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Estimation of carbon stock in areas invaded by invasive plants (*Calliandra houstoniana*) in the Bung Hatta Grand Forest Park, West Sumatra, Indonesia

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Abstract. *Solfiyeni, Azzahra A, Mildawati, Ritonga MA. 2025. Estimation of carbon stock in areas invaded by invasive plants (*Calliandra houstoniana*) in the Bung Hatta Grand Forest Park, West Sumatra, Indonesia. Asian J For 9: 312-321.* Bung Hatta Grand Forest Park, located in West Sumatra, Indonesia, is an ecologically important area characterized by high biodiversity and a significant role in carbon storage. However, the invasion of alien plant species threatens both species diversity and carbon reserves within this ecosystem. This study aimed to quantify biomass, carbon stocks, and carbon dioxide sequestration in areas invaded by *Calliandra houstoniana* and to compare them with non-invaded areas. The research was conducted between September 2023 and February 2024, using a quadrat method. Two plot locations were selected: one invaded and one uninvaded by *C. houstoniana*. At each location, a 20 × 50 meter plot was created, divided into 10 subplots: 10 × 10 meters for tree observation, 5 × 5 meters for sapling observation, and 2 × 2 meters for seedling and ground vegetation observation. Data on trees and saplings were collected using non-destructive methods, while understory vegetation was sampled destructively. The invasion by *C. houstoniana* resulted in substantial declines in ecosystem carbon storage. In the area associated with *C. houstoniana*, the total biomass, carbon stock, and CO_2 sequestration were 66.515 t/ha, 33.606 t/ha, and 123.37 t/ha, respectively, indicating a decrease of 76-78% compared to the area not associated with the species (300.216, 141.11, and 517.8 t/ha, respectively). These findings indicate that *C. houstoniana* association significantly reduces carbon stocks and sequestration capacity. Therefore, immediate management interventions are necessary to control its spread and mitigate further biodiversity and carbon losses.

Keywords: Biomass estimation, *Calliandra houstoniana*, carbon stocks, invasive plants, native vegetation

Abbreviations: AGB: Above-Ground Biomass, CO_2: Carbon Dioxide, DBH: Diameter at Breast Height, GFP: Grand Forest Park, IAS: Invasive Alien Species, IPCC: Intergovernmental Panel on Climate Change, PCA: Principal Component Analysis, THR: Taman Hutan Raya, WW: Wet Weight, DW: Dry Weight, PAST: Paleontological Statistics Software Package

INTRODUCTION

Global warming represents a profound ecological imbalance characterized by increasing average temperatures across the atmosphere, oceans, and terrestrial ecosystems. This phenomenon is primarily driven by elevated greenhouse gas emissions and the disruption of natural ecosystem processes, resulting in climate change manifested through altered temperature and precipitation patterns, biodiversity loss, and a decline in vegetation capacity for carbon sequestration (Bolan et al. 2024). Enhancing carbon sequestration in forest ecosystems is widely recognized as an effective strategy for mitigating greenhouse gas emissions. Indonesian forests, with their exceptionally high biodiversity, play a vital role in absorbing atmospheric carbon through photosynthesis and maintaining complex ecological interactions that regulate carbon dynamics (Al Kafy et al. 2023; Nur et al. 2024).

The carbon sequestration capacity of forests is closely linked to their biomass, which includes above-ground components such as stems, branches, leaves, flowers, and fruits, as well as below-ground structures like roots, and other carbon pools including dead organic matter, soil, and long-lived wood products (Mo et al. 2023). Forests with higher biomass generally store greater amounts of carbon, thereby making substantial contributions to climate change mitigation (Wulandari et al. 2021). However, the continuous rise in atmospheric CO_2 concentrations has intensified the greenhouse effect while simultaneously degrading forest functionality. Consequently, maintaining the integrity of tropical forest ecosystems is critical to preserving both biodiversity and carbon storage capacity.

Bung Hatta Grand Forest Park (Tahura Bung Hatta), located in West Sumatra, Indonesia, exemplifies this dual ecological importance. Serving as both a conservation forest and a buffer zone for the city of Padang, it provides essential ecosystem services such as water regulation, air purification, and biodiversity conservation, supporting numerous rare and endemic species (Solfiyeni et al. 2022a). However, these ecological assets are increasingly threatened by the spread of invasive plant species. Such species often outcompete native vegetation, disrupt ecosystem equilibrium, and diminish biodiversity (Richardson et al. 2014; Solfiyeni et al. 2024a). In Indonesia, alien plant introductions have occurred through cultivation, experimental planting, ornamental landscaping, and botanical garden collections, several of which have been documented as ecologically disruptive (Srivastava et al. 2014; Solfiyeni and Nurmalasari 2025).

Empirical studies have demonstrated the ecological costs of these invasions in Indonesia. For instance, *Bellucia pentamera* altered community composition and reduced species richness in the PT KSI conservation forest, South Solok (Solfiyeni et al. 2023), while *Merremia peltata* invasion lowered carbon stocks in Bukit Barisan Selatan National Park (Mardiati et al. 2018). Globally, numerous studies confirm that alien plant invasions reduce both biodiversity and carbon sequestration potential (Patra and Saikia 2025). These findings highlight that invasive species pose a dual threat by eroding biodiversity and diminishing forest capacity to mitigate climate change.

Despite such evidence, a knowledge gap remains regarding the ecological impacts of *Calliandra houstoniana* in Tahura Bung Hatta. Previous research has reported its dominance and associated declines in species diversity, reflected in high Importance Value Index scores and reduced diversity indices (Solfiyeni et al. 2024b). However, its influence on biomass accumulation, carbon storage, and CO_2 uptake—key ecosystem processes directly linked to climate regulation—remains poorly understood. Addressing this gap is crucial for enhancing scientific understanding and guiding management strategies for invaded conservation forests.

Therefore, this study aims to quantify biomass, carbon stocks, and CO_2 uptake in both *C. houstoniana*-invaded and non-invaded areas of Tahura Bung Hatta. It is hypothesized that invaded areas will exhibit significantly lower biomass, carbon storage, and CO_2 sequestration compared with non-invaded sites. The results are expected to provide empirical evidence of the ecological consequences of *C. houstoniana* invasion on carbon dynamics, offering insights that can support conservation policy and invasive species management in Indonesian tropical forests.

MATERIALS AND METHODS

Study area

This study was conducted in Bung Hatta Grand Forest Park (Tahura Bung Hatta), located in Padang City, West Sumatra Province, Indonesia. The topography of the park varies from flat and hilly terrain to steep slopes ranging between 10% and 50%. The elevation ranges from a minimum of 460 m to a maximum of 740 m above sea level. The region experiences an average annual rainfall of 2,500-4,000 mm, relative humidity between 52% and 89%, and temperatures ranging from 19°C to 32°C (Dinas Pertanian Kota Padang 2017). Field observations were conducted in two distinct areas within Tahura Bung Hatta: one site invaded by *C. houstoniana* and another site not invaded by this species (Figure 1).

Data collection

Data were collected using the quadrat method with purposive sampling. Observation plots were established in two locations within Tahura Bung Hatta: one invaded by *C. houstoniana* and one not invaded (Loc 1 and Loc 2 in Figure 1). At each site, a main plot measuring 20×50 m was established and subdivided into 10 subplots measuring 10×10 m for tree vegetation (DBH≥10 cm). Additional subplots measuring 5×5 m were used for sapling vegetation (young trees with DBH 2-10 cm), and 2×2 m subplots were used for understory vegetation (seedlings and undergrowth with stem diameters <2 cm).

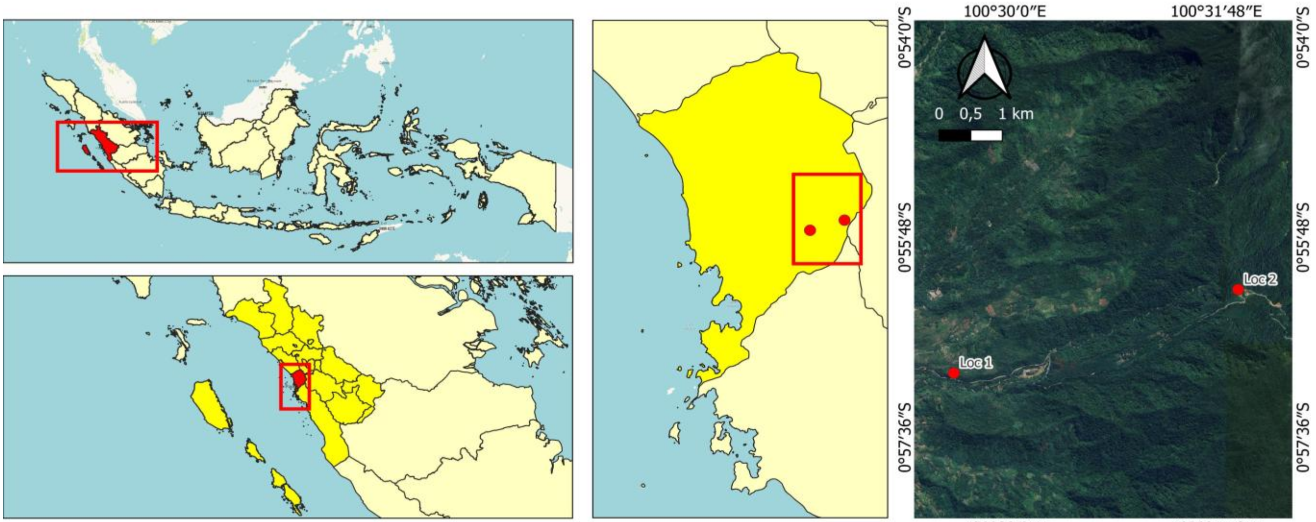

Figure 1. Locations of Loc 1: Invaded and Loc 2: Non-invaded by *Calliandra houstoniana* in Bung Hatta Grand Forest Park, West Sumatra, Indonesia

Tree and sapling data were collected using a non-destructive sampling method following Hairiah and Rahayu (2007). Within each subplot, the number of individuals was recorded, and the diameter and height of each tree and sapling were measured. Plant specimens were collected and subsequently identified at the Andalas Herbarium (ANDA), Universitas Andalas, West Sumatra, Indonesia.

For understory vegetation, destructive sampling was performed. The collected samples were weighed to determine total fresh weight, and approximately 300 g subsamples were taken for drying to obtain dry biomass (Hairiah and Rahayu 2007). The resulting data were then used to calculate biomass, carbon stock, and carbon dioxide sequestration for each vegetation layer.

Data analysis

Biomass

Tree and sapling biomass were estimated by measuring the height and DBH of each individual. The specific gravity (ρ) of wood was obtained from the World Agroforestry Centre (ICRAF 2017) wood density database (http://db.worldagroforestry.org/wd). Above-Ground Biomass (AGB) was calculated using the allometric equation developed by Chave et al. (2014):

$$AGBest=0.0673 \times (\rho D^2 H)^{0.976}$$

Where:
AGB: Above-Ground Biomass (kg)
ρ: Wood specific gravity (g/cm3)
D: Tree diameter at breast height (cm)
H: Tree hight (m)

Understory biomass was determined using destructive sampling following the method of Hairiah and Rahayu (2007). Biomass was calculated using the following equation:

$$\text{Total BK} = \frac{\text{BK sample (g)}}{\text{BB sample (g)}} \text{ x Total BB (g)}$$

Where:
total BK:Total dry weight(g)
total BB:Total wet weight(g)
BK sample: Dry weight of sample (g)
BB sample: Wet weight of sample (g)

Carbon stock

Carbon stock was estimated based on the proportion of carbon contained in total biomass, following Hairiah and Rahayu (2007):

$$Cb=B \times \%C \text{ organic}$$

Where:
Cb: Carbon in biomass
B: Biomass(kg)
%C organic: Percentage of organic carbon content (0.47)

Carbon dioxide sequestration

The amount of carbon dioxide sequestered was determined using the conversion factor recommended by the Intergovernmental Panel on Climate Change (IPCC 2019):

$$\text{Carbon dioxide seuestration} = 3.67 \times Cb$$

Where:
3.67: Molecular weight ratio of CO_2 to carbon
Cb: Carbon stock (kg)

Environmental factors

The environmental factors observed in this study were air temperature and soil pH, measured at three points within each subplot in the morning, afternoon, and evening for 7 days (during sampling in the field). Environmental parameters and carbon stocks were analyzed using Principal Component Analysis (PCA) with specialized statistical software to assess environmental variation between the studied sites.

RESULTS AND DISCUSSION

Individual tree and sapling species at both sites

Impact of Calliandra houstoniana *on tree and sapling composition*

The number of tree and sapling individuals varied between the two sites. The area invaded by *C. houstoniana* showed signs of ecological disturbance that likely hindered the survival and establishment of other species, resulting in reduced species richness compared to the non-invaded site. In contrast, the non-invaded area supported a higher diversity and abundance of native species, indicating a more stable and balanced ecosystem structure. Specifically, plots invaded by *C. houstoniana* contained fewer individual species than those free from invasion. The composition of tree and sapling species recorded in both areas is summarized in Table 1.

Based on Table 1, the number of individual trees in Location 1 was lower than the number of saplings. Conversely, in Location 2, the number of individual trees exceeded that of saplings. This inverse relationship between tree and sapling abundance may be influenced by differences in light penetration and the availability of growing space. Location 2, being a forest densely populated with mature trees, provided limited space and light for sapling establishment compared to Location 1, which contained more open areas and thus a higher number of saplings. This variation may also be attributed to competition for essential resources such as nutrients, water, space, and light, which determine the survival of different vegetation layers (Chou et al. 2018).

Table 1. Tree and sapling species composition in both locations

Tree		**Sapling**	
Species	**Number of individuals**	**Species**	**Number of individuals**
Location 1 (*C. houstoniana* invaded area)			
Calliandra houstoniana (Mill.) Standl.	7	*Calliandra houstoniana* (Mill.) Standl.	54
Casuarina sp.	1	*Dipterocarpus gracilis* Blume	1
Cratoxylum sumatranum (Jack) Blume	1	*Ixonanthes petiolaris* Blume	1
Ficus kerkhovenii Koord. & Valeton	1	*Litsea rubiginosa* (Blume) Boerl.	1
Ixonanthes petiolaris Blume	2	*Macaranga depressa* (Müll.Arg.) Müll.Arg.	4
Macaranga tanarius Müll.Arg.	1	*Macaranga tanarius* Mull.Arg.	2
Macaranga triloba Müll.Arg.	3	*Macaranga triloba* Mull.Arg.	4
Oreocnide sylvatica (Blume) Miq.	1	*Nephelium lappaceum* L.	1
Pandanus sp.	5	*Suregada glomerulata* Baill.	1
Falcataria falcata (L.) Greuter & R.Rankin	4	*Swietenia macrophylla* King	1
Polyscias diversifolia (Blume) Lowry & G.M.Plunkett	2	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	1
Suregada glomerulata Baill.	1	*Oreocnide sylvatica* (Blume) Miq.	1
Symplocos fasciculata Zoll.	1		
Syzygium aromaticum (L.) Merr. & L.M.Perry	2		
Total number of individuals in Location 1	32		72
Location 2 (*C. houstoniana* non-invaded area)			
Aglaia oligophylla Miq.	1	*Liquidambar excelsa* (Noronha) Oken	2
Alangium chinense (Lour.) Harms	1	*Baccaurea deflexa* Müll.Arg.	2
Liquidambar excelsa (Noronha) Oken	1	*Baccaurea parviflora* (Müll.Arg.) Müll.Arg.	3
Aporosa benthamiana Hook.f.	1	*Cinnamomum iners* (Reinw. ex Nees&T.Nees) Blume	4
Artocarpus elasticus Reinw.	3	*Ficus parietalis* Blume	1
Castanopsis schefferiana Hance	1	*Knema laurina* (Blume) Warb.	1
Cinnamomum iners (Reinw. ex Nees&T.Nees) Blume	3	*Dendrocnide stimulans* (L.f.) Chew	1
Dipterocarpus crinitus Dyer	2	*Litsea lancifolia* (Roxb. ex Nees) Fern-Vill.	1
Drepananthus sp.	1	*Myristica elliptica* Wall ex Hook.f. & Thomson	2
Durio zibethinus L.	2	*Neonauclea* sp.	1
Ficus depressa Blume	1	*Palaquium* sp.	1
Ficus variegata Blume	1	*Machilus rimosa* Blume	1
Polyspora integerrima (Miq.) Orel, Peter G.Wilson, Curry & Luu	1	*Quercus argentata* Korth.	2
Dendrocnide stimulans (L.f.) Chew	2	*Oreocnide sylvatica* (Blume) Miq.	6
Litsea diversifolia Blume	1	*Syzygium chloranthum* (Duthie) Merr. & L.M.Perry	2
Litsea lancifolia (Roxb. ex Nees) Fern.-Vill.	1	*Syzygium* sp.	3
Mallotus paniculatus Müll.Arg.	1		
Mangifera sp.	1		
Myristica elliptica Wall ex Hook.f. & Thomson	1		
Neonauclea sp.	1		
Nephelium cuspidatum Blume	1		
Palaquium sp.	4		
Pandanus sp.	1		
Machilus rimosa Blume	1		
Polyscias diversifolia (Blume) Lowry & G.M.Plunkett	1		
Quercus argentata Korth.	5		
Quercus oidocarpa Korth.	2		
Strombosia sp.	1		
Styrax benzoin Dryand.	1		
Syzygium racemosum (Blume) DC.	1		
Syzygium sp.	3		
Oreocnide sylvatica (Blume) Miq.	2		
Total number of individuals in Location 2	50		33

In contrast, species richness for both trees and saplings was lower in Location 1 than in Location 2. This difference is likely due to the dominance of the invasive species *C. houstoniana*, which tends to suppress native species by competing more effectively for resources. Solfiyeni et al. (2022b) reported that invasive species possess strong competitive abilities in acquiring nutrients, water, and space, allowing them to dominate ecosystems they invade. Furthermore, Solfiyeni et al. (2024b) highlighted that species diversity is an indicator of ecosystem resilience to environmental changes. The high number of *C. houstoniana* individuals in Location 1 suggests that habitat conditions were favourable for its growth, while simultaneously restricting the establishment of other plant species.

The dominance of *C. houstoniana* may also be explained by its high germination potential and adaptability as a pioneer species. It is capable of rapid germination under favourable environmental conditions, with adaptive traits that enable it to thrive in disturbed habitats. The species spreads efficiently through both wind and animal dispersal, particularly by bats. According to Powell (1997), *C. houstoniana* can produce up to 1,700 seeds per season, facilitating rapid growth and establishment in disturbed areas and along riverbanks.

Biomass of trees, saplings, and understorey at Location 1 and Location 2

In the observation plots, the total biomass at Location 1 was 66.515 tons/ha, whereas Location 2 recorded a total biomass of 300.216 tons/ha. This substantial difference indicates that areas invaded by *C. houstoniana* store considerably less biomass than non-invaded areas. The distribution of biomass across different vegetation layers, viz., trees, saplings, and understory vegetation, at both locations is presented in Table 2.

Table 2 shows clear differences in biomass across vegetation strata between the two locations. Tree biomass in Location 1 was substantially lower than in Location 2, largely due to the smaller number of mature trees in the area invaded by *C. houstoniana*. In contrast, sapling biomass was higher in Location 1, reflecting the dominance of *C. houstoniana* saplings.

The scarcity of mature trees in Location 1 likely resulted from earlier forest disturbance, which facilitated the establishment of *C. houstoniana*. With reduced canopy cover, more light and space became available for saplings to establish, particularly the invasive *C. houstoniana*. This dominance restricts native species regeneration by monopolizing space and resources and by releasing allelochemicals such as phenolics, flavonoids, and alkaloids that suppress the growth and metabolism of neighboring plants (Koodkaew et al. 2018; Mufid and Suyatno 2019).

In contrast, Location 2 supported a higher number of mature trees, resulting in significantly greater total biomass. Tree biomass depends on individual count as well as diameter and height, larger and taller trees store more biomass and carbon. The invasion by *C. houstoniana* thus reduced overall biomass by replacing mature trees with smaller, fast-growing saplings. This pattern is consistent with earlier studies showing that forest disturbances reduce average tree diameter and height, leading to lower biomass accumulation (Kim et al. 2020; Wulder et al. 2020; Lubis and Putri 2023). Biomass is also influenced by wood density; species with higher specific gravity typically store more biomass (Hairiah and Rahayu 2007; Santoso et al. 2021).

Sapling biomass in Location 1 reached 2.95 tons/ha, compared to 2.47 tons/ha in Location 2. The higher sapling biomass in the invaded area was primarily due to the prolific regeneration of *C. houstoniana*, a species known for rapid growth and abundant seed production, up to 1,700 seeds per season (Powell 1997). As a leguminous plant, *C. houstoniana* improves soil nitrogen through symbiotic root nodules, enabling it to thrive in open and nutrient-poor habitats (Hendrati and Nurrohmah 2016; Maulidani et al. 2019). Increased understory and sapling density in such open sites can also result from greater light penetration, which enhances photosynthetic activity and productivity (Pauw et al. 2022).

Dominant species based on biomass contribution

Location 1 contained 14 tree and 12 sapling species, whereas Location 2 exhibited higher diversity with 32 tree and 16 sapling species. Each species contributed variably to total biomass. In Location 1, the highest tree biomass was recorded for *Falcataria falcata* (23.27 tons/ha), while *Calliandra calothyrsus* dominated the sapling layer (1.82 tons/ha). In contrast, in Location 2, *Artocarpus elasticus* contributed the highest tree biomass (74.43 tons/ha), and *Oreocnide sylvatica* accounted for the greatest sapling biomass (0.54 tons/ha) (Figure 2).

Based on Figure 2, the dominant species contributing the highest biomass differed markedly between the two locations. Location 1 was dominated by pioneer species that exhibited strong adaptability to disturbed and invaded environments. *Falcataria falcata*, a fast-growing nitrogen-fixing pioneer species, contributed the highest biomass in this site and played a role in improving soil structure (Kawai et al. 2023). The species composition at Location 1 primarily consisted of plants with high ecological plasticity, enabling them to tolerate environmental stress. According to Lillo et al. (2024), species with high importance values in a given habitat typically demonstrate successful adaptation and persistence under prevailing environmental conditions.

Several other species in Location 1 also displayed pioneer characteristics, consistent with the area being a young secondary forest undergoing ecological succession after disturbance or degradation. Revilla et al. (2024) noted that pioneer species, while essential in early successional stages, do not always facilitate the establishment of shade-tolerant species; instead, they often depend on high light availability and can suppress the germination and growth of species less tolerant to open conditions, such as *C. houstoniana*. This aligns with observations in the present study, where *C. houstoniana* emerged as a dominant pioneer species capable of colonizing disturbed habitats (Solfiyeni et al. 2024b).

In contrast, Location 2, which was free from *C. houstoniana* invasion, supported a diverse assemblage of native species that competed more evenly for nutrients, space, and light. The site was characterized by a closed canopy and reduced light penetration, typical of mature, less-disturbed forest stands. Trees at this location generally had larger diameters, resulting in higher total biomass. Such structural heterogeneity, including variation in tree size and height, enhances forest stability, productivity, and resilience (Ralhan et al. 2024).

Carbon stock and carbon dioxide absorption at locations 1 and 2

The observation plots revealed lower carbon stocks and CO_2 sequestration in areas infested with *C. houstoniana* compared to uninfested locations. Complete data for both sites are presented in Table 3.

Our findings revealed a pronounced difference in carbon stocks between the invaded site dominated by *C. houstoniana* (33.606 t/ha) and the non-invaded site (141.11 t/ha). This pattern is consistent with global evidence showing that plant invasions frequently alter community structure and reduce above-ground carbon storage, particularly when invasive species are fast-growing, have low wood density, and replace large, long-lived native trees (Vilà et al. 2011; Stricker et al. 2016). Although some invasive plants may temporarily enhance productivity, their long-term dominance typically lowers the ecosystem's overall carbon storage potential (Liao et al. 2008).

Table 2. Total biomass at each location

Vegetation Strata	Biomass (tons/ha) — Location 1 (Invaded by *C. houstoniana*)	Biomass (tons/ha) — Location 2 (Non-invaded by *C. houstoniana*)
Tree	63.53	297.73
Sapling	2.95	2.47
Understory	0.035	0.02
Total	66.515	300.216

Table 3. Total carbon stock and carbon dioxide uptake at each location

Vegetation strata	Location 1 (Invaded by *C. houstoniana*)		Location 2 (Non-invaded by *C. houstoniana*)	
	Carbon stock (ton/ha)	CO_2 sequestration (ton/ha)	Carbon stock (ton/ha)	CO_2 sequestration (ton/ha)
Tree	32.2	118.21	139.94	513.6
Sapling	1.39	5.1	1.16	4.25
Understorey	0.016	0.06	0.010	0.043
Total	33.606	123.37	141.11	517.8

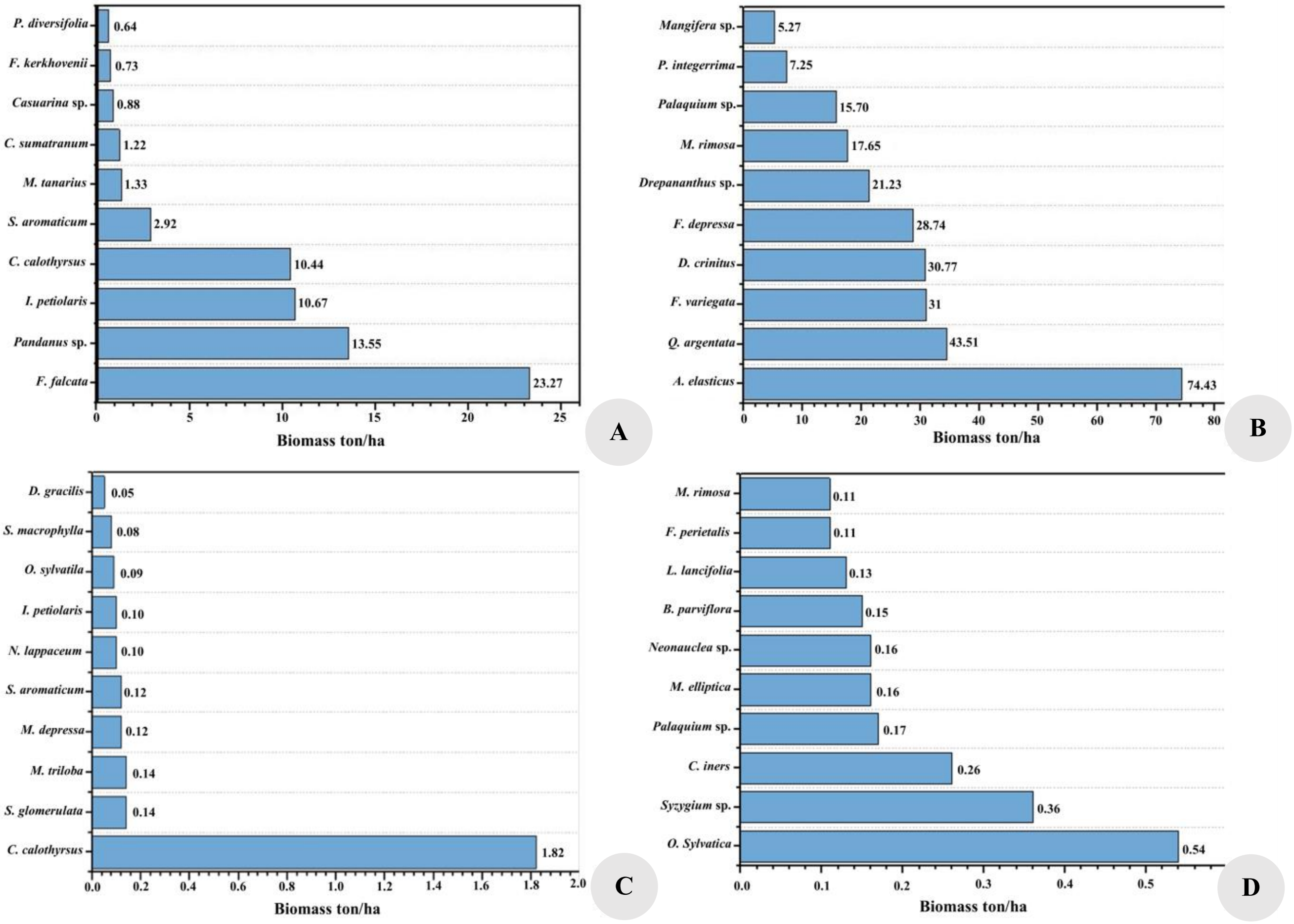

Figure 2. Biomass of 10 tree species in areas study: A. Invaded and B. Not invaded by *C. houstoniana*; biomass of 10 sapling species in areas study: C. Invaded and D. Not invaded by *C. houstoniana*

The markedly higher tree carbon stock observed at the non-invaded site highlights the pivotal role of large-diameter trees in tropical forest carbon storage. A small number of large trees often account for a disproportionately large share of total ecosystem carbon, meaning their loss has significant ecological consequences (Slik et al. 2013; Bastin et al. 2015). Conversely, the dominance of *C. houstoniana* at the invaded site resulted in stands with smaller individuals, thereby reducing both total biomass and carbon pools. This agrees with studies emphasizing that tree size distribution plays a critical role in regulating above-ground carbon dynamics (Bastin et al. 2015).

Understorey vegetation also differed notably between the two locations. While the invaded site supported a greater number of understory individuals, most were herbaceous species with high water content and low dry biomass, contributing minimally to overall carbon stocks. This result aligns with previous findings indicating that understory vegetation contributes relatively little to total ecosystem carbon, largely depending on species composition and tissue characteristics (Lohbeck et al. 2020). Furthermore, invasive plants may indirectly influence soil organic carbon and microbial carbon pools through modifications in litter quality, decomposition rates, and nutrient cycling (Liao et al. 2008).

From a management perspective, these results highlight the importance of controlling invasive species such as *C. houstoniana* to restore conditions favourable for the regeneration of large native trees. Effective management strategies should integrate mechanical or chemical removal of invasive species with active restoration using native taxa known for high carbon storage potential (Stricker et al. 2016). Continuous monitoring of below-ground carbon and soil processes is also essential, as invasions can affect both above- and below-ground carbon pools. Integrating invasive species control into national climate mitigation frameworks, such as REDD+ and ecosystem restoration initiatives, could play a crucial role in safeguarding forest carbon reserves while simultaneously promoting biodiversity conservation (Liao et al. 2008; Vilà et al. 2011).

Effect of *Calliandra houstoniana* invasion on carbon stock value

The presence of *C. houstoniana* significantly influenced both species composition and carbon stock in the study area. As shown in Table 1, the number of species and individual plants differed markedly between the two locations. The dominance of *C. houstoniana* reduced the abundance of native plant species capable of persisting in invaded areas. This reduction was reflected in the carbon stock values presented in Table 3, demonstrating the substantial impact of *C. houstoniana* invasion on ecosystem carbon storage. The statistical analysis of the effect of *C. houstoniana* on carbon stock, conducted using PAST software, is illustrated in Figure 3.

Figure 3 presents the results of statistical analysis conducted using the PAST software. The presence of *C. houstoniana* yielded a p-value<0.05, indicating a statistically significant difference in carbon storage and sequestration between invaded and non-invaded areas. This result suggests that the invasion of *C. houstoniana* contributes to a measurable reduction in carbon stocks. Moreover, the presence of this invasive species may influence climate change by potentially accelerating carbon release into the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC 2019), variations in vegetation structure have significant effects on ecosystem carbon storage capacity.

Relationship between carbon stocks and environmental factors

The distribution of plant species within a given location is strongly influenced by the prevailing environmental conditions (Table 4). As illustrated in Figure 4, the graph depicts the relationship between carbon stocks at both locations and various environmental variables. In the graph, blue dots represent the observation subplots, while black lines denote the vectors of environmental variables. The proximity of a subplot point to a vector line reflects the strength of influence — subplots located closer to a given environmental variable vector are more strongly affected by that factor.

Based on Figure 4, Location 1 represents the area invaded by the invasive plant *C. houstoniana*, whereas Location 2 is a non-invaded site. Environmental conditions differed between the two locations. The dominance of *C. houstoniana* in Location 1 can be attributed to its tolerance of diverse environmental conditions. Conversely, Location 2's more neutral pH created optimal conditions for nutrient absorption, which supported higher species diversity and biomass productivity. According to Marschner (2012), a neutral pH range of 6.0-7.5 is most favourable for plant nutrient uptake, enabling more efficient absorption of essential nutrients.

Table 4. Average results of environmental factor measurements at each location

Parameter	Location 1 (Invaded by *C. houstoniana*)	Location 2 (Non-invaded by *C. houstoniana*)
Average Temperature (°C)	25-27	21-22
Soil pH	6.6-6.7	6.6-6.9

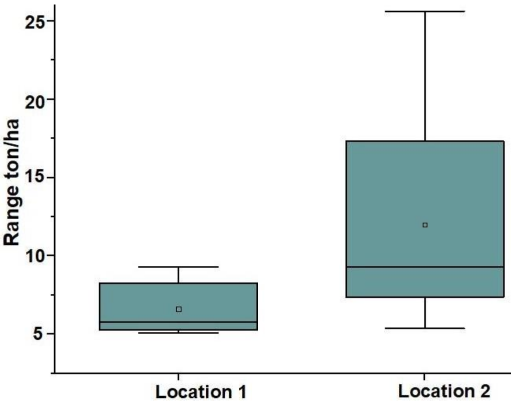

Figure 3. Effect of *C. houstoniana* on carbon stock value of the study sites. Location 1 (Invaded by *C. houstoniana*), Location 2 (Non-invaded by *C. houstoniana*)

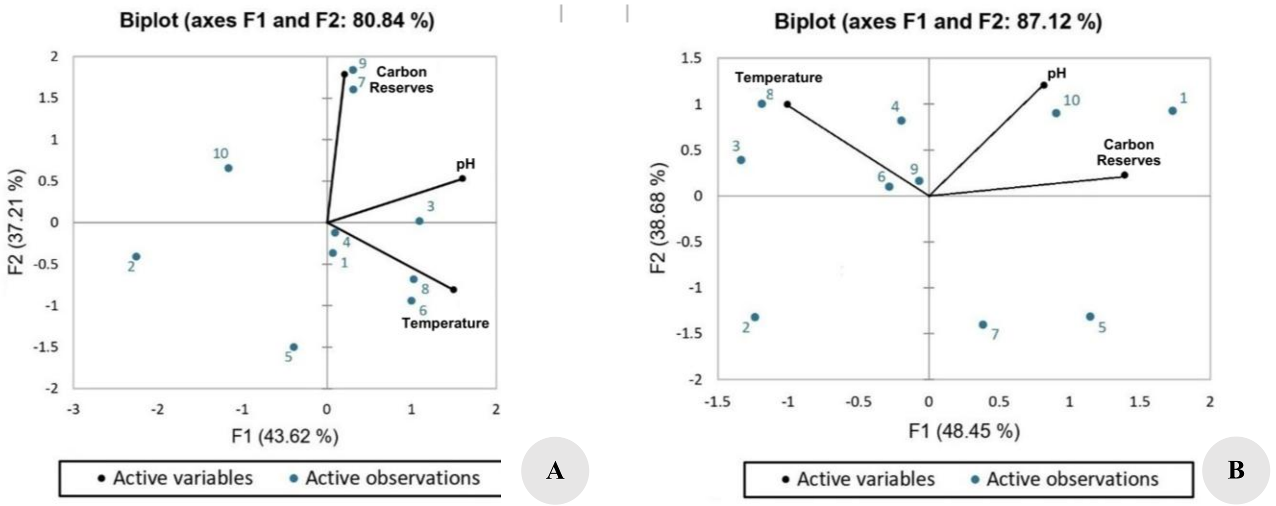

Figure 4. Graph showing the relationship between carbon stocks and environmental factors in areas: A. Invaded by *C. houstoniana* and B. Non-invaded areas by C. *houstoniana*

The ordination analysis showed that the temperature vector formed an angle close to 90° relative to the carbon stock vector at Location 1, indicating a weak or negligible relationship between temperature and carbon stocks. Nevertheless, *C. houstoniana* thrived in these conditions, likely due to its ability to establish in open, unshaded environments and adapt to a variety of growth conditions (Powell 1997). The pH and carbon stock vectors pointed in opposite directions, suggesting a negative correlation between these variables. This observation aligns with Jolliffe and Cadima (2016), who noted that opposing vector directions in ordination analyses signify negative relationships. Hernández-Jiménez et al. (2017) further emphasized that soil pH is a critical factor influencing carbon sequestration and vegetation composition in tropical ecosystems.

The high adaptability of *C. houstoniana* allows it to spread rapidly and dominate ecosystems, which poses a significant threat to biodiversity and ecosystem functioning. Such dominance can lead to biotic homogenization, reducing ecosystem stability and carbon storage potential (Wang and Loreau 2016). Wang et al. (2021) further emphasized that conserving biodiversity is essential for sustaining ecosystem stability at broad spatial scales.

In conclusion, this study demonstrates that the invasion of *C. houstoniana* in Bung Hatta Grand Forest Park is closely linked to prior disturbances that facilitated its establishment. Invaded areas exhibited reduced tree-level vegetation density, increased sapling dominance, and significant declines in biomass, carbon stocks, and CO_2 sequestration compared to non-invaded sites. These changes suggest that *C. houstoniana* invasions contribute to biodiversity loss and diminished carbon storage capacity, potentially exacerbating global climate change impacts.

Effective management should combine mechanical or chemical removal of invasive species with active restoration of native vegetation and long-term monitoring to prevent further spread. Integrating invasive species management into forest conservation policies is critical for maintaining vegetation diversity and ecosystem functioning, particularly carbon sequestration. At the global scale, these findings highlight that invasive alien plants in tropical forests not only threaten biodiversity but also undermine the climate mitigation functions of these ecosystems. Therefore, invasive species management should be an essential component of international conservation strategies and climate policies, especially for tropical forests, which serve as major global carbon sinks.

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