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Invasive *Acacia melanoxylon* Impedes Growth of Commercial Tree Species in the Adjoining Forest Stands in Nabkoi and Timboroa Forest (Kenya)

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Abstract Alien species invasion of the forest ecosystem may lead to structuring of the plant community structure. Invasive *Acacia* is one of the alien tree species in forests. The ecological relationship between *Acacia melanoxylon* invasion and forest ecology is not well understood in tropical humid forest ecosystems. Therefore, the main objective of this study was to determine the influence of *A. melanoxylon* on two commercial forest tree species (*Cupressus lusitanica* and *Pinus patula*) in a humid tropical forest (North Tinderet Forest, in Kenya). Transects measuring 500 m long were used for sampling the uninvaded and invaded sites. Along the transect, three 10 m × 10 m plots were systematically placed at 235 m intervals to enable counting and recording of trees (density), measuring diameter at breast height (DBH) ≥ 1.3 m) as well as tree heights. The study established that the tree density, DBH and height of *Pinus patula* and *Cupressus lusitanica*, were significantly ($P < 0.05$) higher at the non-invaded sites compared to the invaded sites. These findings suggest that *A. melanoxylon* invasion reduced the growths and establishment of commercial tree species. It is thus recommended that future studies on ecological conditions for growth of *A. melanoxylon* should be conducted in controlled environment through growth response measurements which was not possible under the current study. Invasion by *A. melanoxylon* reduce the growth of commercial plantation tree species (*Pinus patula* and *Cupressus lusitanica*) therefore strategies for controlling growth of the *A. melanoxylon* should be done. Future studies should investigate how the nutrient uptake by the commercial plantation tree species is influenced by *Acacia melanoxylon* density.

Keywords: *ecological conditions, acacia, growth, invasiveness, tropical environment, forest growth*

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1. Introduction

There are a number of invasive plant species which have been translocated into new environments, where they have survived, propagated and eventually dominated the alien landscapes [1,2]. In some instances, there are accidental introductions of species that tend to be invasive [3]. Invasive species belonging to the genus *Acacia* are widespread in the global biomes except in the Arctic and Antarctic regions [4,5,6]. The number of acacia species appearing outside their natural range and currently considered invasive are about 22-25 species [7,8].The genus occurs across a wide range of ecosystems, from arid and semi deserts, afro-montane forests, savannah grassland and in plantation forests [9]. In the case of *Acacia melanoxylon*, it occurs, and can grow and survive in almost all the continents in countries such as Europe [10], Oceania [10,11,12], Africa [13,14], South America [15], and Asia [16]. In their new locations, *A. melanoxylon* establish rapidly, grow and dominate the surrounding environments [17,18].

A key aspect of the invasive biology of the *A. melanoxylon* is the knowledge of their impacts on the native tree species. Such impacts can be multidirectional as woody alien species can increase or decrease the ecological features of the native tree species [19,20,21]. The proliferation of *A. melanoxylon* as an invasive species may alter the trophic structures, and change the plant density, composition, biomass and growth of trees [22,23] The structuring effects of invasive species result into partial displacement or complete replacement of the native plant species with the invader [19,24]. In a forest, the *A. melanoxylon* has history of affecting growth and proliferation of the trees in adjoining forest stand [23,24] Limited studies of *A. melanoxylon* on forest growth [25,26], reveal four mechanisms of invasion such as prolific seeding, fast reproduction; high survival ability, and speedy regeneration [27,28]. These mechanisms allow for the invasive *A. melanoxylon* to overwhelm other vegetation establishment and outcompete other forest vegetation in nutrient [29]. Information on the influence of these acacia species may be influenced by the type of species invading, habitat conditions, types of trees invaded as well as the environmental conditions [30,31,32,33]

There is an increasing proliferation of invasive species in the plantation forests in Kenya [34], which may create a challenge associated with such invasion. There is a tendency of the invasive *A. melanoxylon* to affect tree growth, native vegetation establishment and soil quality. Despite this, there are no meaningful studies conducted in Kenya's plantation forest ecosystems to determine the response of trees, vegetation and soils to *A. melanoxylon* invasion. Therefore, this study aims to determine the influence of *A. melanoxylon* on two commercial forest tree species (*Cupressus lusitanica* and *Pinus patula*) in the North Tinderet Forest, North Rift in Kenya. We hypothesize that commercial timber tree species, *C. lusitanica* and *P. patula* within the proximity of invasive species such as *A. melanoxylon* will manifest in reduced growth or decline productive potential assuming all other factors remain constant for a given site.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Nabkoi and Timboroa forests situated within the North Tinderet Forest in Uasin Gishu County (Kenya) (Figure 1). It covers a total area of 3,345.2 km² with a population of 1,163,000 according to the 2019 Kenya National Housing and Demographic Survey Census [35]. The areas occur within longitude 34º50'E to 35º37'E and latitudes 0º03'S to 0º 55'N.

The climate of the area is typically tropical rainforest. The altitude range between 2600 to 2950 m asl however, Timboroa Forest ((2913 m asl) is at higher altitude compared to Nabkoi Forest ((2634 m asl). Annual rainfall range between 1,328 to 1,405 mm. The cyclic pattern of rainfall is long rainy season between March to June, dry season between July and September, short rainy season from October to November, followed by another dry season from December to February. Temperatures range from a minimum of 7ºC (June–August) to a maximum of 29ºC. The two study sites have exotic plantation species, mostly dominated by *Cupressus lusitanica* (Timboroa) and *Pinus patula* (Nabkoi). Within the mosaic of indigenous vegetation and the above commercial timber tree species is *Acacia melanoxylon* which appears to be spreading in the area including within cypress and pine plantations.

Geology is mainly composed of basalt rock boulders of pre-Cambrian formations. There are two main soil types: Soils of the plateaus (Ferralsols) - deep red well-drained soils – red and brown loam as well as the soils of the bottomlands (gleysols) - poorly drained soils - red and brown clay. The topsoil layer is mainly red loam soils rich in organic matter hence susceptible to erosion but suitable for agricultural activities and tree growing.

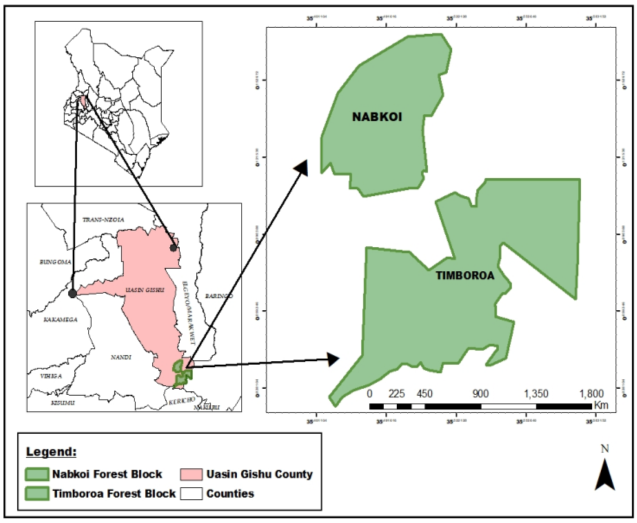

Figure 1. North Rift region of Kenya–Tinderet forest formation and the two selected study forest sites of Nabkoi and Timboroa, Uasin Gishu County

2.2. Selection of Sampling Sites

Field sites were selected based on altitude, slope, and aspect. The study area was divided into two specific study sites from which data was collected. Nabkoi (2634 m asl) and Timboroa (2913 m asl) were chosen to represent the species of interest because of their difference in altitude and proximity (3-4 km apart) within the same forest formation of the study area. For each of the two study sites (Nabkoi and Timboroa) (i) distinct stands *Acacia melanoxylon*, largely taken over natural vegetation, and (ii) stands for each of the two species of interest, *Cupressus lusitanica* and *Pinus patula* were appropriately identified and selected. The uninvaded and invaded stands of each species were compared, at the two sites. In summary, Nabkoi (*Acacia melanoxylon* stands, *Cupressus lusitanica* invaded and uninvaded stands;

Pinus patula invaded and uninvaded stands and the same process repeated in Timboroa).

2.3. Forest Sampling

The fieldwork was carried out from January 2022 to February 2023 covering both dry and rainy seasons. A reconnaissance survey was done in November to December 2021 preceding the fieldwork to identify forest sites to be assessed. The method of systematic sampling was used to select sampling units. In the selected stands, three line transects were established taking into account slope orientation to capture horizontal and vertical variation. On each transect, a 10 m × 10 m plots were established located at 235 m intervals from which measurements were taken (Figure 2). From each of the nine sample plots, assessments of trees were done.

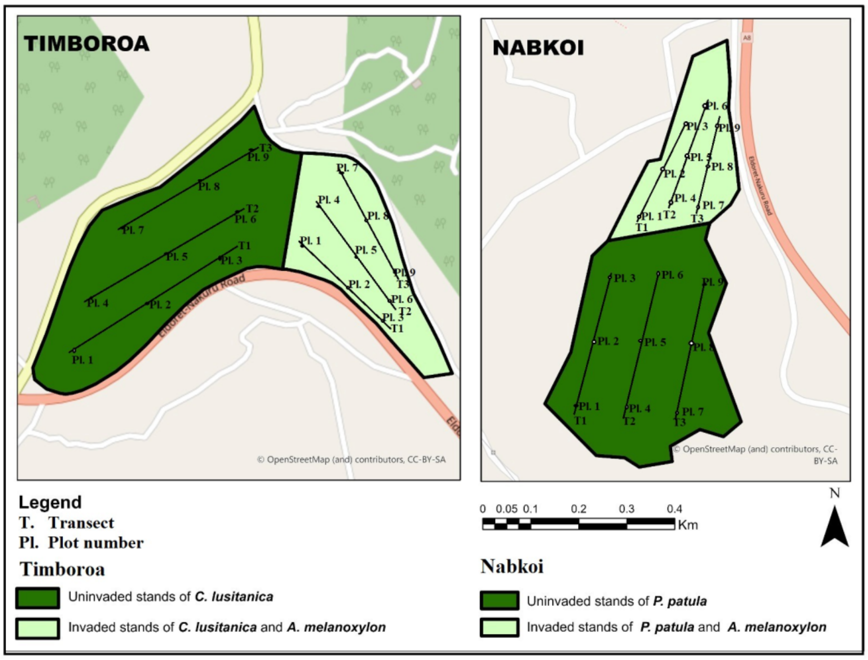

Figure 2. Typical laying-out of line transects in adjacent stands for *Cupressus lusitanica* and *Pinus patula* uninvaded (dark green) and invaded (light green) in the Nabkoi and Timboroa study sites

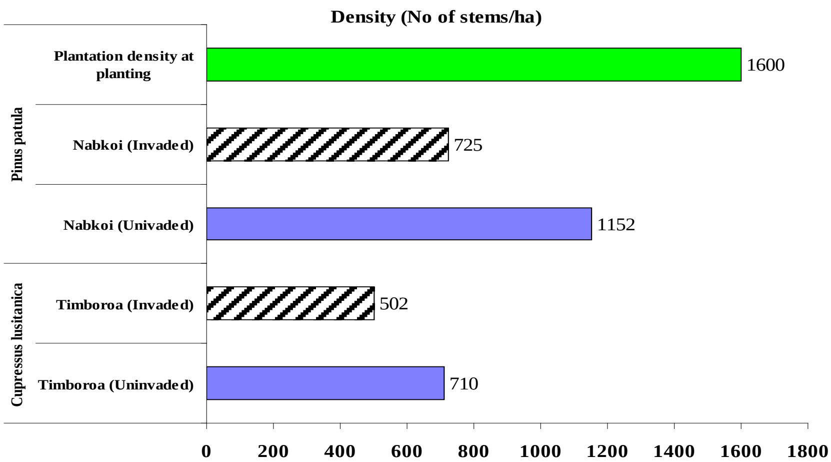

Figure 3. Stand density for *Pinus patula* and *Cupressus lusitanica* stands (Uninvaded and invaded) in Timboroa and Nabkoi study sites

2.4. Field Measurements

2.4.1. Tree Measurements

Every tree in the sample plot (10 × 10 m) had its Diameter at breast height (DBH) measured, i.e., at 1.3 meters above the ground using a diameter tape, taking the necessary precautions not to slant, or loosen the tape and measurements recorded in specially designed data collection forms labelled to indicate site, species (invaded or uninvaded) and plot number. Tree heights were also measured using a Suunto clinometer (by selecting one of the scales on the instruments at 1:15 or 1:20) and measurements appropriately recorded

2.5. Data Analysis

Data collected subjected to statistical analysis using STATISTICA 8.0 [36] and SPSS 23.0 Statistical Packages [37]. In addition, descriptive statistics was used, mean tree dbh, height, diameter size distribution and, plot densities (on a per hectare basis) were used to depict general trends. Densities of shrubs and lianas, and herbaceous plants at the plot level were expressed as the number of individual plants per square metre. The spatial variation in plant density, DBH and height were analyzed using One-way ANOVA and post discrimination of significantly different means done using Duncan's Multiple Range Test (DMRT).

3. Results

3.1. Stand Density

Stand densities for *C. lusitanica* and *P. patula* invaded and those not-invaded (uninvaded) by *A. melanoxylon* are represented in Figure 3). Plantation density for these two species at planting is usually 1600 stems/ha. For both species invaded stands had lower densities than uninvanded ones regardless of the site. Whereas *Pinus patula* performed better in the higher altitude of Timboroa (showing relatively higher levels), the converse was true for *Cupressuss lusitanica*. Stands of *C. lusitanica* had comparatively higher densities in Nabkoi than in Timboroa.

3.2. Average Tree Diameters (Within Plots) for Uninvaded and Invaded Stands

The average tree diameter at the plot level was clearly higher for uninvaded stands than for those invaded by *A. melanoxylon* (Figure 4). Average plot diameters for uninvaded stands of *C. lusitanica* at the uninvaded were 20-30 cm while at the invaded average tree diameters at the invaded stands were 10-12 cm in Nabkoi. In Timboroa, the species plot diameters for the uninvaded stand stood at 30 to 40cm, while plot diameters at the invaded stand were comparable ranging from 25 to 35cm (suppression growth level much less than in Nabkoi). The overall, *C. lusitanica* plot diameters were significantly higher at the uninvaded stands than in invaded ones for both Nabkoi and Timboroa forest sites ($F_{(1, 76)} = 14.411$, df = 1, $P = 0.0002$).

Pinus patula stands followed more or less the same pattern (Figure 5). In Nabkoi uninvaded stand plot diameters were from 20 to 30 cm, while in the invaded stand, they were at a lower level while corresponding to 10-12 cm invaded site. In Timboroa, the uninvaded stand plot diameters ranged from 35 to 45 cm while in invaded were again at a lower level of 25 to 35cm. Similar to *C. lusitanica*, plot diameters for *P. patula*, in uninvaded stands for Nabkoi and Timboroa are significantly higher than invaded ones ($F_{(2, 76)} = 15.412$, $P = 0.0002$).

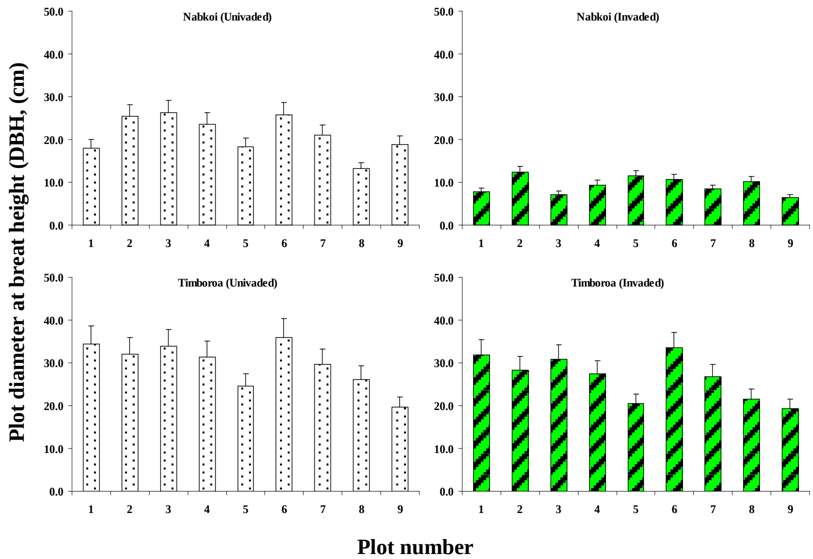

Figure 4. The average tree diameter (within sample plots) levels for *Cupressus lusitanica* for uninvaded and invaded in Nabkoi and Timboroa Forest stands

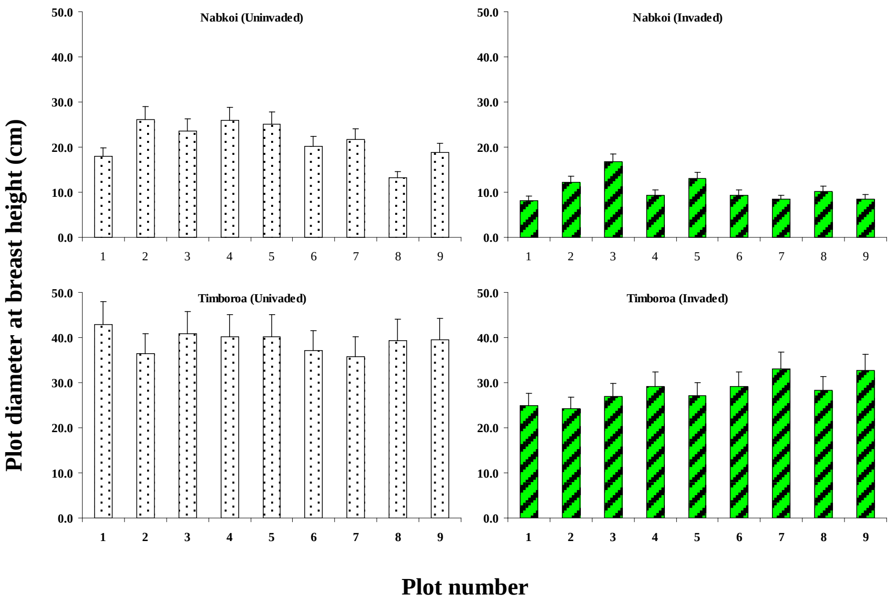

Figure 5. The average tree diameters (within plots) of *Pinus patula* for the uninvaded and invaded forest stands in Nabkoi and Timboroa study sites

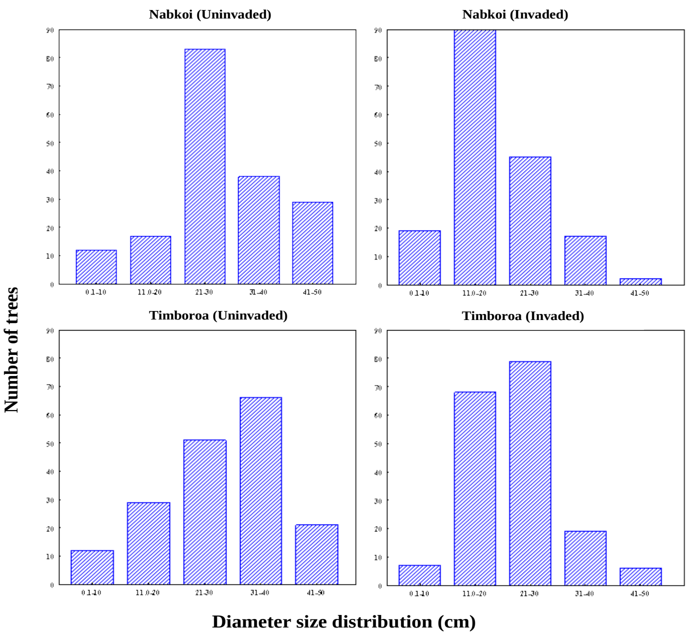

Figure 6. The diameter size structure (distribution) of *Cupressus lusitanica* at uninvaded and invaded sites

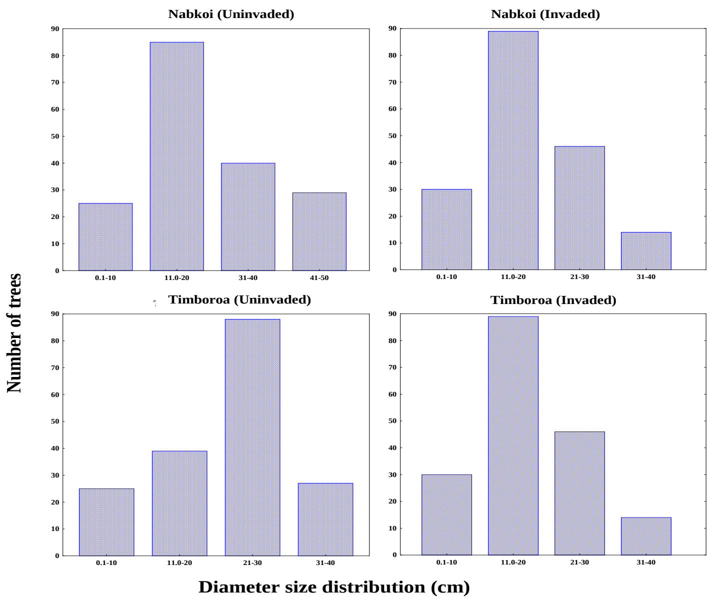

Figure 7. The diameter size structure (distribution) of *Pinus patula* at the uninvaded and invaded stands

3.3. Tree Diameter Size Distribution of Uninvaded and Invaded Stands

Tree diameter size-frequency distributions for two species and study sites are depicted in Figure 6. Most *C. lusitanica* trees in the Nabkoi uninvaded stand were recorded in diameter class 21-30 cm while trees in the invaded stand were considerably much smaller within the diameter class of 11-20 cm. In Timboroa on the other hand, the majority of *C. lusitanica* trees in the uninvaded stand were found within diameter class 31 to 40 cm, and in invaded 21 to 30 cm. It was evident for *C. lusitanica* Timboroa had larger trees than in Nabkoi for in the uninvaded and invaded stands correspondingly.

The diameter class distribution of *P. patula* at the uninvaded and invaded sites is shown in Figure 7. The distribution of most *P. patula* at the Nabkoi uninvaded and invaded site was 11-20 cm. On the other hand, the majority of the *P. patula* at Timboroa uninvaded forest site aggregated towards 31 to 40 cm while at the invaded sites the aggregation was towards 21 to 30 cm.

The relationship between diameter size distribution and the density of *Acacia melanoxylon* is shown in Figure 8. There was a significant negative correlation between the diameter sizes of the timber species in relation to *Acacia melanoxylon* density at all the forest sampling sites. As the density of *A. melanoxylon* increased, the average tree size of the plantation species decreased.

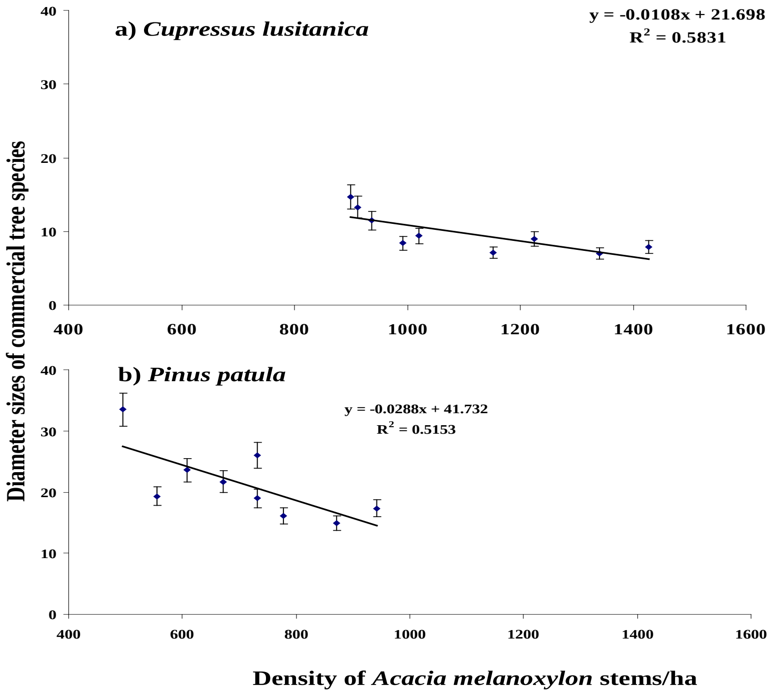

Figure 8. The relationship between the diameter size of *Cupressus lusitanica* and *Pinus patula* with respect to the density of *Acacia melanoxylon* at invaded stands

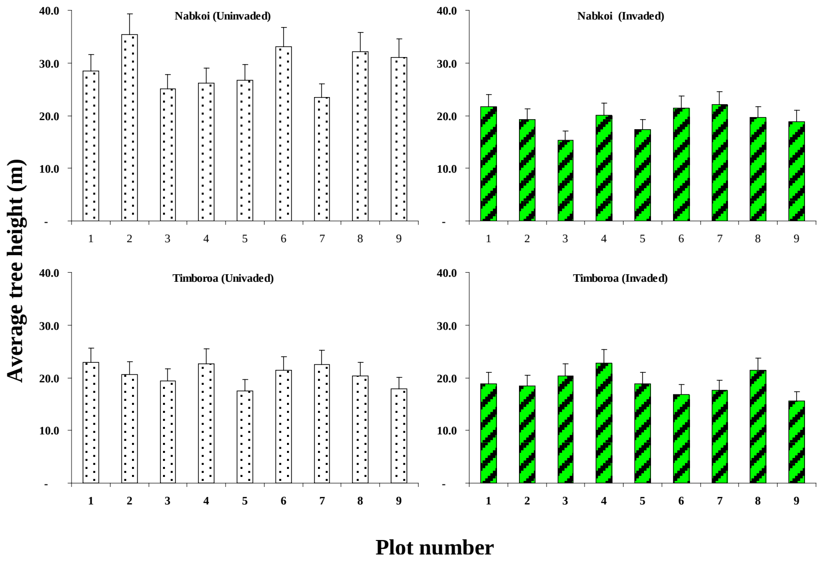

Figure 9. The average tree heights (within plots) profiles for *Cupressus lusitanica* at the uninvaded and invaded stands in Nabkoi and Timboroa study sites

3.4. Tree Height Distributions of *Cupressus Lusitanica* and *Pinus Patula*

The tree plot height of *C. lusitanica* of uninvaded and invaded by *A. melanoxylon* is provided in Figure 9. The average height of *C. lusitanica* at the uninvaded sites in Nabkoi aggregated towards 28 to 35 m in uninvaded sites while at the invaded site it was 18 to 24 m. In Timboroa, the uninvaded sites had tree heights aggregated at 20 to 25 m while at the invaded sites most of the tree species aggregated at 18 to 21 cm. The height of *C. lusitanica*, at the uninvaded sites, was significantly higher than at invaded stands ($F_{(2, 76)} = 4.143$, $P = 0.0012$).

The tree plot height of *P. patula* at the four forest stands (uninvaded and invaded) is provided in Figure 10. The average height of *P. patula* at the uninvaded sites in Nabkoi aggregated towards 12 to 18 m, while at the invaded site it was 15 to 22 m. In Timboroa, uninvaded and invaded sites had tree heights within 20 to 25 m. The height of *P. patula*, at the invaded sites, was significantly higher ($F = 4.112$, $P = 0.0042$ in Nabkoi but no differences in height occurred in Timboroa. Invasion could trigger competition for light increasing height growth.

The relationship between the height size distribution of commercial tree species and the density of *A. melanoxylon* at invaded sites is shown in Figure 11. There was a significant negative correlation between the heights of commercial tree species with *A. melanoxylon* density at all the forest sampling sites.

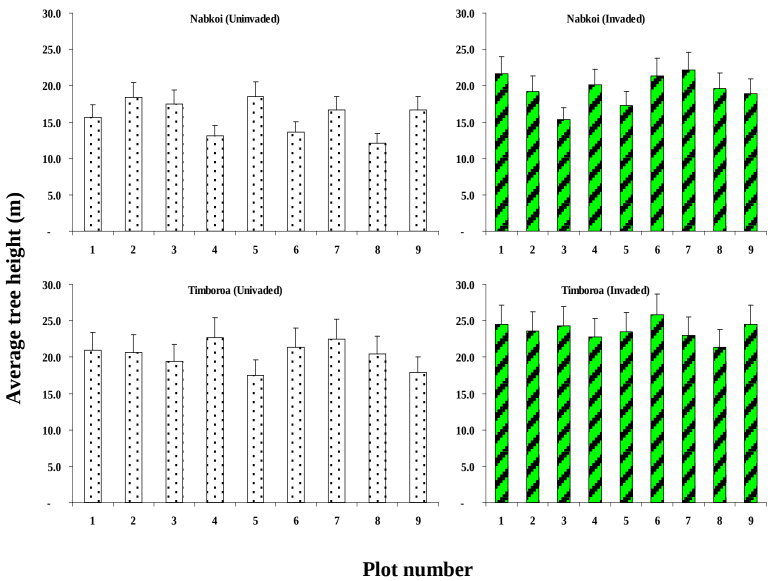

Figure 10. Average tree heights (within plots) profiles of *Pinus patula* in the uninvaded and invaded stands in Nabkoi and Timboroa forest sites

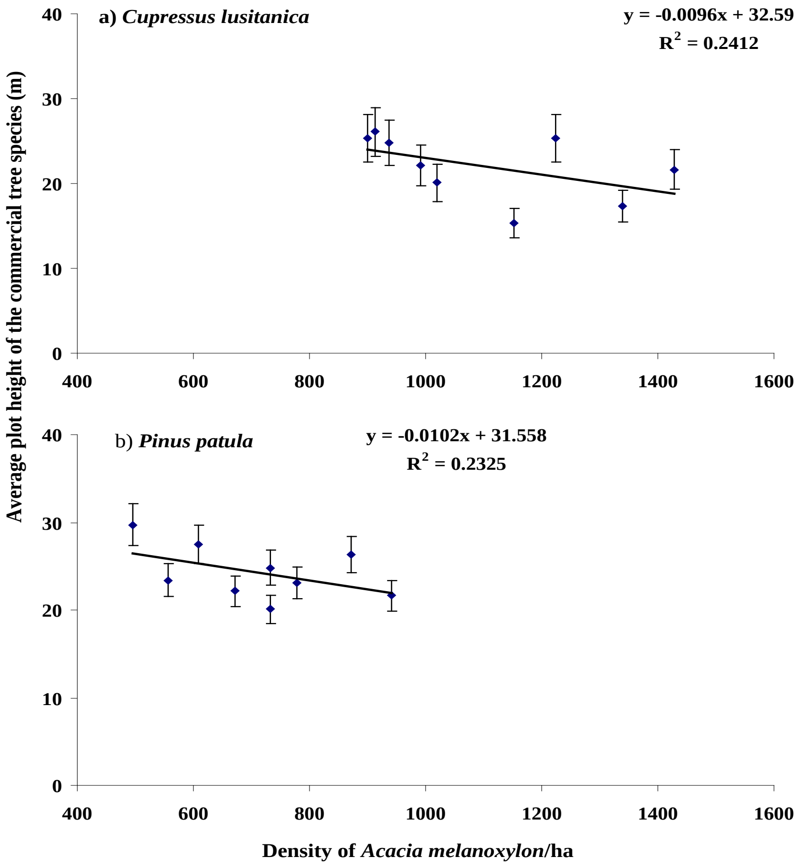

Figure 11. The relationship between the average tree height of *Cupressus lusitanica* and *Pinus patula* with respect to the density of *Acacia melanoxylon* at invaded sites. Density appeared to have little effect on height growth

4. Discussion

The tree density of both *Cupressus lusitanica* and *Pinus patula* was higher at the uninvaded sites compared to the invaded sites in the Nabkoi and Timboroa forest sites. This suggests that invasion by *A. melanoxylon* depressed the tree density by causing higher mortality in invaded stands all other factors being constant. One way in which invasive wood tree species affect resident tree species' biomass is through decimation or extermination. Tree species decimation due to invasion results in the killing of large local tree species by invasive tree species. In comparison with other invasive species, plantations of *A. saligna* have demonstrated a higher capacity to decimate many other native tree species through allelopathy [38]. There are also reports of decimated native tree species by invasive *Acacia caven* in Argentina [39]. *Acacia tortilis* has also a long record of eliminating the native biomass of plant species through smothering effects [40].

The diameter size distribution of *C. lusitanica* and *Pinus patula* at the uninvaded sites (Nabkoi and Timboroa) was higher than at the invaded sites. Furthermore, there was a negative correlation between the diameter sizes of all tree species with *Acacia melanoxylon* density at all the forest sampling sites. These observations suggest that the invasion of *A. melanoxylon* reduced diameter growth through increased soil and water resources. Given the planting density of 1600 trees /hectare, and stands subjected same silvicultural treatments, new trees occupying the site (by invasion) would lead to increased competition as compared to where no invasion exists. Numerous studies have documented the negative impacts of invasive woody species on tree species [8,41,42]. In general, the influence of acacia on other tree species' growth has reported to be antithetical to optimal growth of other species. Invasion by *A. dealbata* has on several occasions reduced plant growth [43,44]. *Acacia saligna* in the Nile Delta Coast of Egypt was reported to cause negative growth of crops and trees in areas of occurrence [45]. The invasive *Acacia mangium* negatively affected the growth of two plant species in paddies [46]. There are also records of invasive *A. auriculiformis* threatening growth in DBH of mangrove trees [47]. *Acacia melanoxylon* has also been established to negatively affect the growth of *Lactuca sativa* [48], which concurs with the current finding.

Generally, the height of both *Cupressus lusitanica* and *Pinus patula* was higher at the uninvaded sites compared to the invaded sites in Nabkoi and Timboroa. Also, there was a negative relationship between the heights of commercial tree species with

Acacia melanoxylon density at all the forest sampling sites. This suggests that invasion by *A. melanoxylon* inhibited the growth of the two plantation species in forests of Uasin Gishu. Studies have documented the negative impacts of invasive woody species on the height of tree species in several environments [8,41,42]. The suppression of growth in the height of other trees by *A. dealbata* has been reported [43,44] *Acacia saligna* also reduced the growth in height of several tree species in the area of occurrence [45]. There are also records of invasive *A. auriculiformis* threatening the height of mangrove trees [47]. *Acacia melanoxylon* has also been established to negatively affect the growth in height of *Lactuca sativa* [48], which concurs with the current funding. Therefore, it is probable that the observed reduction in height of commercial plantation tree species responded to the occurrence of invasive *A. melonaxylon*.

In conclusion, the density of *Pinus patula* and *Cupressus lusitanica* was higher at the non-invaded site than non invaded sites. It was also observed that the invasion of the forest blocks negatively affected the tree growth and establishments of *Pinus patula* and *Cupressus lusitanica*. The density, DBH, the average height and volume of *Pinus patula* and *Cupressus lusitanica* tree species, were higher at the non-invaded sites compared to the invaded sites. While *A. melanoxylon* may be a suitable candidate to provide suites of environmental benefits to the local communities, there is need to control its proliferation in the commercial forest stands.

Competing Interests

The authors declare that they have not competing interest in publication of this manuscript.

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