EFFECTS OF *Bischofia javanica* (BISHOPWOOD*)* ON STAND STRUCTURE AND SPECIES DIVERSITY IN NATURAL AND PLANTED VEGETATION TYPES IN KAKAMEGA FOREST, KENYA

BY

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I56/CE/28406/2013

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (PLANT ECOLOGY) IN THE SCHOOL OF PURE AND APPLIED SCIENCES OF KENYATTA UNIVERSITY

SEPTEMBER, 2018

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DECLARATION

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

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DEDICATION

To my parents, my wife Linda and children – Lincoln, Brianna Leticia and Liam Bransyn for their unwavering support and encouragement throughout my studies.

ACKNOWLEDGEMENT

I express my gratitude to the following for providing me with the opportunity and inspiration to embark on and complete this work. Firstly, I thank the almighty God for giving me the strength, health, wisdom and a sound mind to be able to pursue my studies.

Secondly, my sincere appreciation goes to my supervisors – Dr. Emily Wabuyele of Kenyatta University Department of Plant Sciences and Dr. John Otuoma of the Kenya Forest Research Institute (KEFRI) for their guidance and oversight of the research. Their kind and meticulous input gave me the motivation and courage to forge ahead and complete this task.

Finally, I thank Mr. Joel Mbogani, a member from the community around Kakamega forest for helping in providing local names of tree species and directing me to study sites.

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LIST OF ABBREVIATIONS

BIOTA:	Biodiversity Monitoring Transect Analysis
IVI:	Importance value index
DP:	Disturbed primary forest
OSF:	Old-growth secondary forest
MASF:	Middle-aged secondary forest
YSF:	Young-secondary forest
MIF:	Mixed indigenous forest
BP:	*Bischofia javanica* plantation
CP:	*Cupressus lusitanica* plantation
MP:	*Maesopsis eminii* plantation
PP:	*Pinus patula* plantation

ABSTRACT

Recent studies have indicated that *Bischofia javanica* Blume (Euphorbiaceae), a tree species that was introduced in Kakamega forest as a restoration species in the early 1960s, is gradually recruiting and dominating its secondary and plantation forest stands. It is not clear whether this is a transitional succession process or a permanent takeover of the forest. The species has been reported to be invasive in other parts of the world such as Bonin forest and Oceanic Islands in West Pacific where it has been found replacing native species. In Kakamega forest, invasion by *B. javanica* could lead to significant adverse impacts on its ecological and socio-economic functions. This study sought to determine the distribution, dominance and relative abundance of *B. javanica* in selected vegetation types of Kakamega Forest. The study also aimed at determining the recruitment pattern of the species in the vegetation types and how this may have affected species composition and stand structure. The study was carried out in nine vegetation types, namely: old-growth secondary forest, middle-aged secondary forest, young secondary forest and mixed indigenous, *Maesopsis*, *Cupressus*, *Pinus* and *Bischofia* plantation forests, and the disturbed primary forest. It employed a nested experimental design; the nine vegetation types, which served as treatments of the study, were nested as sub-blocks in Yala, Isecheno and Kibiri forest blocks. Assessment was carried in 30m by 20m sample plots using stratified systematic sampling. Each sub-block had eight sample plots within a forest block making a total number of sample plots to be 216 (3 blocks x 9 vegetation types x 8 sample plots).The plots were located at equidistant points along the transect line laid in the middle of each vegetation type. Data from each plot were collected on tree species types with their local and botanical names and Diameter at Breast Height (DBH) which was measured in cm at 1.3m high. All the data were entered in Microsoft excel and analysed using Analysis of variance (ANOVA) in GENSTAT 18th edition software. Ryan-Einnot-Gabriel-Welsch Multiple Range Test (REGWQ) was used to separate the means between vegetation types. The results indicated that *B. javanica* was the only non-exotic tree species among several native species that recruited in all the vegetation types that were sampled except disturbed primary forest. It was the most abundant tree species, dominating the seedling, sapling and tree densities of plantations and natural forests. In addition, recruitment of the species in the respective vegetation types was found to reduce species diversity of the forest while the species evenness tended to increase. An effective way to manage this invasive tree species is to remove its seedlings and saplings through uprooting and also utilize the mature stems since its wood can provide industrial softwood, pulp and paper. Findings of this study will inform policy makers and resource managers to monitor the range of this tree species.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Degraded forestlands and secondary forests cover significant area in the tropics and currently exceed areas covered by primary forests by a wider margin (FAO, 2005). The cycle of forest degradation usually begins with indiscriminate extraction of high value mature trees and non-wood forest products that reduces the original forest cover and hampers the re-establishment of proper vegetation (Shono*et al.*, 2007). Over the years, forest restoration efforts comprising both natural regeneration and restoration planting have been employed to rehabilitate degraded tropical forests and improve their regenerative capacity, biodiversity value and environmental functions (Parotta, 2000).Most of the restoration planting efforts have tended to target exotic tree species due to their fast growth and ability to mature much faster than indigenous species (Dodson &Fielder, 2006).

However, the interactions of these exotic plants with native species and their accumulated effects in their new habitats are not always monitored over time (Bleher *et al.*, 2006). Thus, the ecological impacts of these introductions remain unknown several decades later, particularly in Kenya (Tsingalia & Kassily, 2009).One of the exotic tree species that was introduced in Kenya, Kakamega rainforest in particular, in the early 1960s is *Bischofia javanica* Blume (Euphorbiaceae) commonly known as Bishop Wood (Schaab *et al.*, 2010). What may not have been taken into consideration during its introduction was the fact that the species has been noted as being invasive and found invading and replacing native trees in forests of Bonin and Oceanic islands in Western Pacific

(Shimizu, 1998; Yamashita *et al*., 2000). Recent observations have indicated that *B. javanica* is beginning to dominate some secondary and plantation forests (Otuoma *et al.*, 2014).

Although Farwing *et al.* (2009) demonstrated that vegetation succession is active in both secondary and plantation forests of Kakamega forest; it is not clear whether the current recruitment of *B. javanica* in these forests is a normal transient successional stage or a permanent invasion of the forest. Given the adverse ecological and socio-economic impacts that a permanent invasion by this species may have on the forest, it is necessary and timely to understand the interactions and effects of *B. javanica* in the forest since its introduction. This study sought to assess the occurrence, relative abundance and dominance of *B. javanica* in secondary and plantation forests of Kakamega forest. Further, the study sought to determine the recruitment pattern and effects of invasion on woody tree species and assess the stand structure of *B. javanica* in selected vegetation types of the forest.

1.2 Statement of the problem and justification

Invasion of forest ecosystems by exotic plant species have elicited concerns for the decline in biodiversity and habitat loss (Binggeli, 1997). These species cause major ecosystem-level changes which include alteration of native species diversity, evenness and richness (Ehrenfeld, 2003). *B. javanica* was used as a key restoration species for degraded lands in the 1950s and 60s because of its broad ecological adaptive range, faster growth and evergreen nature (Hata *et al*. 2006). However, the species became invasive by replacing native species in different parts of the world where it was introduced (Morton, 1974; Yamashita *et al*., 2000). The same has been documented about the species in

Kakamega forest where it was introduced around 1960 (Schaab *et al.*, 2010). There are concerns that the species may eventually convert this rainforest into a *B. javanica* monoculture due to its vigorous growth in degraded sites (Otuoma *et al.*, 2014). Invasion of this rainforest would have severe consequences on ecological and socio-economic functions of the ecosystem. Therefore, it is important to understand the species recruitment pattern in this rainforest and how it has affected the stand structure and species diversity in both natural and plantation forest stands with a view to developing a strategy for managing the species.

1.3 Objectives of the study

This study focused on how the introduction of *Bischofia javanica,* an exotic invasive tree species in degraded sites of Kakamega forest for restoration has influenced plant community composition which in turn influences ecological functions.

1.3.1 General objective

To assess the current status of *Bischofia javanica* and how its establishment and interactions affects stand structure and woody species composition in natural and plantation forest types of Kakamega forest.

1.3.1 Specific objectives

i) To establish the occurrence, relative abundance and dominance of *B. javanica* in natural and plantation forests of Kakamega forest.

ii) To determine recruitment pattern of *B. javanica* and its effect on stand structure in natural and plantation forest types of Kakamega forest.

iii) To determine the effect of *B. javanica* recruitment on woody species diversity and evenness in natural and plantation forests of Kakamega forest.

1.4 Hypotheses

i) There is no significant difference in occurrence, abundance and dominance of *B. javanica* compared to other woody species in natural and plantation forest types of Kakamega forest.

ii) *B. javanica* recruitment has not had a significant effect on the stand structure of natural and plantation forests of Kakamega forest.

iii) Recruitment of *B .javanica* has no impact on woody species diversity and evenness in various vegetation types of Kakamega forest.

1.5 Significance of the study

Data generated from the study will provide the much-needed information for forest managers and other stakeholders in the management of *B. javanica* in the Kakamega forest and other similar ecosystems. It will also shed light on ecological and socio-economic considerations that need to be made before a non-native species are introduced for forest restoration.

CHAPTER TWO

LITERATURE REVIEW

2.1 Invasive plant species

Invasive plants are naturalized plant species that reproduce offspring in large numbers which are dispersed at considerable distances from the parent plants and thus spreading over a wider area (Richardson, 2000). According to Lockwood *et al*. (2007);- invasive plant species are alien plants that are also known as exotic, 'non-indigenous' or 'non-native' which are introduced in an area where they survive, reproduce and their establishment cause environmental or economic harm within the area of introduction.

2.2 Ecological characteristics of an invasive species

Exotic invasive plants often have physiological characteristics that allow them to colonize disturbed sites, and in some cases literally replace existing vegetation (Jeffrey *et al*., 2012). Many invasive plants are often found in the pioneering stages of succession and through direct competition they become dominant plants in the habitats where they establish (Baker, 1986). Most invasive plants have generalist pollination strategies, produce either large numbers of viable seeds that will readily germinate, or seeds with dormancy requirements so that when dormancy is overcome they produce large numbers of seedlings (Bleher *et al*., 2006). Many alien plants adapt to their receptor areas and after several generations experience ecotype differentiation which makes the species well adapted to the new environment (Hao *et al*., 2006). Generally, invasive plants have high photosynthetic, reproductive, respiration, transpiration rates, and behave opportunistically to disturbance (Dodson & Fiedler, 2006). These plants have great ability to acclimate to changes in the environment and quickly respond to changes in environmental resources such as water and nutrients (Chapla & Campos, 2010).

2.3 Effects of invasive plant species on plant community structure

Invasive plant species are harmful because they compete for resources and therefore displace native species in the host region (Vitousek, 1988). According to Baker (1986), although the probability of establishment and spread of invasive species can be low, once they have established and spread progressed, the economic damage can be very high. Invasive plant species influences the succession processes by altering the relative success of native plants both at the seedling stage and during later development (Hao *et al*., 2006). According to the facilitation model of succession, succession begins when there is available space for colonization and some species only modify the environment facilitating their replacement by other species which are physiologically and morphologically better adapted to the environment culminating into a one climax community (Namuta, 1982). Most research indicates that invasive tree species introduced in a forest ecosystem will invade and replace other species in the same ecosystem leading to homogeneity of the forest (Cione *et al*., 2002). A homogenous forest lacks the capacity to supply the resources and meet its ecological and socio-economic functions (Chapla & Campos, 2010).

2.4 Distribution and invasive history of *B. javanica*

Bischofia javanica is native to Australia, China, India, Malaysia and Thailand, it is currently found in Kenya, South Africa, Tanzania, Uganda and United States of America as a result of introductions that have been made over the past century (Orwa *et al*., 2009).

In United States of America, it was distributed by the United States Department of Agriculture in 1915 as an agroforestry tree. Thereafter, the tree was actively promoted by nurserymen and landscapers over several years after World War II (Rafael & Langeland, 2008). Soon, it became evident that the tree was outgrowing other species in home gardens and that it had aggressive and far extensive surface roots. Cutting the tree produced rapid regrowth (Kundu *et al*., 2012). Its fruits are readily consumed by migratory birds like *Turdus migratorious* resulting in wide distribution of seeds that led to rapid spread of the species (Morton, 1976). Their dense shade and perhaps toxins prevented other plants from growing under them and their seeds germinate everywhere (Kundu *et al*., 2012).

The species was reported to have successfully invaded the subtropical forest of oceanic islands in western pacific. It was introduced in Bonin Islands in 1900s as a timber tree (Hata *et al*., 2006) and it was also recognized as a threat to forest ecosystems on the Ogasawara island in Japan by about 1975 (Tanimoto &Toyoda, 1996). This led to forest agency of Japan to conduct a survey of *B. javanica* spread in 1993 and developed strategies for its control (Kundu *et al*., 2012).

In Kenya, *B. javanica* was introduced in Kakamega forest in 1960s as one of the restoration plant species following widespread logging operations (Schaab *et al.*, 2010). According to Tsingalia & Kassily (2009), disturbed sites in Kakamega forest were planted with indigenous and exotic species as plantation forests in a view of providing timber in the future and restoring the degraded forest. The plantations comprises of mixed indigenous species and monoculture of both indigenous and exotic species. Exotic plantations comprised, *Pinus patula* Schlechted & Cham., *Cupressus lusitanica* Mill., *Eucalyptus saligna* Sm. And *Bischofia javanica* Blume (Musila *et al*, 2010).

2.5 Description of *B. javanica*

Bischofia javanica (Euphorbiaceae) commonly known as Bishopwood is medium to fairly large, usually a deciduous plant growing to 22m high (Orwa *et al*., 2009). The tree bole is straight or poorly shaped with rounded crown and smooth branches. Leaves are alternate, long petioled and trifoliate (3 leaflets). The leaflets are shiny, bronze toned, oval-elliptic 15-20cm long, with small toothed margins (Kundu *et al*., 2012). Flowers are tiny, greenish yellow and lacks petals. Fruits are pea sized, berrylike, and fleshy to 9 mm in diameter, brown or reddish or blue black. Seeds are light brown, smooth, ovoid to oblong with one rounded and two flat sides embedded in colorless edible pulp when mature (Figure 2.1).

Bischofia javanica is a fast growing tree species that regenerates from seeds or cuttings or root suckers in moist soils. Seeds are readily consumed and dispersed by migrating birds (Morton, 1974). Its seedlings can grow in the sun or shade and adapt quickly to changes in light conditions (Kamaluddin & Grace, 1992). The tree wood is red, moderately heavy, hard and fine-grained. Its timber is used for constructing bridges, house posts, pile foundation, sleepers, rafters, boats, paper pulps and softwood in industries. The bark yields tannins used in toughening of nets and ropes and a red dye used to stain baskets.

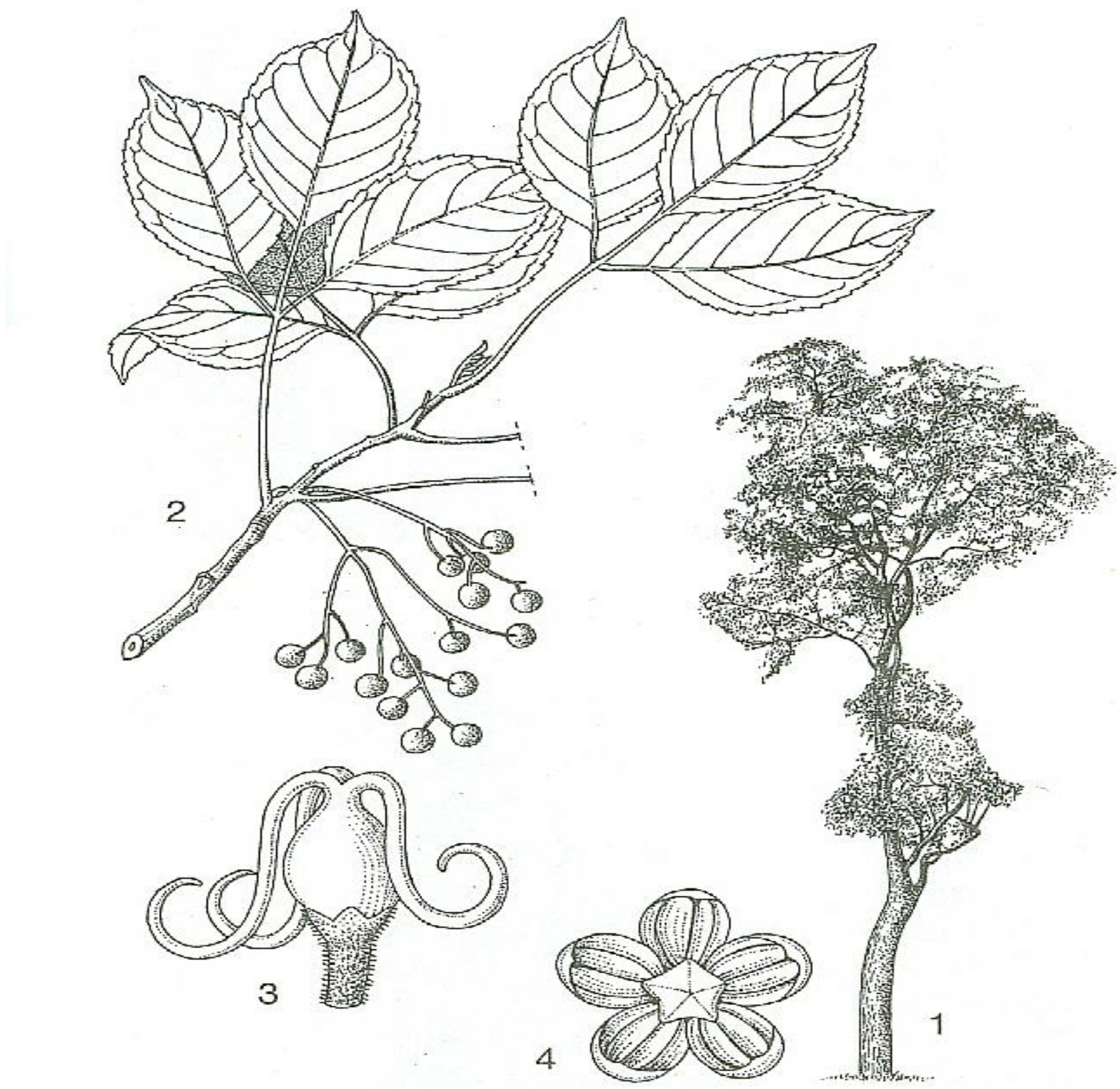


Figure 2.1:*B. javanica* Blume at different stages of growth

1. mature tree; 2. fruiting twig; 3. female flower with calyx removed; 4. male flower. Images not drawn to scale. **Source**: (Rafael & Langelands, 2008)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

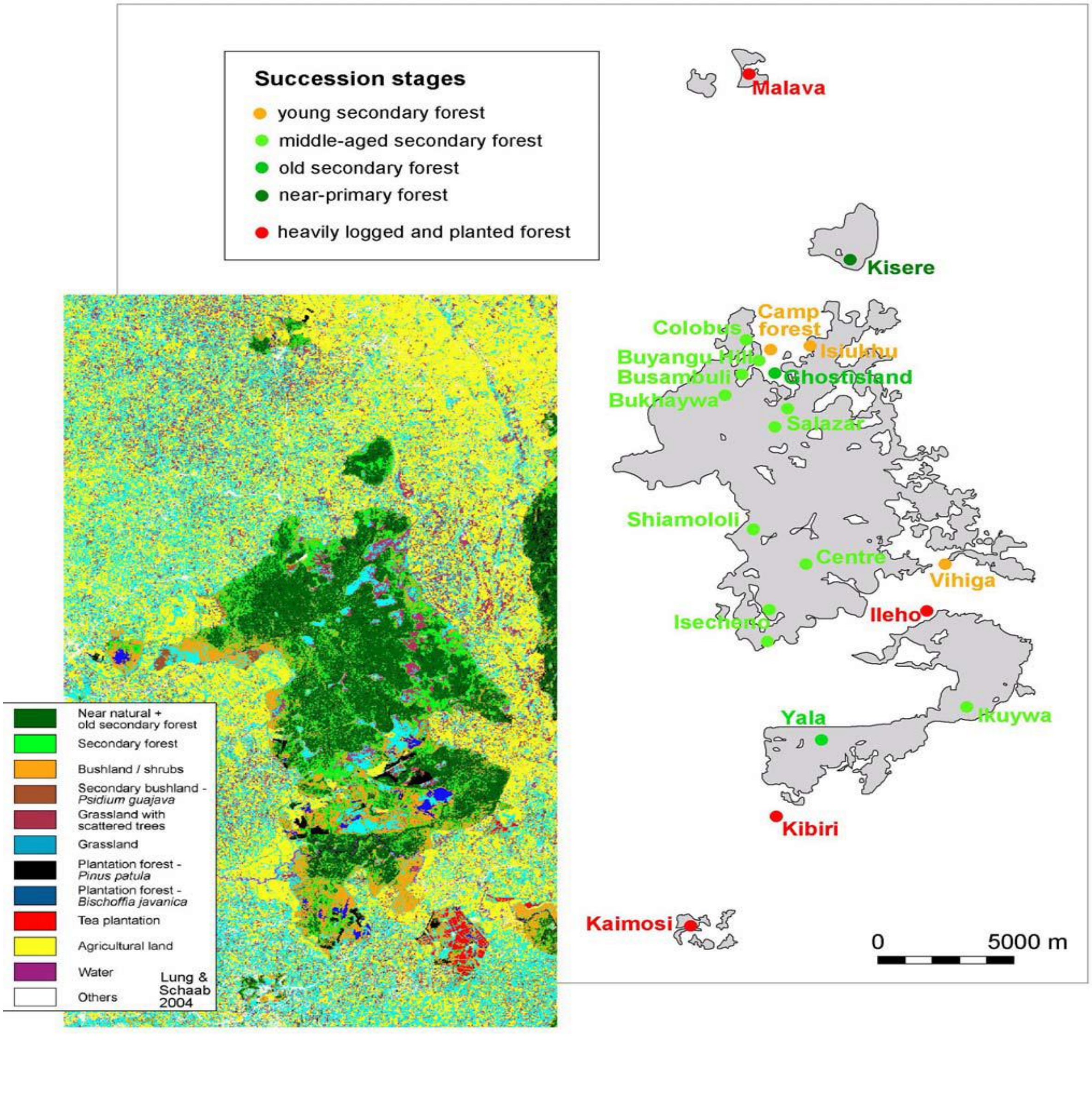


Figure 3.1: Landsat ETM+ land classification result of 2001, source E 02, FH Karlsruhe (Left site) and distribution of the succession stages forming vegetation types in Kakamega forest (right site). (Althof *et al.*, 2004).

3.1.1 Location

Kakamega forest is located in western region of Kenya, Kakamega County, between latitudes 00°08’30.5’ N and 00°22’12.5’ N and longitudes of 34°46’08.0’’ E and 34°57’26.5’E (Figure 2) at an elevation of about 1500 to 1700 m above sea level (Farwig et al., 2009). It is about 43km from Kisumu at the shores of Lake Victoria. Adjacent forests are the Nandi North and Nandi South Forests on an escarpment which borders Kakamega forest to the east (Musila, 2007). Other forests associated with the Kakamega rainforest are Bunyala in the north, Malava, Kisere and Kaimosi forests in the south (Althof *et al*., 2004). The area experiences a hot and wet climate characterized by an annual rainfall of 1,500 to 2,000 mm with dry season from December to March and an average minimum monthly temperature ranges from 11 – 21° C and average maximum monthly temperature ranges from 18 to 29° C (Schaab *et al*., 2010). Kakamega rainforest comprises of Nyanzian and Kavirondian rock formations which are the oldest rocks in Kenya formed in the lower Pre-Cambrian period and the rocks underlying the forest area consist of undifferentiated mudstone and ancient gneisses which are associated with gold bearing and quartz veins (Altholf, 2005). The soils in Kakamega are classified as Acrylic Farrell Soils (FAO, 2003)

3.1.2 Biodiversity and Economic Activities

Kakamega forest harbors about 986 vascular plant taxa of which about 81 are ferns and the rest are spermatophytes (Fischer *et al*., 2010). The forest is also a habitat of about 300 bird species and seven endemic primate species (Otuoma *et al.*, 2014). The vegetation of the forest consists of disturbed primary forest, secondary forest, mixed indigenous plantation forests, indigenous and exotic monoculture plantation forests (Tsingalia &

Kassily, 2009).Some of the indigenous species growing in the forest include; *Zanthoxylum gilletti (*Rutaceae*), Olea capensis (*Oleaceae*), Prunus africana (*Rosaceae*), Markhamia lutea (*Bignoniaceae*), Croton megalocarpous (*Euphorbiaceae*)* and *Maesopsis eminii* (Rhamnaceae). Exotic species include; *Eucalyptus saligna*, *C. lusitanica*, *P. patula* and *B. javanica* (Fischer *et al*., 2010).The vegetation also consists of a mixture of grasslands and shrub lands. The local community is predominantly Luhya with a population of about 280,000 living in the farmlands around the forest (Kiplagat *et al*., 2008). Their major economic activity is farming and they also depend on forest resources like timber, firewood, charcoal burning and grass for their livelihoods (Mutangah, 1996).

3.1.3 Forest blocks and Vegetation types in the study area

The forest blocks where this study was conducted include; Kibiri, Yala and Isecheno since they were subjected to restoration efforts and have similar vegetation types (Figure 3.1). The blocks are described below as per the Forest Department records at Isecheno Station from 1982- 2001 (FAO, 2003); BP, which acted as control where only pure stands of *B. javanica* were established in 1960s; DPF, a natural forest that established long time and there’s natural regeneration of trees; OSF, a disturbed forest that was rehabilitated by replanting with trees during the early restoration of the forest; MSF, a disturbed forest that was rehabilitated during the second phase of restoration in 1960s; YSF, a disturbed forest that was rehabilitated recently about 15years ago and the trees are mostly young; MIF, which was planted with different species of indigenous trees; MP, where only species of *M. eminii* were established; CP exotic monoculture , where only species of *C. lusitanica* were established (Figure 3.1).

3.2 Experimental Design

The study was carried out in Kibiri, Yala and Isecheno blocks of Kakamega forest because these are blocks with similar vegetation types and have been subjected to the same kind of restoration efforts (Althof, 2005). In each of these forest blocks, nine different forest vegetation types were sampled (Figure 3.2). The nine forest types were disturbed primary forest, old growth secondary forest, middle-aged secondary forest, young secondary forest, mixed indigenous forest plantations, *Maesopsis eminii* indigenous monoculture plantations, and *Bischofia javanica*, *Cupressus lusitanica,* and *Pinus patula* exotic monoculture plantations (Farwig *et al*., 2009).The study employed a nested experimental design (Figure 3.3). The vegetation types were treated as sub-blocks which were nested within each of the three blocks (Otuoma *et al*., 2014). The sub-blocks were delineated using forest compartments registers and existing base map (Schaab *et al*. 2010).

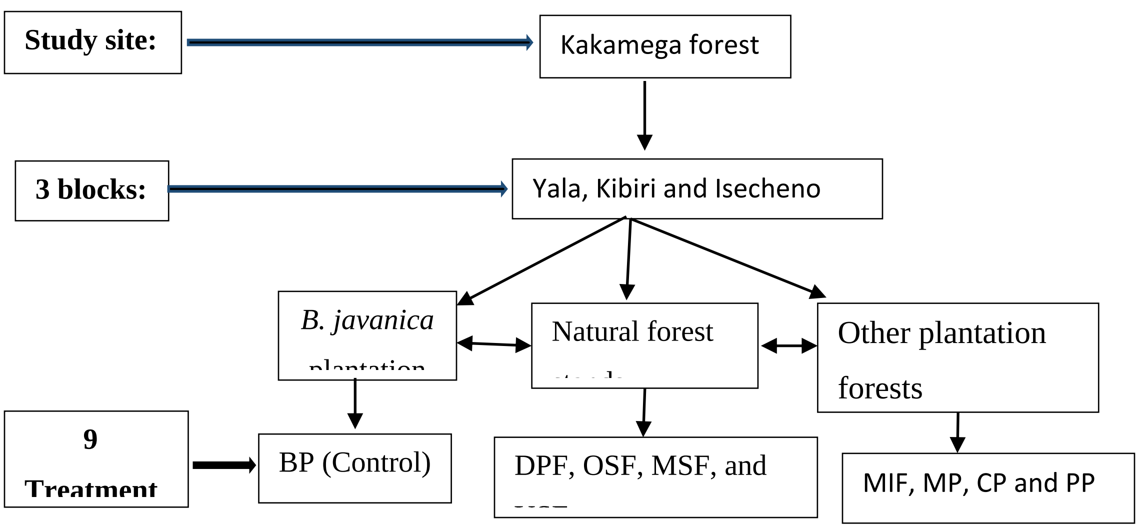


Figure 3.2: Three fractional forest design

BP- *Bischofia javanica* plantation; **DPF**- Disturbed primary forest; **OSF**- Old growth secondary forest; **MSF**-Middle aged secondary forest; **YSF**- Young secondary forest; **MIF**- Mixed indigenous forest; **MP-** *Maesopsis eminii* plantation; **CP**-*Cupressus lusitanica* plantation; **PP-** *Pinus patula* plantation.

3.2.1 Sample size

Eight plots per vegetation type which were treated as sub-block within a block were sampled giving a total of 216 plots (8 plots x 9 vegetation types x 3 blocks). Assessment on trees was carried out in 30m by 20m sample plot sizes which was located in the sub-blocks to measure trees above 10cm DBH (Figure 3.3). Each sample plot comprised of two sub-plots of 10m by 5mfor measuring tree samples between 0.1-10cm DBH, and each sub-plot of 2m by 1mfor sampling seedlings which were below DBH (< 1.3 m high). The sub-plots were nested within the main plot (Otuoma *et al*., 2016).

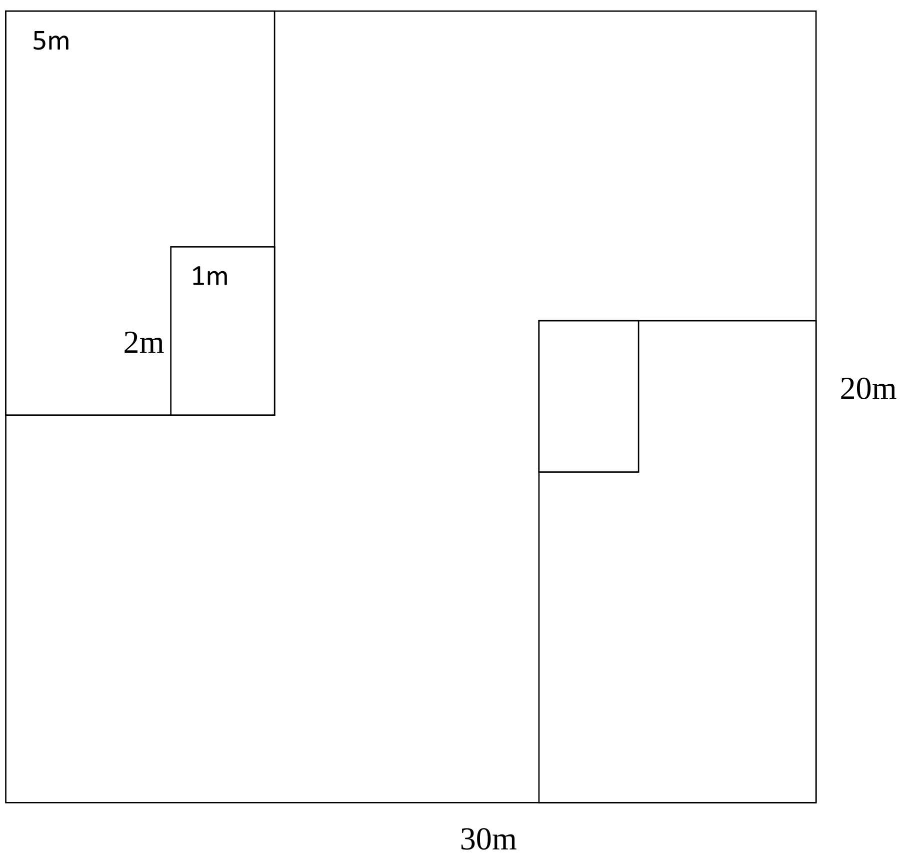


Figure 3.3: Rectangular sampling plot illustrating stratification of sampling units in the Sub-Blocks. Figure not drawn to scale

3.2.2 Layout of plots

Line transects were established in the middle of each sub-block. Sample plots were located at regular intervals along the line of transect (Figure 3.4). A distance of 100m was measured from one edge of the forest along the transect line then two plots each located 50m on either side of the transect line. The next two plots were located in the same manner until eight plots per vegetation type were established according to Fashing *et al*. (2004).

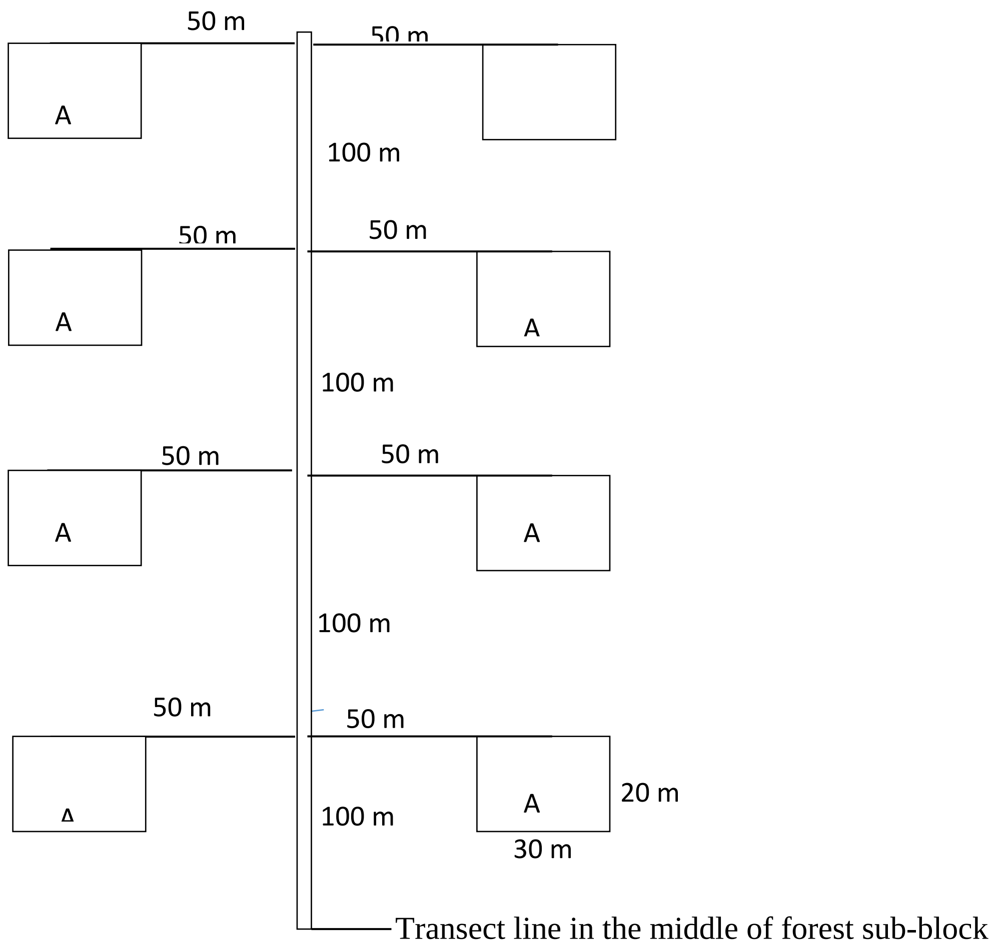


Figure 3.4: Illustration of plot layouts that were used for assessment (Not drawn to scale**)**

Key: **A-** represents the eight sampling plots measuring 30 m by 20 m

3.3 Data collection

Data were collected using the stratified systematic sampling method (Gregoire & Valentine, 2007). They were collected on types of woody species for seedlings, saplings and trees and stem diameter at breast height (DBH) for saplings and trees. Types of woody species were identified by their botanic names with the help of a plant taxonomist. Stem Diameter at Breast Height (DBH) was measured in centimeters at 1.3m above the ground using a diameter tape (Otuoma *et al*., 2016).

3.4 Data analysis

Data on woody species and number of stems were used to derive occurrence, relative abundance, stand structure, woody species diversity and species evenness. Occurrence of woody species was determined by calculating the total number of woody stems and representation of *B. javanica* (where it was found) in the vegetation types of the forest.

Relative abundance of the species was derived using the percentage proportion of the species and its relative basal area was determined to define the area of the forest that was occupied by the cross-section of trees of the species (Kent & Coker, 1992).The formulas used were as follows;

$$\text{Relative abundance} = \frac{\text{Number of stems of the species x 100}}{\text{Total number of stems of all species}}$$

$$\text{Relative Basal Area} = \frac{\text{Basal area x 100}}{\text{Total basal area per ha}}$$

Where;

$$\text{Basal Area } (M^2) = \pi r^2 = 3.142 * \left[\frac{\text{DBH}}{200}\right]^2$$

Dominance of the species was determined using the Importance Value Index in forest vegetation types (McCune, 2002).

$$\text{Importance Value Index} = \frac{\text{Relative frequency + Relative stem density + Relative basal area}}{3}$$

Where, $\text{Relative frequency} = \frac{\text{Number of occurence of the species x 100}}{\text{Number of occurrence all species}}$

Data on types of tree seedlings and DBH of stems were used to derive recruitment pattern and stand structure of the species (Otuoma *et al*., 2014). Recruitment pattern and Stand structure of the species was analyzed using stem density of woody plant species in various DBH size classes which were put at an interval range of 10 cm. The size classes included; Below DBH (plants that were less than 1.3 m high), 0.1 – 10.0 cm, 10.1 – 20.0 cm, 20.1 – 30.0 cm, 30.1 – 40.0 cm, 40.1 – 50.0 cm, 50.1 – 60.0 cm, 60.1 – 70.0 cm, 70.1 – 80.0 cm, 80.1 – 90.0 cm, 90.1 – 100.0 cm and Over 100 cm.

Woody species diversity was calculated using Shannon diversity index (Pena-Claros, 2003).

The formula used for calculating the Shannon diversity index was; $H' = -\Sigma$ (pi 1n pi),

Where, H'= Shannon index of diversity

pi = the proportion of important value of the ith specie (pi =ni / N),

ni = is the important value index of ith species and N is the important value index of all the species

Species evenness was determined using Simpson index of species evenness (McCune, 2002). The equation used to calculate Simpson's index was; $D=1- \Sigma\ (pi)^2$

Where, D = Simpson index of diversity, p_i = the proportion of important value of the *i*th species ($p_i = n_i / N$), n_i is the important value index of *i*th species and N is the important value index of all the species.

All the data were entered in Microsoft excel and then subjected to Analysis of variance (ANOVA) in GENSTAT 18th edition to determine significance levels in different vegetation types. Means were separated using Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ) (Buysse *et al*., 2004).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Occurrence, relative abundance and dominance of *B. javanica*

In this study, total of 12, 286 woody plants consisting 83 species were recorded from the vegetation types in Kakamega forest.

Apart from the BP vegetation type, which was planted exclusively with *B. javanica* and served as the source of the species in Kakamega forest, the species was represented in all other plantation and secondary forest types through natural recruitment in open spaces between planted or naturally growing tree species. However, the species was not represented in the disturbed primary forest (Figure 4.1). *B. javnica* recorded such a high natural recruitment rate in the other plantation and secondary forest types that there was no significant variation between the occurrence in its own plantation and the other vegetation types (Appendix 1). Comparing the other seven vegetation types in which *B. javanica* was represented; only mixed indigenous plantation and old-growth secondary forest were established before the 1960s when the species was introduced to Kakamega forest. The other five plantation and secondary forest types were established after the introduction of *B. javanica* in the rainforest.

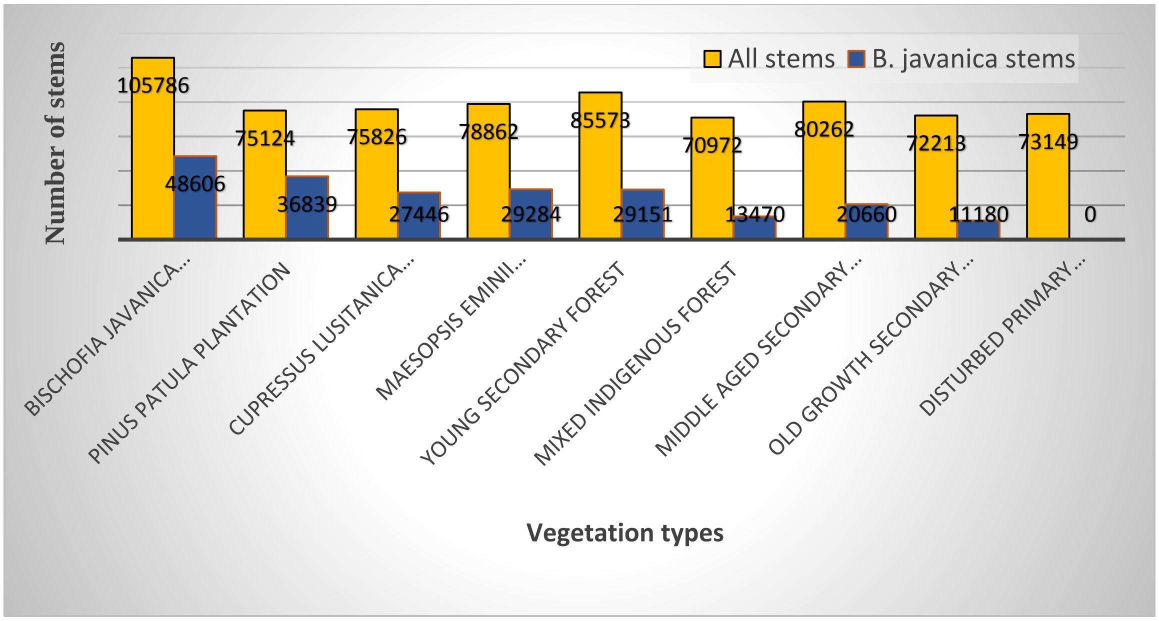


Figure 4.1: Occurrence of *B. javanica* in vegetation types of Kakamega forest

4.1.2 Relative abundance of *B. javanica*

The relative abundance of *B. javanica* varied significantly among the eight vegetation types in which it was represented (P-value< 0.001). Generally, it tended to have a higher relative abundance in plantation forests than in secondary forests (Table 4.1). Among plantation forests, the species had a significantly higher relative abundance in *P. patula* plantations than other plantation types, including its own plantations. This suggests that *B. javanica* regenerated better in *Pinus* forest than in other forest types. In secondary forests, the species was more abundant in younger forest, and this decreased as the stand age increased. For instance, its relative abundance in young secondary forest was 34.06±0.57 which decreased to 25.66±1.28 in middle-aged secondary forests and then to 15.42±0.54 in old-growth secondary forest (Table 4.1).

Table 4.1: Relative abundance of *B. javanica* in different plantation and secondary forest types in Kakamega forest.

Vegetation type	Relative abundance (%)
Pinus patula plantation	$49.03 \pm 0.63_{g}$
Bischofia javanica plantation	$45.95 \pm 0.35_{f}$
Maesopsis eminii plantation	$37.14 \pm 0.78_{e}$
Cupressus lusitanica plantation	$36.2 \pm 0.43_{de}$
Young secondary forest	$34.06 \pm 0.57_{d}$
Middle-aged secondary	$25.66 \pm 1.28_{c}$
Mixed indigenous plantation	$18.99 \pm 0.90_{b}$
Old growth Secondary	$15.42 \pm 0.54_{a}$
P value	<0.001
l.s.d.	1.86

Subscripts with different letters under relative abundance denote significant difference in relative abundance between vegetation types.

4.1.3 Relative basal area of *B. javanica.*

Analysis of the relative basal area of *B. javanica* in the eight vegetation types in which it was represented indicated that it was significantly smaller in secondary forests than plantation forests (P-value< 0.001). For instance, its relative basal area in secondary forests ranged between 3.11±0.61 in Old-growth secondary forest and 4.76±0.47 in Young secondary forest, while it ranged between 5.58±0.09 in MP forest type and 10.76±0.32 in PP plantation (Table 2; Appendix III). The highest relative basal area was recorded in the BP vegetation type.

Table 4.2: Relative basal area of *B. javanica* in different vegetation types in Kakamega forest

Vegetation type	Relative basal area of *B. javanica*
Bischofia javanica plantation	72.56 ± 0.90^{d}
Pinus patula plantation	10.76 ± 0.32^{c}
Cupressus lusitanica plantation	9.25 ± 0.60^{bc}
Mixed indigenous plantation	6.53 ± 2.85^{abc}
Maesopsis eminii plantation	5.58 ± 0.09^{ab}
Young secondary forest	4.76 ± 0.47^{ab}
Middle-aged secondary	3.44 ± 0.67^{a}
Old growth Secondary	3.11 ± 0.61^{a}
P value	< 0.001
l.s.d.	3.23

Superscripts with different letters denote significant difference in relative basal area

4.1.4 Importance value index of *B. javanica*

Bischofia javanica's importance value index (IVI) ranged from 39.51±0.03 in Old-growth secondary forest to 72.83±0.40 in its own plantation (*B. javanica* plantation) (Table 4.3). The index was significantly higher in monoculture plantations than mixed indigenous plantations and secondary forests (P-value < 0.001). In secondary forest stands, the species' importance value index decreased with stand age. For instance, it was significantly higher in Young secondary forest than in Old-growth secondary forest (Table 4.3).

Table 4.3: Importance value index of *B. javanica* in vegetation types of Kakamega forest.

Vegetation type	*B. javanica's* IVI.
Bischofia javanica plantation	72.83±0.40 ^{f}
Pinus patula plantation	53.26±0.17 ^{e}
Cupressus lusitanica plantation	48.48±0.07^{d}
Maesopsis eminii plantation	47.57±0.25 ^{cd}
Young secondary forest	46.27±0.33 ^{c}
Middle-aged secondary	43.04±0.34 ^{b}
Mixed indigenous plantation	41.84±1.21 ^{b}
Old growth Secondary	39.51±0.03 ^{a}
P value	<0.001
l.s.d.	1.49

Superscripts with different letters denote significant difference in importance value index.

4.1.5 Stand structure and recruitment pattern of *B. javanica*

Information on species density and DBH size classes of stems were used to determine stand structure and recruitment pattern of *B. javanica* in the vegetation types respectively.

4.1.5.1 *B. javanica's* contribution to stem density in other vegetation types.

Analysis of the number of stems of *B. javanica* in the vegetation types in which it was represented indicated that the species made a significant contribution in the overall stem density of both plantation and secondary forests of this rainforest (Table 4.4). In the *P. patula* plantation, for instance, *B. javanica* stems comprised 49% of the overall stem density, while in old growth secondary forest and mixed indigenous plantation forest, where it has the least representation; it contributed 15% and 19% of the overall stem density, respectively. (Table 4.4)

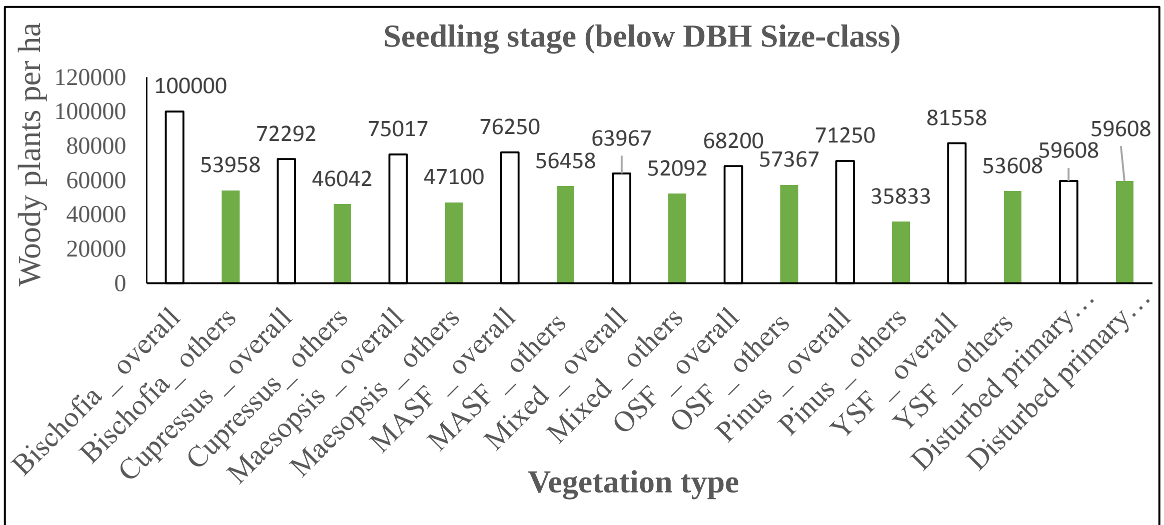
Table 4.4: *B. javanica's* contribution to all tree stems in plantation and secondary forest types of Kakamega forest.

Vegetation type	Overall stem density (stems per ha)	Stem density without *B. javanica* stems (stems per ha)	% Stem density of *B. javanica*
Bischofia javanica	105,786 ± 2,989	57,180 ± 1,255	45.94
Cupressus lusitanica	75,826 ± 1,531	48,380 ± 1,054	36.19
Maesopsis eminii	78,862 ± 353	49,578 ± 802	37.13
Middle-aged Secondary forest	80,262 ± 2,663	59,602 ± 1,190	25.74
Mixed indigenous forest	70,972 ± 433	57,502 ± 950	18.98
Old growth Secondary forest	72,213 ± 3,995	61,033 ± 3,014	15.48
Pinus patula	75,124 ± 635	38,285 ± 225	49.03
Young secondary forest	85,573 ± 5,792	56,422 ± 3,832	34.06

4.1.5.2 Recruitment and distribution of *B. javanica* in DBH size-classes

Apart from the disturbed primary forest where *B. javanica* was not represented, the species comprised a significant proportion of seedlings in all plantation and secondary forests (Figure 4.2) indicating an active natural recruitment process. Recruitment of this species in other forest types was mainly from tree seeds that were dispersed either from its own plantation or from its trees that already established in other plantations and secondary forests. A comparison of the overall woody seedling density, in which *B.*

javanica was included, against that of all other woody species indicated that it contributed a minimum of 18.9% of the seedlings in old-growth secondary forest and a maximum of 85.3% of the seedlings in the *Bischofia* plantation. Therefore *B. javanica* was the tree species with the highest rate of natural recruitment in all the plantation and secondary forests in the seedling stage of this rainforest.

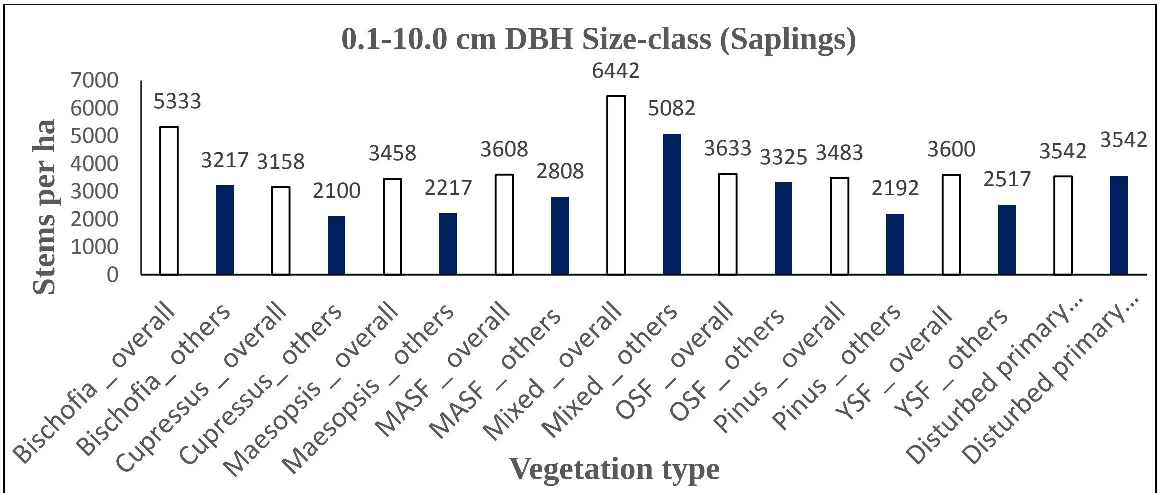


Key: **MASF** - Middle aged secondary forest; **OSF** – Old growth secondary forest; **Mixed** - Mixed indigenous forest; **YSF** – Young secondary forest

- Unfilled bars represent overall woody seedling density with *B. javanica* included, while solid bars represent woody species without *B. javanica*

Figure 4.2: A comparison of woody seedling densities in different vegetation types in Kakamega forest.

A similar pattern of recruitment of *B. javanica* was recorded in the 0.1-10.0 cm DBH size-class (Figure 4.3). The species contributed a significantly high number of stems in this DBH size-class through natural recruitment than all other tree species. Like the seedling stage, the it was least represented in the 0.1-10.0 cm DBH size class in the old-growth secondary forest where itaccounted for 9.3% of the stemswhile it was most represented in the *Bischofia javanica* plantation with 65.8% of all the stems. However, there were generally more tree stems in this size class than in higher DBH classes which meant that as the size classes increased the stems density decreased (Fig. 4.3).



Key: MASF – Middle aged secondary forest; **OSF** – Old growth secondary forest; **mixed** – Mixed indigenous forest; **YSF** – Young secondary forest

- Unfilled bars represent overall woody sapling density, while solid bars represent woody sapling densities of other tree species apart from *B. javanica.*

Figure 4.3: A comparison of woody stem density of tree species in the 0.1–10.0 cm DBH size-class of different vegetation types in Kakamega forest.

Analysis of the recruitment and distribution of *B. javanica* in various DBH size-classes between 10.1 cm and 100 cm indicated that the species dominated almost all the size classes in its own plantation. In fact there were no stems of other tree species that occurred beyond 30 cm DBH size class in this plantation (Fig. 4.4).In addition, naturally recruited stems of this species were not found beyond 50cm DBH class sizes in other vegetation types where it occurred. This was observed in *Cupressus, Maesopsis, Pinus* and mixed indigenous plantations, and also in young secondary, middle-aged secondary and old-growth secondary forests (Fig. 4.4). Although *B. javanica* stems were mostly represented in < 50 cm DBH classes in other plantations and secondary forests, these forest types had other tree stems up to over 100 cm DBH range. Even young secondary forest whose largest stems fell in size range of 70.1 – 80.0 cm DBH size-class did not have *B. javanica* stems beyond 50 cm DBH size class (Figure 4.4).

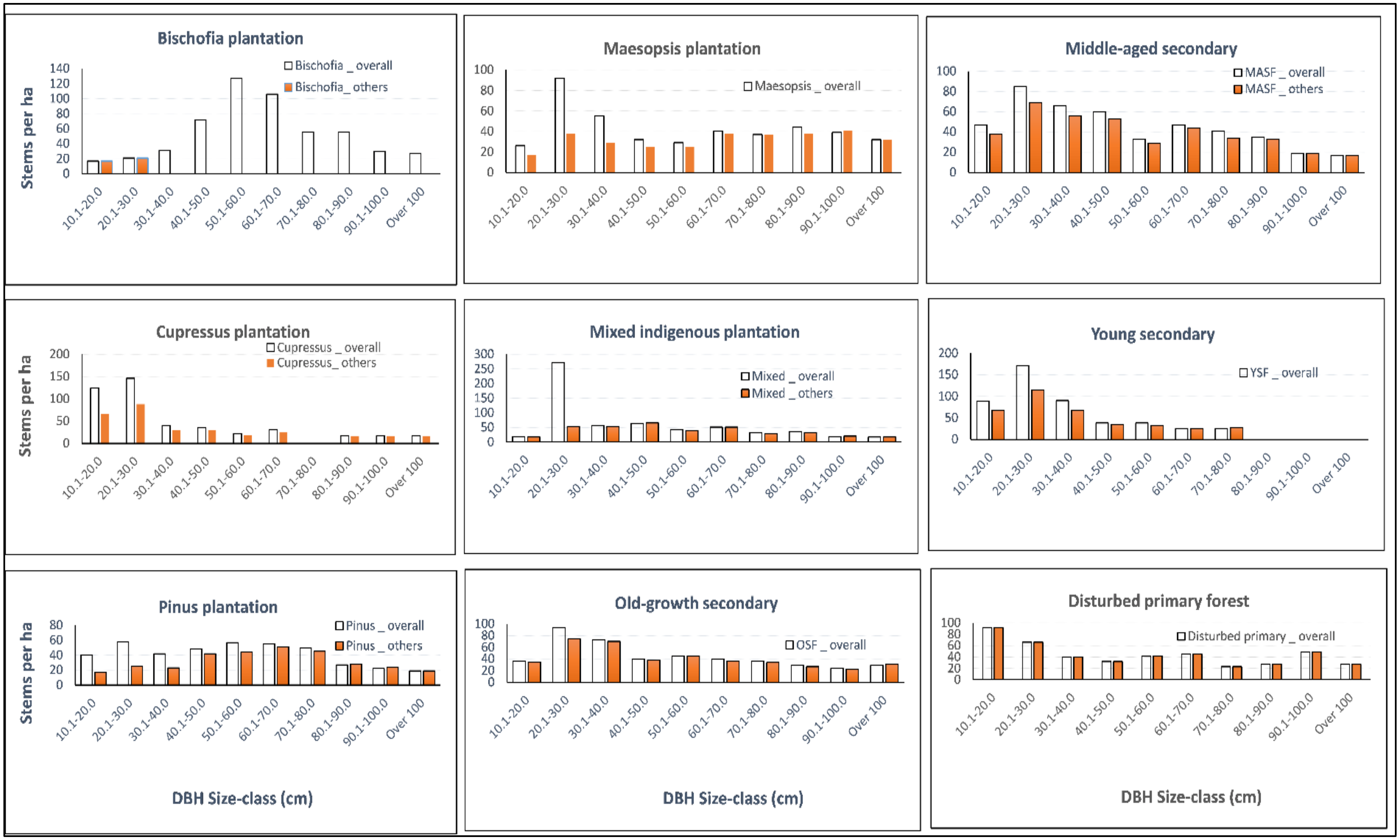


Figure 4.4: A comparison of tree species in the 10.1 and above DBH range of different vegetation types in Kakamega Forest.

-Unfilled bars represent overall woody stem density, while filled bars represent stem densities of all other species apart from *B. javanica*.

4.1.6 Effect of *B. javanica* recruitment on species diversity

Analysis of species diversity indicated that vegetation types where *B. javanica* was abundant tended to have lower Shannon-Weiner diversity index compared to the ones where it was less abundant. Plantations and young secondary forest recorded a lower index which ranged between 1.724±0.00695 in *Bischofia javanica* plantation and 3.06±0.00996 in mixed indigenous plantation. However, old-growth and middle-aged secondary forests recorded slightly higher indices of 3.118±0.00578 and 3.206±0.00889 respectively (Table 4.5).

Table 4.5: Shannon-Weiner indices illustrating the effect of *B. javanica* recruitment on woody species diversity in plantation and secondary forest types of Kakamega forest

Vegetation type	Shannon-Weiner indices
Bischofia javanica plantation	1.724 ± 0.00695^{a}
Pinus patula plantation	2.018 ± 0.02988^{ab}
Cupressus lusitanica plantation	2.275 ± 0.00165^{abc}
Maesopsis eminii plantation	2.344 ± 0.01328^{bc}
Young Secondary forest	2.943 ± 0.02218^{cd}
Mixed indigenous plantation	3.06 ± 0.00996^{d}
Old growth Secondary	3.118 ± 0.00578^{de}
Middle aged secondary forest	3.206 ± 0.00889^{de}
p value	< 0.001
l.s.d.	0.04858

Superscripts with different letters denotes significance difference in Shannon-Weiner index.

4.1.7 Effect of *B. javanica* recruitment on species evenness

The results of this study indicated that relative abundance of *B. javanica* positively correlated with species evenness in the vegetation types of Kakamega forest (Table 4.1 & 4.6). Simpson`s index recorded a higher species evenness in monoculture plantations and young secondary forest where the abundance of *B. javanica* was relatively higher. Mixed indigenous, middle-aged secondary and old-growth secondary forests recorded lower indices (Table 4.6). Since the species contributed a significantly large number of stems in plantation forest stands, its random spread is likely to have increased overall species evenness of monoculture plantations.

Table 4.6: Simpson`s indices of evenness illustrating the effect of *B. javanica* recruitment on woody species evenness in plantation and secondary forest types of Kakamega forest

Vegetation type	Simpson's index
Bischofia javanica plantation	$0.4089 \pm 0.000877_{d}$
Pinus patula plantation	$0.2258 \pm 0.003286_{cd}$
Cupressus lucitanica plantation	$0.1848 \pm 0.001004_{bc}$
Maesopsis eminii plantation	$0.1723 \pm 0.000952_{bc}$
Young secondary forest	$0.1162 \pm 0.004674_{abc}$
Middle Aged Secondary forest	$0.0718 \pm 0.00137_{ab}$
Mixed indigenous plantation	$0.0622 \pm 0.001778_{ab}$
Old growth Secondary forest	$0.0555 \pm 0.000623_{a}$
P value	<.001
l.s.d.	0.06247

Subscripts with different letters indicate vegetation types that are significantly different.

4.2 Discussion

4.2.1 Occurrence of *B. javanica* in vegetation types.

The results of this study indicated that *B. javanica* which was introduced in Kakamega forest as a monoculture plantation was found to occur in almost all vegetation types where it was not planted (Figure 4.1). This observation is in agreement with what has been reported in studies in other tropical forests of the world such as Bonin forest in Oceanic islands and Ogasawara Island of Japan which indicated that after being introduced as timber or ornamental species, it later spread and was found replacing native species as documented by Tanimoto & Toyoda (1996); Morton (1976) and Kundu *et al*. (2012). The findings are also in agreement with the recent studies that have been carried out in Kakamega rainforest in which the species showed properties of invasion in the rainforest (Fawig *et al*., 2009; Otuoma *et al*., 2014).

Most of the tree species selected for restoration in secondary and plantation forests in Kakamega forest were of high value and the rate of their exploitation through selective logging remains high (Altholf *et al*., 2004). Logging of secondary forests and monoculture plantations creates many gaps which gives chance for colonization by invasive species such as *B. javanica.* According to Morton (1976) and Kundu *et al*. (2012), *B. javanica* possesses physiological and morphological characteristics that enable it to establish in disturbed sites and under shade of other trees. Fruits from mature trees are eaten by birds for instance *Tardus migratorius* (Tardiae family) while sometimes blue monkeys shake the trees to fall off the seeds and this contributes to the spread of the species in the different vegetation types.

Another reason for the occurrence of the species in secondary and other plantation forests as highlighted by Otuoma *et al*. (2014) could be that during restoration, species were planted at a spacing of three meters and due to the slow nature of growth of indigenous species; this invasive species easily occupies the interspaces that exist between the planted trees. In addition, the tree species tends to have more dispersal agents for instance birds and primates in the forest and this could have contributed to its rapid spread in the rainforest (Yamashita *et al*., 2000).There were no stems of the species recorded in disturbed primary forest and this could be due to its thick canopy cover and natural recruitment of plants that prevented establishment of the species. In addition, succession was already at advanced stages in this forest types by the time restoration was carried out in 1960s as reported by Fawig *et al*. (2009).

4.2.2 Relative abundance of *B. javanica*

Analysis of relative abundance of *B. javanica* confirmed that it was the most abundant tree species in plantations and some secondary vegetation types of Kakamega forest. The study indicated that the relative abundance of the species tended to decrease with increase in stand age for instance there was lower relative abundance in Old growth secondary forest followed by Middle aged secondary and then Young secondary forest. This phenomenon is akin to findings by Altholf (2005) and Otuoma *et al*. (2014) that the larger trees a vegetation type contains the older the trees are and the more undisturbed is the forest site. Old secondary forest has tall trees and its average DBH is higher than in younger forests and tree species like *Aningeria altisima* Hutch& Dalziel, *Antiaris toxicaria* Lesch and *Funtumia africana* Stapf were abundant and not selectively logged and therefore *B. javanica* was less abundant since there were few gaps for it to recruit. Also there is active natural regeneration of other tree species in this vegetation type compared to younger secondary and plantation forests.

In addition, the tree species was introduced in the forest in 1960s when other tree species had already recruited in Old secondary and disturbed primary forests. The relative abundance of *B. javanica* was higher in middle aged and young secondary forests, which is attributed to the fact that these vegetation types are fragmented and the other tree species are not so tall and mature like in disturbed primary and old growth secondary forests. Also, the frequency of disturbance in young secondary is relatively high. The same trend of age and relative abundance of *B. javanica* was similar in indigenous plantation forests for instance MP had lower abundance with the species than in MIF. The former is an old forest with mature tall trees compared to the latter (Altholf, 2005). In CP, PP and BP monoculture plantations, there was higher relative abundance of the species but existed no relationship between stand age and abundance of *B. javanica.*

This result is same as the findings by Otuoma *et al*. (2014) in which it was reported that forest succession often begins with early successional pioneers in secondary forest stands but succession in plantation forests tends to bypass light demanding early pioneers stage and facilitate long-lived and shade tolerant species such as *B. javanica*. According to Lung & Schaab (2008), silvicultural practices which included weeding and pruning were done in plantation and young secondary forests which could have hindered natural recruitment of other tree species and made it easier for the spread and colonization by this invasive species.

4.2.3 Relative dominance of *B. javanica*

The results of this study confirmed that *B. javanica* dominated all the eight vegetation types where it occurred. However, the relative basal area and importance value index of the species was higher in monoculture plantations than in secondary forests implying that it was more dominant in the former than in latter. Secondary forests had young and smaller trees of *B. javanica* with low DBH which recorded lower relative basal area and the importance value index though the species remain abundant in the forests. In monoculture plantations, the species had mature stems and their DBH was high which caused high relative basal area and importance index. The results suggested that since secondary forests of this forest were never subjected to any silvicultural operations, smaller *B. javanica* stems may have been caused by competition from other naturally recruiting woody species in secondary forests. Plantations were subjected to silvicultural management, such as weeding and pruning, which is likely to have cleared the stands of natural recruits during their early stages of establishment making it easier for *B. javanica* to recruit.

According to Otuoma *et al*. (2014) and Tsingalia (1990), species dominance follows the disturbance gradient in that a more disturbed forest site permits higher dominance of an invasive species. Monoculture plantations like PP and CP are highly logged to provide timber which leaves many gaps that are taken up by the invasive species. Another phenomenon that explains why the invasive species dominated the plantations is the fact that the tree species that were planted for instance *P. patula, C. lusitanica* and *M. eminii have* poor regeneration capacity and there was minimal number of their stems recruiting in their own plantations which makes it easier for *B. javanica* to spread owing to the fact that it is an opportunistic tree species that recruits rapidly where there is a gap.

Secondary forests have permitted the entry of the species due to continued disturbance through silvopastoral and charcoal burning which has hindered natural recruitment of other tree species. But because *B. javanica* is an invasive tree species known to colonize disturbed sites, its recruitment and regeneration from its cut stems is on an upward trend in these forest types of Kakamega forest. However the stems of this invasive species were mostly young trees in secondary forests where it occurred but with the continued overexploitation of the forest, the species is likely to dominate all the forest types in future and mature into large trees.

4.2.4 Stand structure and recruitment pattern of *B. javanica*

This study indicated that the stem density of *B. javanica* greatly contributed to the overall density of stems in plantation and secondary forest vegetation types. For instance the species comprised of 49% in CP which was even higher than 46% in its own plantation. The least stem density of the species was in OSF where 15% was recorded. This is a clear indication that the species had high rate of recruitment in the forest types and their stem density were likely to increase further in future if no action to control its spread is taken. Previous studies in the forest indicated that spacing of planted trees were at about 3 m which presents the natural recruits with a great challenge in reaching the main canopy and it was easier for invasive species such as *B. javanica* to establish and spread more than the indigenous tree species because the latter tended to grow slowly (Pena-Claros, 2003). This phenomenon could be one reason why the density of the species was higher especially in plantation forests.

The species has excellent dispersal agents, and only one mature tree produces a larger number of viable seeds that can germinate and grow both in open gaps and under the shade in the forest. In addition, the cut stems of the species forms multiple regrowth leading to rapid increase in their number in the forest. The other planted species and most naturally occurring have low regeneration capacity compared to *B. javanica.*

Recruitment of *B. javanica* in Kakamega forest vegetation types was found to be high in seedling stage and lower DBH size class of range 0.1 – 10 cm (Appendix III). This observation conformed to the findings by Fashing *et al*.(2004) and Fischer *et al.* (2010) which highlighted that active natural recruitment of trees was taking place in both plantation and secondary forests and that young trees formed a bigger percentage in stem density than mature ones. The study also was in agreement with previous studies done on the characteristics and physiognomy of *B. javanica* which confirmed that the tree species had consistent establishment pattern from seeds and dense regrowth after logging (Tanimoto & Toyoda, 1996; Kundu *et al*., 2012). Large number of seeds dropped off from mature trees and scattered around the parent plants. These seeds needed not to be buried to survive and germinate to produce seedlings. They were found to germinate both in closed canopies and open gaps that existed in the forest. The seedlings of the species were found to grow vigorously both as pioneer and non-pioneer species in the vegetation types of the forest.

In *B. javanica* plantation, there were no stems of other species recorded beyond 30 cm DBH class since the planted trees of *B. javanica* forms a dense closed canopy that could not allow other shade intolerant species to survive. This was an indication of the invasive nature of the species and it was suggested that the properties exhibited by *B. javanica* to this result constitute adaptations of photo-inhibition and by rapidly developing new sun adapted leaves which was a similar observation highlighted by Yamashita *et al*.(2000). The species was mostly not represented in size classes > 50 cm in other plantations and natural forests where it occurred which suggests that the forest is still in its early stages of invasion by the species. According to Pena-Claros (2003), species changes during forest succession may occur slowly and it may take several decades for understorey and sub-canopy species to replace the existing species. Therefore it may take a little longer time for *B. javanica* to completely colonize the rainforest.

4.2.5 Effect of *B. javanica* recruitment on woody species diversity and evenness

Analysis of species diversity and evenness indicated that existence of *B. javanica* in the vegetation types tended to reduce species diversity while the species evenness increased. This finding corroborates the facilitation model of succession which suggests that succession begins when there is available space for colonization and some species for instance native species only modify the environment facilitating their replacement by other species which are physiologically and morphologically adapted to the environment culminating into a one climax community (Long & Lakela, 1971; Namuta, 1982). In the case of Kakamega forest, severe disturbance of the rainforest caused by anthropogenic activities such as selective logging for timber production and charcoal making alters the resource pools in degraded sites and reduction in canopy cover could have facilitated the establishment of *B. javanica* and its increased abundance reduces regeneration of other tree species hence reducing species diversity. Recruitment of the species in Old growth secondary forest however led to a slightly higher diversity index since its relative abundance was too low to cause a shift in Shannon Weiner diversity index. This study projects that species diversity in this vegetation type will reduce in future with the continued recruitment and maturity of the species and this is supported by recent findings which stated that long-lived pioneers of this forest were being replaced by shade tolerant species (Farwig *et al*., 2009).

The Simpson's index of evenness that was used in this study to analyze species evenness indicated that establishment of *B. javanica* in vegetation types increased overall species evenness of vegetation types. This observation was contrary to findings by other researchers for instance Althof *et al*. (2004) and Holt *et al*. (2013) which suggested that a more dominant and abundant species causes a lower index.

Earlier results of this study on recruitment pattern highlighted that *B. javanica*'s recruitment mostly occurred in DBH size class below 50cm in other vegetation types where it was present implying that the stems of the species were mostly young and were not dominating the main canopies of these forest types and hence the evenness remained high with the species. Another scenario to this observation is that disturbance occurred in the forest types leaving randomly distributed patches that were filled by the species which could have contributed to overall evenness of the forest.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study provides evidence that the species was the most abundant woody species dominating seedling, sapling and tree densities in the vegetation types of the rainforest. It was found to occur in almost all the vegetation types. The species recruited more in plantations than natural forests due to high demand of planted tree species such as *P. patula* and *C. lusitanica* which are heavily logged for timber production. This has made it easier for *B. javanica* to dominate the plantations. Natural recruitment of the species was high in lower DBH size classes of < 20 cm in the vegetation types where it occurred. Nonetheless, other species were also recruiting though not as fast as *B. javanica*. This confirms that forest succession was still ongoing in plantation and secondary forests. Establishment of this species in various vegetation types was observed to reduce species diversity which is likely to pose a great challenge on biodiversity conservation and socio- economic functions of the rainforest**.** Therefore, *B. javanica* is in its early stages of taking over natural and plantation forest stands of Kakamega rainforest.

5.2 Recommendations

The following recommendations were made in this study:

- The forest practices need to reduce the risks of invasion by *B. javanica* through minimizing canopy openings during harvesting of other tree species and other silvicultural operations in natural and plantation forests.
- The current policy of no commercial logging in Kakamega rainforest has been effective in conserving biodiversity and forest structure. More strict controls

on logging and charcoal making by the local communities are needed for forests to reduce gap formations which are taken up by the invasive species.

- Forest managers need to consider the history of exotic tree species before they are introduced in degraded sites of the rainforest.
- There's need for surveillance on the range of this species in the vegetation types. Controlling further spread of *B. javanica* in Kakamega forest may involve uprooting seedlings and saplings during firewood collection by the locals and harvesting mature stems to be used in industries since its wood is a good source of industrial softwood, pulp and paper.
- Further research is recommended on the impacts of this invasive species on the glades which exists in different vegetation types of the rainforest.

REFERENCES

Althof, A. (2005). Human Impact on Flora and vegetation of Kakamega Forest, Kenya: Structure, Distribution and Disturbance of Plant communities in an East African Rain Forest. Ph.D. Dissertation, University of Koblenz-Landau, Germany.

Althof, A., Killmann D., Solga A. & Fischer E. (2004). Influence of Natural and Anthropogenic Fragmentation on the Vegetation in Montane Rainforests of Kakamega and Mt. Kenya. *Forest Ecology Journal*, 5, 56-68.

Baker, H. G. (1986). Patterns of plant invasion in North America. *Ecological Journal of Biological Invasions,* 58, 44-57.

Binggeli, P.(1997). An Overview of Invasive Woody Plants in the Tropics. *Tropical forestEcological Journal*, 2, 250-349.

Bleher, B., Uster, D., & Bergsdorf, T.(2006). Assessment of Threat Status and Biodiversity Conservation of Tropical Forests, *Journal of Forest conservation Ecology*, 15, 1159–1177.

Buysse, W., Stern, R., & Coe, R. (2004). Genstat Discovery Edition for everyday use. *International Centre for Research in Agroforestry*, Kenya. P. 114.

Chapla, T. E. & Campos, J. B. (2010). Allelopathic Evidence in Exotic Guava (*Psidium guajava* L.) *Brazilian Biological Technology Journal*, 53, 1359-1362.

Cione, N.K., P.E. Padgett,& Allen,E. B.(2002). Restoration of a native shrub land impacted by exotic grasses, frequent fire and nitrogen deposition in southern California. *Restoration Ecology Journal*, 10, 376-384.

Dodson, E. K. & Fiedler, C. E. (2006). Impacts of restoration treatments on alien plant invasion Ecology. *Journal of Applied Ecology*, 43,887-897.

Ehrenfeld, J. (2003). Effects of Exotic Plant Invasions on Soil Nutrient Cycling Processes. *Ecosysytems*, 6, 503-523.

FAO. (2003). Global forest resources assessment (2005). Country report, Kenya. Food and Agriculture Organization of the United Nations, Rome, P.47.

FAO (Food and Agriculture Organization of United States) (2005). State of the World`s Forests. FAO, Rome, Italy.

Farwig, N., Sajita, N., & Bohning-Gaese, K. (2009). High seedling recruitment of indigenous tree species in forest plantations in Kakamega forest, Western Kenya. *Forest Ecology Journal*, 257, 143-150.

Fashing, P. J., A. Forrestel, C. Scully & M. Cords (2004). Long-term tree population dynamics and their implications for the conservation of Kakamega Forest, Kenya. *Biodiversity and conservation*, 13, 753-771.

Fischer, E., Rembold, K., Althof, A., & Obholzer, J. (2010). Annotated checklist of vascular plants of Kakamega Forest, Western province, Kenya. *Journal of East African Natural History* 99 (2): 129-226.

Gregoire,T. G., & Valentine, H. T. (2007). Sampling strategies for natural resources and the environment. Chapman and Hall, London, P.474.

Hao Zheng, Yun Wu, Jianqing Ding, Denise Binion, Weidong Fu &Richard Reardon. (2006). Invasive Plants of Asian Origin Established in the United States and Their Natural Enemies. Forest Health Enterprise Team, U.S.A, P. 320.

Hata, K., Suzuki, J. I., Kachi, N., and Yamamura, Y. (2006). A 19-Year Study of the Dynamics of an Invasive Alien Tree, Bischofia javanica, on a Subtropical Oceanic Island. *Pacific Science*, 60 (4), 455–470.

Holt, D. V., Wolf, J., Funke, J., Weisbrod, M., & Kaiser, S. (2013). Planning Impairments in Schizophrenia: Specificity, task dependence and functional relevance. Schizophr. *Restoration Journal*, 149,174-179.

Jeffrey, D., M. D. Antonio, Corbin & Carla (2012). Invasive plant Science and Management. Weed Science society of America. *Bio online Journal,* 15, 117-124.

Lockwood, J., Hoopes, M. & Marchetti, M. (2007). *Invasion ecology,* United Kingdom; Blackwell publishing Ltd: Oxford, 17, 386-391.

Long, R. W., & O. Lakela. (1971). A flora of tropical Florida. University of Miami Press, Coral Gables, Florida, 50, 730-734.

Lung, T., & Schaab (2008). Assessing fragmentation and disturbance of West Kenyan rainforest by means of remotely sensed time series data and landscape; metrics, 44, 491-508.

Kamaluddin, M.,& Grace, J. (1992). Acclimation in seedlings of a tropical tree, *Bischofia javanica*, following a stepwise reduction in light. *Annals of Botany Journal*, 69, 557–562.

Kent, M., & P. Coker. (1992). Vegetation description and analysis: a practical approach. Belhaven Press, London, P. 363.

Kiplagat, A. K., J. Mburu & D. N. Mugendi (2008). Consumption of non-timber forest products (NTFPs) in Kakamega forest, western Kenya: accessibility, role, value and to resident rural households, P. 351.

Kundu, M., Schmidt, L. H, & Jørgensen, M. J. (Eds.) (2012). *Bischofia javanica* Blume. Seed Leaflet, P. 157.

McCune, B. (2002). Analysis of ecological communities. Oregon State University, Corvallis, P. 29-55.

Mutangah, J. G. (1996). Investigation of vegetation status and process in relation to human Disturbance in Kakamega forest Western Kenya. PhD Thesis, University of Wales, UK, P.

Morton, J. F. (1976). Pestiferous spread of many ornamental and fruit species in South Florida. Proc. Florida State. *Horticultural science Journal,* 89, 348-353.

Morton, J. F. (1974). Nobody loves the Bischofia anymore. *Proceedings of Florida State Horticultural Society,* 97, 241-244.

Musila, W. M. (2007). Multi-scale Analysis of Spatial Heterogeneity of Kakamega Tropical Forest Soils; Role of Disturbance, Succession, Soil Depth, Trees and Near Infra-Red Spectroscopy. Ph.D dissertation, University of Hohenheim, Institute of Botany, Stuttgart, Germany.

Musila, W., Oesker M., Gliniars R., Todt H., Dalitz, H. (2010). Increasing resilience to climate change of Kenya Biodiversity hotspot through forest restoration. Paper presented at the18th Commonwealth Forestry Conference 28th June to 2nd July 2010 Edinburg, Scotland, United Kingdom.

Namuta, M. (1982). Experimental studies on the early stages of secondary succession on Vegetation. *Forest Ecology Journal*, 48, 141-149.

Orwa, C, A Mutua, A., Kindi R, Jamnadass R., & Simons A.(2009).*Agroforestry Database*; *tree reference selection guide and version 4.0.* World Agroforestry Centre, Kenya.

Otuoma, J., Ouma, G., Okeyo, D., Anyango, B. (2014). Species composition and stand structure of secondary and plantation forests in a Kenyan rainforest. *Journal of horticultural and forestry*, Kenya, 6, 2-11.

Otuoma, J., Anyango, B., Ouma, G., Okeyo, D., Muturi, M. G., & Oindo, B. (2016). Determinants of aboveground carbon offset additionality in plantation forests in a moist tropical forest in western Kenya. *Forest Ecology and Management Journal*, Kenya, P. 61–68.

Parrotta, J. A. (2000). Catalysing natural forest restoration on degraded tropical landscapes. Restoration Research Unit, Chiang Mai University, Thailand, P. 45–54.

Pena-Claros, M (2003). Changes in forest structure and species composition during secondary forest succession in Bolivian Amazon. *Biotropical Journal*, 35, 450-461.

Rafael, & Langeland K. A. (2008).Identification and Biology of Non-native Plants in Florida's Natural Areas. *University of Florida Journal*, P. 257.

Richardson, D. P. (2000). Naturalization and Invasion of Alien plants; Concepts and Definitions. Diversity and Distributions, 6, 93-107.

Schaab, G., Khayota, B., Eilu, G., & Wagele, W. (2010). Rainforest change over time. *The BIOTA East Africa Atlas.* Karsruhe University of Applied Sciences, Germany.

Shimizu, Y. (1988) Vegetation of Mt. Kuwanoki in the Bonin (Ogasawara) Islands with reference to the invasion of an introduced tree species *Bischofia javanica*. *Institute for Applied Geography*, Komazawa University of Tokyo, Regional Views, 1, 31–46.

Shono, K., Cadaweng, E. A., & Durst, P. B. (2007). Application of Assisted Natural Regeneration to Restore Degraded Tropical Forestlands. *Restoration Ecology. Journal*, 15, 62-626.

Tanimoto, T. & Toyoda T. (1996) Survivorship and growth of Akag (*Bischofia javanica*) seedlings under the forest canopy and different temperature conditions. *Bulletin of the Forestry and Forest Products Research Institute, Ibaraki, Japan*, 370, 1–19.

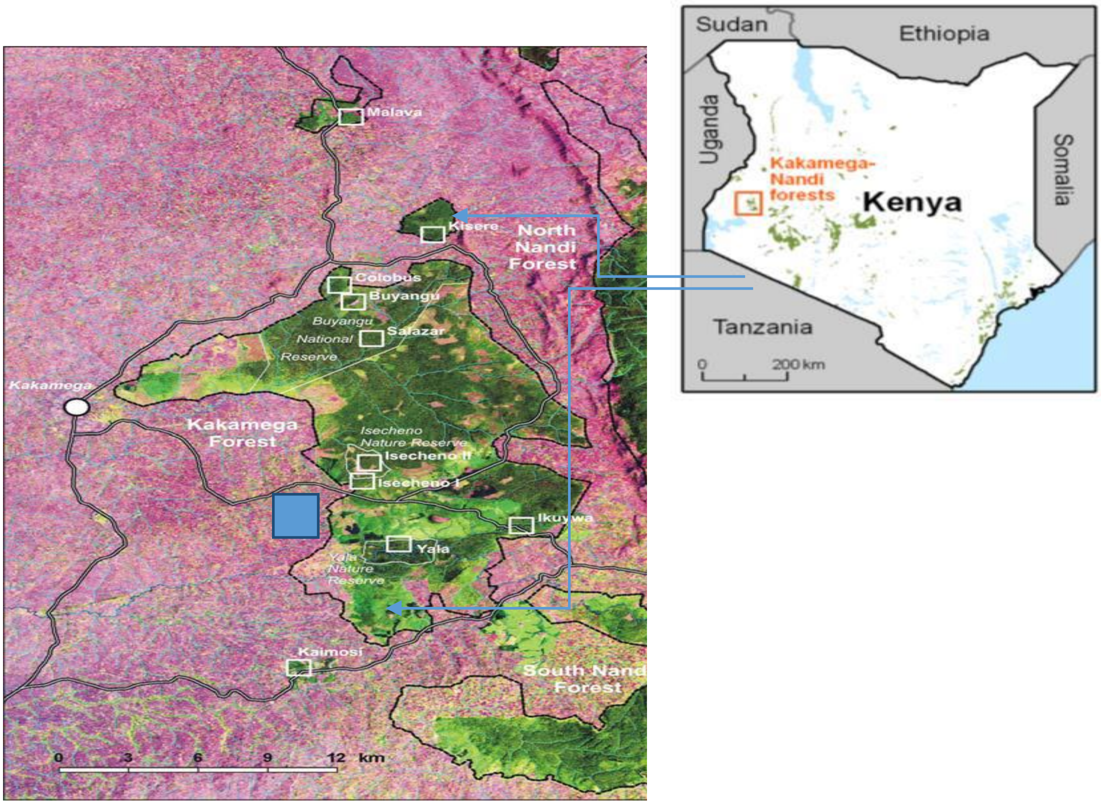
Tsingalia, M. H. (1990). Habitat disturbance, severity and patterns of abundance in Kakamega Forest, western Kenya. *African Journal of Ecology*, 28, 213-226.

Tsingalia, M. H., & Kassily, F. N. (2009). The origins of Kakamega forest grasslands: A critical review. *Journal of Human Ecology*, P. 129-135.

Vitousek, P.M. (1988). Diversity and biological invasions of Oceanic Islands. (Ed. E.O. Wilson), National Academy Press, Washington, DC, USA, P. 181–189.

Yamashita, N., Ishida A., Kushima, H.,& Tanaka, N. (2000). Acclimation to sudden increase in light favoring an invasive over native trees in subtropical islands, Japan. *Ecological J*ournal, 25,412-419.

APPENDIX I: Image of Kakamega Forest



Landsat ETM+ (7) satellite image (05 Feb 2001, spectral bands 5/4/3, contrast enhanced) of Kakamega forest, its peripheral fragments and the Nandi Forests (Picture source: BIOTA E02, Schaab et al. 2010)

APPENDIX II: Relative frequency, Relative stem density, Relative basal area and Importance Value Index of *B. javanica* in vegetation types

BLOCK	VEGETATION TYPE	Relative frequency	Relative stem density	Relative basal area	IVI
Isecheno	Bischofia javanica	100	45.45563044	72.38596451	72.61386
Isecheno	Pinus patula	100	47.99885443	10.74777216	52.91554
Isecheno	Cupressus lucitanica	100	36.66930544	8.897184818	48.52216
Isecheno	Maesopsis eminii	100	37.6570686	5.726927846	47.79467
Isecheno	Young secondary forest	100	33.29841849	3.822413456	45.70694
Isecheno	Middle Aged Secondary	100	25.39242493	2.459020516	42.61715
Isecheno	Mixed indigenous	100	17.3654267	3.670855271	40.34543
Isecheno	Old growth Secondary	100	15.89783557	2.488318721	39.46205
Kibiri	Bischofia javanica	100	46.61833885	74.19713332	73.60516
Kibiri	Pinus patula	100	50.1731708	10.21781724	53.46366
Kibiri	Cupressus lucitanica	100	36.58994761	8.442826129	48.34426
Kibiri	Maesopsis eminii	100	38.14847115	5.417838288	47.85544
Kibiri	Young secondary forest	100	35.16853933	5.333861529	46.83413
Kibiri	Middle Aged Secondary	100	28.00559414	3.132115217	43.71257
Kibiri	Mixed indigenous	100	19.11654264	3.681495709	40.93268
Kibiri	Old growth Secondary	100	16.02350333	2.516080496	39.51319
Yala	*Bischofia javanica*	100	45.76682762	71.09056746	72.2858
Yala	*Pinus patula*	100	48.91341132	11.31202998	53.40848
Yala	*Cupressus lucitanica*	100	35.3354177	10.41452674	48.58331
Yala	*Maesopsis eminii*	100	35.60999313	5.599629475	47.06987
Yala	Young secondary forest	100	33.70822444	5.12607188	46.2781
Yala	Mixed indigenous	100	20.48378949	12.2231279	44.23564
Yala	Middle Aged Secondary	100	23.59592445	4.731418871	42.77578

APPENDIX III: Seedling density of tree species in different vegetation types

Vegetation type	DBH-SIZE CLASS	TREE SPECIES	DENSITY OF STEMS/ha
Bischofia javanica	BELOW DBH (seedlings)	*Albizia gummifera*	5,003
	BELOW DBH (seedlings)	*Allophylus abyssinicus*	10,003
	BELOW DBH (seedlings)	*Antiaris toxicaria*	45,003
	BELOW DBH (seedlings)	*Bischofia javanica*	355,000
	BELOW DBH (seedlings)	*Blighia unijugata*	15,000
	BELOW DBH (seedlings)	*casipourea ruwensorensis*	5,000
	BELOW DBH (seedlings)	*Celtis gomphophylla*	35,000
	BELOW DBH (seedlings)	*Clausena anisata*	75,000
	BELOW DBH (seedlings)	*Fagaropsis angolensis*	5,000
	BELOW DBH (seedlings)	*Ficus exasperata*	5,000
	BELOW DBH (seedlings)	*Ficus sur*	5,003
	BELOW DBH (seedlings)	*Funtumia africana*	60,003
	BELOW DBH (seedlings)	*Leptacrina platyphylla*	5,003
	BELOW DBH (seedlings)	*Maesopsis eminii*	15,003
	BELOW DBH (seedlings)	*Markhamia lutea*	10,003
	BELOW DBH (seedlings)	*Olea capensis*	5,000
	BELOW DBH (seedlings)	*Oncoba spinosa*	5,000
	BELOW DBH (seedlings)	*Polysias fulva*	5,003
	BELOW DBH (seedlings)	*Prunus africana*	35,003
	BELOW DBH (seedlings)	*Psidium guajava*	15,003
	BELOW DBH (seedlings)	*Uvaropsis congensis*	10,003
	BELOW DBH (seedlings)	*vepris nobilis*	15,003
Cupressus lusitanica	BELOW DBH (seedlings)	*Antiaris toxicaria*	75,003
	BELOW DBH (seedlings)	*Bischofia javanica*	205,003

	BELOW DBH (seedlings)	*Celtis gomphophylla*	20,003
	BELOW DBH (seedlings)	*Clausena anisata*	35,003
	BELOW DBH (seedlings)	*Diospyros abyssinica*	5,003
	BELOW DBH (seedlings)	*Dombeya burgessiae*	5,003
	BELOW DBH (seedlings)	*Ficus exasperata*	55,003
	BELOW DBH (seedlings)	*Ficus sur*	25,003
	BELOW DBH (seedlings)	*Funtumia africana*	25,003
	BELOW DBH (seedlings)	*Oncoba spinosa*	5,003
	BELOW DBH (seedlings)	*Prunus africana*	40,003
	BELOW DBH (seedlings)	*Sapium elypticum*	10,003
	BELOW DBH (seedlings)	*solanum incunum*	15,003
	BELOW DBH (seedlings)	*Vitex fischeri*	5,003
	BELOW DBH (seedlings)	*Zanthoxyllum gilletii*	30,003
Disturbed primary forest	BELOW DBH (seedlings)	*Afrofomus africana*	5,003
	BELOW DBH (seedlings)	*Aningeria altisima*	25,003
	BELOW DBH (seedlings)	*Blighia unijugata*	25,003
	BELOW DBH (seedlings)	*Draceana fragrans*	120,003
	BELOW DBH (seedlings)	*Fagaropsis angolensis*	5,003
	BELOW DBH (seedlings)	*Ficus exasperata*	5,003
	BELOW DBH (seedlings)	*Funtumia africana*	55,003
	BELOW DBH (seedlings)	*Markhamia lutea*	20,003
	BELOW DBH (seedlings)	*Mimulopsis solmsii*	65,003
	BELOW DBH (seedlings)	*Prunus africana*	40,003
	BELOW DBH (seedlings)	*Trichilia emetica*	5,003
	BELOW DBH (seedlings)	*Trilepsium madagascariense*	15,003
	BELOW DBH (seedlings)	*Vangueria apiculata*	5,003
	BELOW DBH (seedlings)	*Vepris nobilis*	95,003

Maesopsis eminii plantation	BELOW DBH (seedlings)	*Aningeria abyssinica*	5,003
	BELOW DBH (seedlings)	*Aningeria altisima*	30,003
	BELOW DBH (seedlings)	*Antiaris toxicaria*	5,003
	BELOW DBH (seedlings)	*Bischofia javanica*	225,003
	BELOW DBH (seedlings)	*Blighia unijugata*	15,003
	BELOW DBH (seedlings)	*Draceana fragrans*	55,003
	BELOW DBH (seedlings)	*Ficus exasperata*	203
	BELOW DBH (seedlings)	*Funtumia africana*	50,003
	BELOW DBH (seedlings)	*Harungana madagascariense*	5,003
	BELOW DBH (seedlings)	*Maesopsis eminii*	5,003
	BELOW DBH (seedlings)	*Markhamia lutea*	5,003
	BELOW DBH (seedlings)	*Mimulopsis solmsii*	45,003
	BELOW DBH (seedlings)	*Polysias fulva*	5,003
	BELOW DBH (seedlings)	*Prunus africana*	40,003
	BELOW DBH (seedlings)	*Strombosia scheffleri*	5,003
	BELOW DBH (seedlings)	*Trichilia emetica*	5,003
	BELOW DBH (seedlings)	*Trilepsium madagasariense*	10,003
	BELOW DBH (seedlings)	*Vangueria apiculata*	5,003
	BELOW DBH (seedlings)	*vepris nobilis*	80,003
Middle aged secondary forest	BELOW DBH (seedlings)	*Aningeria abyssinica*	30,003
	BELOW DBH (seedlings)	*Aningeria altisima*	10,003
	BELOW DBH (seedlings)	*Antiaris toxicaria*	20,003
	BELOW DBH (seedlings)	*Bischofia javanica*	160,003
	BELOW DBH (seedlings)	*Blighia unijugata*	30,003
	BELOW DBH (seedlings)	*Casearia battiscombei*	5,003
	BELOW DBH (seedlings)	*Casipourea ruwensorensis*	5,003
	BELOW DBH	*Croton megalocarpus*	5,003

	(seedlings)		
	BELOW DBH (seedlings)	*Draceana fragrans*	15,003
	BELOW DBH (seedlings)	*Erythrococca bongensis*	5,003
	BELOW DBH (seedlings)	*Fagaropsis angolensis*	5,003
	BELOW DBH (seedlings)	*Ficus bubu*	5,003
	BELOW DBH (seedlings)	*Ficus exasperata*	10,003
	BELOW DBH (seedlings)	*Ficus lutea*	5,003
	BELOW DBH (seedlings)	*Funtumia africana*	50,003
	BELOW DBH (seedlings)	*Heinsenia diervilloides*	5,003
	BELOW DBH (seedlings)	*Maesopsis eminii*	10,003
	BELOW DBH (seedlings)	*Markhamia lutea*	30,003
	BELOW DBH (seedlings)	*Mimulopsis solmsii*	20,003
	BELOW DBH (seedlings)	*Olea capensis*	30,003
	BELOW DBH (seedlings)	*Polysias fulva*	5,003
	BELOW DBH (seedlings)	*Prunus africana*	30,003
	BELOW DBH (seedlings)	*Psidium guajava*	10,003
	BELOW DBH (seedlings)	*Sapium elypticum*	10,003
	BELOW DBH (seedlings)	*Shirakiopsis elliptica*	5,003
	BELOW DBH (seedlings)	*Trichilia emetica*	5,003
	BELOW DBH (seedlings)	*Trilepsium madagascariense*	25,003
	BELOW DBH (seedlings)	*Vepris nobilis*	80,003
Mixed indigenous forest	BELOW DBH (seedlings)	*Aningeria altisima*	30,003
	BELOW DBH (seedlings)	*Bischofia javanica*	95,003
	BELOW DBH (seedlings)	*Blighia unijugata*	1,503
	BELOW DBH (seedlings)	*Draceana fragrans*	60,003
	BELOW DBH (seedlings)	*Fagaropsis angolensis*	5,003
	BELOW DBH (seedlings)	*Funtumia africana*	60,003
	BELOW DBH	*Maesopsis eminii*	5,003

	(seedlings)		
	BELOW DBH (seedlings)	*Markhamia lutea*	20,003
	BELOW DBH (seedlings)	*Mimulopsis solmsii*	25,003
	BELOW DBH (seedlings)	*Olea capensis*	20,003
	BELOW DBH (seedlings)	*Polysias fulva*	10,003
	BELOW DBH (seedlings)	*Prunus africana*	55,003
	BELOW DBH (seedlings)	*Trilepsium madagascariense*	20,003
	BELOW DBH (seedlings)	*vangueria apiculata*	5,003
	BELOW DBH (seedlings)	*vepris nobilis*	110,003
	BELOW DBH (seedlings)	*Zanthoxyllum gilletii*	5,003
Old growth secondary forest	BELOW DBH (seedlings)	*Afrofomus africana*	5,003
	BELOW DBH (seedlings)	*Aningeria abyssinica*	20,003
	BELOW DBH (seedlings)	*Aningeria altisima*	15,003
	BELOW DBH (seedlings)	*Bischofia javanica*	95,003
	BELOW DBH (seedlings)	*Blighia unijugata*	40,003
	BELOW DBH (seedlings)	*Casipourea ruwensorensis*	5,003
	BELOW DBH (seedlings)	*Dovyalis macrocalyx*	10,003
	BELOW DBH (seedlings)	*Draceana fragrans*	65,003
	BELOW DBH (seedlings)	*Drypetes gerrardii*	5,003
	BELOW DBH (seedlings)	*Fagaropsis angolensis*	5,003
	BELOW DBH (seedlings)	*Funtumia africana*	75,003
	BELOW DBH (seedlings)	*Markhamia lutea*	40,003
	BELOW DBH (seedlings)	*Mimulopsis arborescens*	5,003
	BELOW DBH (seedlings)	*Mimulopsis solmsii*	35,003
	BELOW DBH (seedlings)	*Prunus africana*	40,003
	BELOW DBH (seedlings)	*Trilepsium madagascariense*	30,003
	BELOW DBH (seedlings)	*vangueria apiculata*	5,003
	BELOW DBH (seedlings)	*Vepris nobilis*	85,003

***Pinus patula* plantation forest**	BELOW DBH (seedlings)	*Antiaris toxicaria*	60,003
	BELOW DBH (seedlings)	*Bischofia javanica*	275,003
	BELOW DBH (seedlings)	*celtis africana*	20,003
	BELOW DBH (seedlings)	*Celtis gomphophylla*	15,003
	BELOW DBH (seedlings)	*Clausena anisata*	10,003
	BELOW DBH (seedlings)	*Ficus exasperata*	15,003
	BELOW DBH (seedlings)	*Ficus sur*	10,003
	BELOW DBH (seedlings)	*Funtumia africana*	70,003
	BELOW DBH (seedlings)	*Markhamia lutea*	10,003
	BELOW DBH (seedlings)	*Oncoba spinosa*	5,003
	BELOW DBH (seedlings)	*Prunus africana*	45,003
	BELOW DBH (seedlings)	*Psidium guajava*	10,003
	BELOW DBH (seedlings)	*Sapium elypticum*	5,003
	BELOW DBH (seedlings)	*solanum incunum*	5,003
	BELOW DBH (seedlings)	*Vepris nobilis*	10,003
Young secondary forest	BELOW DBH (seedlings)	*Aningeria altisima*	45,003
	BELOW DBH (seedlings)	*Antiaris toxicaria*	20,003
	BELOW DBH (seedlings)	*Bischofia javanica*	240,003
	BELOW DBH (seedlings)	*Blighia unijugata*	25,003
	BELOW DBH (seedlings)	*Casearia battiscombei*	5,003
	BELOW DBH (seedlings)	*Casipourea ruwensorensis*	5,003
	BELOW DBH (seedlings)	*Clausena anisata*	10,003
	BELOW DBH (seedlings)	*Draceana fragrans*	10,003
	BELOW DBH (seedlings)	*Erythrococca bongensis*	5,003
	BELOW DBH (seedlings)	*Fagaropsis angolensis*	15,003
	BELOW DBH (seedlings)	*Ficus exasperata*	10,003
	BELOW DBH (seedlings)	*Funtumia africana*	55,003
	BELOW DBH	*Heinsenia diervilloides*	5,003

(seedlings)		
BELOW DBH (seedlings)	*lepidotrichilia volkensii*	5,003
BELOW DBH (seedlings)	*Maesopsis eminii*	15,003
BELOW DBH (seedlings)	*Markhamia lutea*	45,003
BELOW DBH (seedlings)	*Mimulopsis solmsii*	5,003
BELOW DBH (seedlings)	*Olea capensis*	30,003
BELOW DBH (seedlings)	*Polysias fulva*	5,003
BELOW DBH (seedlings)	*Prunus africana*	30,003
BELOW DBH (seedlings)	*Psidium guajava*	10,003
BELOW DBH (seedlings)	*Sapium elypticum*	15,003
BELOW DBH (seedlings)	*Shirakiopsis elliptica*	5,003
BELOW DBH (seedlings)	*Trilepsium madagascariense*	15,003
BELOW DBH (seedlings)	*Vepris nobilis*	85,003

APPENDIX IV: Mean DBH (CM) and Height of *B. javanica* in vegetation types

BLOCK	VEGETATION TYPE	DBH (CM)	HEIGHT (M)
Isecheno	*Bischofia javanica*	51.0728	12.35697161
Isecheno	*Pinus patula*	22.18117	6.754136051
Isecheno	*Cupressus lucitanica*	15.64007	6.149841861
Isecheno	*Maesopsis eminii*	20.12213	7.076786238
Isecheno	Young secondary forest	16.85288	6.276823273
Isecheno	Middle Aged Secondary	20.17046	6.147068516
Isecheno	Mixed indigenous	20.36917	5.069196429
Isecheno	Old growth Secondary	9.28613	6.245659722
Kibiri	*Bischofia javanica*	54.88554	11.16327169
Kibiri	*Pinus patula*	21.78341	6.490656721
Kibiri	*Cupressus lucitanica*	16.73024	6.333962063
Kibiri	*Maesopsis eminii*	19.37331	6.975372761
Kibiri	Young secondary forest	17.77223	6.546098884
Kibiri	Middle Aged Secondary	23.41262	6.610117624
Kibiri	Mixed indigenous	20.36917	4.910446429
Kibiri	Old growth Secondary	6.28613	6.239409722
Yala	*Bischofia javanica*	49.41885	10.85782667
Yala	*Pinus patula*	22.09603	6.901403658
Yala	*Cupressus lucitanica*	18.78983	6.421176112
Yala	*Maesopsis eminii*	19.53501	7.392863249
Yala	Young secondary forest	18.11192	6.68734963
Yala	Mixed indigenous	16.30753	5.434007937
Yala	Middle Aged Secondary	28.83948	7.365483083
Yala	Old growth Secondary	5.50429	7.768784722

APPENDIX V: Species Diversity in vegetation types

BLOCK	VEGETATION TYPE	Count of TREE SPECIES
Isecheno	Bischofia javanica	30
Isecheno	Cupressus lucitanica	27
Isecheno	Disturbed primary	35
Isecheno	Maesopsis eminii	30
Isecheno	Middle Aged Secondary	59
Isecheno	Mixed indigenous	38
Isecheno	Old growth Secondary	37
Isecheno	Pinus patula	25
Isecheno	Young secondary forest	55
Kibiri	Bischofia javanica	29
Kibiri	Cupressus lucitanica	28
Kibiri	Disturbed primary	33
Kibiri	Maesopsis eminii	27
Kibiri	Middle Aged Secondary	59
Kibiri	Mixed indigenous	38
Kibiri	Old growth Secondary	37
Kibiri	Pinus patula	19
Kibiri	Young secondary forest	54
Yala	Bischofia javanica	29
Yala	Cupressus lucitanica	27
Yala	Disturbed primary	35
Yala	Maesopsis eminii	30
Yala	Middle Aged Secondary	59
Yala	Mixed indigenous	38
Yala	Old growth Secondary	37
Yala	Pinus patula	24
Yala	Young secondary forest	54
Grand Total		**994**