CHAPTER 1

INTRODUCTION

1.1. General Introduction

Palms are some of the most important components of tropical and subtropical rain forests. *Nypa fruticans* (Arecaceae) is widely distributed in mangrove forests of Southeast Asia especially in the coastal area around Malaysia. *N. fruticans* is monoecious (Badve & Sakurkar, 2003) and pleonanthic. Pleonanthy refers to plants that flower at the same time as it grows vegetatively, and hapaxanthy refers to plants that flower after terminating its vegetative growth. This palm is a mangrove palm and occupies areas on muddy estuaries, river banks and littoral environments between the mangroves and other forests. In Malaysia, it is locally known as *Nipah* palm. Its inflorescence is used to make sugar, vinegar and its leaves for thatching materials (Kelvin et al., 2001). Alcohol is another product which is obtained from its sugary sap. The study of fruiting and flowering events of Nipah palm is important to understand the reproductive biology of the species population. It is also useful in determining the harvest time to maximize the products from its fruits and inflorescences. Other aspects of population study such as population structure, spatial distribution and growth and age estimation of *N. fruticans* are important factors in order to understand the ecology of palms. Arboreal or tree palms have simple growth forms, so they are perfect for demographic studies (Weiner & Corlett, 1987).

N. fruticans is a monotypic genus of the Arecaceae (or Palmae). Its fronds have characteristics of the pinnate-leaved palms (Fig.1.1).

Palms are plants with microhabitat variables such as topography, drainage, and canopy height that have strong effects on their distribution and abundance (Svenning, 1999). It has been shown that survival, growth, and reproduction are affected by site in plant populations (Berry et al., 2008). So, while palms have slow growth, studies on the effects of environmental factors on growth rate are very important and useful for future natural regeneration. Therefore in this research, we conducted a study on the population, ecology and reproductive biology of *N. fruticans* on Carey Island in Malaysia.

Fig.1.1: *N. fruticans* in Carey Island.

1.2. Study site

Carey Island or Pulau Carey is an island located to the south of Port Kelang within the Kelang Isles in Selangor, Malaysia. It is located about 70 kilometers southwest of the Malaysian capital, Kuala Lumpur. (Figure 1.2). It is separated from the Selangor coast by the Kelang River. At a total of l5000 ha in area, it is the largest island in Kelang Isles as shown in figure 1.3 and 11,700 ha of the area belongs to Sime Darby Plantation Berhad. The island is now largely planted with oil palm, and is divided into the eastern and western regions but its development is more focused on the western region (Noorma Wati Haron, 2006). *N. fruticans* is commonly found at three sites on this island, Eagle Sanctuary and Heritage Resort Real East, Wetland/Wildlife, and Tropical Forest Heritage/West Wing (Noorma Wati Haron, 2006).

Fig1.2: Carey Island (Pulau Carey) in Malaysia.

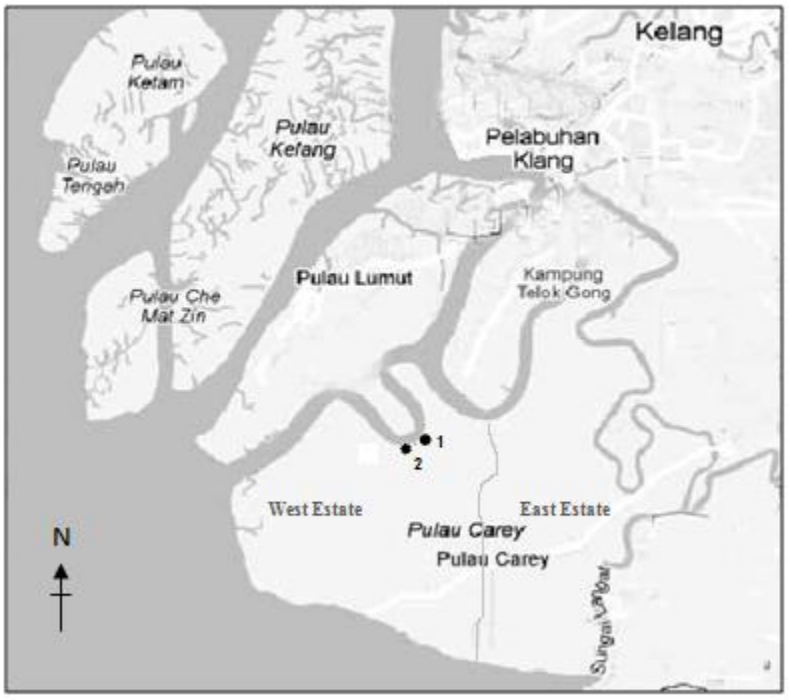


Fig 1.3: Carey Island (Pulau Carey) in Kelang Isles and location of site1 and site2.

Figure 1.3 shows the location of both study sites, site 1 (N 02º 53′ 36.41″ and E 101º 21.′ 00.67″) and site 2 (N 02º 53′ 26.9″ and E 101º 20.′ 26.8″) in the west estate of Carey Island.

1.3. Objectives

Out of the thirty-eight much endangered common palm species in Malaysia, twenty-one species are found only in the Peninsular Malaysia (Johnson, 1996). Although *N. fruticans* is not an endangered palm species, the demographic studies on this valuable palm seem necessary for the prediction of the population of this species for preventing the possible decline of this valuable palm. Information on the population of this species would play a critical role in appropriate utilization of the palm with suitable management in the future.

The objectives of this research are:

1. To investigate the population structure, dynamics and spatial distribution of *N. fruticans.*

2. To study the growth of individuals from the seedling stage to the mature stage and to estimate the age structure of the population of *N. fruticans*.

3. To study the reproductive phenology of *N. fruticans.*

4. To study soil and water quality and to assess the effects of these environmental factors on the demographic structure and the population growth.

CHAPTER 2

LITERATURE REVIEW

2.1. Ecology and distribution

The palm family (Palmae or Arecaceae) is considered as a conspicuous and important element of tropical and subtropical rain forests all over the world with great morphological diversity (Baker et al., 1999). Palms are an essential group in the rain forest in term of structure and number (Kahn & de Granville, 1992: Clark, 1994; Lieberman et al., 1996). In fact, among all palm lands of the world with 2500 - 3500 species in 210 - 236 genera (Jones, 1995), over a third of all palm lands are in the Malesian region. Over a quarter of the palm genera are in the Malaysian region with estimation of 900 species in 52 genera (Van Steenis, 1989).

Palms are considered as one of the largest families with highest economical value in the world (Howard, 2001). Among the palm species associated with mangrove flora, only *N. fruticans* is considered as a major component (Duke, 2006; Dransfield et al., 2008). Thirty-five percent of the world's mangrove forests are located in South East Asia (Alongi et al., 2004). Indo-Malaysia region has the most mangrove species with forty-eight species (Duke et al., 1998). Most of neotropical (light limited areas in tropical regions) under story palms are able to survive for a long time in deep shade environment

(Hodel, 1992), so majority of palms are understory species in the rain forest. *N. fruticans* is among the few palms that grow in mangroves (Osabor et al., 2008) but it cannot tolerate hyper saline habitats. It prefers the calm brackish water. It can be found inland; as far as the tide can leave the palm's floating seeds where the water is saline at high tide and is fresh at low tide.

N. fruticans has a wide distribution on islands and coastal areas of South East Asia, India, Myanmar, Thailand, Malaysia, Indonesia, Philippine, Ryukyu, New Guinea, the Solomon Islands and northern Australia (Joshi et al., 2006). It is widely distributed in mangrove forests of South East Asia especially in the coastal area around Malaysia. It occupies areas on muddy estuaries, environments between the mangroves and other forests, river banks such as Sungai Selangor, in western peninsular Malaysia (Khaironizam & Norma-Rashid, 2003).

N. fruticans is one of the most useful palms as a source of sugar, vinegar and alcohol. The juice or sap obtained from its inflorescence stalk is used for the production of sugar and vinegar, while its mature leaves are used to make roof thatching (Kelvin et al., 2001). Pigs feed on the sap of *N. fruticans,* so this provides protein resources for the community. (Joshi et al., 2006). *N. fruticans* is a monotypic genus, the only species in the genus, *N. fruticans,* and its own subfamily, *Nypoideae* (Dransfield et al., 2008). *N. fruticans* is monoecious palm (Badves & Sakurkar, 2003) and exhibits a colonial growth, forming thick stand or a monospecific edge along coastlines (Tomlinson, 1986). Although there are not many studies on the distribution of *N. fruticans*, few studies has been carried out. Teo et al., (2010) studied on status and distribution of *N. fruticans* in Singapore. Some other researchers have done works on ecology and distribution of *N. fruticans* (Tomlinson, 1971; Hamilton & Murphy, 1988; Gee, 2001; Joshi et al., 2006). Rozainah et al., (2002) studied spatial distribution of two wild *Arenga* (Arecaceae) in Selangor,

Malaysia. Spatial distribution studies have been done on three palm species in Costa Rica (Homier et al., 2002) showed that light gaps as the effective factor while Souza & Martin (2004) discussed that canopy openness did not influence a colonial palm, *Geonoma brevispatha* in south-eastern Brazil. While microhabitat specialization such as flooded conditions at small scales influence the random dispersion of juveniles and limited seed dispersal results in clumped juveniles (Nathan & Muller- Landua, 2000). Boll et al., (2005) examined the effects of environmental conditions such as moisture content, soil and topography condition, and dispersal limitation on distribution of the piassaba palm *Aphandra natalia* (Arecaceae) in Peru. These factors caused clumped mature trees in drier places with the concentration of immature trees around the adults. Wehncke et al.,(2010) investigated on the distribution of Blue fan palm in Mexico and they found that the main factor of seedling distribution patterns was not seed dispersal by rodents but the flooded pulses had significant effect. Edaphic factors (i.e., drainage, soil type) are the major effective factors of distribution of trees in the Costa Rica tropical forest (Lieberman et al., 1985). Johnston (1992) also mentioned that soil moisture and water content might be important factors in tree distribution. Species of *Dacryodes excelsa* and *Manilkara bidentata* are dominant in dry soils with low Ca, Mg and pH; whereas the palm *Prestoea montana* is dominant in wet soils with high Ca, Mg and pH. Variability in soil moisture is influenced by topography, soil properties, vegetation and mean moisture content (Ridolfi et al., 2003). In wet conditions, however, soil properties (porosity, hydraulic conductivity) have stronger influence on soil moisture content. Edaphic factors have impact on the distribution of palms in tropical rain forests (Peres, 1994; Clark et al., 1996; Svenning, 1999; Svenning, 2002; Loo, 2001). Svenning (1999) mentioned that microhabitat heterogeneity such as drainage and regeneration canopy which influence the genetic is important for maintenance of palm diversity.

2.2. Demography

Repeated census of the same area provides suitable data for demographic analysis such as information on survivorship, life expectation, and age structure. This permits the estimation of future population trends under similar conditions (White, 1985). Population structure and growth of palms can be used to identify the ecology of forests. Palms are trees with simple growth form (Weiner & Corlett, 1987), a single apical meristem, a continuous growth, a single leaf production in each node, a constant crown structure and an easy recognition due to morphological features (Tomlinson, 1990), which makes them perfect for demographic studies. *N. fruticans* does not have an upside stem, so growth rate of *N. fruticans* can be based on leaf production and spear elongation. Using the growth information such as leaf production, age of subjects can be estimated by determination of plastochrone (the interval between the two succeeding spear leaves). In timber trees, secondary thickening in meristem, diameter size or annual rings can be used, while for palm populations the best one is age classes. In addition, age of trees has implications in many silvicultural practices. The determination of the life span of a single leaf, which is defined as the time a single leaf enters the crown until its death, is possible by using the plastochrone. In *N. fruticans*, each new leaf has a spear shape with many linear leaflets compacted together that appears in lateral position of leaf petiole. New spear leaf continues to grow progressively. Several studies have shown a correlation between trunk height and age (Weiner & Corlett, 1987). There are many studies on demography of palms in tropical and subtropical forest in some countries such as Brazil, Mexico, North America and Peru, Colombia (Pinard & Putz, 1992; Clark et al., 1996;

Svenning, 2002; Rodrı´guez-Buritica et al., 2005; Boll et al, 2005; Widyatmoko et al., 2005; Sanchez-Velasquez & Rosario Pineda-López, 2010). The population ecology of Buriti Palm (*Mauritia flexuosa* L. f) in Brazil (Sampaio et al., 2008) was carried out.

Pe´rez-Farrera et al., (2006) carried out studies on the demography of the cycad *Ceratozamia mirandae* including its spatial distribution and growth pattern in Mexico. There are not many studies on the demography of palms in Malaysia but few researches have been carried out (Rozainah et al., 1999, 2000). In addition, the control of population size and demographic study in natural environment is important for preservation of rare and endangered species (Sampaio, Schmidt et al. 2008; Sánchez-Velásquez and Rosario Pineda-López 2010). Although *N. fruticans* is not an endangered species, it is one of the highly utilized palms. Hence, many aspects of demographic study such as population structure, density, life stages, growth rate, and rate of death and birth would be beneficial for predicting population changes and preserving this versatile palm in the future. Palms give a wide variety of non-timber products to local community around the world, and almost all parts of palms are harvested (Franklin et al., 2009). Expanded leaves of palms are used to make handicraft and roofing (Peters et al., 2007; Svenning & Macia, 2002) while unexpanded leaves are harvested for making twine or fibers and fragile handicrafts (Runk et al., 2004). Hence, information that have been gathered from demographic study such as survival, growth and reproduction rates of individuals are very useful because by comparing them, the effects of harvesting non-timber products can be assessed (Kathriarachchi et al., 2004 ; Uma Shaanker et al., 2002). For example, harvesting of mature palm leaves causes mortality rate to increase, and growth and reproductive rates in some species to decrease (Endress et al., 2004). In addition to demographic studies, life stages of subjects that have influence on the population dynamics would be recognized. Process of growth in plants is complex, active and extremely inharmonic, and there are

many factors that have significant impact on the growth process (Walter, 2008). In contrast to most animals, plants grow during their whole life span and with more flexibility than animals. Plants can dynamically change their performance to variable environmental conditions (Walter, 2008). Therefore, the demographic study can determine the sensitivities of the population growth to environmental changes in different life stages of trees in the forest. A few studies have been done on factors affecting the growth of palms such as light, soil, salinity and disturbances (Franklin et al., 2009; Tripler et al., 2007; Shackleton, 2002; Svenning, 2002). Disturbance either natural or anthropogenic has an important role in the growth and productivity of colonial plants (Bond & Midgley, 2001). In addition, Svenning (2002) mentioned that among microenvironment factors, crown illumination and forest phase have important effects on growth. Hence using this information, restoration, conservation and management of the tropical and subtropical forests would be effective through sustainable use and better understanding of their ecology.

Palms have a hypogeal germination; it means that the cotyledon does not emerge from the soil (Pinheiro, 2001). In *N. fruticans*, some variations were found. In this monotypic palm, germination starts with the fruits being attached to infruitescence and plumule is extruded at the time of fruit release (Tomlinson, 1986). Some researchers described some variations in germination of palms such as coconut (*Cocos nucifera* L; Arecoideae) (Tomlinson, 1990). In most palm fruits, only one seed develops and propagation via seeds, while Kathiresan & Ravikumar (1995) found that seed propagation of two mangrove species, *Sonneratia apetala B* and *Xylocarpus granatum Koen*, faced complications due to poor flowering, weak seed setting and very short viability of seeds. In a palm, seed endosperm is a nutritive tissue which provides food for the germinating seedling. In palms with hard seeds, this white endosperm is enclosed by a thin, dry,

brown testa under the shell. The embryo of palm seeds are enclosed within the endosperm; which is a soft and partly liquid nutritive tissue, consist of the initial structures including the single cotyledon, together with the radicle (first seedling root) and plumule (first seedling leaf) (Stanton & Flach, 1980). In a mature seed, the endosperm becomes thick and stores carbohydrate for the embryo. During germination, elongation of the epicotyl causes the embryonic originals to be carried out through germination pore but the solitary cotyledon or seed leaf remains in the endosperm. It grows to form a structure which is called a haustorium. The enzymes of haustorium play important roles in solubilisation and absorption of nutrients from the endosperm and their transportation to the young seedling. After the fruits germinate, first simple leaves which are tubular and come together in the form of a spear will appear. The spear of the seedling usually opens with three leaflets and fragile petioles which later develop into many leaflets. Mature leaves are upright pinnate shape with many linear coriaceous leaflets and very stout petiole. Seed production and germination are essential in demographic study because they have an important role in determination of the size structure of the population.

2.3. Reproductive phenology

The plan of floral phenology in this study is to get information on the development of the flowering and fruiting events in *N. fruticans* and to find out the detailed information on its flowering biology. Ninety five percent of all palms are pleonanthic (Tomlinson, 1990) including *N. fruticans*. Pleonanthy in palms means that the plant produces flowers between leaves acropetally as it continues its vegetative growth. On the other hand,

hapaxanthy in palms refers to sudden flower production in a large number after the end of vegetative growth. The main straight and stout inflorescence axis of *N. fruticans* terminates by spherical female flowers while the yellow catkins shape male flowers are on the lower branches of the same inflorescence (Fig 2.1). The immature fruits are translucent, white and hard jelly-like. The fruits are compacted to a large globular head, rising from the mud on a long stack (Tomlinson, 1986; Collinson, 1993). There are various flowering behaviors and phenological patterns in palms with rather long flowering and anthesis periods (Henderson, 1986). In addition, there is a wide range of flowering times in palms. De Steven et al. (1987) believe that pollination, seed dispersal, dormancy, and germination are important for understanding the phenological patterns.

Abiotic factors such as irradiance and water stress have been mentioned as indication for these patterns (Van Schaik et al., 1993). Biotic factors, adaptive and critical phenological patterns have been assessed by Van Schaik et al. (1993). Barford et al. (2003) noted the variations in phenological patterns within *L. spinosa* and the correlation between the flowerings of *Licuala* spp. and the rainfall, while *Johannesteijsmannia lanceolata* exhibits regular flowering each year (Rozainah & Sinniah, 2006). Furthermore, De Steven et al. (1987) and Sist (1989) found that the palm family shows seasonal patterns of flowering and fruiting. Many understory plants of the rain forest like *Ca- lyptrogyne ghiesbreghtiana Linden ex. H. Wendl* can flower at any time of the year and their annual inflorescence production changes greatly with plant size and light environment (Cunningham, 1997). Many studies on phenology of palms has been carried out (e.g., Frankie et al., 1974; Van Schaik, 1986; Newstrom et al., 1994; Sun et al., 1996; De Steven et al., 1987; Lee et al., 1995; Bøgh, 1996; Ervik & Feil, 1997; Peres, 1994) but most of them focused on a single species rather than at community levels (Kuchmeister et al., 1997; Kahn & Granville, 1992; Rozainah et al., 1999; Borchsenius, 1993; Henderson

et al., 2000; Miller, 2002; Rozainah & Sinniah, 2006). Few phenological studies on *N. fruticans* have been done (Haramaini et al., 2009).

Fig. 2.1: The inflorescence of *Nypa fruticans* with 120 cm high.

2.4. Taxonomy and morphology

N. fruticans is a major component of mangrove vegetation (Duke, 2006; Dransfield et al., 2008) with a unique morphology, habitat specificity, and climatic favorite. The *N. fruticans* is a salt water palm, which can tolerate frequent inundation. *N. fruticans* is a palm with dichotomously branched underground rhizomes (Fig. 2.2) and a crown of

leaves measuring up to 10 m long (Tomlinson, 1986; Keng et al., 1998; Dransfield et al., 2008) just above the littoral environment, and it appears to lack a trunk (Mastaller, 1997).

Fig. 2.2: The branching rhizomes in *Nypa fruticans*.

Paleotropics (Indo-Australasia) is the limited natural range of *N. fruticans* although it exists on the neotropics with suitable climate and habitat for recent successful preface of the palm to the Americas (Duke, 1991). The palm family (Palmae or Arecaceae) is one of the largest monocotyledonous families with over 200 genera and approximately 2600 species (Dransfield et al., 2008). Although palms exhibit great morphological diversity, the morphology of palm family is not unique to this family (Uhl et al., 1995). However *Nipah* palm has distinct enough features that separates it from other members of this family, and with its own subfamily, the *Nypoideae* (e.g., Moore, 1973; Uhl & Dransfield, 1987). Tomlinson (1986) divided the palm into Kingdom of Plantae, division of *Magnoliophyta*, class of *Liliopsida,* order of *Arecales,* family of *Arecacea,* subfamily of *Nypoidea,* genus of *Nypa*, and species of *N. fruticans*. The fossil record of fruits and

pollens goes back to the Late Cretaceous further than the Old World, 65-70 million years ago (Gee, 2001) and it may be the oldest palm species (Paivake, 1996).

CHAPTER 3

MATERIAL AND METHOD

3.1. Population structure and dynamics

3.1.1. Population density and spatial distribution

In this study, six plots had been set up at two sites (three plots at each site). For establishment of plots, the area was searched for the viability of subjects because in some places, the density of *N. fruticans* was too low. So, on the basis of a visual survey, three plots were established at site 1 where each plot had a size of 20m×20m, and three plots at site 2 where each plot had a size of 10m×10m (Rodríguez-Buriticá et al., 2005 ; Svenning 2002).

To determine the population structure and to understand the potential of regeneration in the population of this species, *N. fruticans*' development was divided into four developmental stages –seedling, juvenile, adult, and mature:

1. Seedlings- from small plants with one intact leaf to plants with three leaves.
2. Juveniles- a stage with four to seven larger leaves
3. Adults- plants with eight to fourteen leaves.
4. Mature- plants with fifteen to twenty-one leaves which have flowers and fruits mostly.

All *N. fruticans* within the plots were counted and tagged randomly, and each axis with leaves channeled adaxially, distally was considered as a separate plant. The spatial distribution of this species within the plot was calculated using the position of each plant. Its positions / coordinates (x, y) were obtained using a compass and a tape–measure, and then six distribution maps were produced. Using these maps can help us to demonstrate the spatial distribution of species and explain the palm dispersion in relation to seed dispersal agents. To explore the distribution of species, coefficient of dispersion or relative variance was used and it showed three different forms of dispersion: random, clumped and regular. A small square (1cm× 1cm) was tossed on each distribution map. For each throw, the number and frequency of seedling, juvenile, adult, and mature subjects that were trapped in the square were counted, and then these data were used to determine the variance: mean ratio (David & Moore, 1954) with this equation:

$$\frac{\sum x^2 - \left[(\sum x)^2 / n\right]}{x^* \cdot (n-1)},$$

where x is the number of individuals in a square, x^* is the mean number of individuals per square, n is the number of squares tossed= 10° .

The variance compares the number of individuals in each square with the average number of individuals over all of the squares.

From the calculations of the dispersion coefficients, the results can be interpreted as follows: a value equal to one or around one indicates that subjects are distributed randomly; a value higher than one shows the clumped plants, and a value less than one shows that the plants are regular.

3.1.2. Recruits and death

In order to determine the recruit rate, the number of new recruits including the fruits with exerted plumule was observed every two months. For determination of mortality of subjects in each stage during the 15-month study period, observation was done every two months to determine the number of fallen trees.

3.2. Growth

Palm growth is usually expressed as stem length or height increase based on leaf production rate (Pinard & Putz, 1992).In this study, the growth measurement of *N. fruticans* had been done based on leaf production rate and the spear elongation. All subjects at two study sites in each plot were monitored at initial census to record the number of living crown leaves (expended leaves), spear leaves and dead leaves per palm in each stage. Subsequently, the monthly observations were made to count the number of new leaves throughout the 16 months. Then the rate of leaf emergence per year was determined for each individual. For determination of spear elongation, sub samples, twenty subjects including juvenile, adult and mature plants were chosen in each plot.

height increase was measured from spear shape of leaf until the spear leaf began to be expanded and entered the crown. Then the next new spear leaf in the same individual plant was measured from the ground.

The raw data obtained by monthly observations are as below:

Llf: the number of living leaves at initial study. Comprises living crown leaves and spear leaves.

Dlf: the number of dead leaves. Comprises the dry crown leaves and prominent remnants of stout petiole of dead leaves, channeled adaxilly and distally, and circling the living leaves.

Nslf: the number of leaf production. Comprises the number of new leaves produced during the study period.

Tlf: the total number of leaf. Comprises living leaves (Llf), dead leaves (Dlf), and new leaves (Nslf) at the end of the study. Spear elongation: defined as increase in height from the first emergence of the spear leaf until it begins to expand.

Lde: Plastochrone. Interval between appearance the first new leaf and the next leaf.

Lls: Leaf life span. Defined as the period when the leaf stays alive. Comprises from the time from its entrance to the crown, until its death. It is calculated by multiplying the plastochrone by the mean number of living leaves with this equation:

Lls = Lde x Llf

Data were collected throughout the 16 months observations and were grouped according to the developmental stages in MS Excel. Statistic analysis had been done in the SPSS program version 17 by comparison of the mean with standard deviation. By doing one-way ANOVA test, the significant differences of variables among three plots were checked. With independent samples t–test, the significant difference of data between two

study sites was tested. There was a variation in the growth rate of individual subjects in each stage of a plot. Therefore, Tukey test for normal distribution of data when $P > 0.05$ in homogeneity of variance has been done. Games-Howell for abnormal distribution of data when $P < 0.05$ in homogeneity of variance has been done to make the final decision on significant differences in variables among the plots. In addition, linear regression and correlation analysis had been used. Significant or not significant relationship between observed variables, Lde (plastochrone) (y) and the total number of leaves (x) were determined.

3.3. Age structure

The ages, sizes and forms of subjects in the population are an indicator of the population structure. Palms are suitable for demographic studies due to some special and favorable features. This made the age estimation of each subject possible. The age of palms was calculated by multiplying plastochrone and the total number of leaves. Total number of leaves comprised living leaves and dead leaves of each subject at final census.

The average of leaf productions and plastochrones had been used for age calculation of each subject. The ANOVA and t test for determination of significant differences among the plots and the sites had been done. If there weren't any significant differences, one mean was used for both sites. With the following equation, the mean age of each individual was determined:

Age = Lde x Tlf

Counting the leaves was not so difficult in the first census and had been done with the least error. Most error would appear in the determination of plastochrone because the interval between the appearance of leaf and the next was long. For estimation of age of

the species, the mean age estimation of seedlings was added to the mean age estimation of juveniles and adults and this total mean age was added to the age estimation of mature subjects.

3.4. Reproductive phenology

3.4.1 Flowering and fruiting

One hundred and fifteen adult and mature individuals of *N. fruticans* at both sites (six plots) were chosen and their flowering and fruiting status were recorded monthly for the existence of inflorescence and fruit. Then the number of new flowers and fruits per palm were counted during a 14-month period. The stout and vertical inflorescences were visible among the leaves. Weekly field observations of the morphological changes in appearance until the complete cycle of inflorescence and infruitescence were made for all reproductive trees for a period of 3 months. Adult and mature trees with flowers and fruits at the first census were reproductive trees. To study the floral phenology and inflorescence development of *N. fruticans,* seven developmental stages of the inflorescence cycle have been considered:

1- No inflorescence
2- Unexpanded inflorescence.
3- Expanded inflorescence with unopened flowers that were enclosed by bracts.
Lateral branches in this stage completely expanded. Oval shape prohpylls including male buds differentiated from round female buds at center of inflorescence.
4- Expanded inflorescence with opened flowers that were uncovered by bracts. The globular female flowers with green or yellow color were differentiated from yellow catkin-like male flowers.

5- Young fruit including small brown fruit appeared in female flowers and catkin-like flowers released pollen and became black. Male flowers were considered as functional as long as they stayed on inflorescence and including pollens. The female flower were considered flowering until the stigmas turned brown (Inkort et al., 2007).

6- Mature fruit with the first fallen fruit.

7- Dry inflorescence with completely dropped fruits.

Studies of flowering and insect visitation were conducted at two sites by hourly observations from 9 am until 6 pm in order to note the number and behavior of insects visiting the flowers. Due to high tide, entering the site was impossible, so 24-hour detailed observations weren't conducted especially in the morning between 6am to 8am. So there were some limitations even during day time. The observations were not continuous. On many occasions, observations were carried out during low tide when entering the study site was possible. Visiting insects were caught as soon as they were observed around the flowers and then they were killed with Ether and preserved in bottle for determination of pollen load on their foot.

3.4.2. Seed germination

The woody seeds of *N. fruticans* are sphere-shaped and compacted into a ball on a single stout peduncle at the end of the spike. When the fruit is ripe, the ball breaks away and is divided into individual fruits. So, after the fruit detachment occurred, fifty-four fruits were collected from the field in order to test the seed germination of *N. fruticans*. The seeds were planted in six containers with enough depth in order for the roots to develop

properly. The most important thing to be considered for a germination container is good drainage of overload water from the medium. A soil mix of one part peat moss and one part perlite had been successfully used under a wide range of nursery conditions (Meerow, 1991). The mix that is used depends on the natural condition in which the seeds germinate, and also it must have a good drainage and moisture holding capacity. Therefore a soil mix including two parts peat, one part natural forest soil and one part sand was used. The depth at which the palm seed will be sown depends on the size of the seed and species. The large seed of the palm was pressed into the soil and the half of the seed was exposed to air. Seeds were watered 3 times in a week and were observed monthly for six months.

3.5. Soil and water analysis

3.5.1 Soil

3.5.1.1 Sampling and drying

The traditional method of the water content measurement by mass was done by removing a sample, determining its moisture and dry weights. After drying the sample to a constant weight in an oven, the dry weight was obtained. When taking samples, an ordinary spatula was used as a sampling tool because only small samples were required for moisture determination. First, a 10cm space was opened under ground and then lumps at appropriate depth (10cm under the hole) were taken. Three samples in each plot were collected. They were scattered uniformly over the plots and representative of the area. The soil samples were placed in labeled plastic bags and brought to the laboratory. Wet samples were weighed immediately and were placed in a drying oven at 70ºC to dry them to a constant weight. After twenty-four hours they were removed from the oven and

reweighed. In order to get a constant weight, the samples were placed in the oven for the second time and removed after another twenty-four hours, (normally necessary for complete oven drying).

There are a wide variety of methods for determination of soil moisture content and the most common method was given by Gardner (1965). The gravimetric method involves measurement of masses of water and the soil. This method has been accepted as a standard method. The percentage of water content is calculated as follows

$W = M - N / M \times 100$

M= the weight of wet soil (g)

N= the weight of dry soil (g)

3.5.1.2. Particle size

The soil samples were collected inorder to determine the soil particle size analysis using the device of Particle size analyzer, Coulter, model Ls 230. For soil classification, three main fractions are used; sand (50-2000 µm), silt (2-50 µm) and clay (‹ 2 µm) on a triangular system (Balkema, 1986). The classification of soils according to the size of mineral particles is as below:

-clays < 0.002 mm

-silts 0.002-0.02 mm

-sands 0.02-2 mm

-gravel > 2 mm

Different soils have mix of the above particles in different amount and this is shown in a soil triangle in order to identify soil texture.

3.5.1.3. Soil pH and temperature

pH and temperature of three samples in each plot at both sites were measured. Samples were taken monthly during a period of 16 months**.** In order to measure pH and temperature, an IQ multiparameter has been used on site.

3.5.2. Water

At each plot at the two sites, three water samples were collected from the surface of riverbanks and puddles at low tide. They were then transferred from the original place to the laboratory where the physical analysis was made to determine the salinity, total dissolved solid (TDS), and electrical conductivity (EC). Also, metallic concentrations including heavy metals (Pb, Cd, Cu, Zn, As), major metals (Ca, Mg, Na, K, Mn), Fe, and trace elements (Se, Al), Anions (chloride, sulphate, Nitrate) by using optical mission spectrometer, Perkinelmer, were determined. Salinity, total dissolved solid (TDS), electrical conductivity (EC) were taken by using the multi parameter in lab. pH and temperature were measured by using a moveable pH meter and thermometer respectively, and DO measurements were recorded by the DO meter on site in each plot from waterways. These provided quantitative baseline information on the current situation of the ecosystem.

CHAPTER 4

RESULTS

4.1 Population structure and dynamics

4.1.1. Population density and spatial distribution

The number of subjects and the values of coefficient of dispersion in all six plots at both sites are presented in Table 4.1. Figs. 4.1, 4.2, and 4.3 show the spatial distribution of *N. fruticans* in all subjects in three plots at site 1. Figs. 4.4, 4.5, and 4.6 show the spatial distribution of this species in three plots at site 2.

Table 4.1 shows that the highest density of trees belonged to plot 3 at site 2. Also, the number of adult trees in all plots at both sites was very much higher than the number of juvenile and mature trees. In addition, the number of mature trees were higher than juveniles except in plot 2 at site 1.

Table 4.1: The population number of individuals and the values of coefficient of dispersion for *N. fruticans* in six study plots at both sites.

site	plot	Seedling	Juvenile	Adult	Mature	total	Density/m²
1	1	0 _	3 (1.0-Random)	27 (1.4-clumped)	10 (0.6-regular)	40	0.1
	2	0 _	14 (0.8-Regular)	66 (0.4-Regular)	10 (1.1-Clumped)	90	0.2
	3	0 _	9 (0.8-regular)	63 (0.8-regular)	21 (0.8-regular)	93	0.2
2	1	3 (1.0-Random)	4 (0.7-Regular)	19 (0.8-regular)	9 (0.8-Regular)	35	0.3
	2	0 _	3 (1.0-Random)	34 (1.3-clumped)	4 (1.0-Random)	41	0.4
	3	5 (0.8-Regular)	17 (1.9-clumped)	36 (0.6-Regular)	6 (1.0-Random)	64	0.6

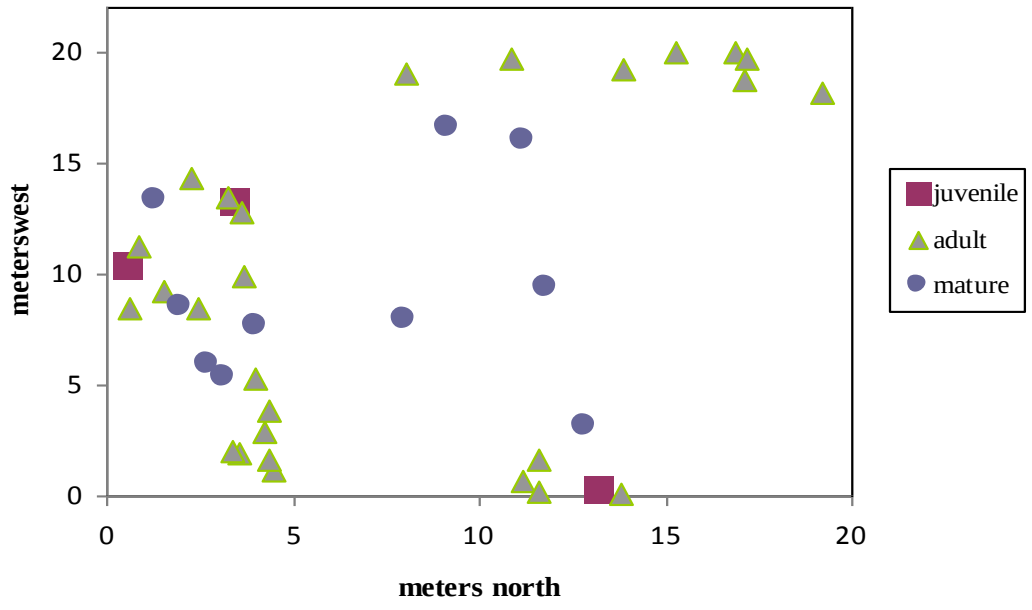


Fig. 4.1: Spatial distribution of *N.futicans* at site 1, plot 1.

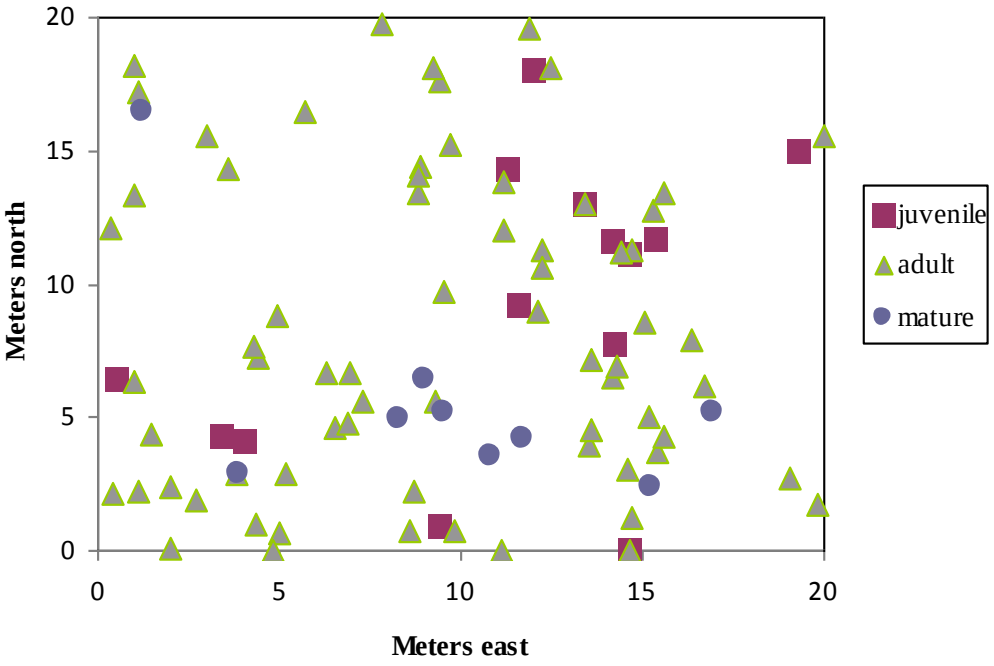


Fig. 4.2: Spatial distribution of *Nypa fruticans* at site 1, plot 2.

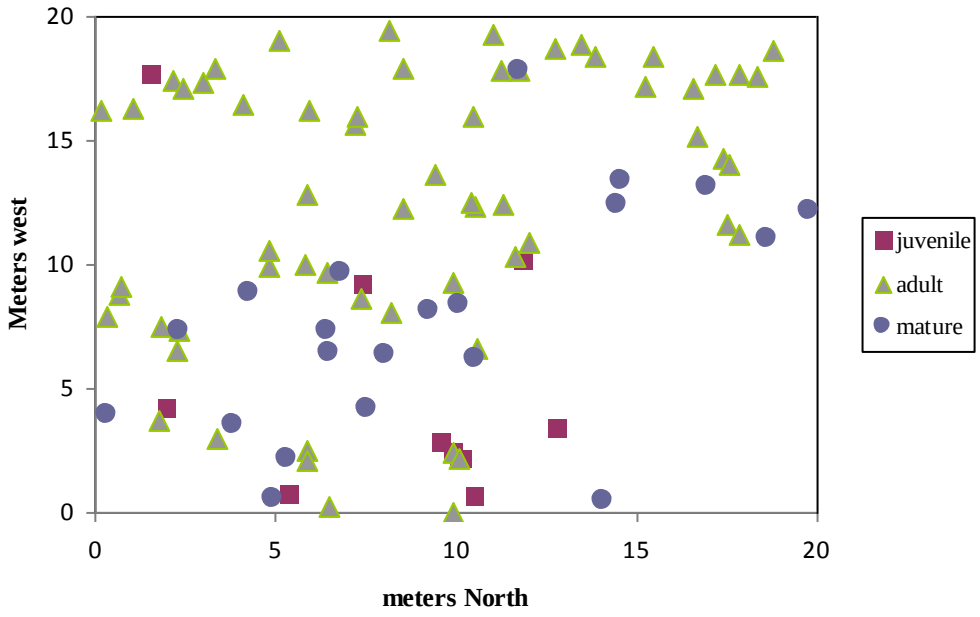


Fig. 4.3: Spatial distribution of *N. fruticans* at site 1, plot 3.

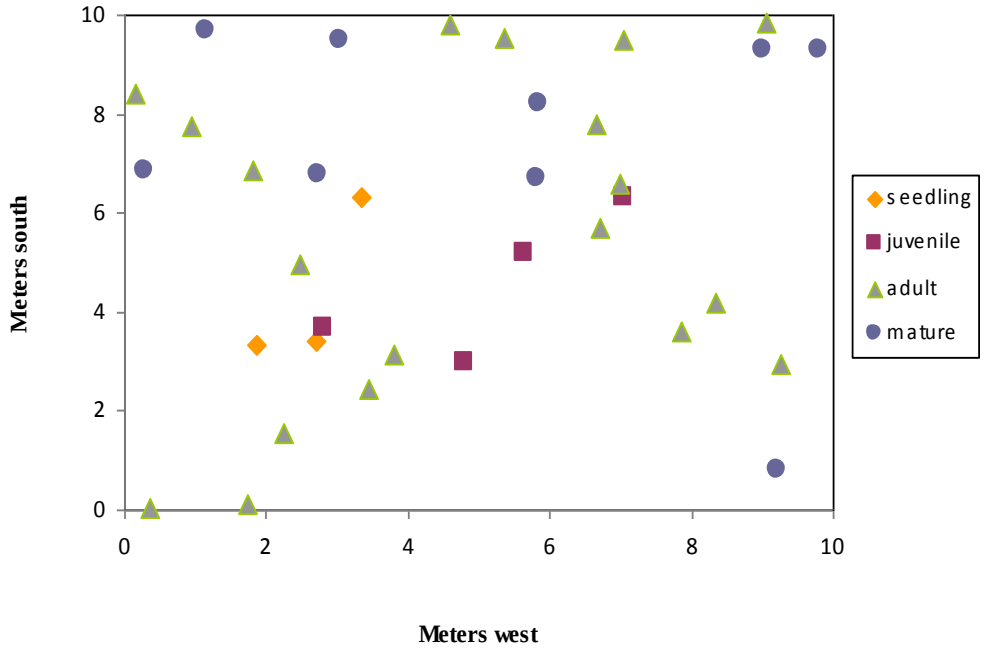


Fig. 4.4: Spatial distribution of *N. fruticans* at site 2, plot 1.

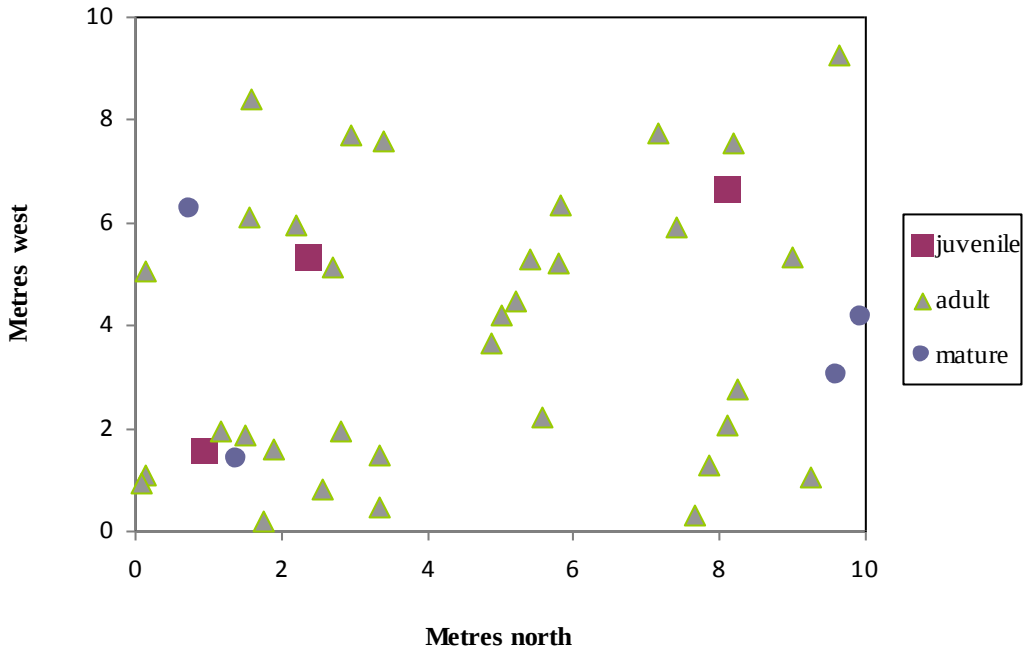


Fig. 4.5: Spatial distribution of *N. fruticans* at site 2, plot 2.

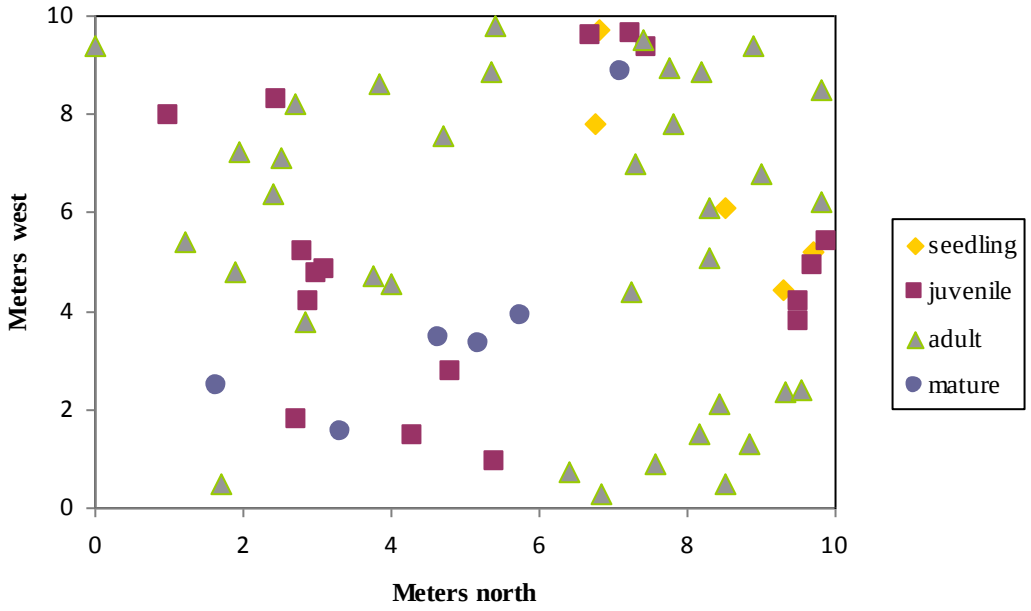


Fig 4.6: Spatial distribution of *N. fruticans* at site 2, plot 3.

Size structures of the species showed high number of adults and mature trees and low number of seedlings. No mortality was observed for trees during the study period. The calculation of coefficients of dispersion shows the seedlings were both randomly and regularly distributed at site 2. Site 1 did not have any seedling. According to my observation at the two sites, most of the new recruits were out of the plots because of surface water run-off. Some of the seedlings were damaged especially in plot 3 at site 2 which was close to the river and therefore subject to water run-off. Juveniles had both regular and random distributions in all plots at the two sites except in plot 3 at site 2 where they were clumped. The values of dispersion coefficients show that the adult trees were regular and clumped at both sites. It means that the plants became clumped as they became adult. Mature trees were placed regularly and randomly at both sites except in plot 2 at site 1 where mature trees were clumped. It means that the plants became less clumped and thinned out as they reached the mature stage.

4.1.2 Population changes

In order to determine if there were any additions to the population, the number of new recruits including the seeds with exerted plumule was counted. In addition, emergence of new subjects that had been speared from rhizome (called vegetative propagation) and mortality of subjects were monitored. According to the bi- monthly observations, high tide washed away most of germinated seeds and caused little establishment of seedlings (only three new seedlings). There were no changes from seedling to juvenile, from juvenile to adult and from adult to mature. So, we had no increase or decrease of subjects, turning into another stage or death in each stage of the trees respectively.

Table 4.2: The percentage of *N. fruticans* in each stage in each plot at both sites.

site	plot	Seedling (%)	Juvenile (%)	Adult (%)	Mature (%)
1	1	0	7.5	67.5	25
	2	0	15.5	73.3	11.1
	3	0	9.6	67.7	22.5
2	1	8.5	8.5	54.2	25.7
	2	0	7.3	82.9	9.7
	3	7.8	26.5	56.2	9.3

Table 4.2 shows that the highest mean percentage of trees belonged to adults and matures which was more at site 1 than site 2 with 69.5% and 19.5% respectively. The mean

percentage of juveniles at site 2 was much more than site 1 with 14.1 %. While the highest percentage of adults belonged to plot 2 at site 2 with 82.9 %.

Table 4.3: The ratio of seedling to juvenile, adult and mature, and the ratio of juvenile to adult and mature and the ratio of adult to mature at first census.

site	plot	Seedling/ juvenile	Seedling/ Adult	Seedling/ mature	Juvenile/ adult	Juvenile/ mature	Adult/ mature
1	1	0	0	0	0.1	0.3	2.7
	2	0	0	0	0.2	1.4	6.6
	3	0	0	0	0.1	0.4	3
2	1	0.7	0.1	0.3	0.2	0.4	2.1
	2	0	0	0	0.08	0.7	8.5
	3	0.2	0.13	0.8	0.4	2.8	6

Table 4.3 shows that the ratio of seedlings to other stages was less than 1 and ratio of juvenile to adult and mature was less than one too except for plot 2 at site 1 and plot 3 at site 2. The ratio of adult to mature was more than 1.

Table 4.4: The ratio of seedling to juvenile, adult, and mature, and the ratio of juvenile to adult and mature, and the ratio of adult to mature at the end of the study (The changes are indicated by highlight).

site	plot	Seedling/ juvenile	Seedling/ Adult	Seedling/ mature	Juvenile/ adult	Juvenile/ mature	Adult/ mature
1	1	0	0	0	0.1	0.3	2.7
	2	0	0	0	0.2	1.4	6.6
	3	0.1	0.01	0.04	0.1	0.4	3
2	1	1	0.2	0.4	0.2	0.4	2.1
	2	0	0	0	0.08	0.7	8.5
	3	0.3	0.16	1	0.4	2.8	6

Table 4.4 shows that the ratio of subjects at each stage had not changed at both sites except for the ratio of seedling to other stages as highlighted in Table 4.4. It increased in plot 3 at site 1 and plot 1 and 3 at site 2 because of the establishment of new seedlings. This was an increase of 3 seedlings during the 16 months study period.

Table 4.5: The number of new recruits and annual recruits (%) of *N. fruticans* at both sites.

site	plot	New recruits (16 months)	Annual recruits (%)
1	1	13	9.7
	2	35	26.2
	3	52	39
2	1	30	36.2
	2	17	20.5
	3	15	18.1

Table 4.5 shows the highest percentage of new recruits (fruits with exerted plumule) and annual recruits were found in plot 3 at site 1 and plot 1 at site 2. The t test showed that there were no significant differences between the two sites in the rate of recruit production per year. So, the mean rate of recruit production per year of *N. fruticans* was 9.2 ± 8.8. The percentage annual recruits at both sites were determined with this equation: (number of new recruits in each plot / total number of new recruits × 100) × 12 / 16. Plot 3 at site 1 and plot 1 at site 2 had the highest recruits rate and annual recruits. This was because of the highest percentage of adult and mature subjects in plot 3 at site 1. The ripe fruits falling down from the mature trees coupled with low salinity at this site encouraged their germination. However, it can be concluded that the recruits rate cannot be used as an indicator of the increase of seedlings due to little establishment of seedlings

compared to the number of recruits. One of the reasons for this was the inundation by high tide. The observations showed dropped fruits were collected first under the parent trees. After a while, most of them were spread around the plots. So, they were moved far away from the parent trees and even out of the plots by high tide. So few seeds would be able to settle in the plots and turn into seedlings.

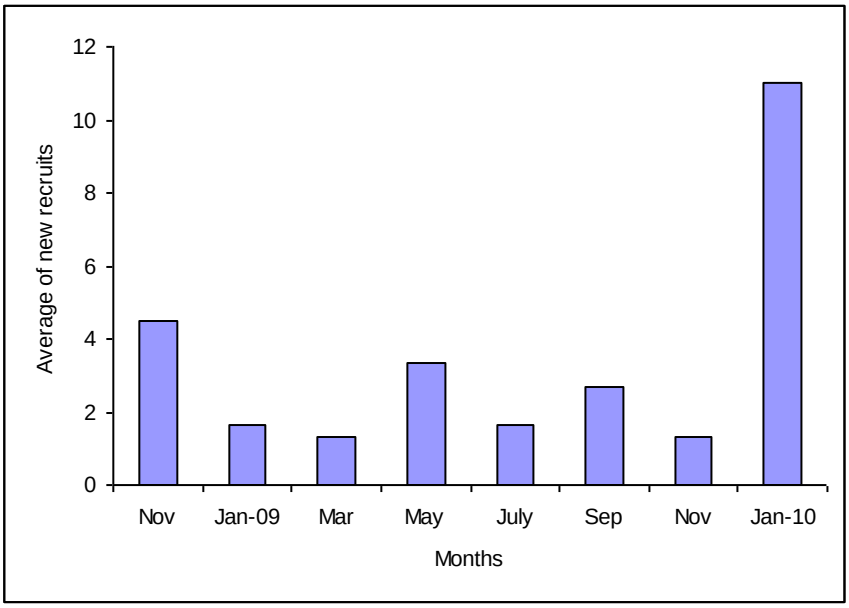


Fig 4.7: The mean number of new recruits during 16 months by bi-monthly observation at site 1.

Figure 4.7 shows that site 1 had the highest number of recruits in January 2010 with an increment of eleven recruitments. The result shows that the total number of new recruits was not significantly related to the months. Although new recruits occurred throughout the year, the number of recruits showed some decrease in certain months (March, July and November).

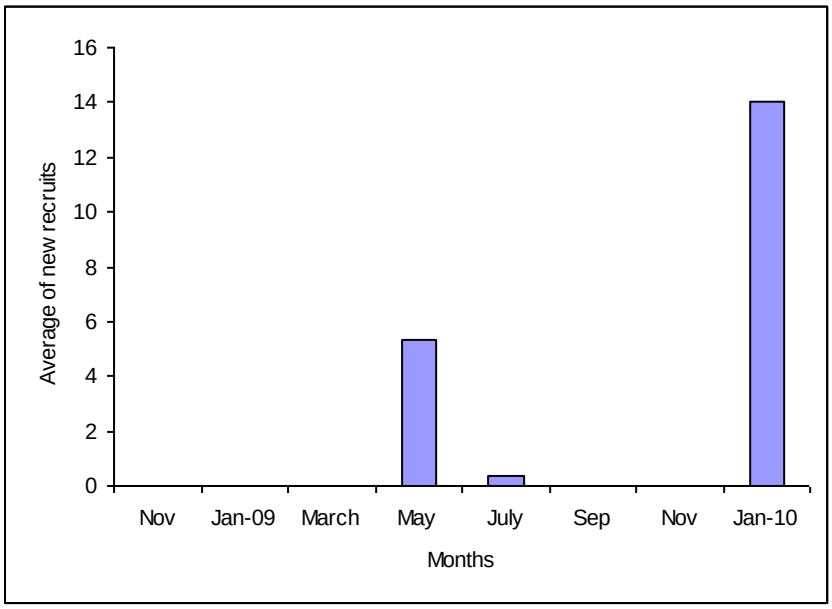


Fig 4.8: The mean number of new recruits by bi- monthly observation duing16 months at site 2.

Figure 4.8 shows that the highest number of new recruits in site 2 was recorded in May with six fruits and January with fourteen recruits. This was because two infruitescences with ripe fruits in plot 1 and plot 2 were dropped. As a result, lots of fruits germinated at the same time. The number of new recruits abruptly decreased in July.

At both sites, there were no death recorded in any stage of the subjects during this study but there were three new seedlings. There were one new seedling established in plot 3 at site 1, one new seedling established in plot 3 at site 2 in October and one new seedling established in plot 1 at site 2 in November. This shows that the rate of new recruitments was low.

4.2. Growth

4.2.1. Leaf production and spear elongation

4.2.1.1. Seedling stage

Growth rate of seedling showed that from total of eight subjects of seedling at site 2, four trees produced 1 spear leaf , one tree produced 6 spear leaves , one tree produced 4 spear leaves, and two trees didn't produced any new leaves.

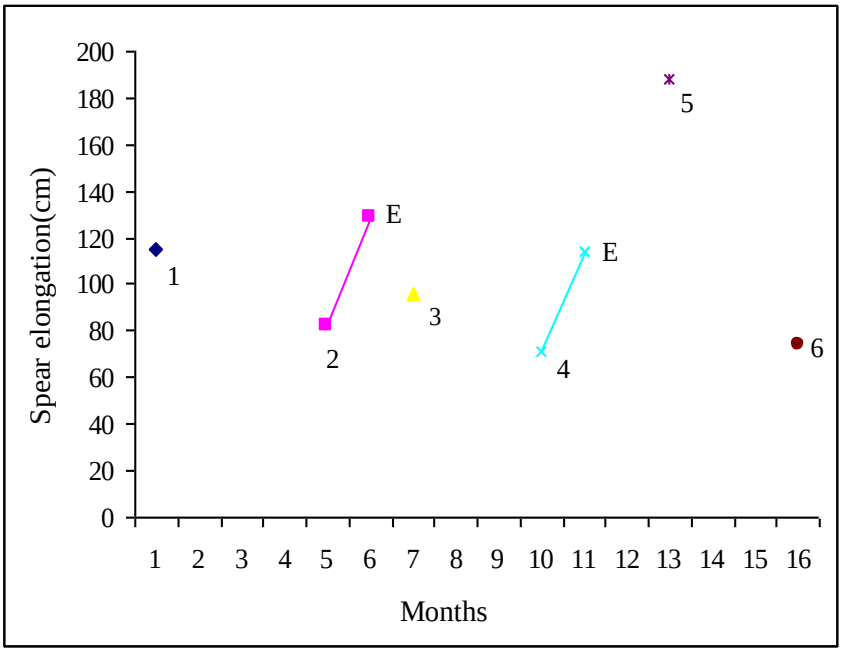


Fig. 4.9: New leaf production and spear elongation in 1 seedling in Carey Island during 16 months. Growth is characterized by spear leaf elongation from appearance of new spear leaf as it develops until the beginning of leaf expansion= E. Leaves without label were still developing.

Figure 4.9 shows that during the study period, the rate of leaf production was high in seedling of *N. fruticans* with six new spears. The leaves expanded very fast in a short interval period, around 1 month.

Table 4.6: The mean of some variables of seedlings of *N. fruticans* at site 2.

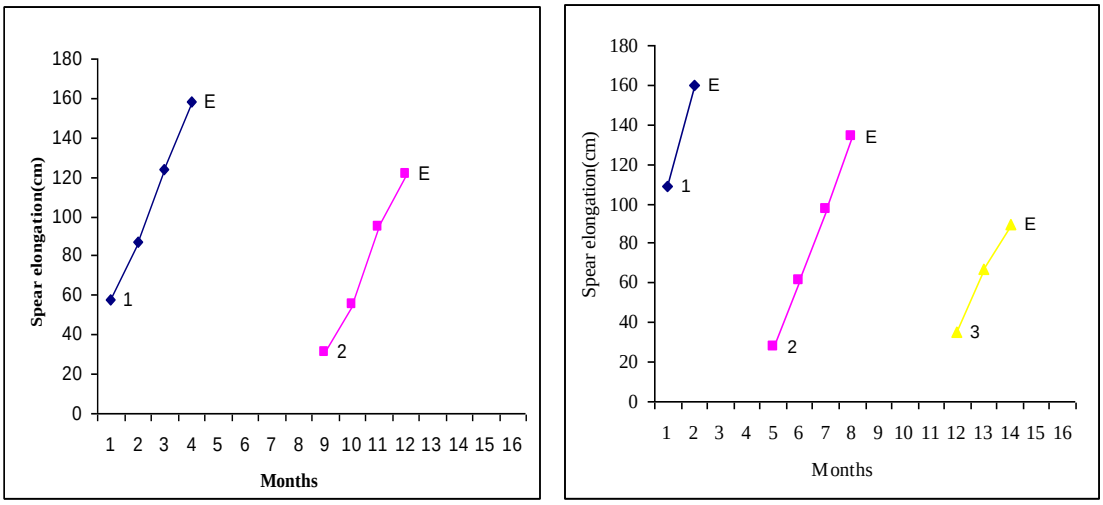
	Means ± sd				
variables	Plot 1	Plot 2	Plot 3	t-test	Total
Llf	2.3 ± 1.1 N=3	-	1.6 ± 0.5 N=5	ns	1.8 ±0.8 N=8
Dlf	0.6 ± 0.5 N=3	-	0.8 ± 0.4 N=5	ns	0.7 ± 0.4 N=8
Tlf	6 ± 3.7 N=3	-	3.2 ± 0.4 N=5	ns	4.3± 2.6 N=8
nslf/year	3.9 ± 0.8 N=3	-	2.4 ± 0.5 N=3	*	2.9±0.9 N=8
Lde(months)	4.4 ± 0.5 N=2	-	3 ± 0.05 N=3	*	3.5 ± 0.8 N=5

ns= not significant difference($P \geq 0.05$).
* = significant ($P < 0.05$).

The t-test in the table 4.6 shows that there was no significant difference among living leaves (F= 5.4, P=0.25, N=8) dead leaves (F= 0.48, P = 0.72, N= 8) and the total number of leaves (F= 18.9, P = 0.1, N = 8) in seedlings between plot 1 and plot 3. There were some significant differences in the rate of leaf production per year, (F = 0.15, P = 0.01, N = 8) and plastochrone (F= 614.4, P = 0.02, N = 5). All of these variables were bigger in plot 1 than in plot 3. Rate of leaf production was more at plot 1 with the mean of 3.9 leaves per year. The mean plastochrone, 4.4 months, is higher in plot 1.

4.2.1.2. Juvenile stage

During the 16-month observation, of the twenty-seven juvenile trees at site 1, ten trees produced 1 spear leaf, nine trees produced 2 spear leaves, four trees produced 3 spear leaves, and four trees did not produce any spear leaf. In site 2, during a 14-month study period in site 2, of twenty-three juveniles, eight trees produced 1 spear leaf, seven trees produced 2 spear leaves, two trees produced 3 spear leaves and six trees did not produce any spear leaf. There was a range of 1-3 spear leaves during this time for each tree. Figure 4.10 shows that annual leaf growth was regular and continuous. It took a long time, around 6 to 10 months, in order for the leaf to begin expanding and enter the crown. Then the new spear leaf was produced.



Site1 site2

Fig 4.10: Caption next page

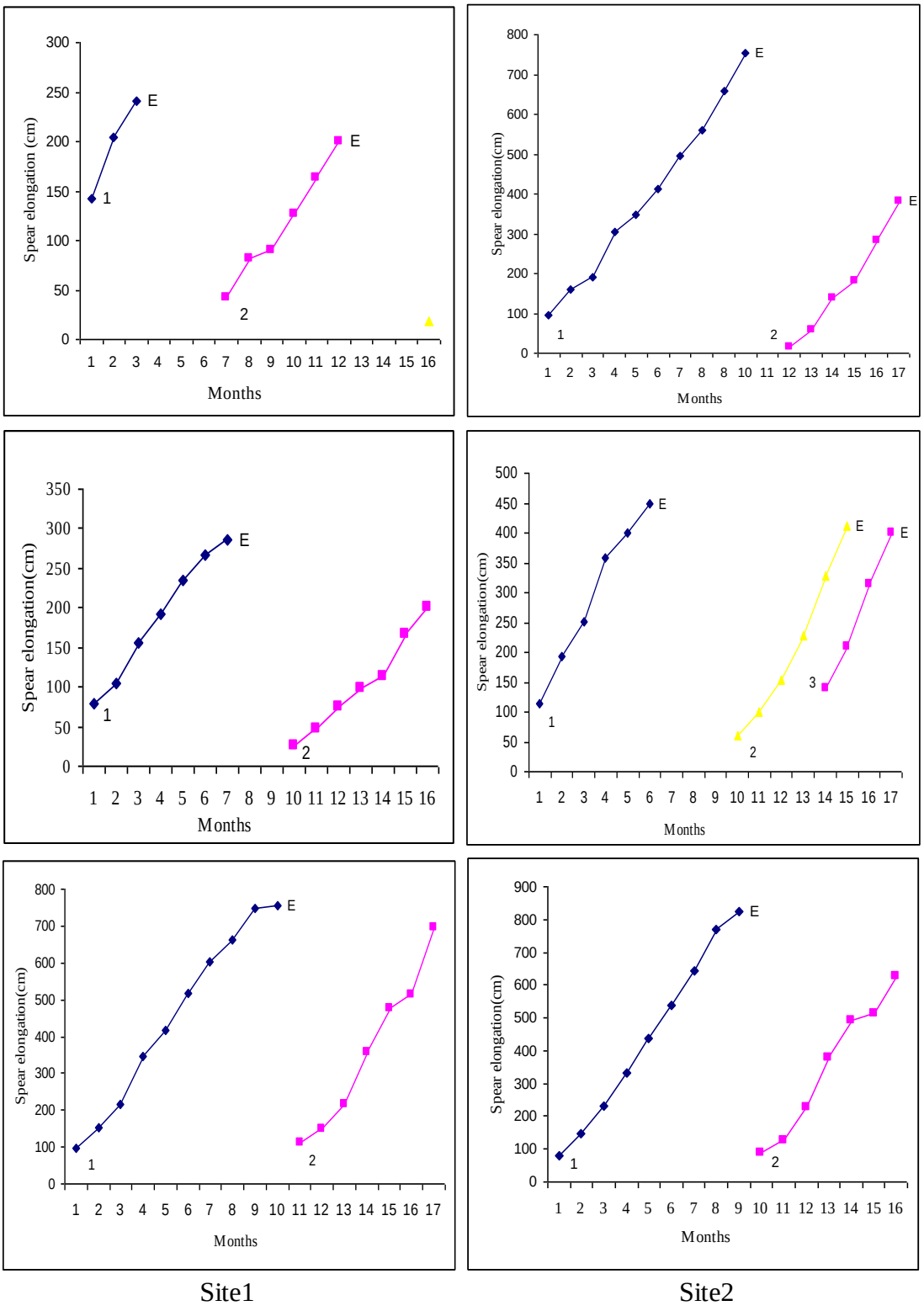


Fig. 4.10: Leaf production and spear elongation in two juvenile trees in Carey Islands throughout 16 months and in six juveniles throughout 17 months at both sites. Growth is characterized by spear leaf elongation from appearance of new spear leaf as it develops until the beginning of leaf expansion= E. Leaves without label were still developing.

Table 4.7: The mean of some variables of juveniles of *N. fruticans* at site 1.

	site 1 (means ± sd)		
	Plot 1	Plot 2	Plot 3
llf	3.2±0.5 N=3	3.6± 0.9 N=14	3.7±0.4 N=9
dlf	3.5± 0.5 [b] N=4	3.3 ± 0.7 [c] N=14	2.3 ±0.8 [bc] N=9
tlf	8 ± 1.4 N=4	8.5 ± 1.1 N=14	7 ± 1 N=9
nslf/year	0.9 ±0.9	1 ± 0.7	1.1 ± .7
Lde (month)	9 ± 0 N=4	10.3±1.4 N=14	10 ± 1.1 N=9
Elongation / month	-	57±21.2 [c] N=4	73.6±34.1 [c] N=4

b= significant between plots 1 and 3 ($P < 0.05$).
c= significant between plots 2 and 3 ($P < 0.05$).

Table 4.7 shows that there was a significant difference on dead leaves between all the plots at site 1 except for between plots 1 and 2 (by using ANOVA and Tukey test). The longest plastochrone, 10.3 months and a bigger number of total leaves, 8.5 leaves belong to plot 2. Also, there were significant differences between plot 2 and plot 3 in spear elongation at site 1 (by using t test). There was no data available for spear elongation in plot 1.

Table 4.8: The mean of some variables of juveniles of *N. fruticans* at site 2.

	Site 2 (means ± sd)		
	Plot 1	Plot 2	Plot 3
llf	4 ± 0.8 N=4	2.6±1.5 N=3	2.8 ± 0.8 N=17
dlf	2.5 ±1.2 N=4	3 ±2.6 N=3	2.9 ±1.3 N=17
tlf	8.7 ± 1.2 N=4	7 ± 1.7 N=3	6.6±1.6 N=14
nslf/year	1.9 ± 0.4	1.1±0.5	0.7 ± 0.7
Lde (month)	7.2± 0.6 N= 4	6.4±0.6 [c] N= 2	8.6 ±0.9 [c] N= 7
Elongation / month	56.2±25.8 N=4	-	35.2±2.1 N=4

c= significant between plots 2 and 3 ($P < 0.05$).

Table 4.8 shows that there was no significant difference in variables among the plots at site 2 except for plastochrone between plots 2 and 3 (by using ANOVA and Tukey test). There was no data available for spear elongation of juveniles in plot 2.

Table 4.9: The total mean of some variables of juveniles of *N. fruticans* at both sites.

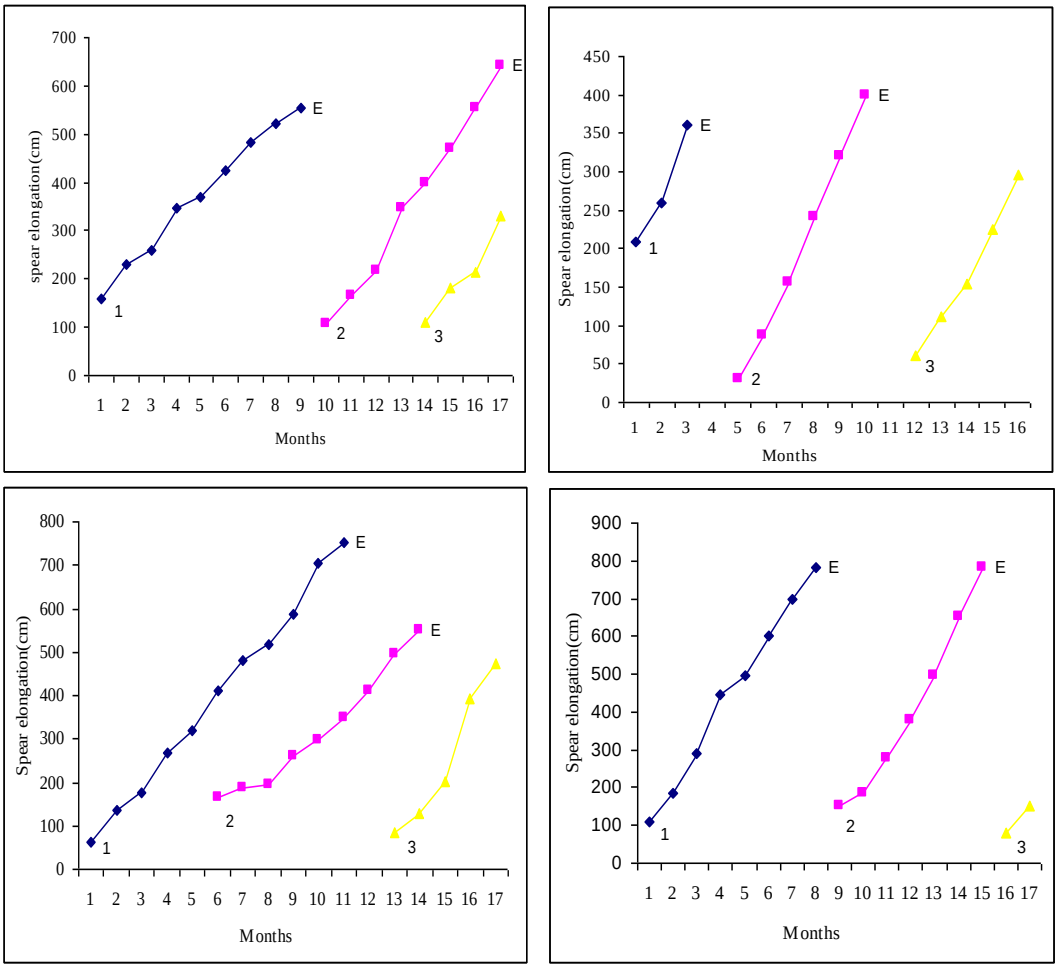
	Means ± sd		
Variables	site 1	site 2	t- test
llf	2.4 ± 0.6 N=26	2.1 ± 0.9 N=24	*
dlf	3 ± 0.8 N= 26	2.8 ± 1.4 N=24	ns
tlf	6.4± 0.7 N=26	5.7 ± 1.2 N=24	*
nslf/year	1 ± 0.7 N=26	1 ± 0.8 N=24	ns
Lde (month)	10±1.2 (n=14)	7.6 ±1.2 (n=13)	*
Elongation / month	65.3±25.1 N=8	45.7±19.2 N=8	ns

ns= not significant difference($P \geq 0.05$).
*= significant ($P < 0.05$).

Table 4.9 shows that spear elongation at site 2 was less than at site 1 but there was no significant difference between both sites (F = 0.50, P = 0.26, N = 16) So the mean of spear elongation in juveniles was 55.5 cm per month for each individual. The rate of leaf production was 1 spear leaf per year at both sites. The mean number of total leaves was bigger at site 1 than at site 2 because the mean number of dead leaves was bigger. There were significant differences in total number of leaves (F = 1.42, P = 0.01, N = 50), plastochrone (F = 0.21, P = 0.0, N = 27), and living leaves (F = 1.40, P = 0.01, N = 50), but no significant differences in dead leaves (F = 4.76, P =0.6, N = 50) and new spear leaves per year (F = 0.08, P = 0.85, N = 50) at both sites.

4.2.1.3. Adult stage

During the 16-month study period at site 1, of one hundred and fifty-seven adults, fifty-six adult trees produced 1 spear leaves, thirty-seven trees produced 2 spear leaves, fourteen trees produced 3 spear leaves, one tree produced 4 spear leaves and there were forty-nine trees that did not produce any spear leaf. During the 16 months study period, of eighty-nine adults at site 2, thirty-three trees produced 1 spear leaves, thirty-four trees produced 2 spear leaves. Nine trees produced 3 spear leaves and thirteen trees did not produce any spear leaf. The rate of leaf production and spear elongation of fourteen adult trees at both sites is shown in figure 4.11.



Site 1 Site 2

Fig 4.11: Caption next page

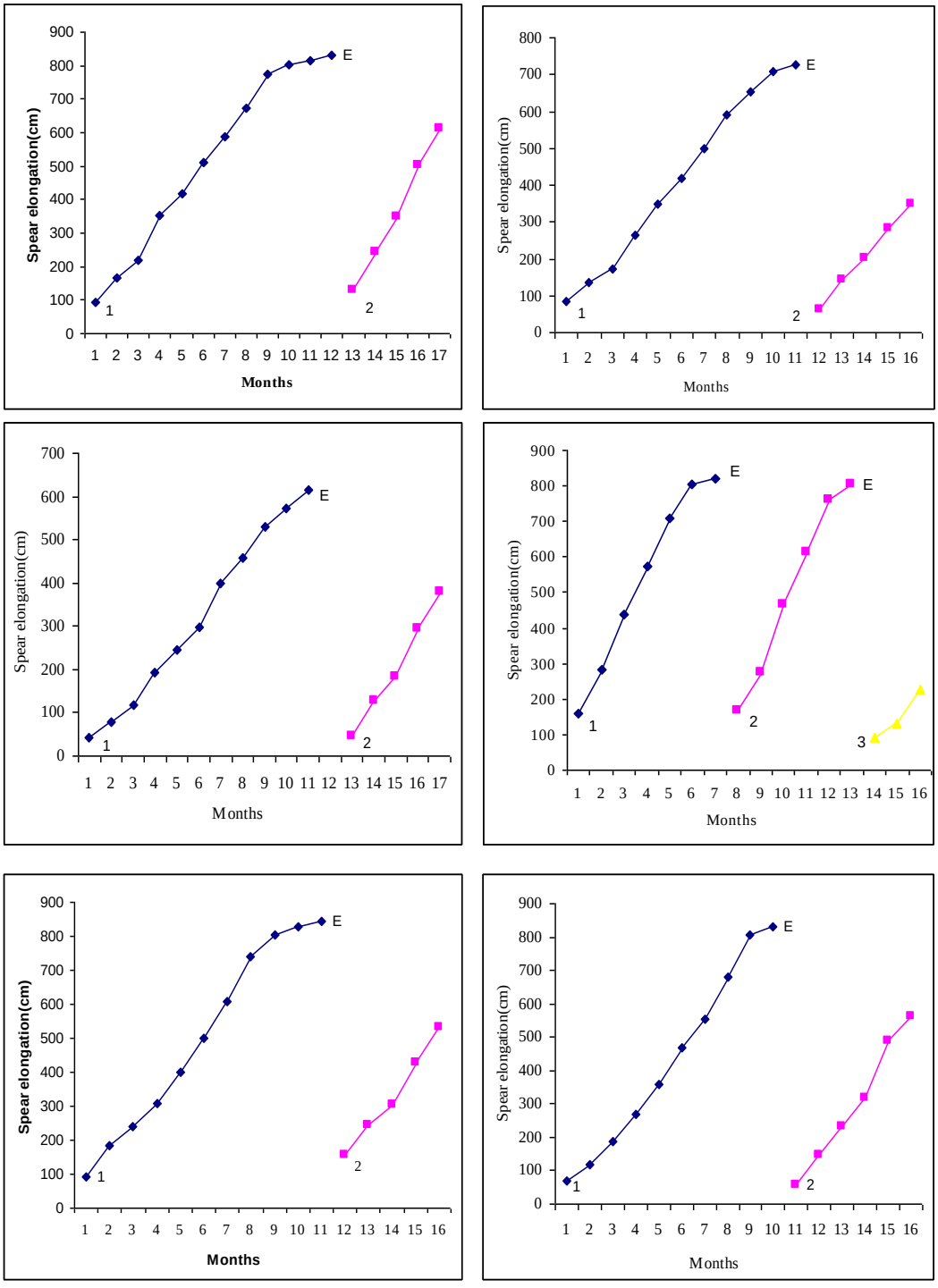


Fig 4.11: Caption next page

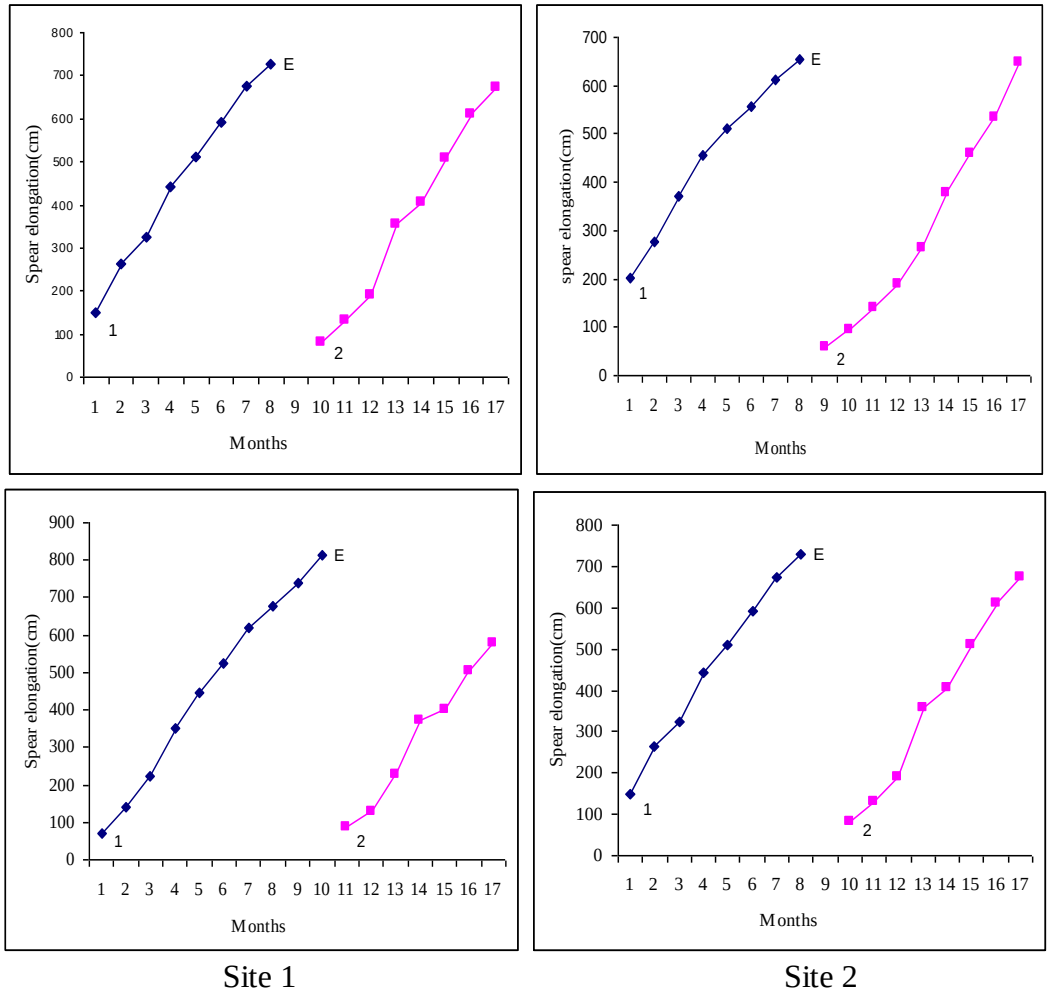


Fig.4.11: Leaf production and spear elongation in nine adult trees in Carey Island during 17 months and in five trees during 16 months at both sites. Growth is characterized by spear leaf elongation from appearance of new spear leaf as it develops until the beginning of leaf expansion= E. Leaves without label were still developing.

The adult trees produced mostly two spear leaves with a long interval period and some of the trees produced three spear leaves. Spear elongation of adult trees had been slow when it reached very high height.

Table 4.10: The mean of some variables of adults of *N. fruticans* at site 1.

	site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
llf	4.1 ± 0.9 N=27	4.6 ± 0.9 N=66	4.7 ± 1.2 N=63
dlf	7 ± 1.5 [a] N=27	5.8 ± 1.8 [a] N=66	6.2± 1.9 N=63
tlf	12.4±2.4 N=27	11.7±1.9 N=66	12 ± 1.9 N=63
nslf/year	0.8 ± 0.6 N=27	0.9 ±0.7 N=66	0.7 ± 0.7 N=63
Lde (month)	10.6±0.7 (N=10)	10.4± 1 (N=19)	10.1±0.9 (N=12)
Elongation / month	81.1±1.1 N=10	78.2±10.2 N=11	81.2±10.9 N=9

a= significant between plots 1 and 2 ($P < 0.05$).

Table 4.10 shows that there was no significance difference among three plots in the variables except for dead leaves. The Tukey test showed that there were significant differences on dead leaves between plots 1 and 2. Adults had the mean of long plastochrone, which was 10 months.

Table 4.11: The mean of some variables of adults of *N. fruticans* at site 2.

Variables	site 2 (means ± sd)		
	Plot 1	Plot 2	Plot 3
llf	5.1±1.3 N=19	5 ± 1.2 N=34	3.5 ± 0.6 N=36
dlf	6.9±2.2 N=19	6 ± 1.3 [c] N=34	7.3 ± 1.9 [c] N=36
tlf	13.6±2.2 N=19	13 ± 2 N=34	11.8±2.4 N=36
nslf/year	1.2 ± 0.7 N=19	1.5±0.6 [c] N=34	0.8± 0.7 [c] N=36
Lde (month)	9.9±1.2 [b] N=9	10.1±0.8 [c] N=17	11.3±0.5 [bc] N=9
Elongation / month	87.9±13.4 N=7	83.8±.12.6 N=15	73.8±14.7 N=9

b= significant between plots 1 and 3 ($P < 0.05$)
c= significant between plots 2 and 3 ($P < 0.05$).

Table 4.11 shows that there were no significant differences in living leaves, total leaves, and spear elongation among three plots at site 2 but there were significant differences in new spear leaf per year only between plot 2 and 3 (by using Tukey test). The Games-Howell test showed significant differences in dead leaves only between plots 2 and 3. In addition, the Games-Howell test showed significant differences in plastochrone among the plots except for between plots 1 and 2. Adults had the mean spear elongation of almost 81cm per month.

Table 4.12: The total mean of some variables of adults of *N. fruticans* at both sites.

	Means ± sd		
Variables	site 1	site 2	t- test
llf	4.6± 1.1 N=156	4.4 ±1.3 N=89	ns
dlf	6.2±0.8 N=156	6.8 ± 1.8 N=89	ns
tlf	12 ± 2 N=156	12.6±2.3 N=89	*
nslf/year	0.8±0.7 N=156	1.1 ±0.7 N=89	*
Lde (month)	10.±0.9 N=41	10.3 ±1 N=35	ns
Elongation / month	80.1±12.7 N=31	81.8±14 N=31	ns

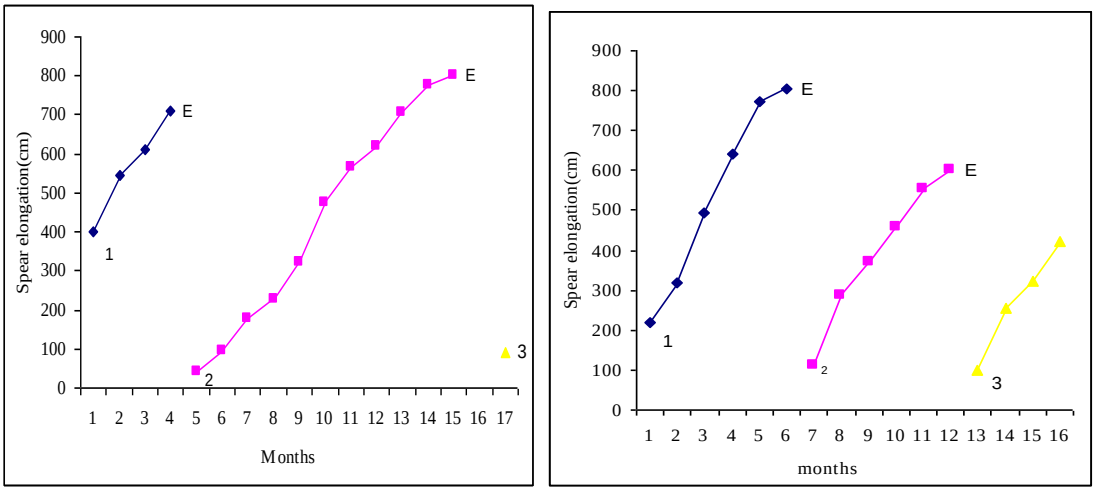
ns= not significant difference($P \geq 0.05$).
* = significant ($P < 0.05$).

Table 4.12 shows there was a significant difference in rate of leaf production (F = 1.13 , P = 0, N = 245), total number of leaves (F = 1.78, P = 0.01, N = 245) between the two sites, but no significances in living leaves (F = 0.09, P = 0.22, N = 245), dead leaves (F = 0.39, P = 0.22, N = 245), plastochrone (F = 0.14, P = 0.89, N = 76) and spear elongation (F = 0.003, P = 0.61, N = 62).

4.2.1.4. Mature stage

During the 16-month study period, of thirty-eight mature trees at site 1, nine mature trees produced one spear leaves, six trees produced two spear leaves. Four trees produced three spear leaves; three trees produced four spear leaves, and sixteen trees that did not produce any spear leaf.

During 16 months, of nineteen mature trees at site 2, twelve mature trees produced one spear leaves, five trees produced two spear leaves; one tree produced three spear leaves. No mature tree had produced four spear leaves. There was only one mature tree that did not produce any spear leaf. The rate of leaf production and spear elongation of eight mature trees is shown in figure 4.12.



Site 1 Site 2

Fig 4.12: Caption next page

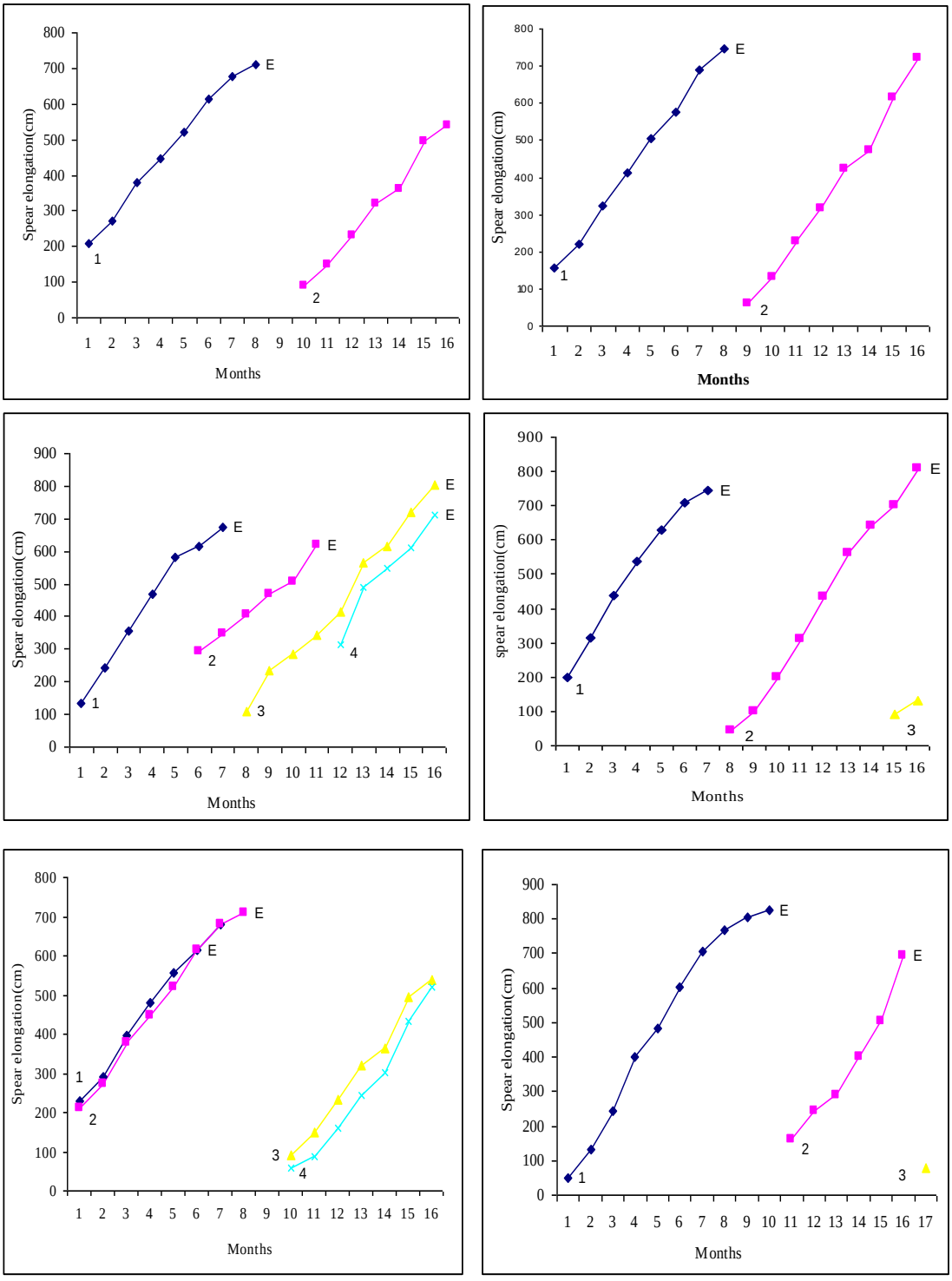


Fig. 4.12: Leaf production and spear elongation in two mature trees in Carey Island during 17 months, and in six mature trees during 16 months. Growth is characterized by spear leaf elongation from appearance of new spear leaf as it develops until the beginning of leaf expansion= E. Leaves without label means that they were still developing.

Table 4.13: The mean of some variables of matures of *N. fruticans* at site 1.

	site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
llf	5.2 ± 0.6 N=10	5.1 ± 1.4 N=10	6.6 ± 3 N=21
dlf	11.3± 1.2 N=10	11.7 ±1.6 N=10	10.4 ±2.7 N=21
tlf	17.1 ±1.6 N=10	18± 1.8 N=10	18.2 ±2.6 N=21
nslf/year	1 ± 0.8 N=10	0.7 ± 0.7 N=10	0.9 ± 1.1 N=21
Lde (month)	10.7 ±0.7 N=4	11.2 ±0.3 N=2	10.1 ±1.4 N=6
Elongation / month	87.7 ±7.3 N=2	–	99.2±7.2 N=3

Table 4.13 shows that there were no significant differences in dead leaves and new spear leaves per year among the 3 plots (by using ANOVA test). Games–Howell test showed there were no significant differences in total number of leaves and living leaves at site 1. At site 1, subjects produced 0.9 spear leaves per year and spear elongation was 91.9 cm per month. There was no data available for spear elongation of matures in plot 2.

Table 4.14: The mean of some variables of matures of *N. fruticans* at site 2.

	Site 2 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
llf	4.3±0.8 [a] N=9	6 ± 1.4 [ac] N=4	4.3±0.5 [c] N=6
dlf	12±0.5 N=9	9.5 ± 1 N=4	11.6 ±1 N=6
tlf	18±2.6 N=9	16.7 ±0.9 N=4	17 ±1.2 N=6
nslf/year	1.2±0.6 N=9	1 ± 0.4 N=4	0.8±0.5 N=6
Lde (month)	9.6±0.6 (n=7)	11.1 ± .2 (n=2)	11 ± 1 (n=3)
Elongation / month	97.8±9.5 N=6	79.1±2.2 N=2	79±22 N=3

a= significant between plots 1 and 2 ($P < 0.05$).
c= significant between plots 2 and 3 ($P < 0.05$).

Table 4.14 shows that leaf production for mature trees at site 2 had a mean of one spear leaf per year. At site 2, Tukey test showed there were significant differences in living leaves in all plots except for between plot1 and 3, but there were no differences in dead leaves, new spear leaves and spear elongation between the plots. In addition, Game - Howell test showed there were no significant differences in total number of leaves in matures. Tukey test also showed that there was no significant difference in plastochrone between the plots.

Table 4.15: The total mean of some variables of adults of *N. fruticans* at both sites.

Means ± sd			
Variables	site 1	site 2	t- test
llf	5.9 ± 2.3 N=41	4.6 ± 1.1 N=19	*
dlf	10.9±2.2 N=41	11.5±.2.1 N=19	ns
tlf	17.8±2.2 N=41	17.4 ±2 N=19	ns
nslf/year	0.9 ± 1 N=41	1±0.5 N=19	*
Lde (month)	10.4±1.1 N=12	10.2 ± .9 N=12	ns
Elongation / month	94.6±8.9 N=5	89.3±15.4 N=11	ns

ns= not significant difference ($P \geq 0.05$).
* = significant difference ($P < 0.05$).

Table 4.15 shows there is significant difference in living leaves ($F = 2.41$, $P = 0.03$, $N = 60$) and rate of leaf production per year ($F = 540.7$, $P = 0.0$, $N = 60$) between two sites while there is not significant difference in dead leaves ($F = 0.01$, $P = 0.35$, $N = 60$), total number of leaves ($F = 1.18$, $P = 0.43$, $N = 60$), plastochrone ($F = 0.001$, $P = 0.6$, $N = 24$), and spear elongation ($F = 2.55$, $P = 0.49$, $N = 16$).

4.2.2. Leaf life span

Leaf life span is defined as the period (year) that a leaf can live on the tree. It can be calculated by multiplying the number of living leaves and plastochrone for each subject.

Table 4.16: The mean of leaf life span of *N. fruticans* in four stages at site 1.

	Site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
Seedlings	-	-	-
Juveniles	3.7±1 N=3	4.2± 1.2 N=14	4.4± 0.8 N=9
Adults	4.5 ±1.2 N=27	5 ± 1.1 N=66	4.8 ± 1.2 N=63
matures	6 ± 1.2 N=10	5.2 ± 1.6 N=10	6.2 ± 2.3 N=21

Table 4.17: The mean of leaf life span of *N. fruticans* in four stages at site 2.

	Site 2 (means ± sd)			
Variables	Plot 1	Plot 2	Plot 3	ANOVA
Seedlings	2 ± 1.5 N=3	_	1.1 ± 0.9 N=5	ns
Juveniles	3.7± 0.7 [ab] N=4	2.3 ±1.1 [a] N=3	2.6± 0.5 [b] N=17	*
Adults	5.3 ± 1.2 [b] N=19	5.6 ± 1.2 [c] N=34	4.3 ± 0.8 [bc] N=36	*
matures	4.7±1.1 [a] N=9	6.6 ±1.7 [a] N=4	4.8 ±0.5 N=6	*

a= significant between plots 1 and 2 ($P < 0.05$).
b= significant between plots 1 and 3 ($P < 0.05$).
c= significant between plots 2 and 3 ($P < 0.05$).

The table 4.16 and 4.17 show that there were no significant differences in the mean of leaf life span in all stages among the plots at site 1 (by using ANOVA test). There were significant differences in the mean of leaf life span among the plots at site 2 except for seedlings. The significant differences among the plots at site 2 were not related to water and soil quality. The possible reason for this may be related to difference in plastochrone.

Table 4.18: The mean of leaf life span of *N. fruticans* in four stages at both sites.

	Means ± sd		
Variables	Site 1	Site 2	t- test
Seedlings		1.5 ±1.1 N=8	-
Juveniles	4.2± 1 N=26	2.7± 0.7 N=24	*
Adults	4.8 ± 1.2 N=156	5 ± 1.2 N=89	ns
Matures	5.9 ±1.8 N=41	5.1± 1.3 N=19	ns

ns: not significant difference ($p \geq 0.05$)
*significances ($P < 0.05$).

Table 4.18 shows that there were no significant differences in mean life span in adults (F= 0.17, P= 0.28, N= 245), and matures (F= 3.2, P= 0.09, N= 58) between two sites except for juveniles (F= 2.57, P= 0.00, N= 50) that had higher level of leaf life span at site 1 than site 2.

4.3 Age structure

4.3.1. Seedlings

The plastochrone (lde) is important in order to estimate the age of subjects. Correlation analysis showed that there was no significant relationship between the plastochrone and the total number of leaves (Pearson Correlation r = 0.172, P value = 0.78, N=5). This means the relationship is not reliable and it is predicted that plastochrone is constant with total number of leaves. Most trees produced new spear leaves after the previous spear leaves were expanded but on some occasions, the next proceeding spear leaf appeared before the opening of the previous leaf. Seedlings grow rather rapidly and there is a short

gap between the previous leaf and next leaf. In this stage, plastochrone is not long, so this results in the higher rate of leaf production per year in seedlings. The seedlings were classified into six age classes as were shown in figure 4.13. They were in age groups 0.5 to 3.5 years with the peak age in the range of 0.5 to 1 year. In the seedlings, the maximum age was 3.3 years old. This age is considered the minimum age in seedling stage based on the samples observed.

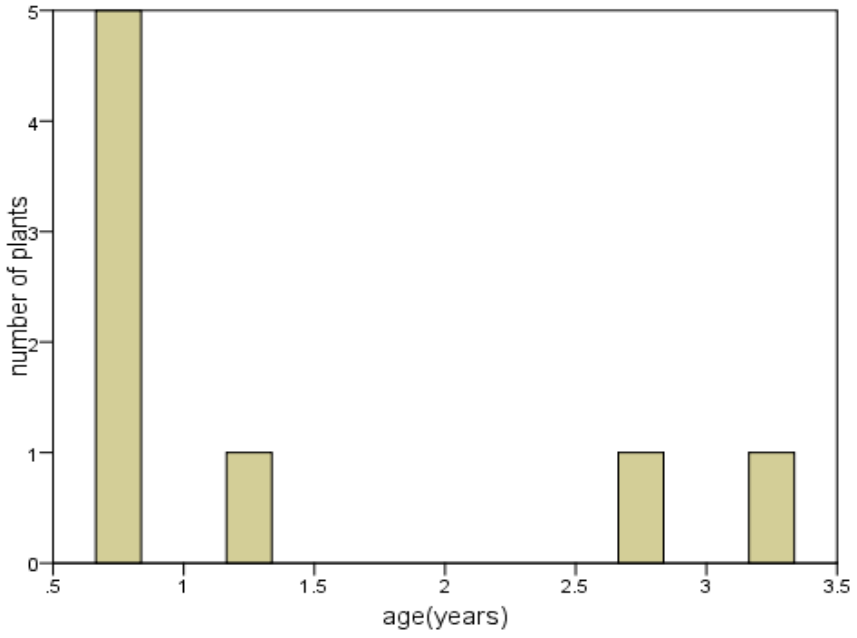


Fig 4.13: The age structure of all seedlings of *N. fruticans* (N=8).

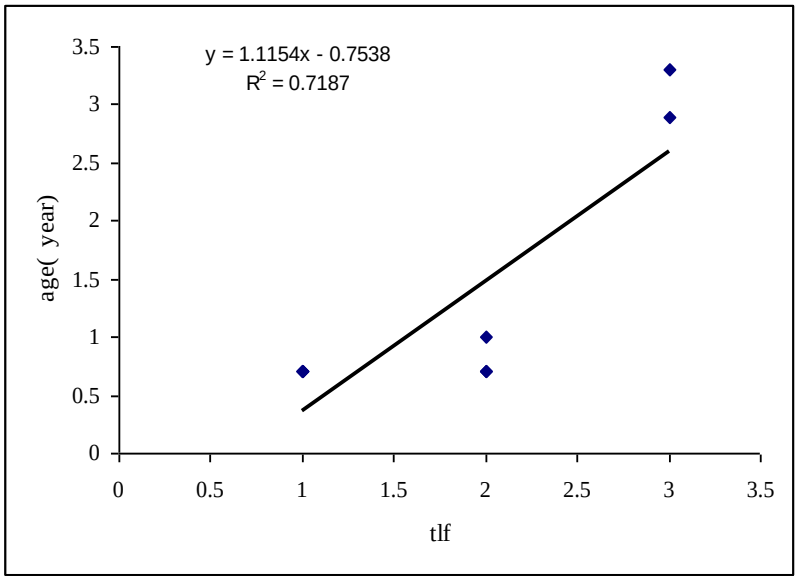


Fig 4.14: The regression between age and the total number of leaves (tlf) in seedlings of *N. fruticans* (N=8).

Figure 4.14 shows the regression between age and the total number of leaves (tlf) in 8 seedlings of *N. fruticans.* The age of the seedlings of *N. fruticans* increases by 1.1 years as the total number of leaves increases by 1 (Fig 4.14)

4.3.2. Juveniles

The longest plastochrone, 10 months, a bigger number of living leaves, 8.5 leaves, and older trees with around 8.3 years were found in plot 2 at site 1. The possible reason for having older plants at site 1 is that the total number of leaves and plastochrone was bigger than at site 2. The mean number of total leaves was bigger at site 1 than at site 2 because the mean number of dead leaves was bigger. Then the age of seedling, 3.3 was added to the time spent in juvenile stage, 8.3, to calculate the age of each juvenile. Therefore, the maximum mean age obtained for juvenile stage is 11.6 years (8.3 + 3.3). This age is the minimum age spent up to the end. The juveniles are classified into seven age classes in age groups 2 to 9 years with the peak age in the range of 5 to 6 years (Fig 4.15).

Correlation analysis shows that there was no relationship between the plastochrone and the total number of leaves (Pearson Correlation r = -0.059, P value=0.77, N=27). This means that the plastochrone was not significantly related to the total number of leaves and it was constant in juvenile stage.

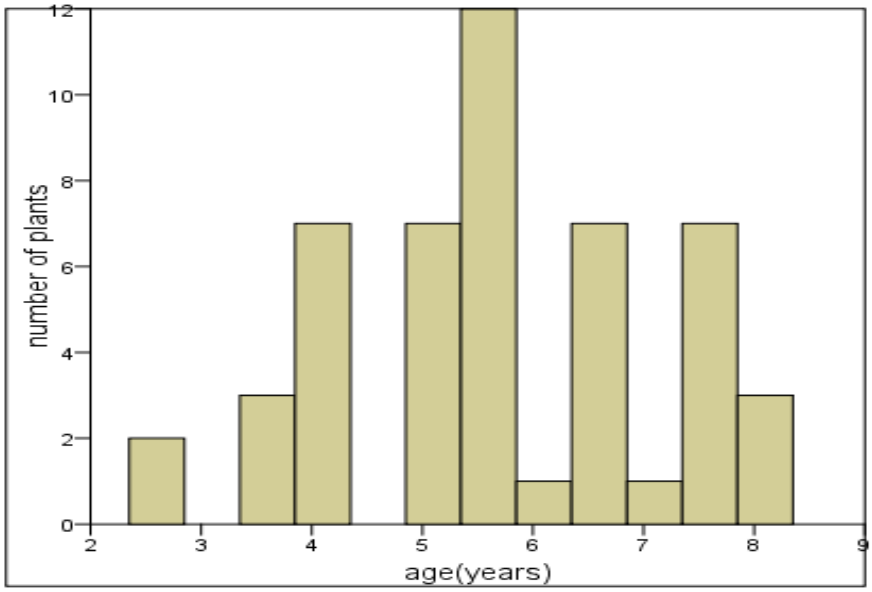


Fig 4.15: The age structure of juveniles of *N. fruticans* (N= 50).

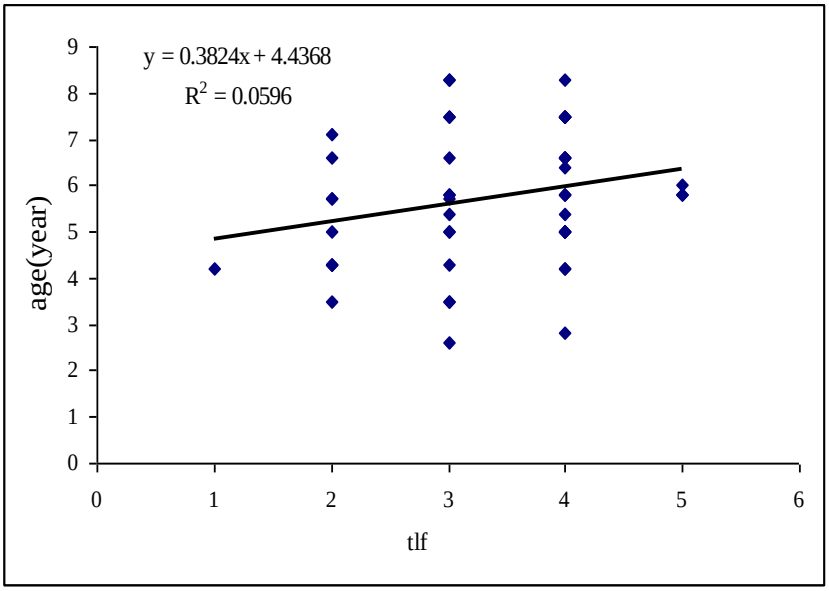


Fig 4.16: The regression between age and the total number of leaves (tlf) in juveniles of *N. fruticans*. (N= 50)

Figure 4.16 shows the regression. between age and the total number of leaves (tlf) in juveniles of *N. fruticans.* The age of the juveniles of *N. fruticans* increases by 0.3 years as the total number of leaves increases by 1 (Fig 4.16)

4.3.3. Adults

Adults at both sites were of the same age range at around 11 years. Adults had long plastochrone of 10 months and the reason for this significant difference between both sites may be related to the small number of adult subjects at site 2 compared to site 1. The maximum age was 16.9 in adult stage. The maximum age in adults was calculated to be 28.5 years (11.6 +16.9) which is considered the minimum age spent up to the end of adult stage. The adults were classified into 6 age classes ranging from 6 to 18 years while the peak age is in the range of 10 to 12 years (Fig. 4.17). Correlation analysis shows the relationship between the plastochrone and the total number of leaves (Pearson Correlation= 0.23, P value = 0.04, N=75).

This means that the plastochrone was not significantly related to the total number of leaves and it was constant in adult stage.

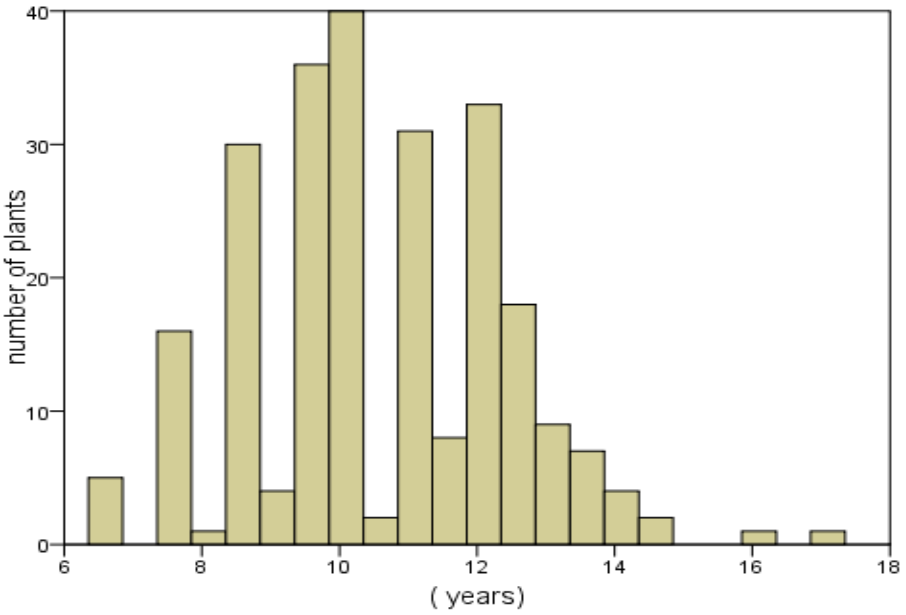


Fig. 4.17: The age structure of adults of *N. fruticans* (N=248).

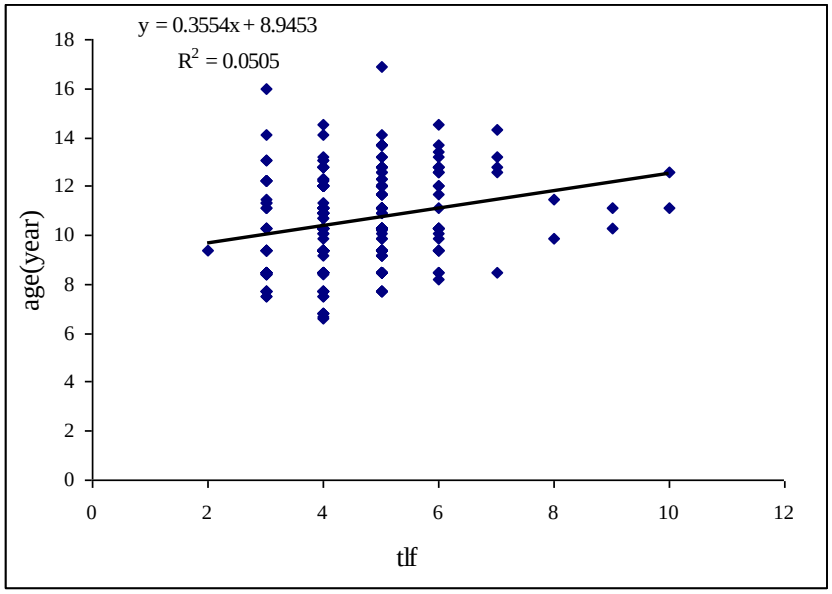


Fig. 4.18: The regression between age and the total number of leaves (tlf) in adults of *N. fruticans*. (N= 248)

Figure 4.18 shows the regression between age and the total number of leaves (tlf) in adults of *N. fruticans*. (N= 248). The age of the adults of *N. fruticans* increases by 0.3 years as the total number of leaves increases by 1 (Fig 4.18).

4.3.4. Mature trees

The mean age estimation of mature trees was 15.1 years old. The mean number of living leaves was bigger at site 1 than at site 2. Therefore the one reason that the oldest mature trees were found at site1 with the age of 19.9 years was related to the total number of leaves. The reason of this significant difference between the valuables such as the mean living leaves and total number of leaves may be due to the small number of trees. The correlation analysis shows that there was no relationship between the plastochrone and the total number of leave (Pearson Correlation r = -0.08, P value = 0.53, N=24). This means that the plastochrone was not significantly related to the total number of leaves therefore the plastochrone was almost constant in mature stage.

The maximum age in the mature stage calculated was 19.9. Then this age was added to the maximum age calculated in adult stage for estimation of the maximum age in mature stage to be 48.4 years (28.5 + 19.9). The mature trees were classified into 6 age classes in age groups of 10 to 22 years, with a peak age in the range of 14 to 16 years the highest peak of numbers in the mature stages at around 14 years. (Fig. 4.19).

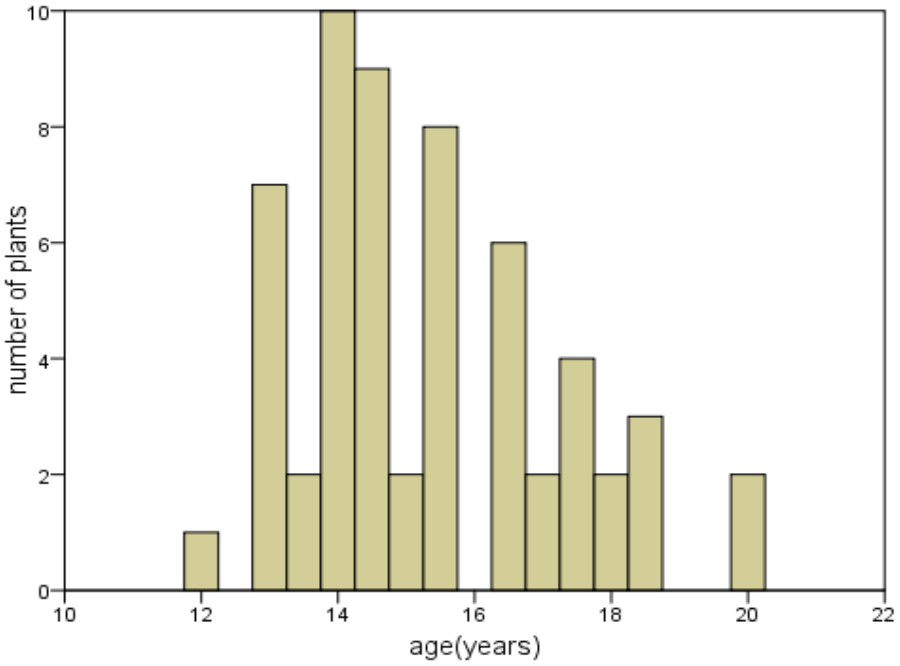


Fig. 4.19: The age structure of matures of *N.fruticans* (N=58).

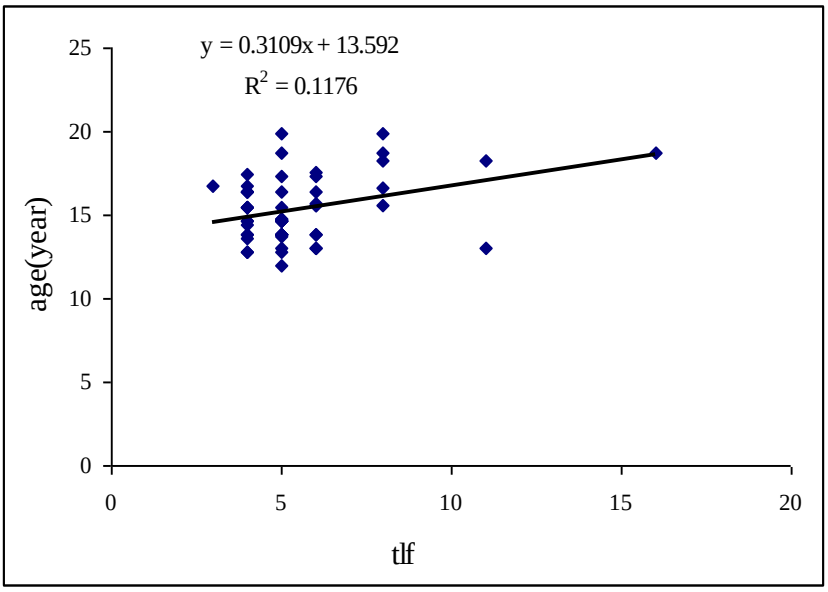


Fig 4.20: The regression between age and the total number of leaves (tlf) in matures of *N. fruticans*. (N= 58)

The figure 4.20 shows the regression between age and the total number of leaves (tlf) in

matures of *N. fruticans.* The age of the matures of *N. fruticans* increases by 0.3 years as the total number of leaves increases by 1 (Fig 4.20).

In total, there was no age gap among the seedling, juvenile, adult and mature stages.

Table 4.19: The mean of calculated age (years) of *N. fruticans* in four stages at site 1.

	Site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
Seedlings	-	-	-
Juveniles	6.6±1.1 N=4	6.6±0.8 N=14	6.6±1.3 N=9
Adults	10.6±2 N=27	9.9±2 N=66	11.8±12.6 N=66
Matures	14.8±1.4 N=10	15.3±1.6 N=10	15.8±2.3 N=21

Table 4.20: The mean of calculated age (years) of *N. fruticans* in four stages at site 2.

	Site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
Seedlings	2.3 ±1.4 N=3	-	0.7 ±0.1 N=5
Juveniles	5.2±0.7 N=4	3.6±0.9 N=3	4.7 ±1.1 N=17
Adults	11.1±1.8 N=19	10.8±1.6 N=34	11.1±2.2 N=36
Matures	14.4±2.1 N=9	15.4±0.8 N=4	15.5±1.1 N=6

Table 4.19 and 4.20 show that there were no significant differences among the plots in the mean age of all stages except for seedlings by using ANOVA test (appendix 9). At site 1, the average age of seedlings were 0.7 – 2.3, 6.5 for Juveniles, 10.9 for adults and 15.1

for matures. Hence, the mean age of a mature subjects at site 1 was estimated to be 33.2 - 34.8 years (0.7 – 2.3 + 6.5 +10.9 + 15.1).

Table 4.21: The mean of calculated age (years) of *N. fruticans* in four stages at both sites.

	Means ± sd		
Variables	Site 1	Site 2	t- test
Seedlings	-	1.3 ±1	-
Juveniles	6.5±1 N=26	4.7 ±1.1 N=24	*
Adults	10.2±1.2 N=158	11±1.9 N=89	*
Matures	15.4±2 N=41	14.9±1.6 N=19	ns

*significances ($P < 0.05$).
ns: not significant difference ($p \geq 0.05$)

Table 4.21 shows that there were no significant differences in the mean age of matures (F=1.11, P = 0.36, N= 60) between both sites but there were significant differences in juveniles (F= 0.12, P= 0.00, N= 50) and adults (F= 0.73, P = 0.001, N= 245) which were older at site 1. At site 2, the average age of seedlings were 0.7 – 2.3, 4.7 for juveniles, 10.9 for adults and 15.1 for matures. So, the mean age of a mature subject at site 2 was estimated to be 31.4 – 33 years. (0.7 – 2.3 + 4.7 +10.9 + 15.1). Hence, the mean age of a mature tree is 31.4 – 34.8 years

4.4. Reproductive phenology

Flowering and fruiting events of *N. fruticans* has been investigated for one hundred and fifteen adults and matures trees during 16 months.

4.4.1. Inflorescence scoring

Table 4.22 shows that in *N. fruticans,* there was an average of 16 rachillaes in the male inflorescence; each rachillae generated around 90.5 male flowers. Total number of male flowers in each florescence was 1448.

Table 4.22: Mean values for male inflorescence in *N. fruticans.* (means ± sd, N=6).

Num of rachillae per infl.	Num of flowers per rachillae	Total male flowers per rachillae
16 ± 3	90.5 ± 6.3	1448

Table 4.23 shows that a female flower has one rachillae; each rachillae bore an average of one hundred and eighteen female flowers. Total number of flowers in an inflorescence was one hundred and eighteen. After pollination the female inflorescence turned into infruitescence. Ninety-six point six (96.6) fruits on each rachillae produced about a total of 96.6 fruits in each infructescence. Since each fruit has one seed, the total number of seeds produced in each infructescence was estimated from the number of fruits, 96.6 seeds. The ratio of male to female flowers was fifteen and ratio of female flowers to fruits 1.2.

Table 4.23: Mean values for female inflorescences in *N. fruticans* (means ± sd, N=6).

Num of rachillae per infl.	Num of flowers per rachillae.	Total female flowers per infl.	Num of fruits per rachillae	Total fruit per infl.	Ratio male: female per infl.	Ratio female: fruit per infl.
1	118 ± 25	118	96.6 ± 23.3	96.6	15	1.2

4.4.2. Inflorescence development

Flowering activity can be observed at any time of the year. Weekly field observations of the morphological changes in appearance for all observed reproductive trees including 115 adult and mature trees were carried out for three months. For the rest of the study period, monthly observations were done. During these 14 months, the number of new inflorescences per palm was counted monthly. Total number of new inflorescence per year for each palm and percentage of flower production were determined. The rate of flower and fruit production per year of *N. fruticans* in Carey Island was calculated during a 14-month study period.

Of the one hundred and fifteen observed trees, sixty-one trees produced seventy-six new inflorescences with the range of 1-3, and forty five trees produced fifty-four new infruitescences with the range of 1-2 during a period of 14 months. Of the sixty-one trees, forty-seven trees produced one inflorescence each; thirteen trees produced two inflorescences, only one tree produced three inflorescences with each tree producing an average of 1.2 inflorescences. Of the one hundred and fifteen observed trees, forty-five

trees produced fifty-four new infruitescences with the range of 1-2 throughout the 14 months. The maximum number of infruitescence being produced by one tree was two. Of the forty-five trees, thirty-six trees produced one infruitescence and nine trees produced two infruitescences with each tree producing an average of 1.2 infruitescences. So, an average of total number of fruits produced by one reproductive tree was 1.2 x (96.6) = 115.9 fruits. *N. fruticans* can flower and fruit throughout its life and there is no regular pattern. Therefore the determination of the exact number of fruits produced by one tree in its life time is impossible. Fifty-three percent (61 / 115x 100 = 53 %) of trees produced new inflorescences. Thirty-nine point one percent (45 / 115 x 100 = 39.1 %) produced new infruitescences throughout the 14 months.

Rate of new inflorescence production for each tree per year throughout the 14 months was one, calculated by this equation: (76 inflorescence/61 trees) x (12 months /14 months) = 1. Rate of new infruitescence production for each tree per year during 14 months was also 1. It was derived by this equation: (54 infruitescence/45 trees x 12 months/14 months = 1). The minimum age of a reproductive tree was about 23.1 years old and the maximum was about 43.2 years old which from 115 samples observed gives 20.1 reproductive years. Although the oldest trees were estimated 48.4 years, it didn't flower during the observation. *N. fruticans* produced one inflorescence per year within 20.1 reproductive years. So, this species produced about 20.1 inflorescences. Results in scoring flower showed that there was a mean of 96.6 fruits in one infruitescence. Therefore, there would be 20.1 number of inflorescence x 96.6 number of fruits = 1941.6 fruits per tree in 20.1 reproductive years.

The results below show the developmental stages of inflorescence in both male and female:

Stage 2-3: 16- 23 days

Stage 3-4: 7-16 days

Stage 4-5: 14-21 days

Stage 5-6: 180 days

Stage 6-7: 30-50 days

The total flowering cycle took 8.2- 9.6 months.

Stage2

Unexpanded inflorescence

Stage3
Spherical and unopened female flower

Stage3
Oval and unopened male flowers

Stage4
Opened female flowers

Stage4
Opened male flowers

Stage5
young brown fruit

Stage5
Pollen released

Stage6

Mature fruit (first fallen fruits)

Stage7

End of flowering cycle with completely fallen fruits

Fig. 4.21: The sequence of male and female flowering events of *N. fruticans* in stage 2 to stage7.

Figure 4.21 shows that in stage 2, the shape and color of inflorescence were the same in male and female flowers. In stage 3, the female flower was differentiated from the male flower by the round shape and yellow color at the tip of the inflorescence trunk. In male flowers, spikes were covered with bracts and were oval shaped below the female flowers. In stage 4, the bracts were removed and yellow round female flowers at end of inflorescence trunks appeared. They could be recognized simply from the male flowers by their catkin shape. When they turned into young fruits in stage 5, they were round and brown in color. Male flowers became black in stage 5 and pollens had been released. In stage 6, the young fruits became mature. This stage was recognized by observation of the first fruit detaching from the cluster of fruits and fallen down. Each infruitescence with a ball shape had a range of 60 - 120 mature turbinate fruits with length between 8cm - 12cm. It also had a diameter of 45cm to 85cm.

4.4.3. Insect visitors

There was a variety of visiting insect at different times. From my observation, at 10am, there were very few visiting insects but at 11.30am, there were a large number of insects which continued until around 1:30 pm. In the afternoon, the activity of visiting insects decreased substantially and even stopped after 2:30 pm. The male flowers had strong and good smell until 2 pm. It seemed that the smell belonged to bracts of male flowers and attracted the visitors. The flowers were opened following a particular top-down pattern on the inflorescence. So, open flowers did not have a random dispersion. I was not fortunate enough to observe whether the male flowers were short-lived or not because the monkeys took them as soon as they were opened, due to the fact that they had shiny yellow color with attractive shapes. I was not able to identify the insect visitors.

4.4.4. Seed germination

The seed germination investigated at the glass house revealed that the rate of germination in this study for *N. fruticans* was low. Of 54 planted seeds in glasshouse, only 9 fruits sprouted (16.6 % of fruits) after 15-46 days with an average of 35.5 ± 10.7 days. The first germination of *N. fruticans* in this study happened after 18 days in a glasshouse. Figure 4.22 shows the percentage of seeds to germinate in *N. fruticans* was low in the glasshouse but it didn't take so long to germinate.

A B

Fig. 4.22: Caption next page.

C D

Fig.4.22: seed germination of *N. fruticans* in glasshouse. A. Cross section of a fruit with white soft endosperm. B. Turbinate fruit of *N. fruticans* with single seed. C. cultivated seeds in a container. D. germinated seeds with exerted plumule.

4.5. Soil and water analysis

4.5.1. Soil

The soils in all the six study plots at both sites were silty-clay with low mean of soil moisture contents percentage of 34.24 ± 6. Soil temperature was 29.6 ± 1º C.The tables 4.24 and 4.25 show the means of pH and temperature and moisture content in each plot at both sites in Carey Island during the 16 months.

Table 4.24: pH, Temperature of soil samples in Carey Island during 16 months at site 1.

	Site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
pH	6.1± 0.2 [b] N=9	6.4 ± 0.3 N=9	6.5 ±0.2 [b] N=9
temperature	29.6± 0.6 N=9	29.4± 0.4 N=9	29.4± 0.4 N=9
moisture content	39.7± 4.2 [a] N=24	36.6± 3.7 [ac] N=24	39.6 ± 4.7[c] N=24

a= significant between plots 1 and 2 ($P < 0.05$).
b= significant between plots 1 and 3 ($P < 0.05$)
c= significant between plots 2 and 3 ($P < 0.05$).

Table 4.24 shows that there are significant differences in soil pH and moisture content between some plots at site1 (by using ANOVA and Tukey test) but there are no significances in soil temperature.

Table 4.25: pH, Temperature of soil samples in Carey Island during 16 months at site2.

	Site 2 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
pH	6.8±0.3 N=9	6.4±0.5 N=9	6.1±0.6 N=9
temperature	29.8±1.3 N=9	29.7±1.3 N=9	29.8±1.3 N=9
moisture content	29 ± 2.5 N=24	29.7 ± 2.7 N=24	28.6 ± 2.7 N=24

Table 4.25 shows that there are no significant differences in soil pH, temperature and moisture content between the plots at site 2 (by using ANOVA test).

Table 4.26: pH, Temperature of soil samples in Carey Island during 16 months at both sites.

	Means ± sd		
Variables	site 1	site 2	t- test
pH	6.5±0.4 N=27	6.4±0.4 N=27	ns
temperature	29.7 ±1 N=27	29.5 ±0.9 N=27	ns
Moisture content	38.7 ± 4.4 N=72	29 ± 2.5 N=72	*

ns= no significant difference ($P \geq 0.05$).
* = significant ($P < 0.05$).

Table 4.26 shows between the two sites, there were no significant differences in the soil pH (F= 0.02, P= 0.65, N= 36) and temperature (F= 0.26, P= 0.52, N=36) but there were significant differences in moisture content (F= 4.15, P= 0.00, N= 102). Soil pH in Carey Island is 6.4 ± 0.4, slightly acidic due to the low tide. For soil to be alkaline, it needs salt water infused from the sea during high tide. The correlation analysis shows that there was no relationship between the soil variables (pH, temperature, and moisture content) and growth of trees (lls, llf,dlf, tlf, lde, nslf and spear elongation) in all stages except for in matures that there were positive relationship relation between soil temperature and leaf life span.(Pearson' correlation = 0.27, $P < 0.05$, N=54).

4.5.2. Water

4.5.2.1 Physical parameters

The mean values of water quality data such as Salinity, pH, temperature, Dissolved oxygen (DO), total dissolved solids (TDS) and electro conductivity (EC) with no

significant differences in results in each plot at both sites are shown in tables 4.27 and 4.28 (appendix 8). One-way ANOVA test for significant differences among the plots and t test for significant differences between the sites in Carey Island have been done. Table 4.27 and 4.28 show there was no significant difference in water valuables in Carey Island among the plots at both sites (by using ANOVA test). The mean of water temperature in Carey Island is 27.3 ± 0.8 Cº.

Table 4.27: The mean of variables of water samples (N=21 in each plot) at site 1during 14 months in Carey Island.

	Site 1 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
pH	6.4±0.2	6.4±0.3	6.4±0.2
Salinity (ppt))	23.2±2	23.5±2.4	23.9±2.6
TDS (ppt)	22.8±2	23.3±2.4	23.4±2.8
EC (ms/cm)	36.9±3.7	37.1±4.1	36.5±4.8
DO (mg/L)	8.3±1.5	8.5±1.1	8.3±1.2

Table 4.28: The mean of variables of water samples (N=18 in each plot) at site 2during 14 months in Carey Island.

	Site 2 (means ± sd)		
Variables	Plot 1	Plot 2	Plot 3
pH	6.5±03	6.4±0.2	6.3±0.4
Salinity (ppt))	25.5±1.9	25.6±2	25.8±1.9
TDS (ppt)	26.6±5.3	24.8±2.1	26.9±4.7
EC (ms/cm)	39.6±3.6	40.5±2.3	40.1±1.4
DO (mg/L)	6.7±1.5	7.2±1.8	6.9±1.6

Table 4.29: The total mean of variables of water Samples at both sites during 14 months in Carey Island.

	Means ± sd		
Variables	Site 1	Site 2	t- test
pH	6.4±0.2 N=63	6.4±0.3 N=54	ns
Salinity(ppt))	23.5±2.3 N=63	25.6±1.9 N= 54	*
Temperature (C^{o})	27.1 N=63	27.5 N=54	*
TDS(ppt)	23.2±2.4 N=63	26.1±4.3 N=54	*
EC(ms/cm)	36.8±4.2 N=63	40.1±2.5 N=54	*
DO(mg/L)	8.4±1.3 N=63	7±1.6 N=54	*

ns = no significant difference ($P \geq 0.05$)
*significances ($P < 0.05$)

Table 4.29 shows that there was a significant difference in salinity (F= 3.5, P= 0.00, N= 117), temperature (F= 3.41, P= 0.01, N=117), TDS (F= 3.77, P= 0.00 , N=117), EC (F= 20.5, P= 0.00, N= 117), DO(F= 6.75, P= 0.00, N= 117) between the two sites except for water pH with the average of 6.4. The means of salinity and TDS, EC at site 2 were higher than at site 1. The mean value of dissolved oxygen at site 2 was less than at site 1 which was 7 mg/L. In seedlings, there was no relationship between water variables and growth (lls, llf,dlf, tlf, lde, nslf and spear elongation). In juveniles, there were positive relationship between pH and lde (pearson' correlation = 0.04, $P < 0.05$, N=50), and also between water temperature with leaf life span (pearson' correlation = 0.031, $P < 0.05$, N= 50) and with new spear leaf (pearson' correlation = 0.036, $P < 0.05$, N= 50). In addition, in juveniles, salinity was negatively related to the total number of leaves (pearson' correlation = - 0.316, $P < 0.05$, N= 50) and new spear leaves (pearson' correlation = - 0.292, $P < 0.05$, N= 50).

In adults, there was a positive relationship between pH (pearson' correlation = 0.20, P < 0.05, N= 117) and water temperature (pearson' correlation = 0.21, P < 0.05, N= 117 and the number of living leaves. In matures, number of new spear leaves was positively related to salinity (pearson' correlation = 0.351, P < 0.05, N= 58), DO (pearson' correlation =0.279, P < 0.05, N= 58), and EC (pearson' correlation =0.32, P < 0.05, N= 58). Also, the correlation showed that there was no relation between TDS, EC and DO, and the growth of trees except for in matures. In matures, DO (pearson' correlation =0.279, P < 0.05, N= 58) and EC (pearson' correlation =0.325, P < 0.05, N= 58) were related with new spear leaf production positively .

4.5.2.2 Heavy metals

The concentrations of Heavy metals (Pb, Cu, Zn, As) for water samples has been determined to relate to growth rates of individuals.

Table 4.30: The mean concentration of heavy metals of water samples at site 1 during 15 months in Carey Island.

Site 1 (means ± sd)				
variables		Plot 1	Plot 2	Plot 3
Heavy metals(mg/L)	Pb	0.02±0.02 N=4	0.003±0.003 N=3	0.01±0.01 N=3
	Cu	0.06± 0.05 N=15	0.06± 0.05 N=15	0.06± 0.05 N=15
	Zn	0.02± 0.01 N=9	0.02± 0.01 N=11	0.01± 0.01 N=11
	As	0.05± 0.1 N=15	0.07± 0.1 N=17	0.07± 0.1 N=17

Table 4.31: The mean concentration of heavy metals of water Samples at site 2 during 15 months in Carey Island.

Site 2 (means ± sd)				
variables		Plot 1	Plot 2	Plot 3
Heavy metals(mg/L)	Pb	0.01± 0.01 N=4	0.02± 0.01 N=4	0.01± 0.01 N=3
	Cu	0.03± 0.03 N=5	0.03± 0.03 N=15	0.01± 0.02 N=15
	Zn	0.02± 0.01 N=7	0.02± 0.02 N=6	0.1± 0.3 N=4
	As	0.09± 0.2 N=8	0.1±0.2 N=10	0.01± 0.01 N=13

Table 4.30 and 4.31 show that there was no significant difference among the plots at both sites in mean concentration of heavy metals by using ANOVA test. (Appendix 8).

Table 4.32: The total mean concentration of heavy metals of water samples at both sites during 15 months in Carey Island.

		(means ± sd)		
variables		site 1	site 2	t- test
Heavy metals(mg/L)	Pb	0.02±0.02 N=8	0.01±0.01 N=7	ns
	Cu	0.06± 0.05 N=45	0.03± 0.03 N=41	*
	Zn	0.02± 0.01 N=31	0.06± 0.01 N=17	ns
	As	0.06± 0.1 N=49	0.07± 0.1 N=31	ns

ns: no significant difference ($P \geq 0.05$)
*significances ($P < 0.05$)

Table 4.32 shows that there was no significant difference between the two sites in the mean concentration of heavy metals, Pb ($F = 6.23$, $P = 0.12$, $N = 12$), Zn ($F = 6.28$, $P =$

0.13, N = 48) and As (F = 0.76, P = 0.95, N = 80), except for Cu (F= 16.7, P = 0.002, N= 86). The mean concentration of Cu at site 2 was less than at site 1.

The correlation showed that in adults and matures, there were not relationship between heavy metals and growth while in seedling there were a positive relationship between Lde (pearson' correlation =0.932, P < 0.05, N= 8) and new spear leaf (pearson' correlation = 0.85, P < 0.05, N= 8),and the concentration of As. Also, in juveniles, there were negative relationship between Zn (pearson' correlation = -0.288, P < 0.05, N=48) and dead leaves, and also negative relationship between As (pearson' correlation = -0.39, P < 0.05, N= 50) and living leave.

Table 4.33: The mean concentration of major and trace metals of water samples at site 1 during 15 months in Carey Island.

Site 1 (means ± sd)				
variables		Plot 1	Plot 2	Plot 3
Major metals (mg/L)	Ca	234.7± 51.5 N=21	208.5± 70.9 N=21	242.5± 54.8 N=18
	Mg	382.8± 191.6 N=21	357.4± 167.7 N=21	364.5± 172.4 N=21
	Mn	0.1± 0.1 N=18	0.1± 0.1 N=19	0.2± 0.1 N=16
	Fe	0.3± 0.2 N=13	0.4± 0.3 N=12	0.2± 0.2 N=12
Trace metals (mg/L)	Al	0.4± 0.2 N=9	0.3± 0.2 N=14	0.2± 0.3 N=16

Table 4.34: The mean concentration of major and trace metals of water Samples at site 2 during 15 months in Carey Island.

Site 2 (means ± sd)				
Variables		Plot 1	Plot 2	Plot 3
Major metals(mg/L)	Ca	104.4± 51.7 N=15	153.6±107 N=18	163.3± 94.4 N=21
	Mg	236.9± 70.4 N=15	223.7± 64.8 N=15	248.8± 39.8 N=15
	Mn	0.04± 0.03 N=15	0.06± 0.04 N=15	0.06± 0.04 N=22
	Fe	0.5± 0.4 N=15	1.3± 2.4 N=15	0.4± 0.2 N=4
Trace metal (mg/L)	Al	0.2± 0.1 N=14	0.2± 0.1 N=9	0.06± 0.05 N=6

Table 4.33 and 4.34 show that there was no significant difference among the plots in mean concentration of major and trace metals at both sites by using ANOVA Test. (Appendix 8).

Table 4.35: The mean concentration of major metals from river water samples at both sites during 15 months on Carey Island.

		(means ± sd)		
variables		Site 1	Site 2	t- test
Major metals(mg/L)	Ca	227.9± 60.7 N=60	143.7± 91.7 N=54	*
	Mg	368.2± 175 N=63	236.5 52.4 N=45	*
	Mn	0.1± 0.1 N=53	0.05± 0.05 N=52	*
	Fe	0.3± 0.3 N=37	0.9 ±1.6 N=34	*
Trace metals (mg/L)	Al	0.3± 0.3 N=39	0.1± 0.1 N=29	ns

Table 4.35 shows that there were significant differences between the two sites in total mean concentration of major and trace metals such as Ca (F= 10.83, P = 0.000, N= 114), Mn (F= 36.25, P = 0.00, N= 105), Mg (F= 62.53, P = 0.000, N= 108), Fe (F= 6.33, P = 0.04, N =71) and their concentrations at site 2 were less than site 1. While there were not significant differences in Al (F= 8.77, P = 0.05, N= 68).

The correlation showed that in seedlings, there were negative relationship between Ca (pearson' correlation = -0.942, P < 0.05, N=8) and plastochrone, and negative relation between new spear leaf production per year and Al (pearson' correlation = -0.725, P < 0.05, N= 8) and Mg (pearson' correlation = -0.090, P < 0.05, N=8). In juveniles, there were positive relationship between Ca and leaf life span (pearson' correlation =0.373, P < 0.05, N= 50) and also between Ca and new spear leaf production (pearson' correlation = 0.327, P < 0.05, N= 50). In juveniles, there were negative relationship between Mg and plastochrone (pearson' correlation = -0.684, P < 0.05, N= 27).

In adults, Ca was related to leaf life span (pearson' correlation = -.0314, P < 0.05, N= 114)., living leaves (pearson' correlation = -0.368 P < 0.05, N= 114) and dead leaves negatively (pearson' correlation = 0.406 P < 0.05, N= 114). There was negative relationship between Mg and living leaves (pearson' correlation = -0.209 P < 0.05, N= 108). Fe was related to dead leaves (pearson' correlation = -0.263 P < 0.05, N= 71) and spear elongation of adults negatively (pearson' correlation = -0.271 P < 0.05, N= 61). In addition, there was positive relationship between Al and plastochrone (pearson' correlation = 0.255, P < 0.05, N= 68). In matures, there was a positive relationship between Ca and spear elongation (pearson' correlation = 0.706, P < 0.05, N= 16), and positive relationship between Al and plastochrone (pearson' correlation = 0.318, P < 0.05, N= 58).

4.5.2.3. Anions

Anion concentrations were determined during 15 months at both sites.

Table 4.36: The mean concentration of anions (ppm) of water samples at site 1 during 15 months in Carey Island.

Site 1 (means ± sd)				
variables		Plot 1	Plot 2	Plot 3
Anions (ppm)	Chloride	23.1± 10.1 N=20	19.9± 12 N=21	23.1± 10.9 N=21
	Sulphate	2.6± 1 N=19	6.5 10.1 N=17	8.2 14.5 N=21
	Nitrate	34.7± 9.2 N=19	33.3± 12 N=15	29.9± 14 N=22

Table 4.37: The mean concentration of anions (ppm) of water samples at site 2 during 15 months in Carey Island.

Site 2 (means ± sd)				
variables		Plot 1	Plot 2	Plot 3
Anions (ppm)	Chloride	19 ±7.6 N=12	21±8.6 N=18	23.5± 8.9 N=13
	Sulphate	1.7± 1 [b] N=13	2.2± 1.1 N=18	2.9± 0.8 [b] N=13
	Nitrate	25.9± 27.5 N=7	40.9± 12.6 N=8	33± 21.7 N=11

b=significant between plots 1 and 3 ($P < 0.05$).

Table 4.36 and 4.37 show that there was no significant difference among the plots in mean concentration of anions (ppm) of water samples at both sites except for sulphate at site 2 by using ANOVA and Tukey test.(appendix 8).

Table 4.38: The total means concentration of anions (ppm) of water Samples at both sites during 15 months in Carey Island.

		(means ± sd)		
variables		Site 1	Site 2	t- test
Anions (ppm)	Chloride	22.1± 10.9 N=62	18.3± 11.3 N=43	ns
	Sulphate	5.8± 10.5 N=57	2.3±1.1 N=44	*
	Nitrate	32.4±12 N=56	33.5 ±21.2 N=26	ns

ns: not significant difference ($P \geq 0.05$)
*significances ($P < 0.05$)

Table 4.38 shows that there was no significant difference in the mean concentrations of Chloride (F=0.348, P=0.09, N= 105) Nitrate (F= 15.87, P = 0.76, N= 82) between both sites but there were significant differences in Sulphate (F= 12.69, P = 0.02, N= 101). The mean concentration of nitrate was higher at site 2 than site 1. In seedlings, Chloride was negatively related to living leaves (pearson' correlation = -0.742, $P < 0.05$, N= 8), total number of leaves (pearson' correlation =-0.902, $P < 0.05$, N= 8) and new spear leaf production per year (pearson' correlation = -0.88, $P < 0.05$, N=8). Sulphate was negatively related to living leaves (pearson' correlation = -0.726, $P < 0.05$, N= 8), total number of leaves (pearson' correlation = -0.904, $P < 0.05$, N=8), new spear leaf production per year (pearson' correlation = -0.862, $P < 0.05$, N= 8) and plastochrone (pearson' correlation = -0.872, $P < 0.05$, N=8). There was no relationship between nitrate and growth of seedlings. In juveniles, There was no relationship between Sulphate and growth of Juveniles while there was positive relationship between Chloride and plastochrone (pearson' correlation =0.533, $P < 0.05$, N=27) and also positive relationship between Nitrate and plastochrone (pearson' correlation =0.399, $P < 0.05$, N= 27). In

addition there was positive relationship between Nitrate and spear elongation of juveniles (pearson' correlation = 0.80, $P < 0.05$, N= 8). In adults and matures, there was no relationship between anions and the growth of trees.

CHAPTER 5

DISCUSSION

5.1. Population structure and dynamics

5.1.1. Population density and spatial distribution

One of the possible interpretations of the clumped dispersion of the adult palms is that this species needs sufficient light to fully grow. Siebert (2000) showed that climbing stem populations of *Desmoncus orthacanthos* Mart. (Palmae) were great in high light environments where light penetrates the forest floor. Spatial distribution investigation on three palm species, *Cryosophila warscewiczii, Euterpe precatoria, and lriartea deltoidea* in Costa Rica showed that adults of *Cryosophila* palms can only be found in light gaps (Homeier, et al., 2002), so the population had a few adults with high number of seedlings. This explanation does not seem logical for *N. fruticans* as it is a mangrove palm and can grow in humid condition under the shade. On the other hand, Souza & Martins (2004) discussed that canopy openness did not influence a colonial palm, *Geonoma brevispatha* in south-eastern Brazil. In addition, the majority of the forest palms grow under the shade of dominating forests trees along stream courses in warm humid condition (Kulkarni & Mulani, 2004). Most of the studies have investigated the clumped or random distributions for adults (Lieberman & Lieberman, 1994) and study of

Debski et al. (2002) showed that tropical tree species populations have clumped or random distribution. Evidence of a clumping distribution for 11 out of the 16 Myristicaceae species; a regular or random distribution for only four species and in three species a regular distribution (Queenborough & Burslem, 2007). The possible reason for thinning out of clumped seedlings (Homeier, Breckle et al. 2002) to randomly dispersed adults in a premontane rain forest have been reported to be canopy competition (Lieberman & Lieberman, 1994). Therefore, this may be the one possible reason for random and regular distribution of adults but the best explanation for the clumped dispersion of the adult palms in *N. fruticans* might be their vegetative multiplication. Population of *Cyrtostachys renda* was dominated by suckers with the wide range of suckers development stages which can tolerate low light conditions and juveniles next to adults may actually be root suckers (Widyatmoko et al., 2005). *N. fruticans* is the estuarine palm with creeping underground stem (rhizome) that branches to create new aerial shoots at close intervals and form dense stands. Seed reproduction is more common for other palms like *Calamus ambraculifera, Bentinckia nicobarica* and *Bentinckia condapanna* (Kulkarni & Mulani, 2004). Mature *N. fruticans* were randomly and regularly distributed except in plot 2 at site 1 that were clumped. By contrast, the mature *Drosophila* palms showed a clumped distribution but juveniles were random (Homeier et al., 2002). Some of the reasons that cause the mature palm to become less clumped are the competition for space, and the lack of resources. It can also be related to the survival of *N. fruticans*, so when they grow older and reach mature stage, their distribution becomes more random and regular. The complete absence of seedlings and the high percentage of adults that were obtained in this study are similar to the results of Weiner and Corlett (1987) from their study on *Livistona endauensis* in Johore, Malaysia. They suggested that *L. endauensis* has the complete absence of seedlings at the low land

diptrocarp forest because these can only be established in tree fall gaps as the species can not compete with other shade tolerant, taller and faster growing trees. In addition, Orellana & Ayora (1993) found the same results as this study at site 1 on *Coccothrinax readii* with high percentages of juveniles and adults but low percentage of seedlings. In contrast, they found that there were no seedlings but mature *Thrinax radiata* in the sand dune coastal ecosystems of Yucatan just like at site 2 in this study. On the other hand, Rozainah et al., (2002) reported high density of seedlings of *Arena westerhouti*, and seedlings and juveniles showed clumped distribution but the stemmed trees were random because of competition for space and resources. They became less clumped when they reached the juvenile stage due to predation and competition. The first effective factor in the distribution of trees will be seed mortality and its survivorship to maturity (Rozainah et al., 2002). In the same study, *Arenga obtusifolia* showed clumped distribution due to the historical conditions, and its colonies are due to the suckering while failure of seed dispersal is the reason for clumped seedlings. While at Kerumutan Reserve there was insufficient recruitment, so practical population establishment was impossible because there were no fertile adult individuals (Widyatmoko et al., 2005). Microhabitat specialization such as flooded conditions at small scales influence the random dispersion of juveniles and limited seed dispersal which results in clumped juveniles (Nathan & Muller- Landua, 2000). Wehncke et al. (2010) studied the distribution patterns of Blue fan palm in three desert oases of northern baja California and found an inverse J distribution with a high number of seedlings and adults in the population and the distribution of seedlings and adults were clumped. Although he identified that rodents and vertebrates were responsible for blue fan palm seed removal/predation in these oases, it did not have a significant effect on blue fan palm establishment. Also, seedling establishment and its density depends on adults density because of tendency of seedling

for establishment near the adults, and the distance from the adult palm caused the decline of seedling density. Flood pulsing is a mechanism that structures the plant communities which are beside the river by flood dispersal (Middleton, 2000). A study of investigation by Boll et al. (2005) on the spatial distribution of the piassaba palm *Aphandra natalia* (Arecaceae) along the Pastaza showed the clumped distribution of immature and mature individuals. The distribution of immature individuals depended on matured individuals presence, reflecting the dispersal limitation. Furthermore, many studies on tropical trees showed that palms often have clumped distributions, linked to dispersal limitation or spatially restricted recruitment (Svenning, 2001; Souza & Martins, 2002; Barot & Gignoux, 2003). Other than dispersal limitation and environmental conditions, the historical events and density dependence (Levine & Murrell, 2003) may also cause clumped distributions.

Pe´rez-Farrera et al. (2006) mentioned that seedlings and juveniles present majority of the population of *Ceratozamia mirandae,* at La Sombra. Many factors have played the rule in the spatial distribution of *C. mirandae*. The steep slop was considered as a fundamental factor in its seed dispersion (Pe´rez-Farrera et al., 2006) but seed dispersal by mammals, peccari species was suggested too by Pe´rez-Farrera & Vovides (2004). At La Sombra, the plants showed a grouped or aggregate distribution and most of the seedlings and juveniles were found around the mother plants and under the shade. In addition, the main factor of seedling distribution patterns was not seed dispersal by rodents but the flooded pulses had significant effect (Wehncke et al., 2010) just like this study that monkeys were not as important factor for seed dispersal and seedling distribution but the flooded pulses had significant effect.

To a large extent, the demographic mechanisms determining the abundance and distribution of a species are the birth and death of subjects (Weiner & Corlett, 1987). Therefore, the number and distribution of *N. fruticans* appear to be primarily determined by their rates of reproduction and survival. In this study, the seedlings are sparse and even completely lacked, while adults and mature palms have very high density in every plot. In conclusion, this could strengthen the hypothesis that this species has no regular regeneration because many seedlings and few adult palms indicate a regular regeneration (Homeier et al., 2002), which did not happened in the population of *N. fruticans.*

In addition, we can conclude that the distribution of the individual plants is primarily influenced by the survival of the new seedling to maturity. Several factors have an impact on the final location of each seed such as surface water run-off, soil erosion, and animal predation. The surface water run off has a strong effect on the seed dispersal in this population.

Environmental factors, especially soil condition, interactions with other species, and dispersal determine the distribution and abundance of a plant species within a particular climatic zone (Weiner & Corlett, 1987). Therefore, the reasons for these distribution patterns are too difficult to be understood easily and many different factors are effective in the development of palm growth during its different life stages.

5.1.2. Population changes

Plot 3 at site 1 recorded the highest recruits rate and annual recruits (fruits with exerted plumule). The reason for this result is that the highest percentage of adults and mature individuals are found in this plot where many mature fruits were ripe and fell down.

There is the high percentage of adults and mature trees at site 2 but most seeds have been washed away outside of the plot. As a result, the recruits rate cannot indicate the increase of seedlings because inundation by high tide results in little establishment of seedlings. The observations showed fruits were dropped first under the parent trees. After a while, most of them spread around the plots and were moved far away from the parent trees by water. Few seeds would be able to settle in the plots and turn into the seedling. This is the reason that there were 162 germinated seeds or new recruits at both sites but there was the establishment of only three seedlings during the 16-month study periods. The surface water run off did not have a strong effect on the survival of seedlings due to a stable status from seedlings to juveniles in this species at the end of the study. So, it is indicated that the environmental condition does not have very negative effects on establishment and growth of *N. fruticans* although prolonged flooding/water logging, severe competition for space, and lack of sunlight exposure caused higher mortality in seedlings of *Cyrtostachys renda* in the kerumutan Reserve (Widyatmoko et al., 2005). Also, Orellana & Ayora (1993) showed that the high mortality of seedlings *Thrinax radiata* in the sand dune coastal ecosystems of Yucatan was due to predation. The high mortality of juveniles and matures of *Thrinax radiata* due to random micro environmental condition which has an effect on its distribution pattern in the ecosystem, therefore it showed that this species does have not adaptability and resistance to the environment (Orellana & Ayora, 1993). While there was no mortality at this study in all stages of trees, so it can be concluded that *N. fruticans* was able to be adapted to the environment at the study site. Early stages of trees (suckers and seedlings) of *Cyrtostachys renda* showed higher mortality but matures experienced very low mortality (Widyatmoko et al., 2005) .On the other hand, leaf shedding and dense individuals (suckers and juveniles) as physical restrictions may cause adverse light microhabitat for seedling establishment which results

in absence of seedlings (Widyatmoko et al., 2005), It can be possible that the explanation for little establishment of seedlings of *N. fruticans* in this study was more than just predation. In addition, results show that the ratio of seedling to juvenile in all plots were less than one. The germination rate is very low in glasshouse; there was no high rate of germination in the wild. This indicates that the seed germination does not have the main important rule in natural regeneration in *N. fruticans* due to little seedling establishment. Suckering as a vegetative regeneration seems to be more critical because a palm strategy for maintenance of successful population recruitment may be because of the establishment of many suckers which is more effective than seed production in swamps (Widyatmoko et al., 2005). It seems that the population is not expanding much because the ratio of seedlings to other life stages was almost unchanged in all plots until the end of the study. The survivorship and population structure of *N. fruticans* in Carey Island appeared to be stable or growing because the total number of trees was almost constant at end of the study while there was not any mortality too. So, it can be concluded that this species appeared to have an ecological tolerance within this area and the habitat specialization created a favorable environment for the palm abundance and distribution. Consequently, with the continuance of this condition, the population would likely to be decreased because the rate of natural regeneration is low. After a long time, the trees will become old and then die. On the other hand, the age estimation of *N. fruticans* showed that this species is a plant with an almost long life span. In addition, young adults are the majority of the population. Decrease in the population cannot be predicted, because the period of study was only 16 months. So, longer observations are needed in the future. The rate of new recruits was an average of nine germinated seeds per year, which is not high while new recruits were produced throughout the year. Thus, this would be another reason for few new seedlings to establish during the study period.

5.2. Growth

5.2.1. Leaf production and spear elongation

Demographic studies focus on important factors such as estimation of the growth, survival, and reproductive of individuals within a population which all of them influence the age, size and life stage of individuals (Stubben 2007). Many demographic investigations have been conducted on palm species due to its feature of life style like its simple growth that cause it to be demographically pleasant (Weiner 1987). Studying on tall palms is difficult because the observation and getting census on growth rate particularly on height is not simple. Bogh (1996) showed growth of rattans *Calamus peregrinus, C. rudentum,* and *C. sp* in Thailand with the high variation in their growth rates are due to light conditions. The three species had the average growth rates of 1.24, 1.42, and 0.20 m year^{-1}. Also, a study on growth rates and age structure of *Arenga westerhouteii* and *A. obtusiofolia* was carried out by Rozainah et al., (1999; 2000; 2002) for 17 months at Bukit Lagong forest reserve. According to Rozainah et al. (2000) the seedlings of *A. westerhoutii* produced 0.7 leaves per year and *A. obtusifolia* had 0.5 leaves per year while *N. fruticans* had higher rate of 3.9 leaves per year. The rate of leaf production in seedlings of *Buteri* palm (*Mauritia flexuosa* L. f., Arecaceae) with an average of 2.82 ± 0.11 leaves per a year in the Jalapao Region (Sampaio et al., 2008) which is almost the same as *N. fruticans* 2.4 leaves per year in plot 3 and less than 3.9 leaves per year in plot 1. Rozainah et al. (2000) mentioned that the juveniles of *A. westerhoutii* and *A. obtusifolia* had one leaf and 0.8 leaves per year which is almost the same as the leaf production of seedlings in *N. fruticans* with 1 leaf per year. Also, the rate

of leaf production in the stemmed trees of *A. westerhoutii* and *A. obtusifolia* was 1.2 leaves per year which is almost the same as the rate of leaf production as in adults of *N. fruticans* (1.1 leaves per year) and matures of *N. fruticans* (1 leaf per year) at site 2 in this study. The stemmed plant of two wild *Arenga* species had more rapid leaf production than leaf production of seedlings in the study of Rozainah et al. (2000) at Bukit Lagong Forest Reserve in Selangor. Therefore, against the stemmed plant of two wild *Arenga* species, the seedlings of *N. fruticans* had so much higher rate of leaf production than juveniles, adults and matures. In many rain forests, palms are numerically and structurally a substantial group (Kahn & de Granville, 1992; Clark, 1994; Lieberman et al., 1996). Hence, an increment in the morphological factors such as leaf production and spear elongation is defined as growth for this species. The most important growth indicator is the rate of leaf production. The growth analysis in four developmental stages of individuals showed that there are significant differences in dead leaves of juvenile trees among some plots at site 1. The possible reason is not related to soil and water quality. It can however be related to plot 3 being near the river, and thus affected by tidal inundation. However, significant differences in dead leaves of adults among some plots at both sites can be related to older adults in plot 1 (site 1) and plot 3 (site 2). In addition, the significant differences in living leaves of matures at site 2 among plots can be due to higher leaf life span in plot 2 that resulted higher number of living leaves in this plot . Seedlings of *N. fruticans* are detected only in one location with significant difference in leaf production among the plots (2.4-3.9 leaves/year) which can be related to considerable variation of the leaf number of suckers and also their faster growth, and when they became juveniles, they have more stable leaf number that is from four to eight leaves. The reason for slower growth of seedlings in plot 3 compared to plot 2 was related to the environment and light condition. Seedlings were under the canopy of the

other trees and they were not in open space as in plot 3. In addition, trees in plot 3 had higher density. Therefore, this shady under story condition in plot 3 was not favorable for producing leaf as much as in plot 2. However, the highest rate of leaf production is in the seedling stage because trees do not allocate much of their energy to height increment. The rate of leaf production is significantly different in all trees between the two sites except for when they were juveniles. The significant difference of leaf production per year in adults with higher rate of 1.1 at site 2 than 0.8 at site 1 which may be related to flowering. Low percentage of adults at site 2 produce flowers, so adults put more energy to produce leaf. In mature trees, the significant difference in producing leaf per year with 1 spear leaf production per year at site 2 and 0.9 at site 1 which is due to age and height of subjects. The mature trees at site 1 were older and had high increment of spear elongation, so they put less energy for leaf production than site 2. Therefore, the lowest rate of leaf production in juvenile, adult and mature trees with around 1 spear leaf per year was not unexpected because of rapid increase in height. The leaf production of *N. fruticans* is not slow and it is continuous. The rate of leaf production of the palm is the same as the adults of *C. renda* growing under low light and flooded condition with leaf production rate of one leaf per year while adults in well drained sites with moderate sunlight had the rate of leaf production up to four per year and it has high survivorship (Widyatmoko et al., 2005). Consequently, the low rate of leaf production results in a low rate of forest generation. In addition, when trees produce reproductive organization such as suckers, they may put less energy allocation to vegetative growth. So, In *N. fruticans*, low rate of leaf production may be related to suckering behavior. (Widyatmoko 2005) had made a study on the demography (age, reproduction, growth, and survivorship) of *C.renda Blume* (Arecaceae) in Kerumutan Reserve, Sumatra. In addition, the difference of the number of new leaves produced per year among the plant stages (adults, juveniles

and seedlings) was the plant size which is dependant with the lowest leaf production in seedling stage. This differs from the results of this study in which seedlings have the highest rate of leaf production. The study of Widyatmoko et al. (2005) showed that adults of *C.renda Blume* have the most reproductive leaf production rate of almost the average of three leaves per year ; Juveniles produced 2.77 leaves per year and suckers produced 1.64 leaves per year. So, against the *C. renda* , the most reproductive stage of *N. fruticans* is seedling with 3.9 leaves per year. The rate of leaf production in adults of *N. fruticans* (1.1 leaves per year) and matures of *N. fruticans* (1 leaf per year) at site2 in this study. In conclusion, the rate of leaf production of adults of *N. fruticans* is low compared to *C.renda Blume.*

Harvesting influence growth, survival, flower and fruit production in C*hamadorea tepejilote, C. radicalis and Sabal uresana* (Endress et al., 2004) .On the other hand, Martinez –Balleste et al. (2008) showed that higher harvest intensity resulted in higher leaf production in palms, *Sabal yapa and Sabal mexicana* Mart. but it did not have any effect on palm growth and leaf size. Therefore, the extraction of palm leaf can be sustainable activity throughout time (Pulido & Caballero, 2006) while intense leaf extraction has a negative effect on the new leaf productions (Endress et al., 2004). It appears that the vigorous vegetative growth observed in this study suggests that limited leaf harvesting will not adversely affect the growth or survival of the species and populations of *N. fruticans*, which will persist despite irregular regeneration and even some disturbances.

There was no significant difference in spear elongation in all stages at both sites. Height increase of spear leaves is rather high each month with the highest rate of spear elongation of 91.9 cm per month in mature trees. It was 80.9 cm in adults and 55.5 cm in juveniles. Widyatmoko et al., (2005) found that plants with 2-4 m height started to

produce flowers, so they may allocate more energy for reproduction than for vertical growth. The reason for high rate of elongation in *N. fruticans* is due to no allocation of energy to increase girth size. *Bruguiera gymnorrhiza* grows tall due to low salinity (Enoki et al., 2009). Light is an important factor that has an impact on growth rates as a restrictive factor in understory palm and with increase of crown illumination growth will increase (leaf length, leaf production, but not leaf number) except for the smallest trees which are neighboring adults, they have negative effect on number of leaves and growth length but survival will reduce in *Geonoma microstates* (Svenning, 2002). Each individual of *N. fruticans* produced one to four spear leaves during this study period but producing four spear leaves was scarce. In conclusion, there are some concerns on the leaf production, and natural regeneration of *N. fruticans* in Carey Island. With proper cultural practices such as increment of light by thinning, acceleration of leaf and fruit production is possible (Breure, 1994).

5.2.2 Leaf life span

The results of leaf life span showed there were no significant differences in all stages among the plots at site 1. There are significant differences among the plots at site 2 except for seedlings. Also, there were no significant differences in all stages between the two sites except for juveniles that had higher life span at site 1 than at site 2. The possible reason for this may be related to significant difference in plastochrone. The correlation between the age and the total number of leaves was not very accurate, because it has got to be assumed that the rate of leaf production or plastochrone was stable. Significant differences in total number of leaves at both sites in juvenile and adults can be related to higher salinity at site 2. There were differences in the number of living leaves of adults

and matures among the plots at site 2 and in the number of living leaves of matures at both sites due to the different growth rates of subjects that was not related to water and soil quality. One possible reason would be related to suckering behavior of subjects or reproductive structure because *N. fruticans* is a colonial and pleonantic palm. Rozainah et al. (2000) mentioned that it is possible that while *A. obtusifolia* is producing suckers, it slows down the leaf production.

Significant differences in dead leaves among the plots at site 1 in juvenile and adults and at site 2 in adults are not related to soil and water quality. It may be related to the location of plots because the third plots in each site were very close to the river. So the effect of tidal inundation is more than the two other plots. Also, this can be related to significant differences in leaf life span among the plots at site 2. Another reason is the height and size of subjects in each plot. Usually, it is implied from the persistence of a species in an area that it tolerates the regular hazardous characterization of that environment.

5.3. Age structure

The maximum time that *N. fruticans* can live vegetatively was calculated as 48.4 years for a mature tree while individuals of *C. Renda* can stay alive more than 80 years. The average age of a stemmed *Arenga westerhoutii* was 64.7, while in *Arenga obtusifolia* the average age was 58 years (Rozainah et al., 2000). Overall, the mean age of a mature individual tree in *N. fruticans* is 31.4 – 34.8 years. It means that the population is young. In addition, age was calculated for matures of *Iriartea* palm about 30 years. (Homeier, et al., 2002).The minimum age of a reproductive tree was about 23.1 years old and the maximum was about 43.2 years old, which gives 20.1 reproductive years. A study by *C.*

Renda conducted in Kerumutan Reserve showed that the palm requires 25- 30 years to reach reproductive maturity (Widyatmoko et al., 2005) which was later than that in *N. fruticans.*

There was no age gap among the seedlings, juveniles, adults and mature stage; and no plants developed from one stage to the next stage during this study period. So *N. fruticans* represents a stable and continuous population. It shows an even age class structure as a palm which was pleonanthy, with flowering and fruiting occurring throughout the year continuously. This flowering behavior or no mortality can be reasons for no age gaps. There are no significant differences in the age structures of all stages among the plots except for seedlings. The reason for the young juveniles to grow at site 2 can be due to the suckering behaviors and suckers turn into the juvenile stage at young age. The age estimation results show that there was the highest peak of numbers in the adults' stage at around 10 years old. This shows that the population was dominated by the young subjects that they may represent an expanding population with a few old early pioneer and many of their descendants or a stable population in which the survival curve is strongly high. The stable environments helped the survival of plants in this species because there was no mortality recorded at both sites. Another possible reason must have been the maximum reproduction. The results also showed that it is likely to be high recruits in the peak periods in adults due to flowering and fallen fruits.

Determination of the age of trees in a forest is beneficial. One of the advantages is demonstration of an arrangement of dominant, minor, and indefinite individuals of each species. The mean age of mature trees is estimated to be 33.2 - 34.8 years in site 1 and 31.4 - 33 years in site 2. Maybe the assumption of a stable growth rate for trees in those stages may be incorrect. So, the best explanation for the difference in the mean of seedlings' age can be related to a small number of subjects in the two plots.

Some of the benefits of age estimation are the management of forest which can produce sustainable products and at the same time the history of forest will be recorded. In addition, on the basis of age estimation of trees, the felling policy can be chosen by a suitable way to continue regeneration of the population for maintenance of resources.

5.4. Reproductive phenology

5.4.1. Inflorescence development and scoring

The complete flowering cycle of *N. fruticans* from bud to ripe fruits took about 8.2- 9.6 months in both male and female flowers. This is not long for palms when *Chamaedorea bartlingiana* took two years to complete this reproductive cycle (Ataroff & Schwarzkopf, 1992). *N. fruticans*, like the majority of palms produce a single stem terminated to inflorescences. During the 14 months study period, the adult and mature trees produced 1 to 3 new inflorescence and 1 to 2 fruits. Productive subjects flowered regularly every year and almost every month. Flowerings recorded in the months of December, January and February were much more than other months, so it cannot be concluded that flowering is not affected by seasons. Within these 14 months period, the rate of flower production was one inflorescence per year for each tree, which can produce 96.6 fruits. The rate of fruits production was one infruitescence. More flowers were produced compared to fruits. There are higher percentages of trees producing flowers than percentages of trees producing fruits. This may provide a good supply of seed for natural regeneration of the population of this species. According to the results of this study, it appears that *N. fruticans* has a low rate of flowering production with 53% of 115 subjects

compared to other palms like *Johannesteijsmannia lanceolata* with 71% of 24 subjects (Rozainah & Sinniah,, 2006).

It is noted that the difference in flowering phenology in plants may be due to the response to different growth condition. We can conclude that there is no concern for fruit production. Limited defoliation and leaf thinning can increase the sap yield (Kiew, 1989).

5.4.2. Insect visitors

Pollinators of palms are usually beetles, bees or flies (Silberbauer-Gottsberger, 1990; Lee et al., 1995; Bøgh, 1996; Martén & Quesada, 2001; Borchsenius, 1993; Barford et al., 2003). Insects or animal pollinations are common in palms. Pollination of palms may also happen by wind. Mui (2009) mentioned *J. lanceolata* is not wind-pollinated.. The plant is under storey in a closed canopy forest, where there is hardly any strong wind. Rozainah et al. (2002) mentioned that *A. westerhoutii* and *A. obtusifolia* cannot be pollinated by wind because of their existence in dense forest in Bukit Lagong Forest Reserve and it has sticky pollen. In addition, *J. lanceolata* is entomophilous and is mostly visited by flies and ants, and rarely by bees (Mui, 2009) while the *N. fruticans* is mostly visited by bees and ants. Of the usual characteristics of a pollination syndrome, it has attractive colorful petals, synchronizing anthesis with pollinator activities, sticky pollen, nectar production, floral fragrance which is conspicuous. Odor of bracts and colorful bracts are the most attractant in *N. fruticans.* In addition, morphology and phenology agree with the syndrome of bee pollination like *Arenga spp.* The exact time of the anthesis in *N. fructicans* was not determined in this study because the high tide early in the morning did not allow its entrance to the forest.

The observation shows that the attractiveness of male and female flowers to insects reduces in the afternoon. In total, bees visited the male flowers much more frequently than female flowers because male flowers have sharp odor of the bracts.

5.4.3 Seed germination

There are various sizes of seeds in palms. The largest seed of any flowering plants in the world belongs to palm (the double coconut, *Lodoeicea maldivica*) while the smallest one belongs to lady palm (*Raphis excelsa*) (Meerow, 1991). Propagation of palms is mostly via seeds and this has caused palms species to be particular among woody plants. There are two main classes of palm seed germination: remote germination and adjacent germination. In palms with remote germination, the seedling stalk develops far from actual seeds. The adjacent germination is the other main type of seed germination where the small part of cotyledon in the seed emerges as a surface that is called bottom. In palms with adjacent germination, there are adventitious roots at the seedling stem base. When infruitecence is completely ripe, mature fruits are detached, and fall down. Then the mature fruits are collected from the ground in the forest to be planted in the glasshouse. For seed germination test, it would be better to collect seeds from completely ripen fruits because age of the seed can directly influence the final percentage of germination. Another factor is the freshness of the fruits. Palm seeds often have slow and uneven germination, so any preplant treatments might speed germination or result in more rates of germination (Meerow, 1991). It has been estimated that over 25% all palms species need over 100 days to germinate and have less than 20 % total germination. (Tomlinson, 1990). The seed germination investigated at the glass house revealed that the rate of germination in this study for *N. fruticans* was low 16.6 % that is almost the same

as the result of the germination test in (*Geonoma macrostachys*, Arecaceae) with germination rate of 15.3 %. Of 150 sown seeds, 23 seeds sprouted and became seedlings. The seed germination of tropical palms can take from 2 weeks to 2 years (or more), but most seeds will germinate after 4 - 6 weeks (Nuyim, 1995). Germination study of *C. Renda* conducted in Bogor Botanic Gardens showed that the palm requires adequate heat to germinate (Widyatmoko et al., 2005). In *N. fruticans* it did not take too long for the first seed germination in the glasshouse. Many other environmental factors have an impact on seed germination. Soil mix, dampness, and temperature are factors that can cause the water penetration to increase or decrease. A good soil mix can hold moisture and at the same time can be well drained. Dampness is essential but very wet soil is harmful because it results in rotting of the plants. Dryness is another limiting factor. So, one of the most common ways to plant tropical palm is to plant rather shallowly. Palms need high temperatures to germinate. *Licuala*, *Bismarckia* or *Cyrtostachys* require heat, around 30º C (Nuyim, 1995). The amount of light is not a factor in germination because palm seeds can germinate in shady places provided that proper temperature and moisture are available. Different species will show different results, so germination of palms cannot be predicted in advance because many factors can speed or cease it. In the forest, seed disposal happened by water at high tide. It causes them to float and even germinate in the water, and then in low tide seeds are deposited on the mud and settled. The seed germination test should be repeated in order to get a confirmed decision on the rate of germination. The results will change with the use of treatments or changing the mix soil. I did try to mimic the natural soil in the forest in order to conclude strongly on the percentage of seed germination. High concentration of seedlings does not necessarily promise high survival rates. The rate of seed germination in the forest was not high and less than the seed germination rate in glasshouse. Most of the germinated seeds were

washed away by tidal inundation. Hence seed germination has no main effects on the natural regeneration of the species.

5.5. Soil and water analysis

5.5.1. Soil

Soil plays an important role in biogeochemical cycling of nutrients and also has very important function as the medium on which food is grown (Radojevic & N Baskkin, 2006). It is the main component of the biosphere which various organisms populate. In addition, soils provide nutrients for plant growth, support to plants, and are a huge reservoir for water, so the loss of the surface soil confines seedling establishment (Kettle, 2010). The major feature of the soil is fertility, or bioproductivity. The fertility depends on physical features such as soil texture (i.e., proportion of sand, sandy loam, clay-loam, and clay in soil), chemical composition (pH, buffering ability, and content of different nutrients and physico- chemical properties (e.g. aeration and water absorption ability) (Radojevic & N Baskkin, 2006). Human activity can severely speed natural processes of water and soil erosion that lead to a decrease of soil fertility. Soil is a combination of minerals (e.g. clay, quartz), water, air, and living organisms. The weathering of rock and the decay of natural matter such as the outer litter layer of dead leaves and twigs, and fallen branches cause soil to be formed. Abrasion, temperature changes, and hydrolysis, oxidation are mechanical and chemical weathering factors (Radojevic & N Baskkin, 2006).

Soil particles can differ in composition and size that largely determine the behavior of the soil (Balkema, 1986). The determination of particle size in soil is one of the important measurements because it influences the amount of water and the transfer rate through

soil. The act of dividing and measuring different parts of soils is called the particle size analysis or mechanical analysis. The result of this analysis is often named texture. The geographical location as well as climate has effects on the chemical and physical properties of soils significantly. Clay particles can absorb water and hold plant nutrients.

Soil moisture content is one of the most soil characterizations measured routinely. It is essential to understand the behavior of the soil as a medium for plant growth. In this study the percentage of moisture content is not significant. It depends on the time the samples were taken. In wet conditions, soil porosity and hydraulic conductivity firmly have definite impact on the variability of the surface moisture content that changes greately in wet conditions (Famiglietti et al., 1998). In this study, there was no significant difference in soil moisture content.

Vegetation canopy, shaded condition, root action and transpiration significantly influence variability of soil moisture, particularly after rainfall (Famiglietti et al., 1998; Ridolfi et al., 2003). There are significant correlations between soil moisture and mangrove vegetation (Ukpong, 1995) and also factors such as increase in topography and disturbance of soil by mud lobsters (Ashton & Mcintosh, 2002).

All collected soils were silty-clay but they differed in little amount of silt and clay in this study. Possible explanation for the homogeneous soil moisture content is water of the upper soil layer has saturated after rainfall. The same soil porosity, water retention, or similar vegetation covers on all sites can also be other factors. Correlation analysis showed that with the increase or decrease of soil moisture content, spear elongation and rate of leaf production of subjects will not change but with increase of temperature, nslf and lls in juveniles, llf in adults will be increased. With the increase of the existence of reeks, rainfall, freshwater supply, evaporation, transpiration nature and soil quality has an

impact on interrelated factors such as soil moisture content and frequency of tidal inundation (Macnae, 1968).

In this study, there was no significant difference in pH of all plots at both sites. The results showed that soil pH was 6.4 and acidic while Joshi & Ghose (2003) presented that soil pH of Mangrove swamps of The Sundarbans was 7.0 to 7.9. In the study of community ecology of the Semantan mangrove forest in Sarawak, similar results to this study has been obtained (Ashton & Mcintosh, 2002). The reasons for the low soil pH could be due to fauna and tree root respiration by oxidation and vegetation. pH is important in soil because it has an important role in mobilizing both beneficial and toxic elements to plants (Boto, 1984). Also, the mangrove can grow better in soils with lower salinity (Kathiresan et al, 1996b). The results of soil analysis showed that the environmental condition of both sites in Carey Island is similar. The significant differences among the plots in leaf life span at site 2 in juveniles, adults were not related to soil pH and temperature but it was predicted that the soil temperature has positive effect on leaf life span of matures. So with the increase of temperature the leaf life span of matures will increase. Long-term study periods are effective in variation of the environmental factors controlling and influencing the structure and productivity of mangrove forests (Day Jr. et al., 1996).

5.5.2. Water

5.5.2.1. Physical parameters

There was no significant difference in water valuables in Carey Island among the plots at both sites but there was a significant difference in all variables between the two sites except for the pH of the water. The average pH of 6.4 for plots and sites showed no

fluctuation and was a little acidic. The study of Kamaruzzaman et al. (2006) on water parameters of Setiu Estuary revealed that the highest salinity was 32.53 ppt. and the lowest was 24.75 ppt and also, pH water was 7.9 – 8.1. Also, Damroy (1995) presented that recorded salinity in Chloudari area with mangrove trees was 30 - 34 ppt and pH was 7.48-8.47. The highest water salinity was 29.97 and the lowest was 21. 30 in this study. So, *N. fruticans* can tolerate salinity but not as much as mangroves and it prefer lower salinity. This is within the natural range for tropical freshwater ecosystem. These chemical variables indicated a general condition at each plot because the time in relation to tidal inundation and meteorology have an impact. Heavy rainfall in wet season is said to be the main factor causing low salinities of 0.5-10 ppt in the Red River estuary and 1-10 ppt in the Mekong Cape. Their mean salt concentration is 22-26 ppt (Hong & San, 1993). Experimental evidence indicate that at high salinity, mangroves spend more energy to maintain water balance and ion concentration rather than for primary production and growth (Clough, 1984). High rainfall in humid areas leaches out residual salts from the mangrove soil. This encourages the growth of mangroves (Kathiresan et al., 1996a.). Salinity at high levels also affects mangroves. Salinity fluctuations also have significant negative effect on the photosynthesis and growth of plants (Lin & Sternberg, 1993). Human activities can destroy areas of mangroves by changing the flow of groundwater and this modifies the salinity levels (Tack & Polk, 1997). Natural waters contain a number of dissolved gases of which oxygen is the most important product and it is vital to the health of the flora and fauna in such waters. However, the amount of DO in natural waters is not static. The natural fluctuations in DO can be considerably modified by pollution. A survey (ASTM publication) of rivers and streams in Western Pennsylvania showed the concentration of DO fell from 7.1 to 1.2 mg/liter due to a large sewage treatment plant. The aquatic biologists suggested that for most species of fish to

survive, the DO concentration should not fall below 5 mg/liter. Therefore, record of DO levels in rivers and lakes is important because dissolved oxygen analysis can provide solution for controlling pollution. The determination of the DO level is useful to know a healthy environment for the flora and fauna. In this study, DO was the range from 3.52-10.2 ppm. Kamaruzzaman et al. (2006) recorded DO from 4.64 to 11.43 mg/l. Also, the range of DO recorded in Chloudari area with mangrove trees was from 5.7 to 9.00 ppm (Damroy, 1995). These results show that DO in some occasion was very low and was not in safe level but in total it is safe. Total dissolved solids are usually discussed for freshwater systems. Salinity includes some of the ions that form the definition of TDS. The main use of TDS is in the study of water quality for stream, rivers and lakes. Major sources of TDS in waters are agricultural run-off, discharge of soil contamination and water pollution discharge from industrial or sewage treatment plants. The most exotic and harmful elements of TDS are pesticides from surface run-off. In the case of hydroponic and aquaculture, TDS is often monitored in order to create a quality water environment which is favorable for organism productivity. In the case of abnormal pH, or reduced dissolved oxygen, TDS is compounded in toxicity. Water can be classified by the amount of TDS per liter (ISBN): fresh water< 1500 mg/l TDS < brackish water< 5000mg/l TDS< saline water. Natural waters contamination has an environmental hazardous effect. According to Malaysian interim water quality standard, Carey Island is classified into class 1 and 2 for the physical and chemical water quality. The water quality is within safe levels as far as the DOE Interim Marine Water Quality and National Water Quality Standards for Malaysia (INWQS) is concerned (Ahmad et al., 2009). However Nitrate, K, Na, Ca presence are higher than the standard. Low levels of heavy metals are within the acceptable limit. Water is saline and slightly acidic. In this project, the relation of water quality with the growth rate has been studied. T-test showed that there were significant

differences in water variables of water samples between the sites except for water pH. Hence, the data on chemical water quality obtained from sampling plots at both sites in Carey Island shows that water pH did not influence the growth rate due to homogenous condition at both sites excerpt for lde of juveniles and llf of adults. If the water becomes more acidic, lde will be longer in juveniles and living leaves of adults will increase. So, the increase of water acidity has negative effect on growth of juveniles. Salinity, TDS, EC and DO showed significant differences at both sites. The mean of salinity, TDS, EC at site 2 was higher than at site 1. The mean value of dissolved oxygen was less at site 2 than at site 1 with the mean of 7 mg/L. Ahmad et al. (2009) obtained the same result for the DO concentration in Sungai Kelantan. The DO concentration at site 2 was a little less than at site 1, it has higher new leaf production in adult and mature trees. As a result, it seems that less DO concentration has no negative impact on the growth rate although it is predicted that with decrease of DO, nslf will reduce according to the correlation test. So, this means that decrease of DO was not as much as that put negative effect on growth. Site 2 had higher mean concentration of salinity, TDS, EC and the higher rate of leaf production in adult and mature trees than at site 1. So, the correlation showed that it can be due to positive effect of higher concentration of salinity and EC on matures but physical parameters of water has not effect on adult. The correlation showed that the higher leaf production in adults at site 2 is not related to physical parameters. The high total number of adults at site 2 is not related to physical parameters. Also, lower llf in matures is not because of physical parameters of water. The high level of llf, lde in juveniles at site 1 is not related to physical parameters, although correlation showed that there is positive relation between pH and lde. This would be because there is no difference between water pH between the two sites. It is expected that with increase of the acidity in water, lde will increase in juveniles. But the high level of tlf at site 1 is

related to the salinity and it is because of low salinity at site1. Also, it is predicted that with the increase of salinity nslf will be decreased in juveniles. Differences in temperatures between sites have no effect on the growth, however it is expected with the increase in temperature, llf of adults will be increased. With the increase in temperature, lls and nslf in juveniles will be increasedIn addition, the result shows that there was no relationship between dlf and spear elongation with the physical parameters in any life stages of trees. These predictions would be beneficial for future growth and natural regeneration of this species. Mangroves have been reported to grow in latitudes where the average sea surface temperature is 24º C (Kathiresan & Bingham, 2001). The climatic factors, temperature, rainfall and wind have the most significant influence on the composition and quality of mangrove vegetation (Hong, 1991). The mean of water temperature at Carey Island is 27.3 ± 0.8 Cº. The correlation analysis showed with the increase in temperature, the rate of new spear leaves per year increased but the rate of spear elongation decreased.

5.5.2.2 Heavy metals, Major metals and Trace metals

Among the pollutants affecting water resources, heavy metals are common because of their strong toxicity even at low concentrations. Heavy metals in waters can have natural (i.e., eroded minerals in sediments, discharge of deposit) or anthropogenic origin (i.e., waste disposal, industrial or domestic effluents). Toxicity of heavy metals to the organisms includes both essential and nonessential trace metals depending on their concentration levels. Dissolved heavy metals (Ag, As, Cd, Cu, Cr, Hg, Ni, Pb, and Zn) can cause toxic effects on organisms in the aquatic system. The pH and oxide reduction

regulates the transference of heavy metals between the dissolved and the particulate phase. The natural levels of heavy metals from aquatic ecosystems have significantly increased in the last decades because of industrial activities and urban developments (Marcovecchio et al., 1995). Therefore, detecting very low levels of heavy metals in natural waters is necessary because it could be quite dangerous for both aquatic biota (Li, Be, Al, Co, V, Se, Sb, Sr, Sn, and Ti). Trace metals occur at trace or ultra trace level in the crust (with the exception of aluminum that is a major component). They are usually included at parts–per–billion (PPb=µg/ L) or at parts-per- trillion (PPt = mg/ L) levels. Mining and industrial activities, high temperature waters may cause higher environmental concentrations. Many of them are considered dangerous or potentially harmful. Major metals are those metal ions whose concentrations are considerably higher than those of other cations in natural waters. The most important major metals, Na, K, Ca, Mg, Mn, and Fe are usually essential nutrients for the animals and the plants. In addition, many metals can produce severe toxic effects when levels are higher than acceptable in the waters. The higher llf, tlf and lde of juveniles at site 1 than site 2 are not related to heavy metal but it is expected to with the increase of Zn and As, the llf and dlf of juveniles decrease. It means that Zn has negative effect on growth but As has positive effect on growth. The high level of nslf and tlf of adults at site 2 than site 1 are not related to heavy metals and the high level of nslf and llf of matures at site 2 than site 1 are not related to heavy metals. Also, the high concentration of Cu at site 1 has no effect on the growth of adults and matures at site 1.

The high level of llf, tlf and lde of juveniles at site 1 than site 2 are not related to Ca, Mg, Mn, Fe and Al. The high level of Ca, Mg and Mn at site 1 than site 2 has no effect on llf and lde and tlf of juveniles. It is expected that with the increase of Ca, lls, llf and dlf of adults will decrease and with the increase of Mg, llf of adults will decrease and with

increase of Fe, dlf and spear elongation of adults will decrease and with the inverse of Al, lde of adults will increase.

The level of nslf and llf of the matures which is higher at site 2 than site 1 is not related to major metals and trace metals but the increase of Ca at site 1 has positive effect on spear elongation of matures. It is expected that with the increase of Al, Lde will be increased in the matures.

The reason of this may be related to the requirement of nutrition in these stages. The best explanation would be discussed by the study of the Physiological and molecular mechanisms of metal tolerance. Therefore, metal tolerance of the subjects at different stages needs a research on molecular and genetic. In addition, the effect of heavy metals and anions on the rate of leaf production depends on both the kind of metals and the stages of trees. Cu, Ca, Mg, Mn, Al, and nitrate had negative effects on the rate of leaf production in matured trees. The one possible reason is because of the higher than standard level of these metals.

5.5.2.3 Anions

Chlorine occurs most often as halides in seawater, in soil and in minerals like halite (NaCl). Chlorine often appears in industrial effluents and it is very toxic to most microorganisms. Chloride is a major ion in surface waters and waste waters. Its concentration in seawater and water from saltwater lakes is usually high but estuarine water has lower concentrations of Chloride. This is because it has mixed with the seawater. The level of chloride in water supplies is 250 mg/L, which is at higher concentrations of chloride. (Radojevic & N Baskkin, 2006). Sulfate is a major ion

occurring in natural waters and wastewaters and is usually quite stable. In fresh, unpolluted waters the concentration is between 5 to 100 mg/l, while in salt lakes it can be as high as 4000-5000 mg/l. The main natural source of sulfate is the chemical weathering and dissolution of sulfur-containing minerals (Radojevic & N Baskkin, 2006). The decay of animal and plant remains is another natural source of sulfate. Anthropogenic sources of sulfate include industrial municipal wastes, agricultural drainage, and run-off. Sulfuric acids of drainage from mines add a large amount of sulfate to surface waters. It can lead to significant acidification in rivers and lakes. Another source of sulfate in surface waters is the deposition of sulfate from the rain. The main reason for the presence of nitrate ions in unpolluted surface waters is nitrification, the oxidation of ammonium ions to nitrate by bacteria species under aerobic conditions. Another significant source of nitrate ions in surface waters is atmospheric deposition (Radojevic & N Baskkin, 2006). The range of its content is about 0.9 - 1.0 mg/l and up to 5 - 10 mg/l due to various discharges (Radojevic & N Baskkin, 2006). Industrial and municipal as well as agricultural effluents can introduce large amounts of nitrate into surface and ground waters. Due to N fertilizers and run-off from animal feedlots, agriculture is a major cause of nitrate pollution and a main environmental concern. Therefore, these are the possible reasons of high concentration of nitrate in water samples at Carey Islands, which are higher than the standard level. The high level of llf, tlf and lde of juveniles at site 1 than site 2 are not related to the concentration of sulphate of site 1 although the concentration of sulphate is higher at site 1 than site 2. It means the higher sulphate level at site 1 has no negative effect on growth of juveniles but it is expected that with increase of nitrate and chloride, lde of juveniles increases and with the increase of nitrate level spear elongation of juveniles increases. In total, the high level of nslf and tlf of adults at site 2 are not related

to anions. The high level of nslf and llf of matures at site 2 than site 1 is not related to anions.

CHAPTER 6

CONCLUSION

6.1. Conclusion

In this study, the seeds of *N. fruticans* were carried out of the plots by water which results in the random distribution of seedlings while, in the dry lands, animals have been considered as the major factor for palm seed dispersal (Zona & Henderson, 1989). So, the clumped dispersion of the adult palms can be their vegetative multiplication. Matured *N. fruticans* were mostly random and regular. Therefore, the number and distribution of *N. fruticans* appear to be primarily determined by their rates of reproduction and survival. In this study also, the seedlings were sparse and even completely baren, while adults and matures had very high density which result in regular regeneration of the population.

Seedlings were detected only in one location with the highest rate of leaf production because of less allocation to height increment. Although the acidity of the water and soil now is at good level but it can be dangerous for the growth of the population in the future. The rate of leaf production is significantly different in all stages except for juveniles. In mature trees, the significant difference in producing leaf per year is due to age and height. In the mature trees, being older and having high increment in spear elongation caused them to put less energy for leaf production. Therefore the lowest rate

of leaf production belonged to juvenile, adult and mature trees because of the rapid increase. In conclusion, rate of leaf production in *N. fruticans* was not very high but it was continuous. The rate of spear elongation per month was rather high with the highest rate of spear elongation per month in matures. With proper cultural practices such as increment of light by thinning, acceleration of leaf and fruit production is possible (Breure, 1994).

The whole flowering cycle of *N. fruticans* took about 8.2 - 9.6 months. Productive subjects flower regularly every year and almost every month with predictable pattern. It cannot be concluded that no seasonality happened in flowering because some fruiting peaks have been recorded. The rate of fruits production was almost high. This provided a good supply of seed for natural regeneration of the population of this species, but it is not concluded that *N. fruticans* has a very high rate of flowering production and seed germination. Although the rather low percentage of moisture content can be influenced by variation in climatic condition such as irrigation, it had no negative effect on the population. Soils at this study were silty-clay. The homogeneous soil moisture content in this study was contributed to similar soil type or similar vegetation covers at the two locations. Therefore, significant differences in some variables of growth among subjects were not related to soil that much. The acidic character of water pH had no negative impact on growth rate and it is in natural range now. The mean of water temperature in Carey Island was high with positive effect on growth. The water was classified as fresh water in terms of TDS concentration because of low concentration TDS. Fertilizers from agricultural run-offs and nitrification, with a source of nitrate ions from the atmosphere seemed a major cause of nitrate pollution in water samples in Carey Island. As regards with Malaysian interim water quality standard, Carey Island was classified into class 1 and 2. The water quality was within safe levels according to DOE Interim marine water

Quality and National Water Quality Standards for Malaysia (INWQS) (Ahmad et al, 2009), except for Nitrate, K, Na, Ca which were higher than standard. Low level of heavy metals was within acceptable limit. Water was saline and slightly acidic. The less DO concentration had no negative effects on the rate of new leaf production in adult and mature trees. Effects of heavy metals, nitrate and chloride concentration were not equal on the growth of the subjects. So, it is necessary to have treatments to decrease the concentration of these metals which is higher than standard level. As a result, the effect of heavy metals on the leaf production depends on the kind of metals and the life stage of trees. Various metals have different effect on leaf production. Therefore, although heavy metal had no negative effect on growth of juveniles and adults, there is an urgent need to control heavy metals because the population growth was most sensitive to tree growth changes, particularly in the mature stage. DO concentrations was within the normal levels and its little decrease has no negative effect on the population growth.

The maximum time that *N. fruticans* can live vegetatively indicate that the population was not so old and the maximum reproductive age was not too high. Overall, the age of *N. fruticans* tells us that the population was young with the capacity of regeneration. The long reproductive cycle and low rate of seed germination did not support the seed germination as the critical means for natural regeneration. The age estimation results showed that the highest peak of numbers was in the adult stage with young age. This shows that the population is dominated by young adult trees. The stable environments helped the survival of plants in this species because there was no mortality. These are indicated by continued regeneration of the populations. In total suckering behavior of subjects or reproductive structure, water run-off was much more effective in determining its distribution, recruits and even growth rate. As growth values, survivals may vary in the population in time, measurements during longer period can provide more precise

results in the future. It is implied from persistence of a species in an area that it tolerates the regular hazardous characterization of that environment. The population dynamics of the palm is not so sensitive to recent environmental condition. So, this study showed that the environmental condition had no negative effect on the growth and survival. The community has a good potential for regeneration. This is related to vegetative germination that has a main role in natural regeneration of *N. fruticans*. It is concluded that lower salinity has positive effect on the growth of juveniles but negative effect on matures and it is not effective in growth of adults. EC, TDS and DO conductivity has no effect on the growth of all stages. In total physical parameters have the most effect on the growth of Juveniles. Heavy metals have an effect on growth of individuals and also an effect of As and Zn on the growth of juveniles. In total effect of environmental factors, it depends on the stages of trees.

The most effect of major and trace metals are on adults which cause the growth of adults to decrease. Nitrate and phosphate has the most effect on the growth of juveniles which has caused it to increase. The major metals and trace metals have affected the differences of growth between sites. But in total, differences in growth of juveniles and adults and matures are not related to anions.

6.2. Suggestion for future research

Demographic studies take a long time and it is difficult for the research to get precise results, so, fast results are not reliable. Therefore, in this research, investigation period of the effects of environment, like water and soil quality need longer research. The effects of other factors especially light, seed dispersal on the growth rate and spatial distribution of

subjects of this species for some possible comparisons and conclusion are not enough and short. Also, in the future, it is better to compare the disturbed and undisturbed sites to understand the impact of environment effectively. Because of limited condition for some observations of pollination, pollinators, and phenology especially early in the morning and at night, the behavior of pollinators and the pollen load need to be studied fully and precisely. In addition, the seed predation, seed dispersal and suckering behavior of the species need to be investigated more precisely and longer time research is needed because of little settlement of seedlings due to tidal inundation. Hence, longer investigation is necessary to follow the fate of seeds washed away by water on the basis of casual observations. The genetic processes that may affect the survival of a population should be investigated. The suckering behavior of the palm need observations and its relation to leaves growths are important to understand resource allocation. This requires excavation works and can be costly. In addition, although there was no mortality, longer study on the population dynamics for long-term survival and future conservation is needed to confirm the stability of the population. In addition, some attentions are needed in the future especially in mature stages of trees to assure the stability or expanding the population in response to the changes.