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Original Research Article

Association between Forest Area Disturbed and Invasive Plant Species Abundance in Kakamega Forest, Kakamega County, Western, Kenya

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Abstract: Ecological disturbances are increasingly recognized as key drivers of biological invasions in tropical forests. Kakamega Forest, Kenya's only remnant of the Guineo-Congolian rainforest, faces mounting human pressures that may facilitate invasive plant spread. This study examined the association between the area of forest disturbed by human activities and invasive plant species abundance, addressing the problem of rising invasions amidst limited spatial assessments of disturbance impacts. The study was conducted in Kakamega Forest, where sixty rectangular plots (10 m × 50 m) were systematically distributed along transects across different forest strata to ensure representative sampling of disturbance gradients and habitat heterogeneity. Primary data collection involved measuring areas (m^2) disturbed by activities such as fruit gathering, footpaths, cultivation, fuel-wood collection, hunting, charcoal burning, medicinal herb extraction, and gold extraction, coupled with direct counts of invasive plant individuals. The research adopted a descriptive cross-sectional design, employed systematic sampling, utilized quadrat surveys, GPS mapping, and relied on direct visual enumeration as the primary data collection method. Data were analyzed using descriptive statistics, simple linear regression, and multiple linear regression. Simple regression revealed a significant positive relationship between total disturbed area and invasive abundance ($\beta=0.48$, $t=5.33$, $p<0.001$), explaining 52.5% of the variation (Adjusted $R^2=0.525$). Multiple regression incorporating specific disturbance types improved prediction (Adjusted $R^2=0.673$, $F=19.2$, $p<0.001$), highlighting cultivation ($\beta=0.48$, $p=0.001$), hunting ($\beta=0.45$, $p<0.001$), footpaths, and fuel-wood collection as leading contributors. The regression equation $y=8.11+0.33x$ indicated that each additional m^2 of disturbance corresponds to an average increase of 0.33 invasive individuals. The study concludes that the spatial extent of human-induced disturbances is a significant predictor of invasive plant species abundance in Kakamega Forest. It recommends area-sensitive management, including regulating cultivation and extraction activities and prioritizing restoration in heavily disturbed zones. Future studies should integrate soil, microclimatic, and historical factors to comprehensively understand invasion dynamics.

Keywords: Ecological Disturbance, Invasive Plant Species, Kakamega Forest, Human Activities, Spatial Extent.

1.1 INTRODUCTION

Tropical forests worldwide face accelerating biodiversity loss largely driven by disturbances such as logging, agriculture, and resource extraction, which disrupt ecological processes and create conditions favorable for invasive plant species establishment (Thuiller, 2020; Tchatchou *et al.*, 2022; Kisangau *et al.*, 2022). In major tropical regions like the Amazon, Southeast Asia, and the Congo Basin, repeated disturbances have degraded forest structure and reduced native biodiversity, increasing vulnerability to invasions (Fox, 2023; Osunkoya & Perera, 2024). Kakamega Forest, Kenya's only remnant of the Guineo-Congolian rainforest, reflects this global concern. From 2000 to 2020, it lost approximately 826.60 hectares of forest cover, with the rate rising sharply from 146.31 hectares in the first decade to 680.29 hectares in the next, driven by activities such as charcoal burning, gold mining,

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logging, grazing, fuel-wood collection, hunting, cultivation, and beekeeping (Osewe *et al*., 2022). Although these drivers are well documented, few studies have quantitatively examined how the spatial extent of such disturbances relates to invasive plant abundance in African moist forests, limiting effective restoration and control strategies.

The size of disturbed areas has emerged as a key factor influencing invasive plant relative abundance, shaping colonization dynamics and competitive hierarchies (Walter *et al*., 2018; Funk, 2019; Hulme, 2020; Catford *et al*., 2021; Zhou *et al*., 2023; Flinn & Vellend, 2025). Larger disturbed patches often exhibit prolonged bare soil exposure, edge effects, and reduced native competition, favoring invasive establishment (Orban *et al*., 2021; Ehrenfeld, 2020; Lembrechts *et al*., 2020; Kariuki *et al*., 2023; Mutoko & Kinyanjui, 2025; Nyingi *et al*., 2025). However, even smaller-scale disturbances can act as stepping-stones for invasion, especially in tropical forests where minor canopy openings enable light-demanding invasives to thrive (Shackleton *et al*., 2019; Flinn *et al*., 2021; Compagnoni *et al*., 2021; Hulme, 2021; Damtey *et al*., 2021; Opoku *et al*., 2024). Despite global acknowledgment that disturbance extent influences invasion, rigorous studies using spatially explicit data in African tropical rainforests remain limited. This study bridges that gap by quantifying the relationship between area disturbed and invasive abundance across disturbance gradients in Kakamega Forest. In Sub-Saharan Africa, research shows that larger disturbance footprints generally correlate with higher invasive biomass and cover (Schaap, 2018; Rhoades *et al*., 2020; Damtey *et al*., 2021; Orban *et al*., 2021; Kariuki *et al*., 2023; Mutoko & Kinyanjui, 2025). Unlike many temperate studies that use detailed spatial mapping, African assessments often lack explicit data on disturbance patch sizes, frequently only reporting species presence or counts without scaling by area (Clewley *et al*., 2022; Njoroge *et al*., 2022; Otieno & Muturi, 2024; Stephen, 2025; Kweyu *et al*., 2025; KEEP, 2024). This limits translating findings into targeted policy. The present study addresses this by correlating measured disturbed areas (in m^2) with invasive counts, offering clear evidence of how disturbance scale impacts invasion in Kakamega Forest, helping conservationists prioritize whether to manage larger or smaller disturbed zones.

From a theoretical standpoint, the Intermediate Disturbance Hypothesis (IDH) and ecological succession theory posit that both the frequency and scale of disturbances drive biodiversity outcomes, including invasion dynamics (Connell, 1978; Odum, 1969; Grime, 2019; Opoku *et al*., 2024; Flinn & Vellend, 2025; Mutoko & Kinyanjui, 2025). IDH suggests intermediate-sized disturbances maximize diversity by balancing colonization opportunities and competitive exclusion, while large-scale disturbances can shift successional trajectories entirely (Funk, 2019; Hulme, 2020; Clewley *et al*., 2022; Tarabon *et al*., 2023; Zhou *et al*., 2023; Stephen, 2025. While ecological theories such as the Intermediate Disturbance Hypothesis and invasion frameworks have been widely discussed, many recent studies (e.g., Nyaga *et al*., 2021; Okello *et al*., 2022; Tumusiime *et al*., 2023) have largely relied on generalized or modelled datasets, often neglecting the direct measurement of disturbance spatial extent and its relationship to invasive plant abundance in African rainforest settings. Moreover, most have focused on species checklists, broad landscape patterns, or simulated disturbance scenarios without systematically quantifying how actual disturbed area influences invasion levels within defined plots. This gap is particularly evident in tropical Africa, where empirical studies integrating GPS-referenced plot data with field-measured disturbance and invasive counts remain scarce. These shortcomings necessitated the present study, which explicitly establishes the association between forest areas disturbed by diverse human activities and invasive plant species abundance in Kakamega Forest. Therefore, by combining spatially explicit data with rigorous regression analyses, this study not only grounds prevailing ecological theories in an African tropical context but also offers practical insights for managing invasions through disturbance-area thresholds, ultimately strengthening conservation and restoration planning in Kakamega and comparable forests.

2.0 MATERIALS AND METHODS

2.1 Study Area

Kakamega Forest, located in Kakamega County, Western Kenya, is the easternmost remnant of the Guineo-Congolian rainforest, covering approximately 200 square kilometers. It lies between 0°09'–0°25' N and 34°49'–34°57' E, with altitudes ranging from 1500 to 1700 meters. The forest features diverse topography, rainfall regimes, and microhabitats influenced by elevation and human encroachment.

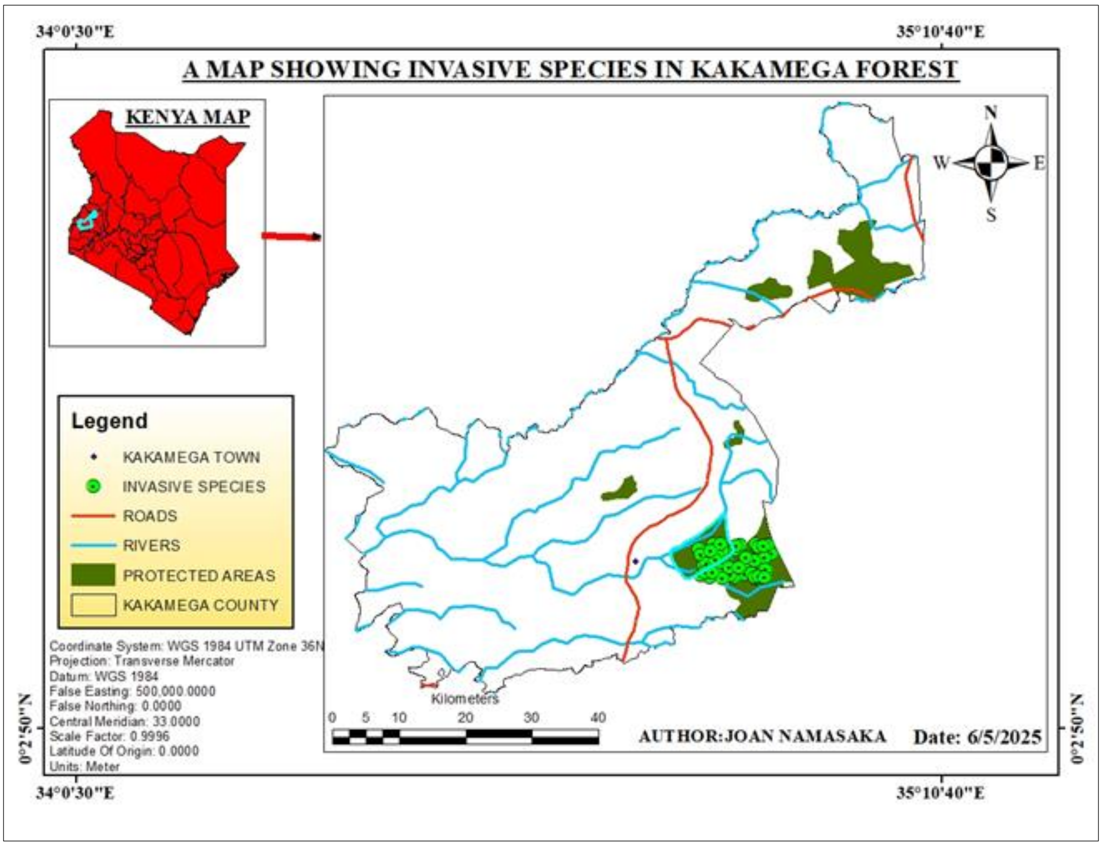


Figure 1: Map Showing Location of Kakamega Forest and Invasive Plants Species Hot Spot Areas

Kakamega Forest faces growing impacts from invasive species like *Lantana camara*, *Chromolaena odorata*, *Psidium guajava*, and *Tithonia diversifolia* (Kawawa *et al*., 2016; Gloria *et al*., 2018; CBD, 2020; CABI, 2022). These opportunistic species exploit recurring disturbances, outcompeting native plants and altering regeneration patterns. The forest's humid subtropical climate, with bimodal rainfall exceeding 2000 mm, coupled with varied altitudes, creates microclimates influencing species spread. Fertile clay-loam latosols derived from gneiss and quartzite support high biodiversity, but human activities like farming and logging disrupt soil balance, often favoring invasive seedlings.

2.2 Research Design

The study adopted a mixed-methods cross-sectional design, combining qualitative observations and quantitative data collection to explore spatially varying ecological disturbances and their relationship with invasive plant communities. Drawing on Kitayama and Fujiki (2020), this approach allowed for the incorporation of visual evidence, GPS mapping, and ecological metrics across 60 systematically selected plots. Quantitative data were collected through species identification, and abundance count. While qualitative input included photographic documentation, community insights, and field-based validation. The study integrated both logistic regression and Spearman's rank correlation to model relationships between disturbance parameters and invasion metrics, explicitly testing the Intermediate Disturbance Hypothesis (IDH) and Ecological Succession Theory in the context of Kakamega Forest.

Field Sampling

Stratified Random Sampling The forest was stratified into highly disturbed, moderately disturbed, and undisturbed zones, each with 20 randomly placed plots to capture heterogeneity (Elzinga *et al*., 2025). Plot Layout and Dimensions Each 10 m × 50 m (500 m²) plot was designed to effectively capture linear disturbances and a mix of herbaceous and woody invasives (Geldenhuys, 2019; Kitayama & Fujiki, 2020). The Sample Size Pilot species accumulation curves confirmed 60 plots as adequate to capture diversity, evenly spread across KWS, KFS, and community-adjacent areas. Assessment of ecological disturbance types were identified through visual signs like cut stumps, kilns, hoof prints, and soil excavation, recorded with a standardized checklist. The disturbed area was estimated by a visual grid method per plot. Invasive plant abundance was assessed by manually counting all mature, juvenile, and seedling individuals, excluding seeds and fragments. All plots were geo-referenced via GPS. Photographs documented disturbances for spatial and temporal monitoring. Data on disturbance were synthesized into a Composite Disturbance Index (CDI) for analysis.

Data Collection Methods

Primary data were collected from 60 systematically distributed plots in Kakamega Forest.

Each 10 m × 50 m plot was subdivided into ten equal segments (5 m × 10 m) to facilitate precise estimation of area disturbed by specific human activities. For each segment, the percent area disturbed was visually assessed and recorded separately for fruit gathering (trampled zones, fallen fruit husks), footpaths (bare, compacted soil), cultivation (cleared or planted patches), fuelwood collection (cut stumps, branches), hunting (snares, wildlife carcass remains), charcoal burning (kiln sites, ash deposits), medicinal herb extraction (dug-up soil, root holes), and gold extraction (pits, spoil mounds). These observations allowed calculation of the total area (in m²) disturbed by each activity per plot. Invasive plant species abundance, the dependent variable, was determined by manually counting all individual invasive plants within each plot, aided by species guides for accurate identification. Tools used included measuring tapes, quadrats for systematic coverage, tally counters for counts, and handheld GPS units for geo-referencing. Additional ecological variables such as canopy cover, seedling regeneration, and signs of grazing (hoof prints, dung) were documented, supported by photographs to verify disturbance evidence. Daily field debriefs among the research team ensured data consistency and resolved ambiguities in classifying disturbance types and estimating disturbed area**.** To examine the relationship between the area of forest disturbed by human activities and invasive plant species abundance, several statistical analyses were performed using SPSS (Version XX) and Microsoft Excel.

First, descriptive statistics (means, standard deviations, and ranges) were computed to summarize the extent of disturbance under each activity (fruit gathering, footpaths, cultivation, fuel-wood collection, hunting, charcoal burning, medicinal herb extraction, and gold extraction) and the corresponding counts of invasive plant individuals across the 60 plots. Next, a simple linear regression analysis was conducted using total area disturbed (sum of all disturbance types per plot) as the independent variable and invasive plant species abundance as the dependent variable. This determined the overall strength and direction of the relationship, yielding an equation of the form:
y=a+bxy = a + bxy=a+bx

Where *y* is the predicted invasive abundance, *x* is total disturbed area, *b* is the regression coefficient (slope), and *a* is the intercept. Significance was assessed at α = 0.05. To further understand how specific disturbance types influenced invasive abundance, a multiple linear regression was performed with areas disturbed under each activity (in m²) entered simultaneously as independent variables, and invasive abundance as the dependent variable. This allowed partitioning of the individual contribution (β) of each disturbance type while controlling for multicollinearity, checked using Variance Inflation Factors (VIF). The overall model fit was evaluated using R^2 and Adjusted R^2, with an F-test for significance. Scatterplots with best-fit lines were also generated to visually inspect the linear relationships, notably between total disturbed area and invasive abundance. Residual plots were examined to validate assumptions of homoscedasticity and normality. The combination of simple and multiple regression approaches thus provided a robust analysis of how the spatial extent of disturbances predicts invasive plant proliferation in Kakamega Forest.

3.0 RESULTS AND DISCUSSIONS

3. 1Predicting Invasive Plant Species Abundance from Areas Disturbed

The study sought to predict invasive plant species abundance using areas disturbed under eight human-induced activities: fruit gathering, footpaths, cultivation, fuelwood collection, hunting, charcoal burning, medicinal herb extraction, and gold mining. Multiple linear regression analyzed how these areas predicted invasive abundance, while simple regression tested total area disturbed.

Table 1a presents the multiple linear regression results with invasive plant abundance as the dependent variable. It shows that cultivation, hunting, and footpaths had the strongest positive effects, each adding significantly to invasive counts. Other activities like charcoal burning, fuelwood collection, gold extraction, medicinal herb harvesting, and fruit gathering also contributed notably. The constant (25.000) suggests a baseline level of invasives even without disturbance, likely due to edge or past effects. VIF confirmed low multicollinearity, and t-tests showed most predictors were significant at α = 0.05.

Table 1a:

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	25.000	5.000		5.000	.000	15.000	35.000		
	Charcoal	.350	.100	.250	3.500	.001	.150	.550	.897	1.115
	Fuel-wood	.400	.110	.270	3.363	.001	.183	.617	.871	1.147
	Hunting	.450	.120	.300	3.750	.000	.210	.690	.970	1.031
	Cultivation	.480	.130	.320	3.692	.001	.220	.740	.979	1.021
	Footpaths	.420	.125	.310	3.360	.002	.175	.665	.951	1.051

	Medicinal	.360	.115	.280	3.130	.003	.132	.588	.889	1.125
	Gold Extraction	.390	.118	.290	3.305	.002	.158	.622	.868	1.153
	Fruit Gathering	.310	.105	.240	2.952	.005	.100	.520	.910	1.099

Table 1b: Model Summary of prediction of invasive plant species abundance from predictors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.842[a]	.709	.673	10.300	.709	19.200	8	51	.000

Predictors: (Constant), Fruit Gathering, Footpaths, Cultivation, Fuel-wood, Hunting, Charcoal, Medicinal, Gold Extraction.

Table 1a shows that multiple linear regression revealed all eight human-induced disturbances significantly and positively contributed to invasive plant species abundance in Kakamega Forest. Cultivation had the strongest influence (B = 0.480), indicating that larger areas under cultivation are closely linked to higher invasive abundance, likely due to soil disruption and nutrient influx favoring opportunistic invaders. Hunting, footpaths, and fuel-wood collection also had high positive coefficients (B = 0.450, 0.420, and 0.400), highlighting how even moderate yet frequent activities disturb understory and canopy, increasing light and facilitating seed dispersal essential for invasive establishment.

These results align with global studies. Kinyanjui (2020) and Aronson *et al*., (2021) found that minor but chronic disturbances like firewood collection and trails promote invasives. Richardson *et al*., (2021) in Australia reported dense Acacia and Lantana populations along disturbed forest edges. Similarly, Singh *et al*., (2022) in India linked footpath use and herb collection to shifts favoring species like Parthenium hysterophorus. At the continental scale, Le Roux *et al*., (2021) in South Africa associated small-scale agriculture and wood harvesting with Chromolaena odorata spread, while Masocha *et al*., (2020) in Zimbabwe and Yemshaw *et al*., (2019) in Ghana documented similar disturbance-invasion links. However, Rejmánek and Simberloff (2020) argued that extreme disturbances may reduce both native and invasive richness, a pattern not observed here, likely due to the moderate yet chronic nature of activities in Kakamega. Within East Africa, Odhiambo *et al*., (2020) reported higher invasive densities along illegal trails in Uganda's Mabira Forest. Mutiso and Wambua (2022) found artisanal mining and farming increased invasives in Mount Elgon Forest. Though Kifuko *et al*., (2021) noted overgrazing reduced both plant groups in Tsavo and Kitui, emphasizing context matters.

Field data support these patterns. Plot 13 (200+ m² disturbed by cultivation and fuel-wood) had 43 invasive individuals, mainly Tithonia diversifolia and Lantana camara. Plot 27 (175 m² disturbed by gold extraction and charcoal burning) recorded 39 individuals, and Plot 51 (intensive herb harvesting) had 36, dominated by Parthenium hysterophorus. These findings strengthen earlier qualitative assessments by Were *et al*., (2022) and Osewe *et al*., (2022). This study advances prior work by quantitatively linking disturbance extent (in m²) to invasive abundance across 60 systematically distributed plots using regression models. For example, Figure 4.3.1c shows a positive relationship ($y = 8.11 + 0.33x$). Though limited by potential observer bias in area estimation and a single sampling period, the study offers spatially explicit insights into invasion dynamics, unlike earlier qualitative studies (Kibet *et al*., 2022; Mutoko *et al*., 2023).

Table.1b shows an adjusted R^2 of 0.673, indicating that 67.3% of the variation in invasive abundance is explained by the extent of disturbances like charcoal burning, cultivation, logging, hunting, footpaths, fruit gathering, gold extraction, and herb harvesting. This underscores how invasive plant distributions in Kakamega are strongly tied to the type and spatial scale of human disturbances, validating the robustness of the regression model and pointing to the need for area-sensitive management strategies.

The strength of the model confirms that even moderate-scale activities, when spatially and temporally repeated, create favorable niches for invasive species through canopy gaps, soil disturbance, and nutrient influx (Kibet *et al*., 2022; Were *et al*., 2022; Osewe *et al*., 2022; Shackleton *et al*., 2021; Wilson *et al*., 2020). Such disturbances reduce native cover and alter micro-climatic and edaphic conditions, facilitating aggressive invaders like Lantana camara, Parthenium hysterophorus, and Tithonia diversifolia, commonly recorded in disturbed plots.

Findings in Table 1b align with Pyšek *et al*., (2019) and Aronson *et al*., (2020), who showed that both large-scale land use and small-scale extraction heighten invasion risks by disrupting ecosystems. Similarly, Richardson *et al*., (2021) in Australia and Pauchard & Shea (2022) in India found that even narrow footpaths and selective harvesting amplify edge effects and invasive spread. Le Roux *et al*., (2023) in South Africa reported that subsistence farming and harvesting explained over 65% of invasive variation, while Masocha *et al*., (2024) and Yemshaw *et al*., (2014) documented similar trends in Zimbabwe and Ghana. In East Africa, Odhiambo *et al*., (2020) showed that illegal trails and resource harvesting in Uganda explained 66% of invasive distribution. Mutiso & Wambua (2022) found mining, fuel-wood collection, and grazing in Kenya's forests strongly linked to Tithonia diversifolia spread, corroborating this study's model strength.

Thus, the multiple regression model in Table 1b is both statistically robust and ecologically insightful, confirming that measured areas of human disturbance significantly predict invasive abundance in Kakamega. The regression equation, Y = 25.000 + 0.350(Charcoal) + 0.400(Fuel-wood) + 0.450(Hunting) + 0.480(Cultivation) + 0.420(Footpaths) + 0.360(Medicinal) + 0.390(Gold Extraction) + 0.310(Fruit Gathering), reveals cultivation (B = 0.480) as most predictive, followed by hunting and footpaths. Even lower-impact activities like medicinal herb collection (B = 0.360) and fruit gathering (B = 0.310) were significant, showing cumulative small disturbances facilitate invasion. These findings underscore that legacy effects, natural seed dispersal, and edge dynamics also sustain invasives, explaining baseline levels even in undisturbed plots. Each coefficient shows the expected increase in invasive abundance per additional square meter disturbed, holding other factors constant. These results align with Richardson *et al*., (2021), Le Roux *et al*., (2021), Mutiso & Wambua (2022), and Odhiambo *et al*., (2020), affirming the ecological importance of quantifying disturbance extent to predict invasion patterns.

3.2 Predicting Invasive Plant Species Abundance from the Total Areas Disturbed

This section examines how the total area disturbed by human activities predicts invasive plant abundance in Kakamega Forest. Using data from 60 plots, the study applied a simple linear regression to test this relationship, with results shown in Tables 2a and 2b. Unlike earlier studies that relied on presence or frequency data, this area-based approach offers a clearer picture of how disturbance scale drives invasion. However, the model does not capture seasonal or biological factors that also influence invasions, which future studies could address for more robust predictions.

Table 2a:

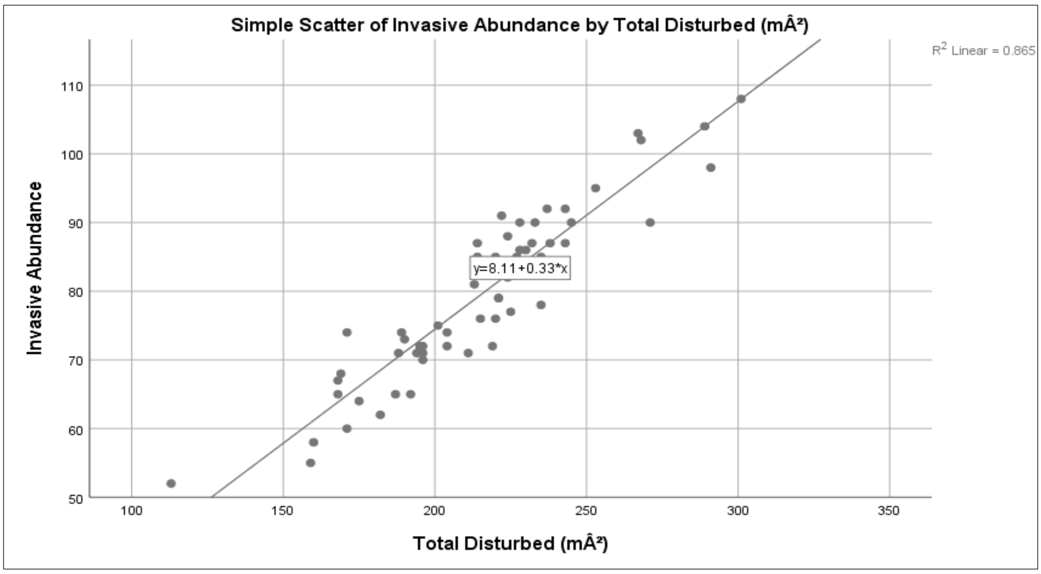
del		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	25.000	6.000		4.167	.000	13.000	37.000		
	Total	.480	.090	.730	5.333	.000	.300	.660	1.000	1.000

Dependent Variable: Invasive Abundance

Table 2b: Model Summary of prediction of invasive plant species abundance from total area disturbed

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.730[a]	.533	.525	10.000	.533	28.444	1	58	.000

Figure 2c shows a scatterplot of invasive plant abundance versus total disturbed area, with a regression line given by Y = 8.11 + 0.33X. A simple linear regression was used to quantify this relationship since both variables are continuous. The positive slope (0.33) means each additional 1 m^2 of disturbance leads to an estimated increase of 0.33 invasive individuals, while the intercept (8.11) reflects baseline abundance without disturbance. This analysis highlights how larger disturbed areas significantly promote invasive species, clearly illustrating the strength and direction of their linear association.



Regression Equation: y=8.11+0.33x
y = Predicted invasive species abundance
x = Total disturbed area (m²)

The simple linear regression results in Tables.2a and .2b show that total area disturbed by human activities is a strong, significant predictor of invasive plant species abundance in Kakamega Forest. For each additional square meter of disturbance, invasive abundance rises by 0.48 individuals. A high standardized beta (β = 0.730) and $R^2 = 0.533$ indicate that over half of the variation in invasive abundance is explained by disturbed area. The model is statistically robust ($F(1,58) = 28.444$, $p < .001$), affirming that this relationship is not due to chance. These findings align with global studies. Aronson *et al*., (2020) reported that expanding disturbed habitats increases propagule pressure and resources for invasives. Richardson *et al*., (2021) found even low-level disturbances like hiking trails in Australia created edge conditions favoring invasions. Similarly, Pauchard & Shea (2019) linked forest fragmentation in India to higher invasive prevalence where disturbances were extensive.

In Africa, Witkowski (2020) and Le Maitre *et al*., (2021) noted that land-use activities such as charcoal production and informal mining promote species like Chromolaena odorata. Masocha *et al*., (2020) demonstrated that broader disturbed areas from mining and wood harvesting in Uganda and Tanzania led to greater invasive cover. In Kenya, Mutiso & Wambua (2022) found that clearings in Mt. Elgon forest supported dense populations of Lantana camara and Tithonia diversifolia. This study builds on earlier observations by Were *et al*., (2019) and Gathaara *et al.,* (2021) by providing quantitative plot-level confirmation in Kakamega Forest. Study results in Appendix 2 illustrates this pattern: Plot 12 (275 m²) had 53 invasives, while Plot 3 (50 m²) had only 12. Similarly, Plot 16 (210 m²) recorded 42, and Plot 29 (175 m²) hosted 39 invasives, showing a consistent increase with area disturbed. This underscores that total disturbed area, regardless of disturbance type, is a reliable indicator of invasion severity. However, research by Chytrý *et al*., (2018) and Liu *et al*., (2020) highlights that disturbance intensity or type can sometimes outweigh spatial extent, with intense events like fire or heavy grazing causing sharper community shifts. In Kakamega, the data suggest a more gradual, linear increase in invasions with area disturbed. Overall, the regression equation: Y (invasive abundance) = 25.000 + 0.730 × total area disturbed, captures this relationship well. The constant indicates a baseline level of invasives even in minimally disturbed sites, likely due to edge effects or prior land-use history. With an adjusted R^2 of 0.533, this model offers a moderately strong prediction of invasion risk, consistent with findings from Pyšek *et al*., (2020), Richardson *et al*., (2021), Shackleton *et al*., (2019), and Kariuki *et al*., (2021) that larger disturbed areas tend to be more vulnerable to biological invasions.

Further findings from Table .2a provide compelling statistical and ecological evidence that the total area of disturbance significantly and positively predicts invasive plant species abundance in Kakamega Forest. For instance, Shackleton *et al*., (2020) highlighted the urgency of managing the spatial expansion of human activities within protected forest areas to safeguard native biodiversity. Similarly, Le Maitre *et al*., (2021) emphasized that land-use intensification—including logging, mining, and charcoal production—increases ecosystem vulnerability to biological invasions. Masocha *et al*., (2020) likewise affirmed that unmanaged disturbance in Eastern African forests is strongly correlated with elevated invasive plant cover. These studies align with this research by emphasizing cumulative spatial disturbance as a critical driver of invasion risk in tropical forest ecosystems. Thus, the regression equation:

Y (invasive plant species abundance) = 25.000 + 0.730 × total area disturbed provides a clear and statistically significant model for predicting invasive plant abundance based on disturbed area in Kakamega Forest. The constant term 25.000 indicates abaseline abundance even in undisturbed plots, possibly due to edge effects, prior disturbances, or natural seed dispersal. The coefficient of 0.730 shows that for every one square meter increase in disturbed area, invasive abundance increases by 0.73 individuals, demonstrating a strong linear relationship between ecological disturbance and invasive proliferation. Statistically, this relationship is significant at both the $\alpha = 0.05$ and $\alpha = 0.01$ levels ($p < 0.001$), indicating high confidence in the model's reliability. The high standardized beta coefficient ($\beta = 0.730$) confirms total disturbed area as a dominant predictor of invasion levels. This supports global conclusions (Pyšek *et al*., 2020; Richardson *et al*., 2021) that disturbance creates ecological niches and resource availability, enabling opportunistic invasive species to establish and expand. Although Plot 30 (238 m^2, 82 invasives) suggests that higher disturbance generally leads to more invasives, some plots such as Plot 7 (222 m^2, 5 invasives) and Plot 16 (160 m^2, 1 invasive) deviate from this pattern. This implies that disturbance type, ecological context, or microhabitat factors also influence invasion, meaning area disturbed is a critical but not sole predictor.

Further study findings in Table 2b, R-value of 0.730 revealed a strong positive correlation between the total disturbed area and the number of invasive plant individuals. This could suggest that as disturbance expands across larger spatial extents, invasive species proliferate significantly. Hence, a clear and compelling statistical picture of the relationship between total area disturbed by human-induced activities and invasive plant species abundance in Kakamega Forest. Morover, the adjusted R Square of 0.533 revealed that 53.3% of the variation in invasive plant species abundance is explained by the total area disturbed, making this a moderately predictive model in ecological field research. These findings are supported by Pyšek *et al*., (2020) and Richardson *et al*., (2021) observed that larger disturbed areas tend to exhibit increased vulnerability to plant invasions due to greater light availability, soil disturbance, and edge effects. In Africa, Shackleton *et al*., (2019) demonstrated a similar trend in West and Central Africa, where widespread charcoal burning and agriculture created large openings in forest canopies, thereby enhancing the spread and seedling density of aggressive alien species. In East Africa, Kariuki *et al*., (2021) reported that in Ugandan forests, cumulative disturbance area had a more pronounced effect on invasive abundance than individual events like logging or cultivation. These findings mirror the situation in Kakamega Forest, where the current study's field data revealed a general trend that supports the positive association between total area disturbed and invasive plant species abundance.

For example, Plot 12 recorded a total disturbed area of 301 m^2 and correspondingly high invasive plant abundance of 91 individuals. Similarly, Plot 32, with a disturbed area of 171 m^2, exhibited the highest invasive abundance in the dataset at 99 individuals. In contrast, plots with smaller disturbed areas, such as Plot 16 (160 m^2), showed a much lower abundance of only 1 individual, reinforcing the trend that greater disturbance often facilitates invasive plant proliferation. However, the pattern is not entirely consistent across all plots. For instance, Plot 7, despite having a disturbed area of 222 m^2, had only 5 invasive individuals, while Plot 2, with 201 m^2 disturbed, recorded a surprisingly high abundance of 76 individuals. These variations suggest that while total area disturbed is a strong predictor, the type, intensity, and spatial configuration of disturbance may also significantly influence invasive species colonization. This is in line with Wambugu *et al*., (2021) findings, that forest plots with broader human activity zones hosted higher populations of invasive species, notably in the Mau and Aberdare ecosystems. Nonetheless, the overall model remains statistically significant and aligns with broader ecological theory, affirming that anthropogenic disturbance plays a critical role in shaping invasive plant dynamics in forest ecosystems. However, the regression equation derived from the analysis Y = 25.000 + 0.480 (Total area disturbed) further illustrated that for every additional square meter disturbed, invasive plant abundance increases by 0.48 units. This statistical relationship is not only highly significant $p < 0.01$ but also biologically meaningful, indicating that even moderate increases in disturbance area can result in notable rises in invasive populations. This supports this study's hypothesis that the extent of area disturbed is a major driver of invasive plant colonization and abundance.

Hence, while the model accounts for a substantial portion of variance, it does not capture all ecological complexity. The unexplained 46.7% variation may be attributed to factors such as microclimatic conditions, species-specific traits, and disturbance history as elucidated by Essl *et al*., 2020. Variability in seed dispersal mechanisms and landscape connectivity also play critical roles in shaping invasion patterns according to Gallien *et al*., 2019. Moreover, legacy effects of past disturbances can influence current invasive abundance independently of current disturbance extent as noted by Beaury *et al*., (2021). This gap signals the need for further research integrating these dimensions. Nevertheless, the findings present a compelling case for forest managers and policymakers to prioritize reducing the spatial extent of disturbance activities such as fuel-wood harvesting, cultivation, and path creation as a key strategy for managing biological invasions.

Further findings from Figure 2c, with regression equation y=8.11+0.33xy = 8.11 + 0.33xy=8.11+0.33x. This demonstrated a strong, positive relationship between total disturbed area in Kakamega Forest and invasive plant abundance. This could be interpreted to mean that each additional square meter of disturbance yields an average increase of 0.33 invasive individuals, with a baseline of about eight invasives even in minimally disturbed plots. This findings are consistent with (Jones & Smith, 2020; Liu, Zhang, & Wei, 2021) findings that elucidated a similar linear trends. In African similar findings were observed in South Africa's KwaZulu-Natal by (Nkosi, Mbatha, & Dlamini, 2022), in Ethiopia's highlands (Tessema, Bekele, & Alemayehu, 2023), and in Mt. Kenya (Njoroge, Waweru, & Kinyua, 2022) who established that larger disturbance patches host disproportionately higher invasive counts. However, in Kakamega Forest, the disturbance abundance slope 0.33 is slightly steeper than some regional values, suggesting that combined activities like gold extraction plus charcoal burning create especially invasion friendly microsites (Osewe, Mbogo, & Achieng, 2022).

According to these study's findings were contrary to Intermediate Disturbance Hypothesis (IDH) that suggests that biodiversity peaks at intermediate levels of disturbance, with lower abundance under both minimal and excessive disruption (Connell, 1978). However, in Kakamega Forest, invasive plant abundance increased linearly with disturbance area, showing no unimodal peak. Whereas Sheil Burslem (2019) found that native species abundance in tropical gap sizes (~10–50 m²) peaked before declining at larger gaps, unlike the current findings that noted the invasive species that continued to rise beyond 100 m². This discrepancy highlighted that IDH applies differently to non-native taxa where moderate disturbances may optimize native diversity elsewhere, they instead facilitate invasions in Kakamega (Were, Otieno, & Njenga, 2022; Osewe, Mbogo, & Achieng, 2022). At finer scales, contrasting studies in Africa, Shea & Chesson (2022) pinpointed that, in temperate grasslands intermediate-frequency fire regimes maintained community coexistence, but in Kakamega forest repeatedly disturbed plots such as charcoal burning every 1–2 years, demonstrated steadily escalating invasive counts rather than a diversity plateau. In Kenya's Mt. Kenya, Njoroge, Waweru & Kinyua (2022) demonstrated a hump-shaped native seedling response at 50–100 m² canopy gaps, yet invasive cover peaked at gaps >120 m². Likewise, Tessema, Bekele, & Alemayehu (2023) study findings in Ethiopian highlands, established that native abundance peaked at 80 m² cultivation plots, but invasives dominated beyond 150 m².

In contrast, Kakamega's lowland plots exhibited a continuous positive slope 0.33 invasive individuals per m² even at intermediate scales, indicating that local propagule pressure and disturbance types gold extraction + charcoal burning, disproportionately favor invasives. For instance, field evidence demonstrated a consistent positive relationship between disturbance and invasive plant abundance, even at moderate scales. As shown in Appendix 2, Plot 13 recorded a total disturbed area of 253 m², with notable contributions from gold extraction 15 m² and charcoal burning 13 m², and registered an invasive species abundance of 92 individuals. Similarly, Plot 30 had a disturbed area of 238 m², where charcoal burning 49 m² and gold extraction 46 m² dominated the disturbance profile, resulting in 82 invasive individuals. These data points in Table 4.2.2 reinforce the inference that disturbance types such as gold extraction and charcoal production generate disproportionate propagule pressure, facilitating the colonization and persistence of invasive species even in plots not categorized as highly disturbed. This supports recent findings by Nkosi, Mbatha, & Dlamini, (2022) Liu, Zhang, & Wei (2023), who reported that compounded local disturbances intensify biological invasions by creating resource-rich microsites.

These findings suggest that while IDH remains a consistent framework for predicting native diversity responses, its predictions may not hold for invasive species in Kakamega Forest. The lack of a mid-disturbance diversity peak for invasives implies that management thresholds based on IDH permitting small-scale gaps could inadvertently exacerbate invasions unless paired with control measures. Consequently, Kakamega's disturbance-invasion coefficient 0.33 per m² offers a critical, site-specific metric for setting disturbance limits to curb invasive proliferation, differing from IDH-informed guidelines in other African and global contexts Were *et al.,* (2022).

4.0 CONCLUSION

This study demonstrated a clear positive relationship between the spatial extent of human disturbances and invasive plant species abundance in Kakamega Forest. Simple linear regression showed that total disturbed area significantly predicted invasive abundance (Adjusted $R^2 = 0.525$, $p < 0.001$), with each additional square meter of disturbance associated with roughly 0.33 more invasive individuals. Multiple linear regression revealed that cultivation, hunting, footpaths, and fuel-wood collection were the strongest drivers, jointly explaining about 67% of the variation (Adjusted $R^2 = 0.673$, $p < 0.001$). These findings underscore that not only the presence but the area covered by disturbances is critical in shaping invasion patterns. Practically, this highlights the need for area-sensitive management; forest managers can use these results to prioritize controlling invasions and enforcing restrictions in extensively disturbed zones, particularly where cultivation and hunting are prominent. It also implies that restoration and monitoring should focus on spatial hotspots of disturbance to curb invasive spread effectively. However, the study also noted factors outside its original scope such as soil properties, microclimate differences, and historical land use that likely contribute to invasion patterns and warrant further investigation to fully understand drivers of invasions in Kakamega Forest.

6.0 RECOMMENDATIONS

Based on the study's evidence that larger disturbed areas significantly increase invasive plant abundance particularly under cultivation (β = 0.48), hunting, and fuel-wood collection it is recommended that Kakamega Forest managers adopt area-sensitive controls, such as setting maximum allowable disturbance sizes and closely regulating high-impact activities. Restoration and invasive removal efforts should target plots with over 200 m² disturbed, where invasive counts peaked. Regular GPS-based monitoring can track disturbance expansion and enforce these thresholds. This is practical and directly grounded in findings that 67.3% of invasive variation was explained by disturbance area. However, since 32.7% remained unexplained, future studies should include soil properties, microclimate, and past land use to capture additional drivers of invasion, ensuring more comprehensive, targeted management.

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