Climate Change

Invaseness impact of *Mesosphaerum suaveolens* ([L.] Kuntze) on Kolda's flora under changing climatic conditions in the subtropical forest of southern Senegal

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ABSTRACT

Invasive alien plants represent a global challenge and are increasingly becoming widespread components of tropical and subtropical ecosystems worldwide. These plants can cause profound and sometimes irreversible ecosystem changes by altering floristic composition and reducing biodiversity. However, there remains a knowledge gap regarding their effects on native species under the Sudanian conditions of West Africa. To help narrow this knowledge gap, a study was conducted to assess how the invasion of *M. suaveolens* (pignut) affects the diversity and composition of native flora in the Kolda district, located in the Sudanian zone of southern Senegal. During two years of investigation, the flora of fallows, croplands, and rangelands was compared in terms of species composition, diversity, evenness, and abundance. The present study revealed that the flora consisted of 83 distributed in 52 genera and 15 families. During the first year of survey, 28, 33, and 34 species were recorded in rangelands, croplands, and fallows, respectively, whereas in the second year, 40, 46, and 50 species were recorded in rangelands, fallows, and croplands, respectively. Pignut had the most significant average Importance Value Index (IVI) in Fallows and Rangelands regardless of the year, at the same time, it has been reported as the fifth (year 1) and second (year 2) most important species in Croplands. Results also showed that diversity indices (Margalef, S-W and Pielou) decreased significantly with each increase in pignut density and dry matter. This preliminary study provides a baseline for further research aimed at determining the effects of pignut (*M. suaveolens*) on native vegetation under Sudanian environmental conditions, as well as the underlying mechanisms driving changes in the native flora.

Keywords: Invasive alien plant, *Mesosphaerum suaveolens*, species diversity, species composition, Importance Value Index, Sudanian zone, Temperature change, Climate Change

1. INTRODUCTION

West Africa is subdivided into five bioclimatic zones, reflecting variations in temperature, rainfall, and vegetation patterns. Among them, the Sudanian region, situated between the Sahelian and Guinean regions, constitutes an extensive ecological belt with a 5- to 7-month wet season (USAID-CILSS-USGS, 2022).

The region is considered a key biodiversity hotspot in Africa, particularly for its exceptional species richness resulting from the combined interaction of its geography, climate, seasonal rainfall patterns and particular ecosystems. However, changes in global temperature and precipitation patterns are projected to significantly affect the structure and functioning of tropical grasslands. (Grimm et al. 2013, Campo 2016, Allen et al. 2017). This phenomenon has contributed to accentuate the alteration of natural habitats and the proliferation of invasive alien species (Seifu et al. 2017; Weiskopf et al., 2020).

Biological invasions are recognized as the second most significant driver of biodiversity loss, after habitat destruction (Mack et al. 2000, Meiners et al. 2001, Holzmueller & Jose 2009, Seifu et al. 2017). In fact, it reduces species richness through interspecific competition.

Invasive alien species (IAS) compete with native plants for space, light and nutrients in addition to adversely affecting species evenness among plant communities (Sharma et al. 2009). They also disrupt ecosystem functioning, contribute to biotic homogenization cause severe socio-economic constraints. *Mesosphaerum suaveolens* is a pantropical aromatic herb native to Mexico to tropical America. It is a fast-growing invasive species with detrimental effects on native plant species which it progressively depletes within invaded habitats (Hutchinson & Daziel 1963, Harley 1988, Padalia et al. 2014). Pignut has successfully spread across tropical Africa, Asia, and Australia (Hutchinson and Daziel 1963, Sharma et al. 2017). *M. suaveolens* has been characterized as one of the most invasive species in tropical and sub-tropical ecosystems (Afolayan 1993, Padalia et al. 2014). Specifically, it has naturalized across several West African countries, including Cameroon, Nigeria, Burkina Faso, Benin, Niger, Liberia, and Senegal (Randall, 2017; Kâ et al. 2020a).

In savannah ecosystems, the dominance of *M. suaveolens* has been associated with phenotypic plasticity, prolific seed production, livestock unpalatability, and allelochemical effects. These mechanistic events inhibit the seed germination of native species (Aboh et al. 2008, Sharma et al. 2009, David et al. 2020), hence they jeopardize natural ecological successions as well as the existence of vulnerable taxa and wildlife within invaded ecosystems (Padalia et al. 2014).

In Senegal, *M. suaveolens* has established and spread across the high rainfall and warm sub-tropical regions, in the eastern and southern parts of the country (Kâ et al. 2020a). Although *M. suaveolens* has been reported as ruderal in many areas where it has naturalized (Keller & Armbruster, 1989). In southern Senegal, *M. suaveolens* occurs across diverse ecosystems—including croplands, woodlands, rangelands, roadsides, and watercourses—and is recognized as one of the five most noxious weeds (Kâ et al. 2020a & 2020b).

However, there is a notable lack of systematic studies assessing the impact of *M. suaveolens* on native vegetation in the subtropical zone of southern Senegal. Nevertheless, comprehensive knowledge of the invasion range of alien species is vital for a thorough understanding of their ecological dynamics. Such knowledge will guide policymakers in conservation and management planning (Padalia et al. 2014).

This study was conducted to assess and quantify the ecological impact of *M. suaveolens* in the Kolda district according to the land use system. Therefore, we performed specific surveys during two years to evaluate the effect of *M. suaveolens* invasion on the natural vegetation of a Sudanian ecosystems based on species number and dry matter, richness, diversity and equitability.

2. METHODOLOGY

Case Study

The study was carried out in the Kolda district (12° 53'N, 14° 57'W), which is located in the sudanian zone of the Senegal and covers an area of 13,771 km² (Fig. 1). The Kolda district has a mean elevation of about 63 m above sea level. The region experiences a unimodal rainfall pattern, extending from early June to late October (4 to 5 months), followed by a prolonged dry season spanning from November to May (7 to 8 months) in a year. Based on meteorological data (1991–2020), annual mean temperatures at Kolda station is 28°C and average annual precipitation ranges from 800 mm to the northern to 1200 mm in the southern.

The soil texture is sandy or sandy-clay. At least 80 tree species, unique to this bioclimatic region, contribute to the diverse flora of the Sudanian zone (Aubreville, 1938). In the northern part of the Sudanian Region, tree savannas are the predominant vegetation type, in contrast, some places close to Guinean zone in the southern, reaches of this region typically transition into denser wooded savannas and open woodlands (USAID-CILSS-USGS, 2022). The herbaceous flora in this zone is dominated by tall, perennial grasses, mainly of the genus *Andropogon* and the new invasiveness *Mesosphaerum suaveolens* (Kâ et al., 2020b).

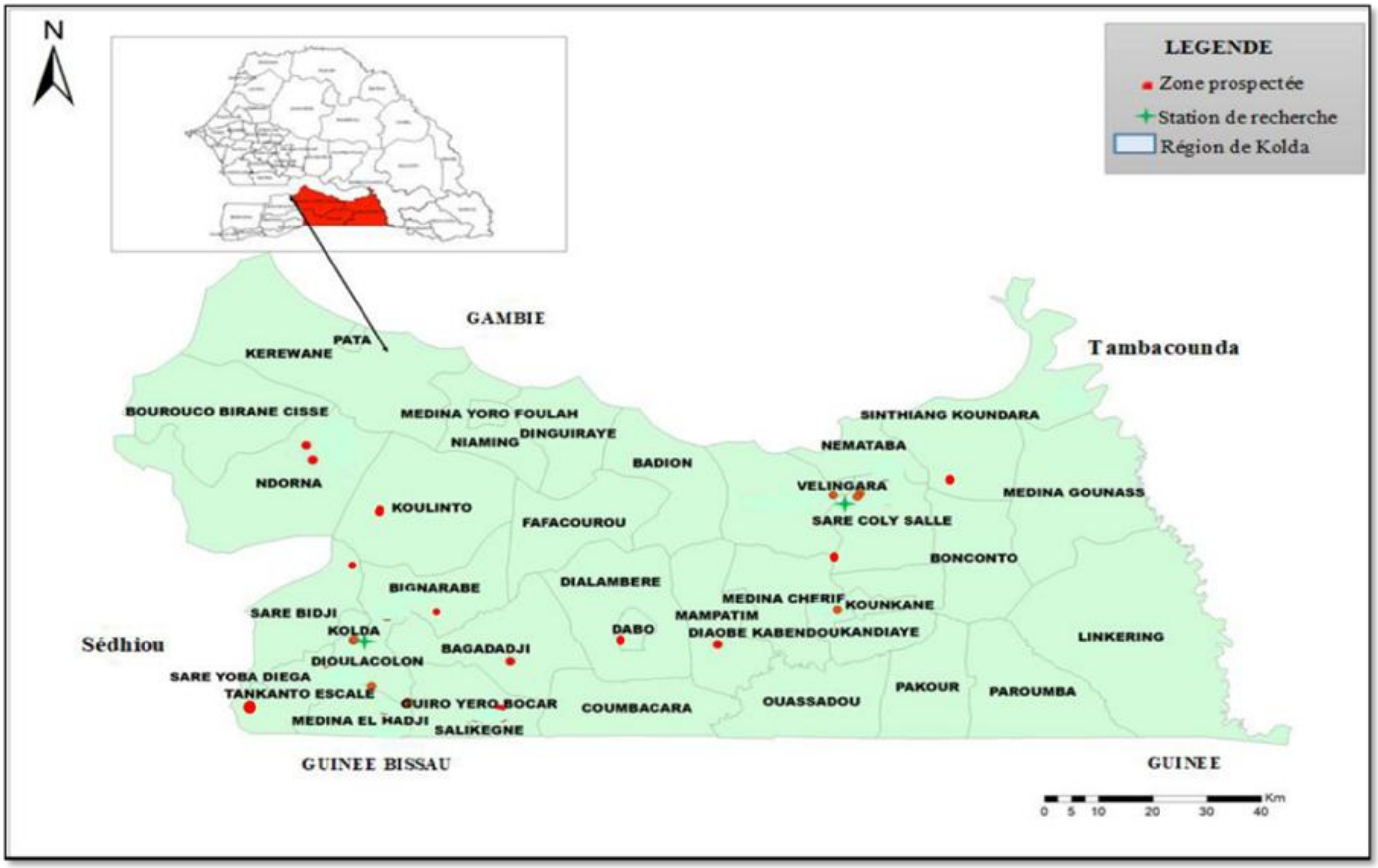

Figure 1: GIS location map of study area

Vegetation analysis

A quadrat-based survey was conducted to assess herbaceous species in rangelands, croplands, and fallows across the Kolda district during the 2021 and 2022 post-rainy seasons. At each location, quadrats of 50 cm * 50 cm were established randomly (~50 m from one another). A total of 74, 89 and 113 quadrats were recorded respectively in Rangelands, Fallows and Croplands resulting in 276 quadrats over the two years of investigation. For proportional allocation, the number of quadrats that was selected for each system was proportional to the area of that system with respect to the total land occupation. The number of quadrats sampled depended on the part of the system in land occupation. In each quadrat, all the herbaceous species were collected and identified. They were kept in bags and oven-dried at a temperature of 65 ° C. for 72 h to obtain the aboveground dry biomass. Specimens were initially identified in the field, while those that could not be determined on-site were collected and subsequently taken to the Kolda Livestock Research Center for identification using classical taxonomic literature (Bérhaut 1967; Le Bourgeois & Merlier 1995) and 'African Plant Database' an on-line e-flora.

Data analysis

Phytosociological attributes, including the Importance Value Index, Species Diversity, Richness, Evenness, and species composition of each land-use system, were recorded.

These indices were used to assess changes in species diversity associated with each land-use system and *M. suaveolens* invasion. The mean *Importance Value Indices* (*IVI*) were calculated for each location by using the formula described by Curtis (1959): $IVI = RF + RD + RA$;

where *RF* = Relative Frequency, *RD* = Relative Density, and *RA* = Relative abundance.

Species richness (S) is the simplest measure of biodiversity representing the total number of plant species documented from the sampled plots.

Shannon-Wiener diversity Index (H') estimates the diversity of plant assemblages in a habitat. It reflects the community structure in terms of complexity of the habitat i.e. a higher index value indicates greater community diversity (Shannon & Weaver 1949).

H' were calculated for each location by using the equations: $H' = -\Sigma(\text{pi lni pi})$;

where S = the number of species, pi = the proportion (n/N) of individuals belonging to species i, H' = the Shannon-Wiener Index, and ln = the natural logarithm (i.e. base 2.718).

Margalef's index (RMg) was used as a measure of species richness (Margalef, 1958). $RMg = (S - 1) / \text{In N}$

Simpson's index of dominance (D) is used to evaluate the extent to which one or a few species dominate a given community: $D = \Sigma pi^2$ (Simpson, 1949). This index ranges from 0 to 1 and indicates the number of chances of a particular species that could be encountered during sampling i.e. a higher the index less diverse the community is.

Evenness index of Pielou (J') is defined as: $J' = H'/\ln(N)$. This index indicates the degree of distribution of species in a community or habitat (Pielou, 1975). H' is Shannon-Wiener diversity index, ln' the natural logarithm and N the number of individuals of all species recorded from the sampled area.

Statistical analysis

All the data relating to the indices of diversity and aboveground dry biomass production were first tested at the 5% level to verify the normality and homogeneity of the variance using the Shapiro-Wilk normality test and Levene's test. The results being significant, the *non-parametric* test of Kruskall-Wallis followed by the test of paired comparisons of Mann-Whitney, according to Hammer et al. (2001) was used for the comparison of data on diversity of land use systems with significance levels of 5%. A two-tailed Mann-Whitney U test was used to compare the density and above-ground dry biomass production of *M. suaveolens* with those of the overall averages of the remaining species in the different land use systems. To assess the relationships between the density of *M. suaveolens* and the diversity indices (H ', J', D, Mg) and the biomass production of associated species, the Spearman correlation test and the Loess regression analysis were carried out by testing their statistical significance at the 5% level. All statistical analyses were done with the software R version 3.6.3. The core packages *ggpubr*, *patchwork*, *Hmisc, ggplot2* and dependencies were used for statistical analyses, data handling and visualization.

3. RESULTS

The overall floristic survey of the vegetation of Kolda district depicts the presence of 83 species belonging to 52 genera and 19 plant families, as shown in Table 1. During the first year of investigation, 28, 33, and 34 species were recorded in the Rangelands, Croplands, and Fallows, respectively, whereas in the second year, 40, 46, and 50 species were documented in the Rangelands, Fallows, and Field Crops, respectively.

Among the 15 families, Fabaceae predominated with 21 species (25.3%), followed by Poaceae 16 (19.3%), Cyperaceae 11 (13.3%) and Malvaceae 9 (10.8%). Except for Convolvulaceae (7 species), Rubiaceae (7 species), Lamiaceae (3 species) and Amaranthaceae (2 species), the remaining families (7) were each represented by a single species.

Of the recorded 83 species, the proportion of indigenous species was higher, constituting 61% of the total. It appears from this study that four of the five most common plant species were alien. During two years of investigation, *Mesosphaerum suaveolens* had the highest average IVI value in Fallows and Rangelands, with respectively 209 and 162 in first year and 194 and 156 in second year. The species was also reported as the fifth and the second most important species in Croplands in 2021 and 2022, respectively. In Croplands, the flora was dominated by *Mitracarpus hirtus* regardless of the year of survey.

Table 1: The list of plant species found in the study sites with their family and Importance value index (IVI).

Species	Fam.	Sta.	IVI					
			Year 1			Year 2		
			Crops	Fallows	Rangelands	Crops	Fallows	Rangelands
Mesosphaerum suaveolens (L.) Kuntz.	LAM [D]	NN	63.3	209.1	162.3	75.6	194.3	155.9
Mitracarpus hirtus (L.) DC.	RUB [D]	NN	112.3	60.7	-	105.9	16.2	3.2

Species	Fam.	Sta.	IVI					
			Year 1			Year 2		
			Crops	Fallows	Rangelands	Crops	Fallows	Rangelands
Digitaria horizontalis Willd.	POA [M]	NN	108.6	69.8	15	47.6	75.5	16.7
Diodella sarmentosa Sw.	RUB [D]	NN	-	32.1	91.6	5.2	-	84.4
Dactyloctenium aegyptium (L.) Willd.	POA [M]	N	63.4	60.6	-	35.5	42.4	2.5
Cyperus cuspidatus Kunth	CYP [M]	NN	52.3	43.2	-	17.2	10.1	-
Spermacoce radiata (DC.) Hiern	RUB [D]	N	-	-	41.1	-	-	19.5
Andropogon pseudapricus Stapf	POA [M]	N	-	10.6	60.6	2.5	17	51.7
Ctenium elegans Kunth	POA [M]	N	-	-	33	-	-	23.8
Hibiscus cannabinus L.	MLV [D]	N	25.7	44.3	41.3	10.5	34.8	9.4
Spermacoce stachydea DC.	RUB [D]	N	21.6	27.7	28.8	42.5	22.4	11.3
Kyllinga squamulata Thonn. ex Vahl	CYP [M]	NN	72.9	29.1	13.6	8.6	4.3	-
Tephrosia pedicellata Baker	FAB [D]	N	14.4	47.6	-	-	5.7	13.9
Cenchrus polystachios (L.) M.	POA [M]	N	-	-	-	8.6	14.4	35.6
Eragrostis tremula (Lam.) H. ex St.	POA [M]	NN	19	16.7	22.7	33.2	8.2	13.4
Mariscus hamulosus (M. B.) S.S. H.	CYP [M]	NN	12.9	34.8	-	5.7	-	-
Urochloa maxima (Jacq.) Webster	POA [M]		-	-	-	-	-	15.6
Tephrosia bracteolata Guill. & Perr.	FAB [D]	N	-	-	34.5		3.9	7.7
Crotalaria retusa L.	FAB [D]	N	11.9	-	-	12.7	27	6.2
Stylosanthes fruticosa (Retz.) Alston	FAB [D]	NN	-	15.6	20.8	2.5	14.5	15.4
Cyperus amabilis Vahl	CYP [M]	N	23.8	17.8	-	8.6	2.4	-
Alysicarpus ovalifolius (Sc.) J. L.	FAB [D]	N		10.6	16.1	-	11.5	-
Bulbostylis barbata (Rottb.) C.B.C.	CYP [M]	NN	11.9	-	-	-	-	-
Ocimum americanum L.	LAM [D]	N	-	-	-	11.4	-	-
Oldenlandia corymbosa L.	RUB [D]	N	12.4	16.1	6.9	18.3	2.4	-
Bulbostylis hispidula (Vahl) R.W. H.	CYP [M]	N	19.6	5.5	7.6	-	-	-
Digitaria exilis (Kippist) Stapf	POA [M]	N	18.3	6.6	-	10.8	5.1	-
Sida rhombifolia L.	MLV [D]	N	4.6	-	-	20.5	5.4	-
Mariscus squarrosus (L.) C.B. Clarke	CYP [M]	N	25.9	-	7.4	4.6	2.4	-
Ipomoea eriocarpa R. Br.	CNV [D]	NN	11.4	-	-	2.5	15.8	-
Senna obtusifolia (L.) H.S. I & B.	FAB [D]	NN	11.9	10.6	-	9.2	7.1	-
Indigofera nigritana Hook. f.	FAB [D]	N	-	5.5	13.6	-	-	-
Zornia glochidiata Rchb. ex DC.	FAB [D]	N	-	-	15.1	-	3.9	-
Chamaecrista mimosoides (L.) Greene	FAB [D]	N	-	-	9.3	-	-	-
Chamaecrista absus (L.) H.S. I & B.	FAB [D]	N	-	-	14	-	5.6	8.1
Acanthospermum hispidum DC.	AST [D]	NN	-	-	-	6.5	-	11.1
Sida urens L.	MLV [D]	NN	-	-	-	8.8	-	-
Cantinoa americana (Aubl.) H. & P.	LAM [D]	NN	-	-	-	8.6	-	-
Chamaecrista nigricans (V.) Gr.	FAB [D]	N	4.6	11.2	13.7	2.5	3.9	15.3
Indigofera dendroides Jacq.	FAB [D]	N	-	-	-	-	-	8.5
Sida linifolia Juss. ex Cav.	MLV [D]	NN	-	15.6	-	2.5	8.3	6.2
Indigofera pilosa Poir.	FAB [D]	NN	-	-	13.7	2.5	-	-
Cyperus rotundus L.	CYP [M]	NN	8	-	-		-	-
Commelina benghalensis L.	CMM [M]	NN	13.3	-	-	2.5	-	-

Species	Fam.	Sta.	IVI					
			Year 1			Year 2		
			Crops	Fallows	Rangelands	Crops	Fallows	Rangelands
Xenostegia pinnata (H.C.) A.R. S & S.	CNV^{D}	N	4.6	10.6	-	5.2	2.4	4.2
Schizachyrium sanguineum (R.) A.	POA^{M}	NN	-	-	-	-	7.4	-
Buchnera hispida B.H. ex D.D.	ORO^{D}	N	-	11.8	-	3.8	10.6	2.5
Indigofera microcarpa Desv.	FAB^{D}	NN	-	-	6.9	-	-	-
Ipomoea vagans Baker	CNV^{D}	N	11.4	-	-	-	2.4	-
Oldenlandia herbacea (L.) R.	RUB^{D}	N				6.9		-
Urena lobata L.	MLV^{D}	N	-	5.5	13.7	5.2	5.4	4.6
Chamaecrista rotundifolia (Pers.) G	FAB^{D}	NN	-	6.1	-	3.8	-	9.9
Crotalaria goreensis Guill. & Perr.	FAB^{D}	N	-	10.6	-	-	-	2.5
Chrozophora senegalensis (L.) A. J.S.	EUP^{D}	N	4.6	-	-	8.2	-	-
Cyperus esculentus L.	CYP^{M}	N	-	6.1	-	-	-	-
Jacquemontia tamnifolia (L.) Griseb.	CNV^{D}	NN	-	10.6	-	3.8	3.9	-
Sida acuta Burm. f.	MLV^{D}	NN	4.6	-	-	6.7	6.8	-
Kohautia tenuis (B.) Mabb.	RUB^{D}	NN		-	7.6	6.2		4.2
Cyperus iria L.	CYP^{M}	N	4.6	6.6	-	-	-	-
Pandiaka angustifolia (V.) Hepper	AMA^{D}	N	-	-	6.9	-	-	4.2
Corchorus tridens L.	MLV^{D}	NN	4.6	5.5	-	9.5	2.4	-
Eleusine indica (L.) Gaertn.	POA^{M}	N	-	6.6	-	3.8	-	-
Indigofera microcarpa Desv.	FAB^{D}	NN				-	2.4	7.9
Andropogon gayanus Kunth	POA^{M}	N	-	-	7.1	-	5.1	2.5
Celosia trigyna L.	AMA^{D}	NN	5.8	-	-	3.8	-	-
Cenchrus biflorus Roxb.	POA^{M}	NN	4.6	-	-	-	-	-
Waltheria indica L.	MLV^{D}	NN		5.5	-	-	5.4	2.5
Ipomoea heterotricha Didr.	CNV^{D}	NN	5.8	-	6.9	2.5	2.4	-
Bulbostylis hispidula (C.) V. B.	CYP^{M}	N	-	-	-	7.4	2.4	2.5
Indigofera hirsuta L.	FAB^{D}	N	-	-	-	3.8	5.4	2.5
Cenchrus pedicellatus (T.) Morrone	POA^{M}	N	-	-	-	3.8		-
Indigofera macrocalyx Guill. & Perr.	FAB^{D}	N	-	-	-	-	2.4	5
Paspalum scrobiculatum L.	POA^{M}	N	-	-	-	-	3.3	-
Citrullus colocynthis (L.) Schrad.	CUC^{D}	N	-	-	-	2.5	-	-
Indigofera bracteolata DC.	FAB^{D}	N	-	-	-	-	-	2.5
Eragrostis ciliaris (L.) R. Br.	POA^{M}	N	-	-	-	2.5	-	
Pogonospermum ciliatum (J.) D. & K.	ACA^{D}	N	-	-	-	-	-	2.5
Sesamum indicum L.	PED^{D}	N	-	-	-	2.5	-	2.5
Setaria pumila (Poir.) Ro. & Sc.	POA^{M}	N	-	-	-	-	-	2.5
Triumfetta pentandra A. Rich.	MLV^{D}	N	-	-	-	-	-	2.5
Sesbania rostrata Br. & Ob.	FAB^{D}	N	-	-	-	2.5	2.4	-
Merremia aegyptia (L.) Urb.	CNV^{D}	NN	-	-	-	-	2.4	-
Distimake aegyptius (L.) A.R. S. & St.	CNV^{D}	N	-	-	-	-	2.4	-

D= Dicotyledons, M = MonocotyledonsNN = Non Native, N = Native, H = Herb, S = Shrub, CL:Climber, L:Liana, P = Perennial, A = Annual, UN = Uninvaded, IN = Invaded.

A Three letter acronym for the family name as per Weber (1982) and Brasher and Snow (2004).

Effects of land use system on species diversity

All the calculated indices (Margalef, Shannon-Wiener, Simpson, Evenness) of diversity differed significantly amongst the different land use system, as indicated in Figure 2. The non-parametric Kruskal-Wallis test showed that Margalef, Shannon and Evenness indices was significantly higher in the Fallows and Croplands systems whereas Simpson index was dominant in the Rangelands. The dominance of Simpson index in Rangelands confirms a low diversity and the predominance of *M. suaveolens* characterized by very high IVI of 162 (year 1) and 156 (year 2).

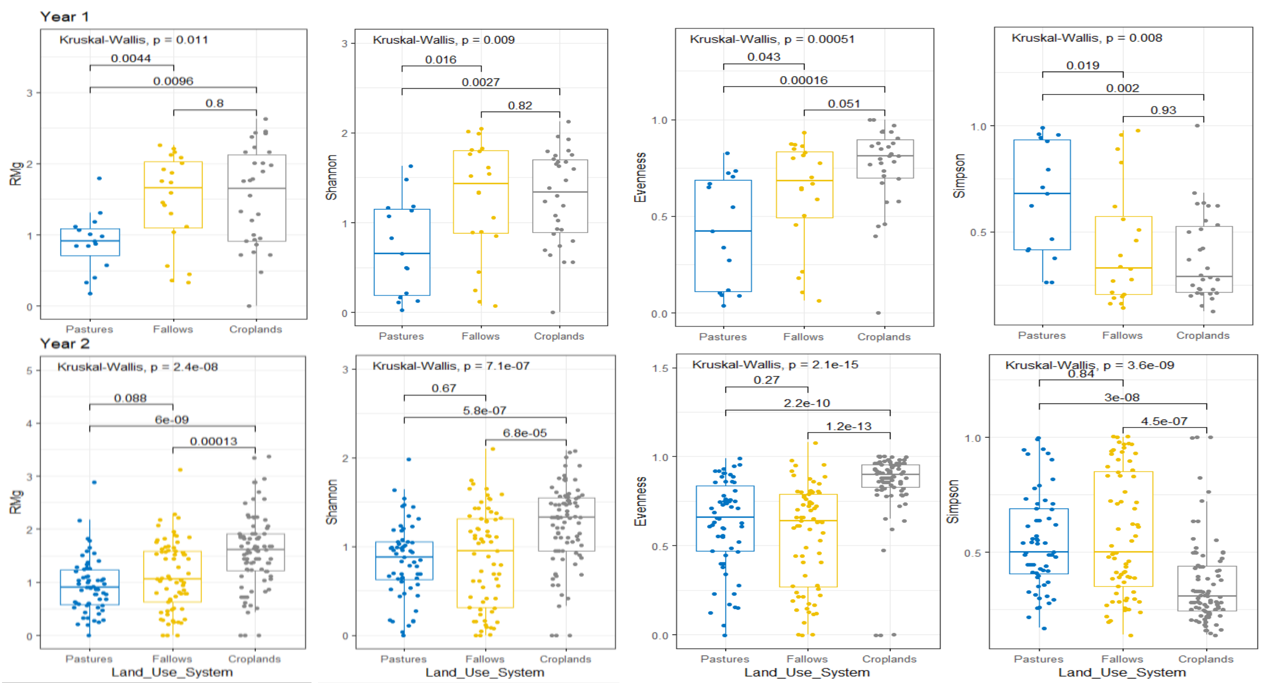

Figure 2 : Effects of land use system on species diversity

Effect of *M. suaveolens* invasion on density and above-ground dry biomass of associated species

The Mann-Whitney-Wilcoxon (MWW) test showed that the density of *M. suaveolens* is not significantly different from the density of 27 and 40 other species gathered respectively in first and second years of the survey in Rangelands. In fact, the density of *M. suaveolens* is an average of 483 individuals.m^{-2} in the first year and 79 individuals.m^{-2} in the second year while, the other species together have respectively 350 individuals.m^{-2} and 82 individuals.m^{-2} (Fig. 3). It emerges from this result that *M. suaveolens* occupies an important place in Rangelands in terms of the number of individuals per unit area. Results of first year of survey in Fallows land showed that the density of *M. suaveolens* (311 individuals.m^{-2}) was not significantly different from the density of 33 other species (134 individuals.m^{-2}) while the density of pignut was significantly higher in the second year (95.9 individuals.m^{-2}, p=2.6 e^{-06}) compared to that of the other 46 others species combined (32.6 individuals.m-^{2}).

In field crops, the density of *M. suaveolens* was significantly lower (Wilcoxon test, p_1 = 4e^{-9}, p_2 = 2.22e^{-16}) compared to that of the other species combined, regardless of the year of survey. Cropland appears to reduce the density of *M. suaveolens* benefiting other species.

Effect of *M. suaveolens* invasion on above-ground dry biomass of associated species

The non-parametric paired MWW test showed that species dry matter varied significantly in Croplands (p=1.3e^{-6}) and Fallows (p=0.005). In Fallows, the highest biomass was recorded for *M. suaveolens* (325 g.m^{-2}) while in Croplands the dry matter of other species combined (97 g.m^{-2}) was significantly higher. The aboveground dry biomass of *M. suaveolens* is greater in Fallows land while it is low in Cropland (Fig. 4). Cropland also appears to have negative effects on the development and biomass production for *M. suaveolens*.

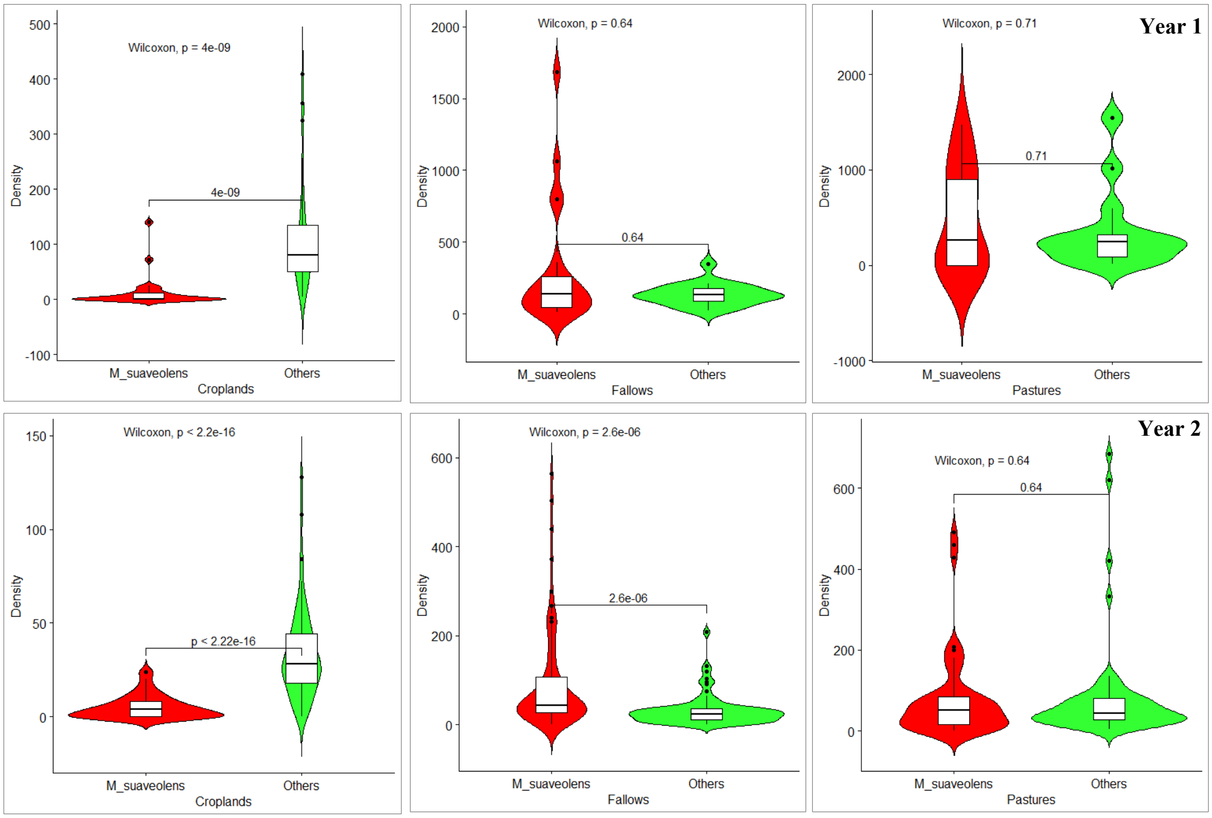

Figure 3: Effect of *H. suaveolens* invasion on density and above-ground dry biomass

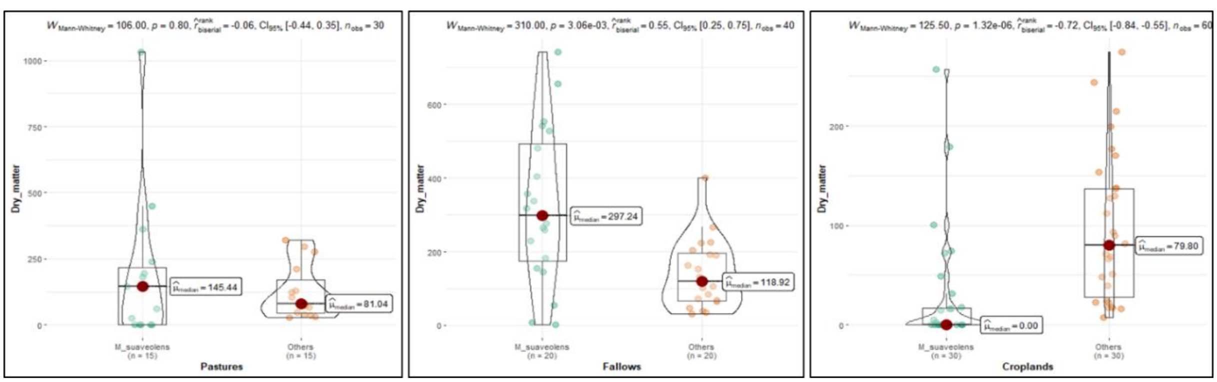

Figure 4: Effect of *M. suaveolens* invasion on above-ground dry biomass

Relationship between *Mesosphaerum suaveolens* parameters and diversity indices

Spearman's correlation test showed significant dependence of *M. suaveolens* density with Shannon, Pielou and Simpson indices. Thus, an increase in *M. suaveolens* density resulted in a significant decrease of *Shannon* and Pielou indices while the opposite effect was observed in the case of the Simpson index. A positive correlation was also observed between *M. suaveolens* density and the dry matter to Simpson index (Fig. 5). However, *M. suaveolens* dry matter was significantly and negatively correlated to Pielou's index. Furthermore, RMg, Pielou and Shannon indices followed the opposite trend from the Simpson index.

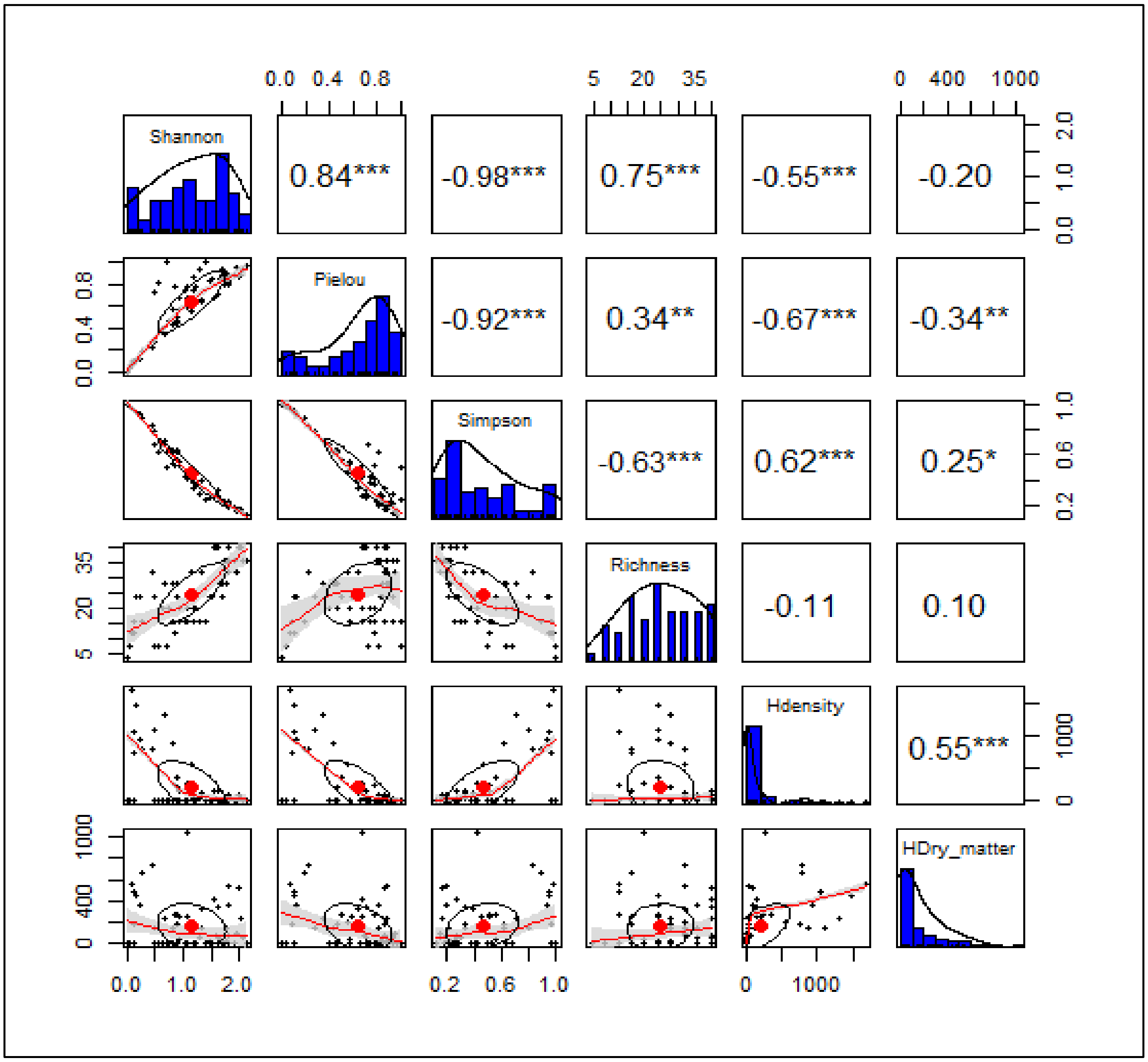

Figure 5: Correlation matrix of variables. Every correlation coefficient which matches two variables was also calculated with spearman method using R software. Numbers range from -1 to 1 are Spearman's rank correlation coefficients of variables on horizontal and vertical axes. '*' *indicates the statistical significance of the correlation.*

4. DISCUSSION

This new study conducted in Senegal showed the potential impact of invasive *M. suaveolens* on vegetation according to land use system under sub-tropical conditions of southern Senegal. The dominance of *M. suaveolens* was much more significant in the Fallows and Rangelands as indicated by their higher IVI values. Elevated IVI scores signify the ecological dominance and adaptive success of a species in an ecosystem (Odum 1971). The findings of this study align with other recent studies which have also suggested that *M. suaveolens* invasion in the savannah zone was higher in Fallows and Rangelands savannah than in Croplands (Aboh et al. 2008).

The greater influence of *M. suaveolens* is also reflected by their higher biomass in fallows (average dry weight ~324 g.m-^{2}) and rangelands (average dry weight ~189 g.m-^{2}) compared to the croplands (average dry weight ~27 g.m-^{2}). The success of *M. suaveolens* in fallows and rangelands might be due to several factors. Among them are prolific seed production (>2000 m^{2}), seed dimorphism, autogamic and allogamic modes of reproduction and allelochemicals released that inhibit the growth and establishment of other species (Raizada, 2006). Further studies have also reported that the species was unpalatable for livestock which explained their higher density and biomass in rangelands (Aboh et al. 2008, Chatri et al. 2014, Sharma et al. 2017).

In croplands, *M. suaveolens* is not ranked among the most dominant species, and its density and dry matter production are significantly lower than those of other species. According to Raizada (2009), the limited invasion of *M. suaveolens* in croplands can be attributed to the cultivation of tall-growing crops such as pearl millet (*Pennisetum glaucum*), the use of chemical herbicides, and regular weeding practices.

Results of this study indicate that invasion by *M. suaveolens* is associated with a decline in species diversity, cover, equitability and composition. Species richness, Shannon-Wiener and Pielou indices of diversity declined in each increase of *M. suaveolens* density and biomass. Our results coincide with previous studies that have reported a decline in species diversity following *M. suaveolens* invasion (Sharma et al. 2009; Sharma et al., 2017, Aboh et al. 2010, Padalia et al. 2014).

M. suaveolens outcompetes native herbaceous flora for resources, e.g., light interception, moisture uptake, and nutrient assimilation because of its vigorous growth and taller size. Furthermore, the species releases allelopathic chemicals that disrupt the growth and establishment of native species (Sharma et al. 2017). It is worth noting that such modifications could contribute to limiting the natural regeneration of native plants.

M. suaveolens is an opportunistic species and grows faster than the native species and affects negatively the biodiversity of the newly invaded area (Padalia et al. 2014, Sharma et al. 2017). According to Shrestha et al. (2019) it is important to note that invasive species such as *M. suaveolens* are projected to exhibit significant range expansions due to their phenotypic plasticity and competitive advantages.

Consequently, there is an urgent need to devise effective and sustainable long-term management strategies. Previous studies have demonstrated that manual eradication through the excavation of rhizomes present in the soil remains the only effective approach for the complete elimination of the species (Ahmed et al., 2020). However, this method is both costly in terms of resources and time, and its large-scale implementation poses significant practical limitations.

5. CONCLUSION

The present study provides us with a glimpse of the detrimental impact of an invaded species, *M. suaveolens*, on the vegetation of three land use systems (croplands, fallows and rangelands) in the sub-tropical zone of Senegal. There is substantial evidence that the diversity index, density and biomass of native vegetation decrease with the increase of *M. suaveolens* cover, density and dry matter. These indicators are nonetheless insufficient to give all the information required by a land manager. Hence, more work will be necessary to elucidate how to maximize the biodiversity within invaded ecosystems. For better management and policy of sub-tropical ecosystems, it is therefore imperative to understand the impact of alien invasive species such as *M. suaveolens* on ecosystem pools and fluxes.

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Authors contributions

SLK and MG conceived and designed the experiments. SLK performed the experiments and analysed the data. SLK, MG and MOL sought funding. SLK, MG and RNO wrote the first draft.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study are present in the paper.

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