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Influence of Invasive *Acacia melanoxylon* on the Forest Stand Volumes and Annual Increment of Commercial Tree Species in Two Humid Forests (Nabkoi and Timboroa Forests, Kenya)

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ABSTRACT

Background and Objective: 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 *Acacia melanoxylon* on the volume and annual increment of two commercial forest tree species (*Cupressus lusitanica* and *Pinus patula*) in a humid tropical forest (North Tinderet Forest, in Kenya). **Materials and Methods:** Data were collected using a 10×10 m plot overlaid on a 500 m transect in univaded and invaded sites. Tree density, Diameter at Breast Height (DBH) >1.3 m and tree heights were measured. Volume and the mean annual biomass increment (MAI) were calculated. **Results:** There were significantly ($p<0.05$) higher tree densities, DBH and height in Timboroa than Nabkoi regardless of invasion. Further, the increased density of *Acacia melanoxylon* suppressed the volume of commercial tree species. These findings suggest that *Acacia melanoxylon* invasion reduced volume through reduced annual growth increment of commercial tree species. The proactive management of invasive *Acacia melanoxylon* should be considered to prevent the loss of tree volumes. **Conclusion:** However, the complexity of controlling both invasion and restoration side effects highlights the importance of taking a preventive approach.

KEYWORDS

Ecological conditions, acacia, forest stand volume, mean annual increament (MAI), invasiveness, tropical environment

INTRODUCTION

There have been a total of 443 tree species declared invasive by the Global Invasive Species Database (GISD)[1,2]. Countries in Sub-Saharan African Africa (SSA) have the highest number of invasive species[3]. Among the species reported in the regions, some species of acacia are listed in the land species

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category of 100 awful invasive alien species[4]. The genus *Acacia* (Mill.) (belongs to the family Fabaceae, subfamily Mimosoideae and includes roughly 1300 species[5]. The genus is broad, including segregate genera *Senegalia* and *Vachellia* but excluding *Faidherbia*. Acacia dominates the structure and floristic composition of woodland, wooded grassland and bushland[6,7]. The genus occurs across a wide range of ecosystems, from arid and semi-deserts, afro-montane forests, savannah grassland and plantation forests[8,9].

It is not clear when some non-native acacia species were introduced in Kenya perhaps due to several species, each with an overlapping history[10]. There are 12 species of Acacia known in Kenya mostly introduced into specific areas for economic or environmental purposes[11] and include *Acacia tortilis*, *Senegalia mellifera*, *Vachellia reficiens*, *Acacia lahai*, *Senegalia senegal*, *Vachellia seyal*, *Vachellia drepanolobium*, *Acacia elatior*, *Vachellia xanthophlea*, *Acacia mearnsii*, *Acacia brevispica* and *Acacia melanoxylon*. Among these, four acacia species including *Acacia mearnsii*, *Acacia tortilis, Vachellia seyal* and *Acacia melanoxylon* are confirmed as invasive although the level of extirpation they cause to the environment is not clear[7,12,13].

A key aspect of the invasive biology of *A. melanoxylon* is the knowledge of their impacts on the native tree species. The proliferation of *A. melanoxylon* as an invasive species at the ecosystem level may lead to a reduction in tree growth parameters such as DBH and height growth, as well as changes in the biometric information[14,15]. In commercial forests, the tree value is determined using volume which is a function of the DBH and height of the tree[16]. In forests, *A. melanoxylon* may affect tree growth parameters.

In-depth studies of *A. melanoxylon* in forests should look at volume estimates and annual biomass increment[17,18]. Information on the influence of acacia species is determined by the type of species invading, habitat conditions, types of trees invaded as well as the environmental conditions[19-22]. Despite this, there are no meaningful studies conducted in Kenya's plantation forest ecosystems to determine the response of tree volume estimates and annual biomass increment to *A. melanoxylon* invasion. Therefore, this study determined the influence of *A. melanoxylon* on the volume and annual increment growth of two commercial forest tree species (*Cupressus lusitanica* and *Pinus patula*) in the North Tinderet Forest, North Rift in Kenya. The study hypothesized that commercial timber tree species, *C. lusitanica* and *P. patula* within the proximity of invasive species such as *A. melanoxylon* will manifest in reduced volume and annual biomass increment.

MATERIALS AND METHODS

Study area: The study was conducted in the Nabkoi and Timboroa forests situated within the North Tinderet Forest in Uasin Gishu County (Kenya). It covers a total area of 3,345.2 km^2 with a population of 1,163,000. The areas occur within Longitude 34°50'E to 35°37'E and Latitudes 0°03'S to 0°55'N.

The climate of the area is typically tropical rainforest. The altitude ranges between 2600 to 2950 masl, however, Timboroa Forest (2913 masl) is at a higher altitude compared to Nabkoi Forest (2634 masl). Annual rainfall ranges between 1,328 to 1,405 mm. The cyclic pattern of rainfall is a 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 7°C (June-August) to a maximum of 29°C. 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.

The 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.

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 masl) and Timboroa (2913 masl) 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[23] 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).

Forest sampling: The fieldwork was carried out from January, 2022 to February, 2023 covering both dry and rainy seasons. A reconnaissance survey was done from 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, 10×10 m plots were established located at 235 m intervals from which measurements were taken (Fig. 1).

Field measurements: Every tree in the sample plot (10×10 m) had its Diameter at Breast Height (DBH) measured, i.e., at 1.3 m 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 measured using a Suunto clinometer (Suunto PM5/360PC) at a scale of 1:15 or 1:20).

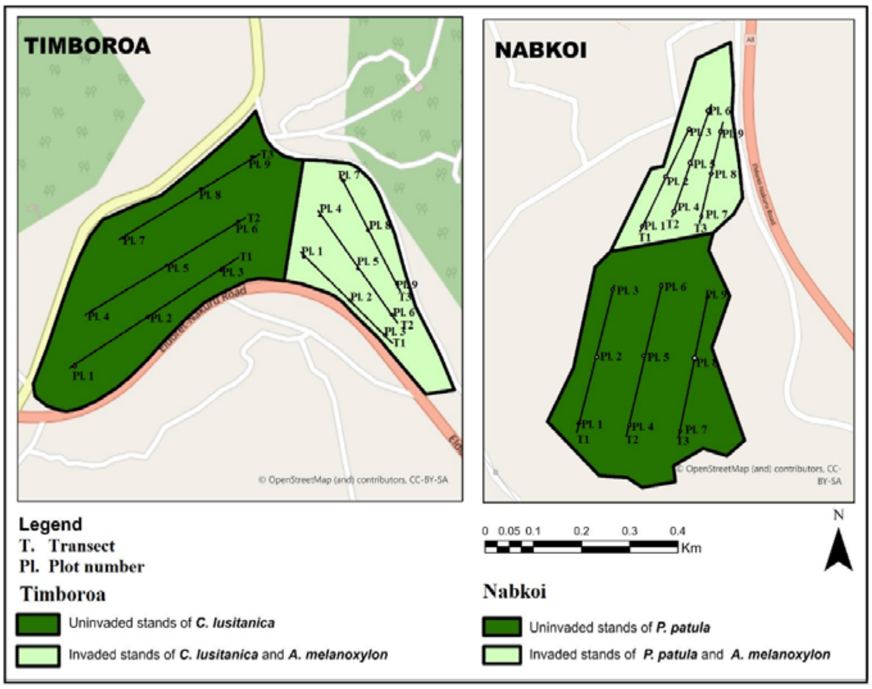

Fig. 1: Typical laying-out of line transects in adjacent stands for *Cupressus lusitanica* and *Pinus patula* uninvaded (dark green) and invaded (light green) in the Nabkoi and Timboroa study sites

Tree volume data: To assess stand volumes, tree models for *Cupressus lusitanica* and *Pinus patula* applicable to Kenya and routinely used by the Kenya Forest Service were applied to compute the volume of every tree measured within a plot. Tree volumes were then totaled to obtain plot volumes and the blow-up factor (1/size of the plot in hectares = 1/0.01 = 100) was reported on a per-hectare basis. Mean annual growth increments (MAI) for every stand found by dividing volume per hectare (from sample plots) by stand age. The tree volume models used were:

$$\textit{Cupressus lusitanica}\text{: } V = 0.01352-0.00005069D+0.0001769DH+0.00002895D^2H$$

$$\textit{Pinus patula}\text{: } V = -0.00041-0.0000571D^2+0.0001352DH+0.00003313D^2H$$

where, V is individual tree volume in m^3 and D is diameter at breast height in cm and H is tree height in m.

Statistical analysis: Data collected were analyzed statistically using STATISTICA 8.0 and SPSS 23.0 statistical packages. In addition, Mean±SEM was used to summarize the trends in tree density, diameter size distribution, height, volume and MAI (on a per-hectare basis). Spatial trends were analyzed using one-way ANOVA followed by *post hoc* Duncan's Multiple Range Test (DMRT). Results were declared significant at $p<0.05$.

RESULTS

The volume of *P. patula* and *C. lusitanica* were significantly ($F_{(1, 82)} = 8.457$, df = 24 and p = 0.0034) higher in uninvaded sites compared to the invaded site at Nabkoi and Timboroa (Fig. 2).

The volume of *P. patula* at the invaded and uninvaded forest sites is provided in Fig. 3. The volume of *P. patula* was higher in uninvaded sites compared to the invaded sites at Nabkoi and Timboroa forest sites (F = 16.123, df = 24 and p = 0.0034). The volume of invaded is much more depressed in Nabkoi than in Timboroa.

The volume of commercial tree species relative to density of *A. melanoxylon* is shown in Fig. 4(a-b). There was a significant negative correlation ($p<0.05$) between the volumes of commercial tree species with *A. melanoxylon* density at all the forest sampling sites. Thus, as the density of the invasive species increased, the productivity of the planted species reduced.

Stand growth statistics for the two species are summarized in Table 1. Invaded stands volumes were drastically reduced compared to uninvaded stands. Mean annual biomass increments (MAI), (used for

Table 1: Summarized stand data for the two commercial species in the study sites

	Nabkoi		Timboroa	
Species	Uninvaded	Invaded	Uninvaded	Invaded
Cupressus lusitanica				
Stand age (year)	16.8	15.8	16.8	15.0
Area (ha)	20.0	20.3	15.8	15.9
Density (stems/ha)	1100	857	709	501
Volume (m^3/ha)	600.4	83.2	457.1	252.8
MAI (m^3/ha/year)	35.7	5.3	27.2	16.9
Pinus patula				
Stand age (year)	16.8	15.8	16.8	15.8
Stand area (ha)	15.8	10.2	15.7	10.6
Density (stems/ha)	1152	690	724	402
Volume (m^3/ha)	336.5	73.5	781.7	290.0
MAI (m^3/ha/year)	20.0	4.7	46.5	18.4

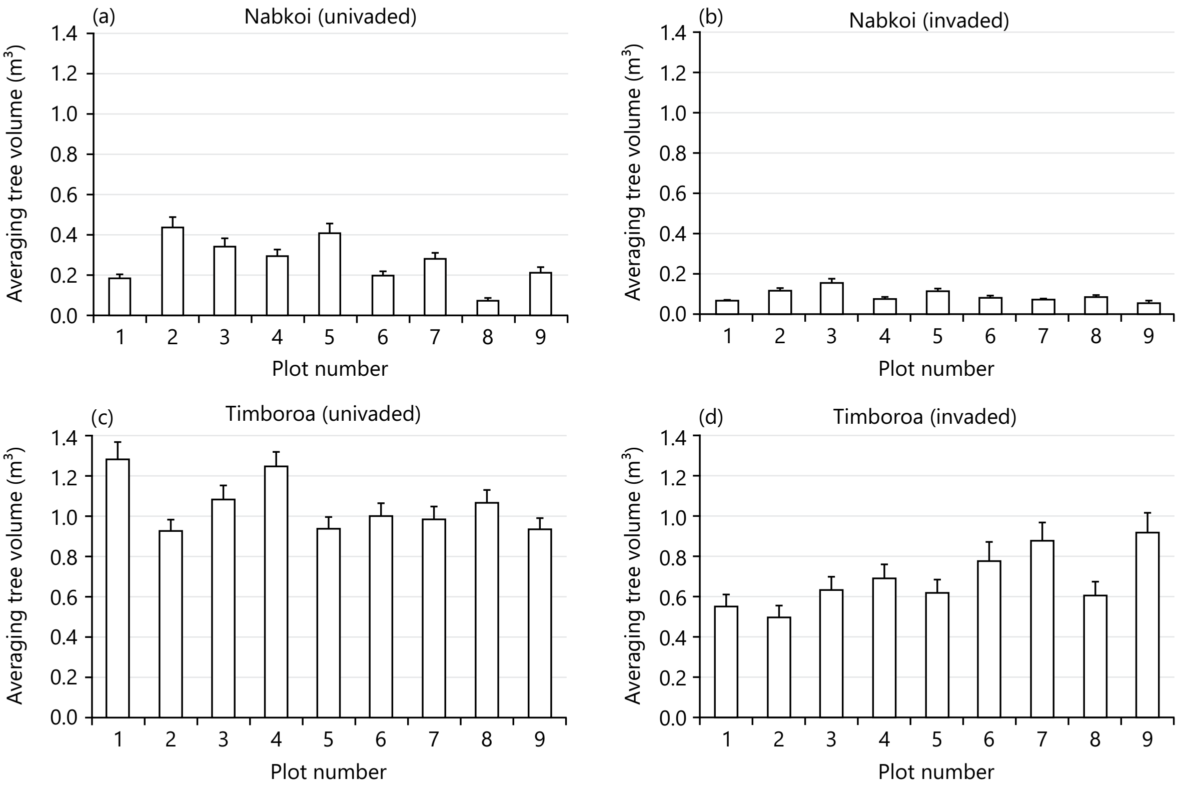

Fig. 2(a-d): Plot volumes (derived by averaging individual tree volumes within a plot) distribution of *Cupressus lusitanica* at the uninvaded and invaded stands in Nabkoi and Timboroa forests

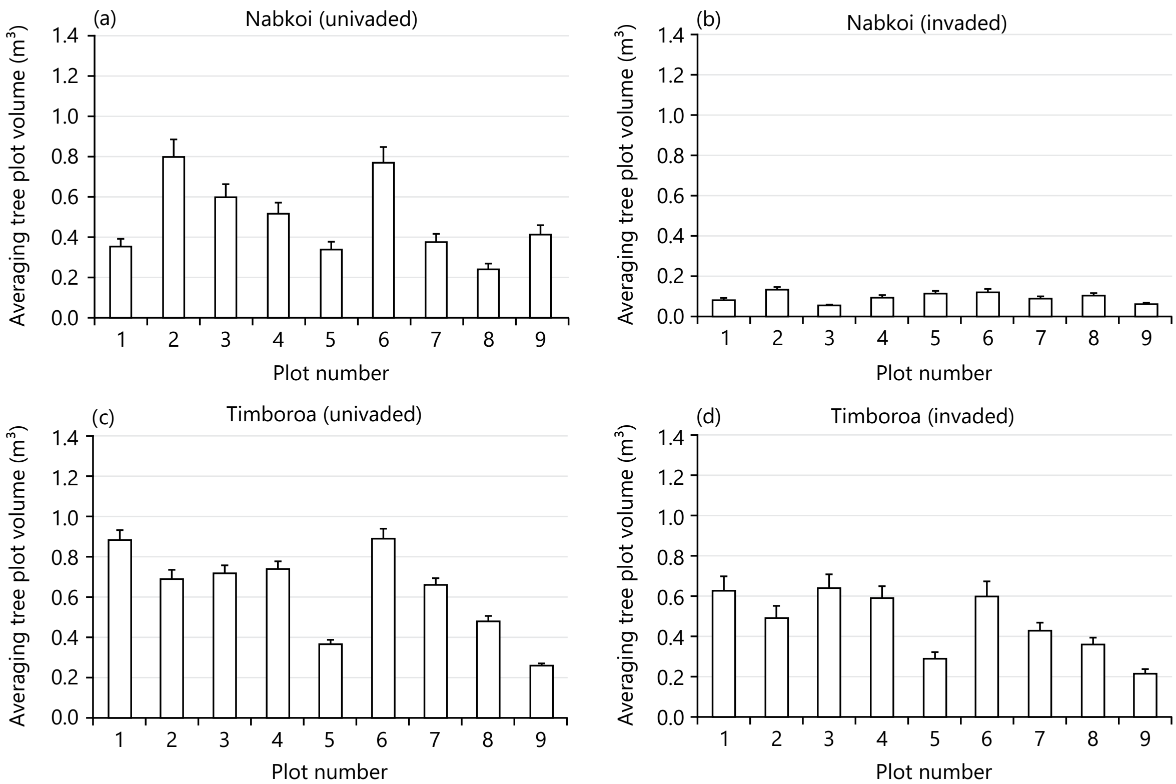

Fig. 3(a-d): Plot volumes for *Pinus patula* at the uninvaded and invaded sites of Nabkoi forest site in Nabkoi and Timboroa forests sites

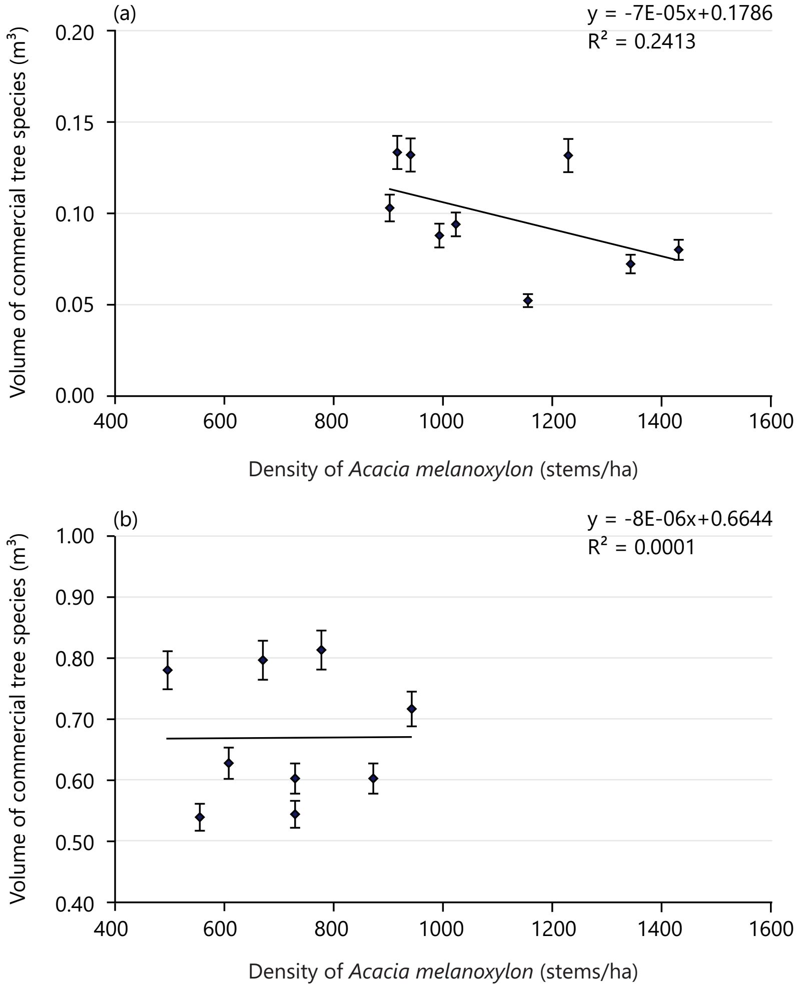

Fig. 4(a-b): Relationship between tree volume/plot of, (a) *Cupressus lusitanica* and (b) *Pinus patula* with respect to the density of *Acacia melanoxylon* at the invaded sites

comparison to take into consideration age factor), increments of volume/ha for invaded stands as percent of uninvaded sites reduced by as much 38-85 in *C. lusitanica* and 60-77 in *P. patula*. For both species, lower altitude stands in Nabkoi were affected more than in Timboroa.

DISCUSSION

The volume and MAI of the commercial tree species (*P. patula* and *C. lusitanica*) were higher in uninvaded sites compared to the invaded sites at Nabkoi and Timboroa forest sites. This suggests that *A. melanoxylon* invasion negatively affected the volume of commercial tree species. There are several mechanisms that invasive plants including acacias might use to reduce the overall tree productivity of other species. First, is competition for resources between invasive and native plants which is a crucial process in the competitive interactions that may ultimately affect native vegetation patterns of growth and biomass increments[24]. Invasive plants also appeared to modify the ecosystem's abiotic processes, like hydrology and disturbance regimes which tend to lower biomass increase and volume[25].

Most acacia species inhibit the growth of other plant species through chemical interference or allelopathy which has been reported to reduce biomass increment in trees[26]. Most species of invasive acacia have allelochemicals in roots, stems, flowers and leaves which may affect the volume of trees in ways that are still not determined due to few studies in this realm. The results of the current study suggested that the invasion by *A. melanoxylon* reduced the volume of *C. lusitanica* and *P. patula* in the plantation forests.

It is also possible that *A. melanoxylon* has a strong impact on resource availability and soil or microclimatic characteristics, as suggested in several studies throughout the world[27-29]. In many areas, competition exclusion affects canopy cover and competition for growth resources such as light intensity, air temperature and humidity, which will eventually affect the growth of forest-adjacent trees[30]. Therefore, the current study seems to suggest that *A. melanoxylon* affects the growth of adjacent forest trees through competitive exclusion.

CONCLUSION

The study concluded that the comparison of uninvaded and invaded forest stands, the volume and the mean annual increment (MAI) in invaded sites was depressed by as low as 35% in higher altitudes and 85% at the lower altitudes depicting a reduction in volume due to *A. melanoxylon* invasion was dependent on the altitude. Further, as the number of individual trees of *A. melanoxylon* (density) increased in the stand, there was a corresponding decline in commercial species volume. The proactive management of invasive *A. melanoxylon* should be considered to prevent the loss of tree volumes. However, the complexity of controlling both invasion and restoration side effects highlights the importance of taking a preventive approach.

SIGNIFICANCE STATEMENT

In the forest, there may be accidental or deliberate introductions of invasive species, which may negatively or positively affect the forest ecosystem. The main concern of invasive species is their effect on the growth and establishment of commercial tree species, which may generally affect the overall volume of forest products. This study aimed to determine how invasive species affect the volume of commercial forest plantations. The study was conducted in a humid forest in Kenya for 13 months. The study established that in areas that were invaded by acacia, the volume was lower and therefore concluded that invasion reduced the volume of commercial tree species. The information is useful for the management of commercial forest plantations to enhance the wood industry.

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