (4)
	Michamvi Bagged S	2.55b (11)	5.65ab (14)	1.70 (20)	3.95b (12)
	Michamvi Control	2.10b (9)	7.45a (18)	1.30 (15)	6.15ab(18)
	Michamvi Pollen S	0.90b (4)	7.90a (19)	0.75 (9)	7.20a (21)
	Nyeke Bagged	4.10ab (17)	1.94b (5)	0.50 (6)	1.40c (4)
	Nyeke Bagged S	2.60b (11)	5.50ab (13)	1.20 (14)	4.30b (13)
	Nyeke Control	2.10b (9)	5.70ab (14)	1.55 (18)	4.25b (13)
	Nyeke Pollen S	2.15b (9)	5.75ab (14)	0.75 (9)	5.00ab(15)
C. tagal	Michamvi Bagged	15.85a (34)	2.60d (3)	1.00b (6)	1.60e (3)
	Michamvi Bagged S	5.55bc (12)	11.10bc(14)	3.40a (21)	7.70c (12)
	Michamvi Control	4.75bc (10)	12.55b (16)	2.15ab(14)	10.40b(17)
	Michamvi Pollen S	2.05c (4)	17.75a (23)	1.65 b (10)	16.26a(26)
	Nyeke Bagged	9.10b (20)	2.70d (3)	1.00b (6)	1.70e (3)
	Nyeke Bagged S	3.95c (9)	7.30c (9)	2.15ab(14)	5.15d (8)
	Nyeke Control	3.20c (7)	12.75b (16)	2.50ab(16)	10.25b(16)
	Nyeke Pollen S	2.00c (4)	11.25b (14)	2.05a (13)	9.20bc(15)
R. mucronata	Michamvi Bagged	7.90a (29)	1.95b (4)	0.85 (9)	1.15c (3)
	Michamvi Bagged S	2.60bc (10)	6.20ab (13)	1.35 (15)	4.80b (12)
	Michamvi Control	2.70bc (10)	7.10a (14)	1.10 (12)	5.95b (15)
	Michamvi Pollen S	1.00c (4)	10.20a (21)	0.70 (8)	9.55a (24)
	Nyeke Bagged	6.80ab (25)	2.45b (5)	1.05 (12)	1.40c (3)
	Nyeke Bagged S	1.89c (7)	6.73ab (14)	1.68 (18)	5.05b (13)
	Nyeke Control	2.20bc (8)	7.45a (15)	1.30 (14)	6.15b (15)
	Nyeke Pollen S	1.70c (6)	7.35a (15)	1.10 (12)	6.20b (15)
	SE	1.72	1.61	0.64	0.91
	P Values	<.0001	<.0001	<.0001	<.0001

Means number (± SE) followed by the different letters are significantly different at P < 0.05). The number in brackets are percentages. (n= 392).

7.4 Discussion

In all four mangrove species, bagged experiment showed a high percentage of flower and fruit abortion and lowest number of fruits produced compared to other treatments. These results are similar to those obtained by Tomlinson *et al.* (1979)

who reported a threefold increase in fruit set in open cross hand pollination treatment in *Rhizophora mangle* compared to self-pollinated treatment. The lower percentages of fruits set and fruit produced could be attributed to the exclusion of pollinators resulting in decrease in the number of fertilized flowers and the subsequent reduced fruit emergence. These results agree with those of Coupland *et al*. (2006). Also, fruit set in bagged treatment of *A. marina* in south eastern Australia reported similar results; produced few numbers of fruits than unbagged or control (Clarke and Myerscough, 1991, Clarke, 1992).

In Michamvi forest fruit set was highest in the open plus supplement treatments while in Nyeke it was highest in the control. This indicates that there could be pollinator limitation in Michamvi. Nyeke is close to Jozani conservation area and near cultivated farms and both could be the source of pollinators. Michamvi on the other hand is more than 20 km from Jozani thus explaining why pollen supplement boosted pollination and the subsequent fruit production. This further shows that plants can compensate fertilization through hand cross pollination. In addition bagged experiments had high rates of flowers abortion compared to the control and pollen supplemented treatments. This could mean that effects of lack of pollination start much earlier before fruit set. Thus the cause of reduced number of fruits is a combination of flower and fruit abortion.

It is also possible that plant ability to supply adequate resources such as nutrients to sustain fruit growth plays a role in fruit abortionElsewhere in this study it was found that there was young and mature fruits in CT, RM and BG throughout the year. This is likely to affect the number of fruits set and may be indirectly associated with fruit abortion. This finding agrees with that of Stephenson *et al.* (1988a and 1988b) and Bangerth (1989) that, the existence of emerging and mature fruits can inhibit subsequent fruit set and growth of a young fruits. This inhibition could be triggered by antagonism for available assimilates, by dominance due to production of plant growth regulators from the developing fruit (Tamas *et al.*, 1979; Stephenson *et al.*, 1988b; Bangerth, 1989). Thus this study has established that cross pollination is an important factor in fruit production and subsequent regeneration of mangroves.

CHAPTER EIGHT: GENERAL DISCUSSION, CONLUSIONS AND RECOMMENDATIONS

8.1 General discussion

8.1.1 Floral Phenology

In this study, floral phenology was used to refer to the timing of reproductive events including bud production, flowering, and fruit set and fruit formation. Understanding floral phenology may help us to understand how human activities may affect plant reproduction. This study sought to provides basic information on floral phenology of four mangroves species from two study sites, Michamvi and Nyeke mangrove forests, in Zanzibar. This is the first detailed study on the phenology of four major mangroves existing in Zanzibar. Previous phenological studies were mainly on agricultural crops and forest trees but mostly reported on reproduction cycles on monthly bases (Morellato *et al.,* 2000; Rivera and Borchert, 2001; Fuchs *et al.*, 2003; Borchert, 2005; Nadia *et al.*, 2012). The study was designed to generate knowledge that would be used in the development of Zanzibar environmental strategic conservation plan for coastal marine biodiversity.

Results obtained from this study showed that phenological patterns vary among mangrove species and between sites. The study found that *Rhizophora mucronata, Bruguiera gymnorrhiza* and *Ceriops tagal* produce buds, flowers and fruits throughout the year with the exceptional of few weeks. *Avicennia marina* on the other hand, produced for seven month between the last week of September and the first week of May. Peak reproduction season was in dry period between mid-

October and March for all four species in both sites. Therefore, it is safe to conclude that reproduction cycle for most mangrove species is continuous.

Although, the phenological variations between the two sites were significant, it was not large. This is because the two sites are situated in southern region of the island and have similar climatic conditions. Previous study on mangrove phenology reported that, their reproduction cycles are influenced by day length, rainfall and temperature (Nadia *et al.*, 2012). Studies conducted in the Caribbean Islands reported that increased rainfall caused increase in flower production in Rhizophora *mangle* and *Lagunculatria racemosa* though it had no effect on flower production by *Avicennia germinans* (Fernandes, 1999; Sånchez-Nůńez and Pineda, 2011). Similar results were reported by Tyagi (2004) on family *Rhizophoraceae*. He reported that, there is significant variation on flowering pattern in wet and dry zone of low precipitation, with higher flower production being recorded in the dry zone. Similar results were obtained in this study as *Ceriops tagal* peak flowering and fruiting was in dry season. These findings support another study by Nadia *et al.* (2012) who reported that, dry season and high temperatures were positively related to peak fruiting time of *Ceriops erectus*. This study, it was found that rainfall and RH had no effect on bud, flower and fruit production.

8.1.2 Pollination and reproductive relationships

There was a positive relationship between number of buds and number of flowers produced in all species and sites. Relationship between number of flowers and number of fruits set was positive but weak in some mangroves spp in both sites. For example, a weak relationship between flowers and fruit set was found in *A .marina* in both sites. This indicates that the number of fruits set did not just depend on the number of flowers, but also other factors probably insect visitors and visit frequency and other, abiotic and biotic factors. Other studies suggests that *A. marina* is protandry and has a short duration of a mean of 3.3 days when individual flowers are open compared to other species of mangroves whose flowers are open for a long periods. Thus, the chances of pollination are short (Primack, 1985).

There was a positive relationship between the number of flowers and number of insect visitors, and visits in all mangroves species and sites. Therefore, the study suggested that an increase in the number of flower produced ultimately leads to an increase in the number of pollinators and indirectly the number of fruits produced. This finding corroborates results obtained by Jacobs *et al.* (2009a) who reported a positive linear relationship between the proportion of ivy flowers, *Hedera helix* (Araliaceae), and fruit set. The four mangroves species investigated in this study produced flower buds in the same periods indicating the possibility of pollinator competitions among mangroves species consequently reducing pollinator mediated relationship. Pollinator competition was also inferred from a study by Landry (2013) who found that the relationship between number of flowers, fruits set, insect visitation, and visitation rates *L. racemosa* increased significantly when *A. germinans* stopped flowering.

The relationship between fruits set and fruits produced in *C. tagal* was negative in Michamvi and no relationship was noticed in Nyeke. This shows that the number of fruits produced was not depend on the number of fruits that set. Thus, fruit production in *C. tagal* depends on other variables. Undoubtedly, soil nutrients are the major limiting factor on growth and development for many plant and tree species. Other studies have reported that plant resources play a major role in increasing or reducing fruit set and fruits in many tropical tree populations (Jones and Comita, 2008). Increases in the concentrations of N, Mg and Fe in flowers of orange trees grown in calcareous soil led to more fruit set and high maturation index (Pestana *et al.,* 2005). Competition for available assimilates is another factor that can limit fruit production. Plant hormone Auxin produced by developing fruits can inhibit growth of young fruits and subsequently falling to the ground (Bangerth, 1989).

8.1.3 Pollinator abundance and diversity

About 70 species in seven orders and 40 families were observed visiting mangroves flowers of the four common mangroves species at Nyeke and Michamvi mangroves forests. The number of species recorded in this study was high with *Ceriops tagal* recording 64 species in Nyeke and *Rhizophora mucronata* recording 31 species. The most abundant pollinator species was *Apis mellifera* and was found in all the four mangroves species and in both study sites. This observation agrees with Willmer (2011) that *Apis mellifera* is a dominant pollinator in many trees and plants. Dipteran species, *Eristalis sp,* of family Syrphidae was found mostly on *Avicennia marina.* Dipterans are attracted by the colour of the flower (Lunau and Wacht, 1994; Kelber *et al.,* 2003). This implies that there is an existence of pollination variations among mangroves trees and possibly influenced by flower morphology and colour of the flower.

In contrast, the two study sites vary significantly in the abundance and diversity of pollinators. Generally, there were more pollinators in Nyeke than in Michamvi. Most likely the reason for this scenario is the distance of the two sites from the sources of pollinators. According to Klein *et al*. (2007), there is an inverse relationship between pollinator abundance and species richness and distance from the forest, source of pollinators and is influenced by pollinator size and nesting requirements. Nyeke is about 1-3km while Michamvi is more than 25km from Jozani National Reserve forest which probably acts as the source of pollinators for these study sites. The higher number of pollinators and species diversity in Nyeke could be attributed to its closeness to Jozani National Park.

8.1.4 Effect of pollination on flower abortion, fruits set and fruit production

This experiment meant to provide insights into the importance of insect pollinators on fertilization and fruit production. In Michamvi, fruit set was significantly higher in unbagged flowers with pollen supplement whereas in Nyeke it was highest in the control. This suggests that fruit production in Michamvi may be affected by pollinators' pollen limitation. The presence of fruits in the bagged treatments indicates that the four mangroves species not only depend upon insects for pollination but also are self-pollinated. However, pollinators predation, distance from Jozani national forest, pollinators foraging behavior, floral morphology and weather are some of other factors that could have influenced fruit production. In contrast to these finding, a study by Yun Gao *et al.,* (2006) on the pollination ecology of *Paraboea rufescens***,** revealed that, self-pollinated inflorescences had the highest fruit set and compared to hand cross-pollinated open-flowers.

This study found that not all flower buds developed into fruits in the four mangroves species studied. In *A.marina,* only about of 26% of the buds developed into fruit but half of them dropped. In *R.mucronata* only 40% of buds give rise to fruits and half of them reached maturity. For the other two species, *B. gymnorrhiza* and *Ceriops tagal*, only 30% of buds reached fruit set. This indicates that many flowers were aborted or were not fertilized. This could be due to absence of pollinators during flowering, competition of mangroves species for pollinators through flower morphology and nectar. Also, it could be associated with plant resources for sustaining growth of fruits set and fruiting. This study showed that, there were variations in the relationships between explanatory and response variables among mangrove species and site. These variations of relationships could be attributed to some factors in both sites; the abundance and pollinator's species richness, pollinator's competition during nectar foraging, weather, continuing flower-fruit production, existing soil nutrients and pollinators limitation predations. In all four mangroves species the highest positive relationship was found between buds and flowers in both sites. This indicates that the number of fruit produced will depend on the conversion rate of flower buds into flowers, corroborating result by (Garner and Lovatt, 2008).

Effect of pollinators mediated relationship was reported by Landry (2013) and showed that between two mangrove species there were overlapping flowering phenologies, fruit set, insect visitation, and visitation rates. For *L. racemosa* the relationship increased significantly when *A. germinans* stopped flowering. Although, soil nutrient was not observed as limiting factors of mangrove reproductive growth and development, but soil nutrients and salinity was found to affect plant species productivity requirement and growth rates in some studies (Lambers and Pooter, 1992; Pestana *et al.,* 2005; Jones and Comita, 2008).

8.2 Conclusions

- Mangroves floral phonological patterns differed between sites and among species at weekly level. *A. marina* had the shortest reproductive cycle compared to the other species. There were reproductive period overlapping in *Ceriops tagal*, *Bruguiera gymnorhiza* and *Rhizophora mucronata*.

- For all four mangroves species the number of flowers produced depends on the number of buds produced.

- It is not very clear whether fruits set and fruits produced depend on the number of pollinators and visits since their relationship was very weak.If There could be a relationship but but is masked by other unknown limitations.

- The study confirmed that there are variations in insect flower visitors among mangroves species investigated. Mangroves species *Ceriops tagal* in Nyeke mangrove forest had the highest insect species richness compared to other species. The two study sites varied in species diversity and the abundance of individual species.

- Hyemenopteran, *Apis mellifera*, *patellapia sp* and *Hypotrigona gribodoi*; Dipteran, *Senaspis sp, Eristalis sp, Exoprosopa rubescens, Bombylius sp,* and Coleoptera *Luciola sp* were the dominant insect pollinators of the four mangroves species in this study.

8.3 Recommendations

1. There is a need to establish reproductive phonological data base to cover wide range of mangroves species in other parts of mangroves growing areas of Zanzibar.
2. It is important to conduct intensive research to get better understanding of the effects of soil and climatic variations on the phenology of mangroves and other forest and crop plant.
3. There is a need to assess effect of mangroves population densities and their reproduction cycles.
4. Other biological and non-biological factors that hinder fruit production of four mangroves species are unknown. Therefore it is important to investigate these factors.
5. There is a need to find out what causes the variation of individual insect species in relation with mangroves species
6. There is a need to assess contributing factors that make Nyeke mangroves forest to have higher number of pollinator species than Michamvi.
7. Intensive research study is required to find out the cause of high fruit abortion in four mangroves species.
8. There is need to establish sustainable restoration, conservation and monitoring of diverse pollinators communities living in these two mangroves ecosystem in Zanzibar.
9. There is need tp assess effect of mangroves forest proximity to fruit set for formed fruits and other crops.

8.4 Future prospects

Mangroves ecosystems around the world are gifted by diversity of vertebrates and invertebrates species. Unfortunately, these diversity ecosystems are currently endangered due to increases of un-planned economic investments, urbanisation due to increasing population density, increases land demand for Agricultural, unemployment in particularly in developing countries and climate change. Climate change may worsen the situation and their impact has been noticed in many part of the world. In Zanzibar, Pemba island sea water rise and Tsunami are among the effect of mangroves deforestation and climate change. In this case micro and macro fauna and flora are endangering of disruption and extinction.

Most research work on climate change were based on agriculture food security and projection on temperature rise and uneven rainfall (Al Nino and LA-Nina), whereby their impacts are directly connect with pollination ecosystem and aquatic biodiversity as whole. In East Africa research on mangroves ecosystem based on pollination services and climate change are very limited, mainly based on mapping, prediction and modeling. Climate change and destructions of mangroves ecosystems has a direct influence on pollination services, reproduction and regenerations of mangroves forests. Therefore any increases of temperature will results in direct effect of pollinator's biodiversity and species richness. Therefore further studies on mangroves pollinators' biodiversity, effect on climate change, causes of anthropogenic, macro flora and fauna and social economic activities are significant for developing policies for conservation.

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