# INTERACTION OF *BISCHOFIA JAVANICA* AND ITS EFFECT ON SPECIES DIVERSITY AND STRUCTURAL COMPOSITION OF SECONDARY AND PLANTATION FORESTS IN A KENYA RAINFOREST

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*Submitted September 2017; accepted December 2017*

We studied the effects of *Bischofia javanica* on species diversity and structural composition of plantation and secondary forests in Kakamega rainforest in western Kenya. The invasive exotic tree species was introduced to the area in 1960s and planted as a pure plantation stand to assist in rehabilitating logged primary forest sites. By 1990s, the species had established in nearby secondary and plantation forest stands in which it was not planted. The study sought to determine how invasion of the exotic species had affected species diversity, species evenness and stand density in plantation and secondary forests within the rainforest. The study was carried out in nine forest types, namely: old-growth secondary forest, middle-aged secondary forest, young secondary forest, mixed indigenous plantation, *Maesopsis*, *Cupressus*, *Pinus* and *Bischofia* monoculture plantations, and disturbed primary forest. These forest types were nested as sub-blocks in three forest blocks. The results indicated that *B. javanica* was the only non-native woody species among several native woody species that recruited naturally in plantation and secondary forests. It did not grow in the disturbed primary forest. Its recruitment was significantly more aggressive than that of native species. It lowered species diversity but increased species evenness in all plantation and secondary forests. Its relative abundance was 30.6%, dominating the seedling, sapling and tree densities of plantation and secondary forests. It is necessary to remove the tree species from the rainforest before it takes over the whole forest ecosystem.

Keywords: Interactions, rainforest, species introduction, forest invasion, species diversity, stand composition

## INTRODUCTION

In the 20th century, introduction of tree species was common in forest management, particularly in the tropics (Pryde et al. 2015). Species were mainly introduced for forest restoration and timber production (Davis et al. 2012). Most of the introductions targeted exotic tree species because of their fast growth and wide ecological range (Kundu et al. 2012). However, the interactions of these exotic species with native species and their effects on their new habitats were not always monitored (Bleher et al. 2006). Thus, the ecological impacts of most introductions remain unknown several decades later in many parts of the world (Tsingalia & Kassily 2009). One of the exotic tree species that was introduced to Kenya slightly over five decades ago was *Bischofia javanica*. The species, which belongs to the Euphorbiaceae family and whose origin is considered to be tropical Asia, lower Himalayas and Pacific islands, was introduced to many parts of the world after World War II as an ornamental tree (Howard 1951, Morton 1984, Hata et al. 2006). It was a favourite among nurserymen and landscapers because of its rapid growth and dense dark green glossy foliage (Streets 1962, Morton 1984). Soon it was observed that the tree was growing too fast, commonly reaching a height of 12 to 18 m within a decade (Morton 1984, Langeland et al. 2008). In most cases, it self-propagated beyond its allotted space in home gardens or forest plantations into forest reserves by establishing in open spaces, growing to occupy the canopy and subcanopy layers thereby altering the plant community structure (Morton 1984, Hata et al. 2006, Langeland et al. 2008). This was aided by the fact that its pea-sized, berry-like, fleshy fruits were readily consumed by migrating birds which distributed its seeds over large areas, giving rise to volunteer seedlings in natural habitats (Langeland et al. 2008). Efforts were made to destroy it by cutting it down and chopping off its coppices, but the tree still exists in most places mainly because it was able to spread using its surface roots (Morton 1984).

*Bischofia javanica* was introduced to Kenya's Kakamega rainforest in the early 1960s to assist in rehabilitating forest sites that were degraded due to logging of primary forest (Tsingalia 1990). Prior to this introduction, the forest was pristine until 1923 when the discovery of gold led to logging operations to clear up some areas for gold mining (Mitchell 2004, Otuoma et al. 2014). By 1952, about 15% of the primary forest had been cleared (Schaab et al. 2010). Commercial logging intensified between 1952 and 1985, leading to further decrease in the primary forest cover by about 63% (Wass 1995, Schaab et al. 2010). Most of the logged forest sites regenerated naturally into secondary forest, but some were turned into plantation forests. The plantations comprised exotic tree species, such as *Cupressus lusitanica*, *Pinus patula*, *Eucalyptus saligna* and *Bischofia javanica*, which were established between 1952 and 1968 as monoculture plantations (Glenday 2006, Schaab et al. 2010).

*Bischofia javanica* is now dominating secondary and plantation forests of this rainforest (Otuoma et al. 2014). Although vegetation succession is active in the secondary and plantation forests, it is not clear whether the current recruitment of *B. javanica* in both sites is a temporary successional stage or a permanent invasion of the rainforest (Farwig et al. 2009). Given the adverse ecological and socioeconomic impacts that a permanent invasion by this species may have on the rainforest, it is prudent and timely to understand the interactions and effects of *B. javanica* in the rainforest since its introduction. In this paper, we present the interactions and effects of the tree species on species diversity and structural composition in secondary and plantation forests of this rainforest. Findings of the study are expected to assist forest managers and policy makers to manage the spread of this invasive species within this rainforest and elsewhere and also to develop strategies for managing future species introductions in this rainforest and other similar ecosystems.

## MATERIALS AND METHODS

### Study area

Kakamega forest is an eastern relic of the African equatorial rainforest. It is located in western Kenya between latitudes 0° 8' and 0° 22' N and longitudes of 34° 46' and 34° 57' E at an elevation of 1600 m above sea level (Farwig et al. 2009). It is about 43 km from the shores of Lake Victoria. The area experiences a hot and wet climate characterised by an average monthly rainfall of 72 mm during the dry months of December till March and 256 mm during the wet months of April till November (Mitchell 2004). The average minimum and maximum monthly temperatures range from 11 to 21 and 18 to 29 °C respectively (Althof 2005). The soils in Kakamega are classified as Acrylic Farrell Soils (FAO 2005). The forest harbours over 400 plant species of which about 112 are woody species, about 300 bird species and 7 endemic primate species (Otuoma et al. 2014). The vegetation of the forest consists of a disturbed primary forest, secondary forest in different stages of development, mixed indigenous plantation forests, and indigenous and exotic monoculture plantation forests (Tsingalia 1990). The forest supports a population of about 280,000 people who live in its surroundings and depend on it for timber, firewood, pasture, twines and vines, and indigenous fruits and vegetables (Otuoma et al. 2016).

### Study design

The study was carried out in Kibiri, Yala and Isecheno blocks of Kakamega forest. In each of these forest blocks, nine different forest vegetation types were sampled. The nine forest types were disturbed primary forest, old growth secondary forest, middle-aged secondary forest, young secondary forest, mixed indigenous plantation forest, *Maesopsis eminii* indigenous monoculture plantation, and *Bischofia javanica, Cupressus lusitanica* and *Pinus patula* exotic monoculture plantations. The study employed a nested experimental design. The nine vegetation types were treated as sub-blocks which were nested within each of the three forest blocks. The sub-blocks were delineated using forest compartments registers and existing base maps (Schaab et al. 2010). In each sub-block, assessment was done in 30 m × 20 m sample plots. The 30 m × 20 m sample plot was used to assess trees whose diameter at breast height (DBH) was ≥ 10 cm. A subplot of 10 m × 5 m was nested within the 30 m × 20 m sample plot and used to assess saplings of 0.1–9.99 cm DBH. A smaller subplot of 2 m × 1 m was nested within the 10 m × 5 m subplot and used to assess woody seedlings (NAFORMA 2010).

### Data collection

Data on woody species types and DBH were collected for saplings and trees using the stratified systematic sampling method (Gregoire & Valentine 2007) while tree seedlings were counted. Woody species were identified by their botanical names with the help of a plant taxonomist. DBH was measured in cm using diameter tape.

### Data analysis

All data were entered into Microsoft Excel computer software. Data on woody species types were used to derive woody species richness. Data on seedling counts were used to obtain woody seedling density, while data on stem DBH were used to derive sapling and tree density. Woody species diversity was calculated using Shannon–Weiner diversity index based on data on species richness and relative abundance (Pena-Claros 2003). Similarly, the data on species richness was used to determine woody species evenness using Simpson's diversity index. In order to determine the effect of *B. javanica* on species diversity, species evenness and stand composition of the nine vegetation types, woody species diversity, species evenness, seedling density, sapling density and tree density were subjected to analysis of variance (ANOVA) at 5% significance level. Means were separated using Ryan–Einot–Gabriel–Welsch multiple range test at 5% significance level (Buysse et al. 2004).

## RESULTS

### Woody species richness

The woody species richness of monoculture plantation forests increased from single tree species to between 22.7 ± 1.9 in *Pinus* monoculture plantation and 29.7 ± 0.3 in *Bischofia* monoculture plantation due to natural recruitment of woody species (Table 1). As a result of this, there was no statistically significant difference in woody species richness between plantation and old-growth secondary forests. However, relatively younger secondary forest stands, i.e. young secondary forest and middle-aged secondary forest had significantly higher woody species richness than old-growth secondary forest and plantation forests ($F_{(1, 8)} = 34.79$, $p < 0.001$). These monoculture plantations were expected to remain pure stands of single tree species established and maintained primarily for timber production. However, these results suggested that natural forest regeneration was just as active in plantation forests as it was in secondary forests. Of the natural recruits that were recorded by

**Table 1** Woody species richness in plantation and secondary forests of Kakamega rainforest in western Kenya

| Vegetation type | Species richness |
|---|---|
| *Pinus* plantation | 22.7 ± 1.9 a |
| *Cupressus* plantation | 27.3 ± 0.3 ab |
| *Maesopsis* plantation | 29.0 ± 1.0 ab |
| *Bischofia* plantation | 29.7 ± 0.3 ab |
| Old-growth secondary forest | 31.3 ± 5.7 abc |
| Disturbed primary forest | 34.3 ± 0.7 bc |
| Mixed indigenous plantation | 38.0 ± 0.0 c |
| Young secondary forest | 54.3 ± 0.3 d |
| Middle-aged secondary forest | 59.0 ± 0.0 d |
| LSD | 6.3 |
| p value | < 0.001 |

Different letters in the species richness column denote significant difference in mean species richness between vegetation types species, *B. javanica* was the only one that was not native to the rainforest. The species dominated all the canopy strata of plantations, young secondary and middle-aged secondary forests. Natural recruitment occurred from the soil seed bank, stump sprouts and newly dispersed seed. However, being a recently introduced species to this rainforest, *B. javanica* recruited mainly from newly dispersed seed from its plantation or from its trees that established earlier in other forest types. The only vegetation type in which *B. javanica* did not recruit was the disturbed primary forest.

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

The occurrence of *B. javanica* decreased the rate of recruitment of additional species in plantation and secondary forests in which it was represented. Analysis of woody species diversity when *B. javanica* stems were discounted resulted in higher Shannon–Weiner diversity index in all the plantation and secondary forests than when the stems were included (Table 2). The diversity index was higher in forest types with least number of *B. javanica* stems (i.e. old-growth secondary forest) but lower in plantations and young secondary where the abundance of the species tended to be high (Table 2).

The occurrence of *B. javanica* increased species evenness in the plantation and secondary forest stands in which it was represented. Analysis of woody species evenness when *B. javanica* stems were discounted resulted in lower Simpson's index of species evenness in all the eight vegetation types than when *B. javanica* stems were included except for the young secondary forest (Table 3).

## Contribution of *B. javanica* to density of woody seedlings

Apart from the disturbed primary forest where *B. javanica* was not represented, the species comprised a significant proportion of the woody seedling density of all plantation and secondary forests, indicating a high rate of

**Table 2** Shannon–Weiner indices illustrating species diversity with and without *Bischofia javanica* in plantation and secondary forests of Kakamega rainforest in western Kenya

| Vegetation type | Shannon–Weiner species diversity index | |
|---|---|---|
| | *B. javanica* stems included | *B. javanica* stems excluded |
| *Bischofia* plantation | 1.724 ± 0.00695 | 2.898 ± 0.02287 |
| *Cupressus* plantation | 2.275 ± 0.00165 | 2.524 ± 0.00549 |
| *Maesopsis* plantation | 2.344 ± 0.01328 | 2.603 ± 0.02305 |
| Middle-aged secondary forest | 3.206 ± 0.00889 | 3.410 ± 0.00234 |
| Mixed indigenous plantation | 3.060 ± 0.00996 | 3.079 ± 0.0033 |
| Old-growth secondary forest | 3.118 ± 0.00578 | 3.113 ± 0.00277 |
| *Pinus patula* plantation | 2.018 ± 0.02988 | 2.208 ± 0.04272 |
| Young secondary forest | 2.943 ± 0.02218 | 3.351 ± 0.00146 |

**Table 3** Simpson's indices showing species evenness with and without *Bischofia javanica* in plantation and secondary forests of Kakamega rainforest in western Kenya

| Vegetation type | Simpson's index of species evenness | |
|---|---|---|
| | *B. javanica* stems included | *B. javanica* stems excluded |
| *Bischofia* plantation | 0.4089 ± 0.000877 | 0.0730 ± 0.001742 |
| *Cupressus* plantation | 0.1848 ± 0.001004 | 0.1410 ± 0.00078 |
| *Maesopsis* plantation | 0.1723 ± 0.000952 | 0.1222 ± 0.003009 |
| Middle-aged secondary forest | 0.0718 ± 0.001370 | 0.0445 ± 0.000133 |
| Mixed indigenous plantation | 0.0622 ± 0.001778 | 0.0592 ± 0.000209 |
| Old-growth secondary forest | 0.0555 ± 0.000623 | 0.0552 ± 0.000297 |
| *Pinus patula* plantation | 0.2258 ± 0.003286 | 0.2018 ± 0.004052 |
| Young secondary forest | 0.1162 ± 0.004674 | 0.4850 ± 0.000472 |

natural recruitment (Table 4). Analysis of the representation of *B. javanica* as a proportion of the overall woody seedling density indicated that its contribution to seedling density of the rest of the plantation and secondary forests ranged between 15.9% in old-growth secondary forest and 49.7% in *Pinus* plantation (Table 4). *Bischofia javanica* had the highest seedling density in all the plantation and secondary forests of this rainforest.

## Contribution of *B. javanica* to sapling density

*Bischofia javanica* saplings comprised a significant proportion of the sapling density of all plantation and secondary forests, except in the mixed indigenous plantation (Table 5). The contribution of the species saplings, as a proportion of the overall sapling density, in different vegetation types ranged between 8.5% in old-growth secondary forest and 39.7% in its plantation (Table 5). In secondary forest stands, density of *B. javanica* saplings decreased with increase in stand age.

## Contribution of *B. javanica* to tree density

*Bischofia javanica* trees comprised a significant proportion of the stem density of the plantation and secondary forests, except that of mixed indigenous plantation (Table 6). Most of the plantation and secondary forests had tree stems > 100 cm DBH, but *B. javanica* stems were only represented in the 10–50 cm DBH range. This suggested that natural recruitment of *B. javanica* in these vegetation types began after the other species had established. Nonetheless, the fact that *B. javanica* had stems of up to 50 cm DBH in these plantation and secondary forests indicated that the natural recruitment of this species in this rainforest began well over two decades ago.

**Table 4** Contribution of *Bischofia javanica* to the woody seedling density of different plantation and secondary forests in Kakamega rainforest in western Kenya

| Vegetation type | Density of woody seedlings | | Proportion of *B. javanica* seedlings (%) | p value |
|---|---|---|---|---|
| | *B. javanica* included | *B. javanica* excluded | | |
| *Pinus* plantation | 71,250 ± 625 | 35,833 ± 208 | 49.7 | < 0.001 |
| *Bischofia* plantation | 100,000 ± 2828 | 53,958 ± 1160 | 46.0 | 0.001 |
| *Maesopsis* plantation | 75,017 ± 361 | 47,100 ± 838 | 37.2 | < 0.001 |
| Young secondary forest | 81,558 ± 5769 | 53,608 ± 3795 | 34.3 | 0.005 |
| *Cupressus* plantation | 72,292 ± 1627 | 46,042 ± 1160 | 36.3 | < 0.001 |
| Middle-aged secondary forest | 76,250 ± 2526 | 56,458 ± 1102 | 26.0 | 0.007 |
| Mixed indigenous plantation forest | 63,967 ± 3533 | 52,092 ± 2930 | 18.6 | 0.004 |
| Old-growth secondary forest | 68,200 ± 3992 | 57,367 ± 2951 | 15.9 | 0.009 |
| Disturbed primary forest | 59,608 ± 1722 | 59,608 ± 1722 | 0 | 1.000 |

**Table 5** Contribution of *Bischofia javanica* to sapling density of different plantation and secondary forests in Kakamega rainforest in western Kenya

| Vegetation type | Sapling density (0.1–9.99 cm DBH) | | Proportion of *B. javanica* stems (%) | p value |
|---|---|---|---|---|
| | *B. javanica* included | *B. javanica* excluded | | |
| *Bischofia* plantation | 5333 ± 158.3 | 3217 ± 96.1 | 39.7 | 0.001 |
| *Pinus* plantation | 3483 ± 8.3 | 2192 ± 16.7 | 37.1 | < 0.001 |
| *Maesopsis* plantation | 3458 ± 8.3 | 2217 ± 33.3 | 35.9 | < 0.001 |
| *Cupressus* plantation | 3158 ± 109.3 | 2100 ± 112.7 | 33.5 | < 0.001 |
| Young secondary forest | 3600 ± 25.0 | 2517 ± 72.6 | 30.1 | 0.002 |
| Middle aged secondary forest | 3608 ± 144.6 | 2808 ± 115.8 | 22.2 | 0.001 |
| Mixed indigenous plantation | 6442 ± 2891.7 | 5082 ± 2,031.9 | 21.1 | 0.255 |
| Old growth secondary forest | 3633 ± 8.3 | 3325 ± 62.9 | 8.5 | 0.034 |

DBH = diameter at breast height

**Table 6** Contribution of *Bischofia javanica* to the tree density of different plantation and secondary forests in Kakamega rainforest in western Kenya

| Vegetation type | Tree density (10.0–> 100 cm DBH) | | Proportion of *B. javanica* stems (%) | p value |
|---|---|---|---|---|
| | *B. javanica* included | *B. javanica* excluded | | |
| *Bischofia* plantation | 518.4 ± 9.8 | 29.2 ± 4.2 | 94.4 | < 0.001 |
| *Pinus* plantation | 418.5 ± 4.4 | 317.7 ± 5.4 | 24.1 | < 0.001 |
| *Maesopsis* plantation | 425.1 ± 1.0 | 319.2 ± 1.7 | 24.9 | < 0.001 |
| *Cupressus* plantation | 435.6 ± 17 | 295.2 ± 14.6 | 32.2 | 0.002 |
| Young secondary forest | 475.6 ± 6.7 | 368.5 ± 10.9 | 22.5 | 0.001 |
| Middle aged secondary forest | 448.9 ± 5.5 | 392.4 ± 8.3 | 12.6 | 0.005 |
| Mixed indigenous plantation | 609.2 ± 208.1 | 379.3 ± 0.7 | 37.7 | 0.331 |
| Old growth secondary forest | 447.5 ± 1.3 | 414.4 ± 0.9 | 7.4 | < 0.001 |

DBH = diameter at breast height

## DISCUSSION

### Natural recruitment in plantation forests

Natural recruitment of native species in plantation forests is common in most humid tropical forests (Farwig et al. 2009). The recruits often arise from the soil seed bank, live stumps or seed dispersed from nearby mature trees (Mladenoff 1990, Shono et al. 2007). In plantations, recruits increase the woody species richness beyond what was originally planted. In most cases, however, the recruits comprise native tree species from the nearby natural forest and not exotic species. This is because native species have a competitive edge over exotics in their natural range (Parrotta et al. 1997, Pawson et al. 2010). In Kakamega rainforest, *B. javanica*, an exotic species that was introduced only just over five decades ago, had recruited alongside native species and ended up being the tree species with the highest relative abundance and this has raised ecological concerns. Its relative abundance was far greater than that of the three most abundant long-lived native tree species combined, which suggested that the exotic species had high growth vigour and ability to outcompete native tree species.

Results in this study indicated that *B. javanica* was not found in any of the disturbed primary forest stands. The species was perhaps unable to establish in the primary forest due to unavailability of canopy gaps. Similarly, its relative abundance was much lower in old-growth secondary forest stands (10.6%), which had relatively fewer canopy gaps than younger secondary forest stands and plantation forests. The recruitment *B. javanica* was thus opportunistic and depended on the existence of large canopy gaps. According to Farwig et al. (2009), logging operations in old-growth secondary forest at an early stage when the stands were younger created adequate canopy gaps which might have allowed the establishment of this invasive species. However, this argument can only be true if we assumed that the seedlings and saplings of the *B. javanica* that recruited in the old-growth secondary forest were only from mature trees that were already established in this forest type. It is also possible that the old-growth secondary forest still had a few canopy gaps that supported the establishment of the exotic species. A relative abundance of 30.6% of all woody stems in the rainforest over a period of five decades raised questions regarding the silvicultural management of plantation and secondary forest stands in this rainforest.

### Silvicultural management of forest stands in Kakamega rainforest

The results of this study indicated that monoculture plantations of this rainforest were not of pure stands as they were intended to be. With the lowest species richness at 22.7 ± 1.9, all the plantation forests have become mixed species stands. Since most recruits were native woody species, the plantations were likely to look more like secondary forests than plantation forests. For many decades establishment of forest plantation in Kenya had been carried out under non-resident cultivation (Kagombe & Gitonga 2005). This system relies on allocating recently established plantation forests to forest adjoining households to grow crops as they maintain the planted trees for the first two to three years (KEFRI 2004). After about three years, the trees began to swamp crops and farmers abandoned such plantations for newly established ones. Apart from one or two pruning or thinning operations between the time farmers abandoned the plantations and the time the trees mature in 25 to 30 years, the plantations did not receive much silvicultural attention. Natural recruitment of native woody species began in the plantations immediately after farmers stopped silvicultural practices (such as weeding) and continued until the trees mature. Given the aggressive recruitment nature of *B. javanica*, the species was able to recruit and grow very quickly in these plantations after the farmers abandoned them, establishing many individuals in a short period of time. Thus, by the time the native species established, *B. javanica* already had significantly higher relative abundance.

On the other hand, secondary forests of this rainforest were established following the clear-felling of primary forests or old-growth secondary forests (Otuoma et al. 2016). Secondary forests that developed from such clear-felled sites were never subjected to any silvicultural operations. The absence of silvicultural management gave *B. javanica* a head start over native species in recruitment and growth in the exposed forest floor. Native species go through the conventional stages of secondary forest succession, while *B. javanica*, together with pioneer native species survive all the successional changes leading to significantly higher relative abundance for the species.

## Managing existing *B. javanica* seedlings, saplings and trees in the rainforest

In Kakamega rainforest, close to a third of all the seedlings, sapling and stems in plantation and secondary forests belong to *B. javanica*, and therefore managing its population is likely to present a great challenge. On the other hand, if the exotic species is not managed, it is likely to cause an ecological catastrophe because it will continue to recruit. The invasion of *B. javanica* on the native forest ecosystems is, however, not unique to Kenya. This species has been reported to invade subtropical forests in oceanic islands in the far east and also in western Pacific (Hata et al. 2006). *Bischofia javanica* was introduced to these islands either as a timber species or an ornamental species, but it later became a threat to native forest ecosystems (Tanimoto & Toyoda 1996). In Ogasawara Island, Japan, managing *B. javanica* has become a big challenge because stumps regrow rapidly after cutting, resulting in more stems of the species (Yamashita et al. 2000). This compelled the forestry agency of Japan to develop strategies for its control (Kundu et al. 2012).

An effective way to manage *B. javanica* is to remove its seedlings, saplings and stems. This approach, however, presents two challenges. First, the cost of removing *B. javanica* in the whole forest is likely to be enormous. Second, it is one of those species that coppice and will certainly regenerate from stump sprouts. Moreover, it can also sprout from its surface roots (Morton 1984, Hata et al. 2006). The species has never been harvested for timber since its introduction, but its wood can provide industrial softwood and pulp and paper, which can offset some of the costs associated with removing it from this rainforest. Forest adjoining households who collect dead wood from the forest to use as firewood, can be allowed to harvest *B. javanica* for firewood and timber. Its seedlings and saplings can be easily uprooted during firewood collection. However, appropriate measures would be necessary to ensure that its stumps do not coppice when the trees are felled. This may entail chopping off its stump sprouts repeatedly to kill them (Kamondo et al. 2014). Extreme caution would be necessary to ensure that the removal of the stems causes as little damage as possible to other woody species in the plantations and secondary forests in which *B. javanica* occurs.

## Managing future species introductions

Over the past two decades, Kenya has put in place legislation and policies to guide the importation of any biological material into the country. For instance, the Kenya Plant Health Inspectorate Service has been established to ensure that all plant materials are thoroughly vetted before being allowed into the country (KEPHIS 2017). Working within these guidelines, it is essential for forest managers and policy makers to monitor species introductions over several decades, even for those species that appear largely harmless, in order to ensure that they do not become invasive, parasitic or distort the ecological balance over time. Some of the key attributes that make *B. javanica* and some other exotic species invasive, which should be considered when screening tree species in future introductions, include rapid growth, the ability to tolerate shade, having a short juvenile period, self-pollination, early onset and consistent production of seed, small seed size, large number of seeds in each flowering phase, good seed viability, seed dispersal by frugivores and high seed germination rate (Kolar & Lodge 2001).

## CONCLUSIONS

*Bischofia javanica* is in its early stages of taking over natural and plantation forest stands in Kakamega rainforest due to its high rate of dispersal and dense growth. The situation exemplifies the impact of poor introductions of exotic tree species to forests in foreign lands. Although measures are currently in place to check new introductions, controlling the spread of *B. javanica* in areas where it has already established remains a major challenge, particularly in resource-poor developing countries. The situation calls for measures to monitor the growth behaviour of new introductions for a few decades in order to ensure that they are indeed harmless to their new environments.

## ACKNOWLEDGEMENTS

We thank the Kenya Forest Service and Kenya Wildlife Service for granting us permission to the study site. We thank Mbogani J from the forest adjoining community for helping with local names of plant species.

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