The impact of the invasive tree *Cedrela odorota* on the Electric Blue Gecko *(Lygodactylus williamsi)* and its habitat (*Pandanus rabaiensis*) in Kimboza Forest Reserve, Tanzania

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ABSTRACT

Non-native plants are a major cause of habitat loss and fragmentation that lead to biodiversity loss. Geckos are particularly vulnerable to habitat alterations due to their small range and their restricted and specific terrestrial habits. However, our understanding of how introduced plants affect geckos, is poor. In this study, we investigate the potential effects of non-native and invasive neo-tropical tree *Cedrela odorata* on the critically endangered electric blue gecko, *Lygodactylus williamsi,* and its sole habitat, *Pandanus rabaiensis*. We used 107 square (10 m x 10 m) sample plots distributed systematically throughout the forest to assess the extent and effects of *C. odorata* on *P. rabaiensis* forest patches. We compared the abundance of *L. williamsi* on 125 *P. rabaiensis* trees growing in a mixture with *C. odorata,* native trees, and in pure stands and at three canopy cover categories (0–30%, >30–50%, and > 50%). We found an inverse relationship between the abundance of *C. odorata* trees (diameter at breast height (DBH)> 10 cm) and the abundance of *P. rabaiensis*. Spatially, the two trees dominated different parts of the forest. In contrast, the abundance of *L. williamsi* was not significantly affected by the presence of *C. odorata*. However, change in the canopy cover of the trees growing above the *P. rabaiensis* significantly affected the abundance of *L. williamsi*. The abundance of *L. williamsi* in a 0–30% cover was significantly higher than 30–50% and > 50% canopy covers. The findings of this study suggest that if left unmanaged, *C. odorata* could continue to take up the space that could be occupied by *P. rabaiensis* and other native plants, and thus limit the population size of an endangered species.

1. Introduction

Non-native plants (also known as exotic plants) have been intentionally or accidentally introduced from one geographic area to another over the past 200 years, and the frequency of introduction is rising globally (Clements et al., 2022). A recent study found that about 10,616 non-native plants have been introduced to Africa, out of which 90% became naturalized and 10% invasive (Richardson et al., 2022). The introduced plants that become invasive (hereafter: Invasive alien plant species, IAPS) have distinct high colonization rates, produce reproductive offspring in very large numbers, and change the structure and functions of invaded ecosystems (Pyšek and Richardson, 2010). Prevention of the introduction and spread of IAPS is considered the most cost-effective and environmentally friendly strategy to manage invasions but it has proved to be difficult to implement in Africa (Hulme, 2003) due to several factors

including low awareness and a lack of sustainable funding (Boy and Witt, 2013).

African forests have experienced relatively few invasions (Richardson et al., 2022), but have caused severe impacts on native species. The invasive *Maesopsis eminii* has reduced the abundance, richness, and diversity of native trees in Amani Nature Reserve (Binggeli, 1989; Mwendwa et al., 2020). Similar effects have been reported for invasive trees *Acacia mearnsi*i, *Prosopis juliflora*, and *Senna spectabilis* (Obir, 2011). Generally, the impacts of IAPS on resident plant species in forest ecosystem is well documented globally (e.g. Fridley et al., 2007; Langmaier and Lapin, 2020; Vilà et al., 2011; Van der Meersch et al., 2021; Wardle and Peltzer, 2017). However, the effect of IAPS on geckos is poorly understood. Geckos are particularly vulnerable because of their small home range and their restricted and specific terrestrial habits. Studies conducted in Australia, and North America showed that IAPS can have negative impacts on reptiles. Leslie and Spotila (2001) found that the invasive *Chromolaena odorata* is negatively impacting the breeding biology of the Nile crocodile and the invasive buffel grass (*Cenchrus ciliaris*) reduced prey or habitat diversity for reptiles (Schlesinger et al., 2020). Other impacts of IAPS on reptiles include a change in thermal environment (Carter et al., 2015; Garcia and Clusella-Trullas, 2019; Zani and Rollyson, 2011), obstruction of movements or visibility (Anderson, 2007; Germano et al., 2012), reduction in species richness and abundance (Abom et al., 2015), and reduction in body condition (Gray and Steidl, 2015). It has been found further that the response of reptiles to habitat changes are species specific and context-dependent (Schlesinger et al., 2020).

Cedrela odorata is a tree native to the neo-tropics ranging from Mexico through Central America to Argentina including the Caribbean (Ricker et al., 2013). The tree has been introduced to various African countries including Tanzania, Uganda, Madagascar, South Africa, and several Southeast Asian and Pacific countries, where it is established in a monoculture plantation for timber (Finer et al., 2014). In West Africa, *C. odorata* is planted in agroforestry systems (Van der Meersch et al., 2021). The timber from *C. odorata* is also used to make cigar boxes, musical instruments, light construction, veneer, and plywood (Rocas, 1983). *Cedrela odorata* is an invasive species in most of the areas where it has been introduced. The tree is invasive in the Galapagos (Haysom and Murphy, 2004; Trueman et al., 2014; Rivas-Torres et al., 2018a), Ghana (Anning et al., 2018), Ivory Coast (Van der Meersch et al., 2021), Tanzania (Binggeli et al., 1998; Dawson et al., 2008; Haysom and Murphy, 2004), South Africa (Haysom and Murphy, 2004), Pacific Islands (Haysom and Murphy, 2004), and in Australia (Csurhes and Edwards, 1998). However, in its natural environment, the tree is not regenerating well and has been listed as vulnerable species (IUCN, 2019).

According to interviews with the local communities, *C. odorata* was introduced to Kimboza Forest Reserve, Tanzania between 1957 and 1960 to provide timber species for local communities surrounding the forest and release the logging pressure on indigenous tree species. Surveys conducted in the Kimboza forest in 1983 (Rodgers et al., 1983) and 2002 (Malimbwi, 2002) found that *C. odorata* constituted on average 5% and 12% of all stems respectively. A recent study conducted in 2017 found that *C. odorata* trees (DBH ≥10 cm) comprised on average 32% of the stems (Kilawe et al., Unpublished). It has been speculated that the spread and dominance of *C. odorata* in Kimboza Forest Reserve could negatively affect the population of the critically endangered endemic electric blue gecko (*Lygodactylus williamsi*), and its sole habitat (*Pandanus rabaiensis*) (Doggart et al., 2004; Flecks et al., 2012a; MNRT, 2004) but there is no empirical evidence from a systematic study. *Cedrela odorata* forms dense stands, particularly after recurrent fires and could consequently affects the microclimate (light, temperature, moisture, humidity) of the invaded areas. A change in light regimes could affect the gecko in terms of feeding, breeding, and avoidance of predators. Furthermore, *C. odorata* has also been found to have a negative effects on the growth of other plants (Rivas-Torres et al., 2018b; Van der Meersch et al., 2021), a characteristic that could affect *P. rabaiensis*.

This paper aims to assess the effects of *C. odorata* on *L. williamsi* and its habitat *P. rabaiensis*. We make three predictions; (i) an increase in the abundance of *C. odorata* will negatively affect the abundance of *P. rabaiensis*, and (ii) the presence of *C. odorata* will negatively affect the occurrence of *L. williamsi* and (iii) a dense canopy cover of *C. odorata* above *P. rabaiensis* reduces the abundance of *L. williamsi*.

2. Study species

2.1. Cedrela odorata Linnaeus

Cedrela odorata is a single stem tree that can reach up to 40 m tall. The trunk is cylindrical and free from branches up to about 2/3 of the height. The leaves are pinnate (to 80 cm long), with 10–22 pairs of stalked leaflets. *C. odorata* produces numerous small flowers in large inflorescences (30 cm). The fruits are hanging in leathery brown capsules (to 3.5 cm) that open in 5 sections to release about 50 tiny winged seeds. The leaves and flowers have a strong smell. In Kimboza forest *C. odorata* fruit sets between January and June and matures during the dry season (September-November), just before the onset of short rains. Seeds are wind dispersed and seedlings of the tree have been observed in most parts of the forest. Forest fires produce the best habitat for natural regeneration. However, the species also readily establishes itself on fallen logs, rocks with sparse soil, and forest gaps. The species is a habitat generalist but it grows well in rainfall between 1 200–2 400 mm and in well-drained limestone soils (Holdridge et al., 1971). The tree is currently the most dominant in the Kimboza forest reserve, consisting of about 32% of all trees (Kilawe et al., Unpublished).

2.2. Pandanus rabaiensis Rendle

Pandanus rabaiensis is a single stem tree that can reach up to 25 m tall, with a unique and recognizable tree structure. The tree forms 1–7sub-crowns and it produces stilt roots up to 5 m high. The bole and stilt roots have small sharp conical spines. The leaves have spiny edges too and can reach 3–4 m when young but are reduced to 2–3 m when the tree matures (Fish, 1983). Flowers are borne on large inflorescence producing large (15–30 cm long) compound fruits that consist of dozens of tightly aggregated drupes. Each drupe

produces 1–7 seedlings. Seeds are dispersed by primates, rodents, and water, as a result, the tree is abundant in flooded swampy areas and rocks where it forms dense stands referred to as 'Pandanus stand'. The tree also occurs in other parts of the forest where it grows individually (Flecks et al., 2012a). The tree occasionally reproduces vegetatively, a fallen broken branch or tree top can sprout and grow into a mature tree. *Pandanus rabaiensis* is the second most abundant tree species in Kimboza Forest Reserve covering about 17.6% of the total area (Flecks et al., 2012a). However, the species is listed as near threatened in the IUCN Red List of Threatened Species (IUCN, 2009). *Pandanus rabaiensis* is the sole habitat for the electric blue gecko, *L. williamsi.* Geckos use the *P. rabaiensis* for breeding, resting, and feeding on insects that congregate to breed in the water-filled leaf axils (Lehtinen, 2002).

2.3. Lygodactylus williamsi Loveridge

The electric blue gecko, *Lygodactylus williamsi*, is a small, diurnal and territorial lizard.

in the family *Gekkonidae.* The gecko is considered the most colorful of all 210 species or races of African geckos (Loveridge, 1952). The dominant males have a bright and vibrant turquoise-blue body, and uniquely retain this colour throughout the year, whilst females are greenish-bronze (Loveridge, 1952, Fig. 1). The gecko is territorial and dwells exclusively on the leaves of *P. rabaiensis* (Flecks et al., 2012a). *Lygodactylus williamsi* was reported as abundant and widespread in the Kimboza forest in the 1990s (Bayliss, 1994). However, the illegal pet trade and habitat loss led to a severe decline in the population of *L. wiliamsi* prompting its categorization as Critically Endangered by the IUCN Red List in 2012 (Flecks et al., 2012b). In 2012 the wild population of *L. williamsi* was estimated to be 148,684 mature individuals (Flecks et al., 2012a). Our regular field investigations in the Kimboza forest since 2016 support the view that the illegal trade in the species has now stopped thanks to a ban on wild-caught *L. williamsi* trade by the European Union and enforcement of local laws on trade involving live animals. We suspect that the population size of the gecko has now returned to pre-harvesting years.

3. Material and methods

3.1. Description of the study area

The study was conducted in Kimboza Forest Reserve in Morogoro Region, Tanzania. The forest covers an area of 4.05 km^2 and is found in Morogoro Rural District at an elevation between 170 and 400 m a.s.l. (Fig. 2). Kimboza is among the few remaining lowland forests (below 1500 m) that were once part of the South Uluguru Montains rainforest. The forest lies on a karstic crystalline limestone formation (Rodgers et al., 1983). It is characterized by an oceanic climate with 1 683 mm mean annual rainfall falling in two seasons: Heavy long rains between March and May and light short rains between October and December. The temperatures range between 22 °C and 35 °C with the hottest being between January and March and the coolest between May and August. Kimboza forest sits on the calcite and dolomite marbles that form a distinctive karstic landscape (Rodgers et al., 1983). Much of the forest has a high groundwater table and several streamlets that supply water to the Ruvu River. However, the North East part of the forest is dry and the water table is probably low. The vegetation has been described as a transitional forest between Coastal and Eastern Arc Mountain Forests (Burgess et al., 1998). The forest has been described as and is one of the most biodiversity valuable dry forests on limestone in Africa (Cheek et al., 2007). It has close to 400 vascular plant species (364 in 1983 according to Rodgers et al., 1983) of which 17 species/sub-species are strictly endemic and 27 are near endemics. Furthermore, the forest has about 83 birds, 16 mammals, six amphibians, and 10 reptile species (Doggart et al., 2004). Kimboza forest is categorized as an IUCN category IV-Habitat/Species management area and holds special significance for the conservation of *L. williamsi* (Burgess et al., 1998). The forest was gazetted as a forest reserve by Government Notice (GN) No. 417 of 11/07/1964. The reserve is owned by the Central Government under the Forest and Beekeeping Division of the Ministry of Natural Resource and Tourism and is jointly being managed by Tanzania Forest Service Agency (TFS) and the communities living adjacent to the forest. Under the joint forest management, the communities are allowed to access the forest for worship and beekeeping, and collection of forest products like firewood and local medicine (Ministry of Natural Resources and Tourism MNRT, 2004). The communities are usually involved in forest protection activities including forest patrol, fire prevention, and suppression activities. Some of the adjacent communities have also been identified as the underlying causes

Fig. 1. A photograph of an adult male (left) and female (right) *Lygodactylus williamsi* on a leaf of *Pandanus rabaiensis* in Kimboza Forest Reserve. Photos by John Lyakurwa.
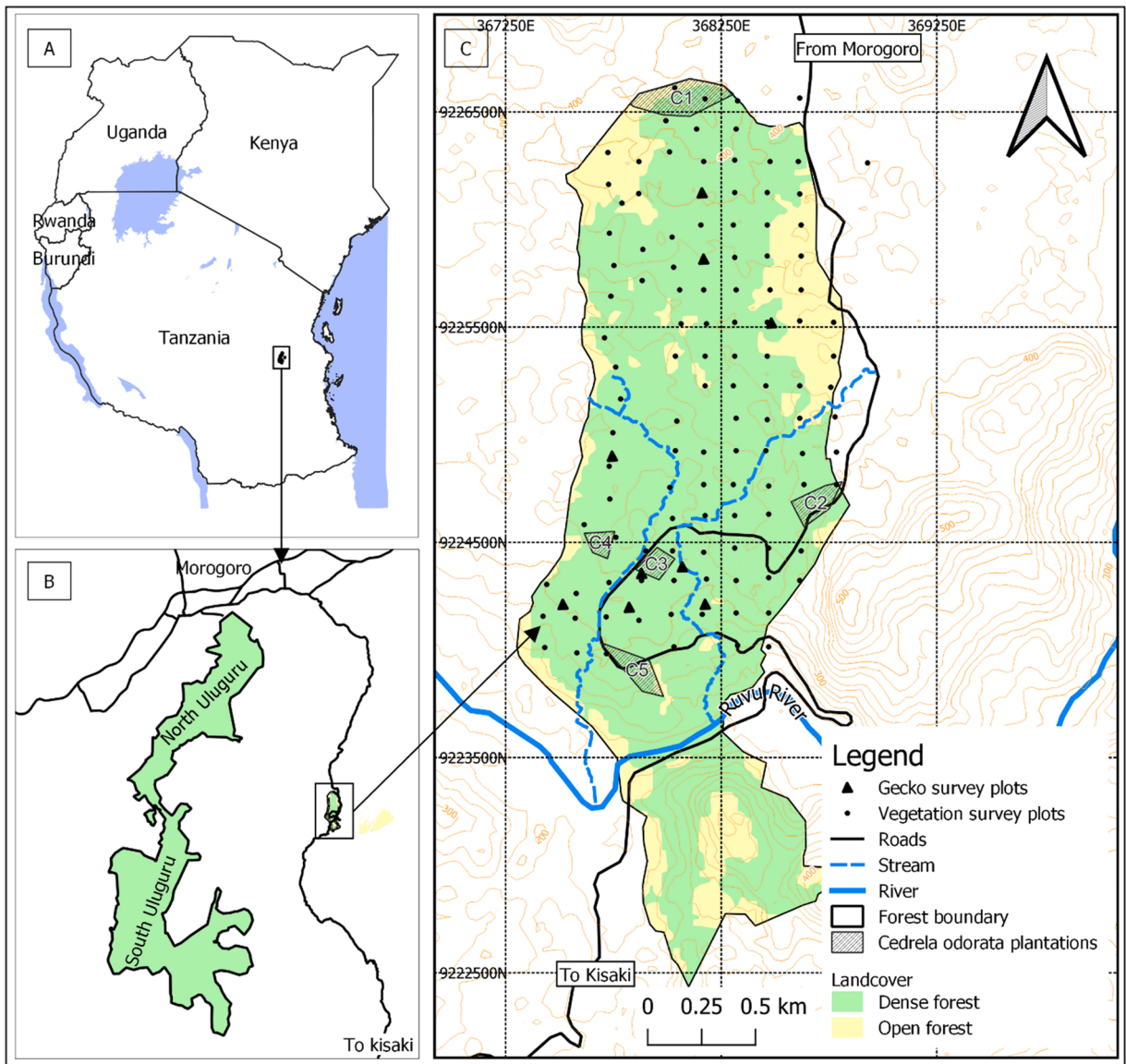
Fig. 2. Location map of the study area showing (A) the position of Uluguru Mountains in Tanzania (B) the position of Kimboza Forest Reserve in relation to Uluguru Mountains, and (C) land cover map of Kimboza Forest Reserve. The map was created by Omega Emmanuel Kaaya.

of forest disturbance through wildfires, hunting, and illegal logging (Kacholi, 2020; Kilawe et al., 2021).

3.2. Sampling design and data collection

3.2.1. Impacts of C. odorata on P. rabaiensis

A forest inventory was carried out in November 2016. A systematic random sampling design was employed where plots and transects were established at a fixed distance but with a random start. The forest was divided into 17 line transects that run North-South through the reserve and 120 square (10 m x 10 m) sample plots (See Fig. 2). Both inter-plot distance and inter transect distance was 150 m. Within each main plot, two sub-plots measuring 2 m x 2 m were established in the North and South corners of the main plot, yielding a total of 240 sample sub-plots. Out of 120 plots, 13 were not accessible due to the presence of massive rock boulders. Therefore, 107 main plots and 214 sub-plots were surveyed. The center of the plot was marked with a metal tag and located using a Global Positioning System (GPS) (see supplementary materials). The abundance and diameter at breast height (DBH) of all *C. odorata* with DBH $\geq$ 5 cm were recorded in each main plot and those with diameter < 5 cm were recorded in each sub-plot. The abundance, diameter, and tree height for all *P. rabaiensis* were recorded in each main plot. The density of *C. odorata* was categorized into three arbitrary size classes as trees (DBH $\geq$ 10 cm), poles (DBH > 5 cm < 10 cm), and saplings (Diameter < 5 cm). The

classification of *P. rabaiensis* was rather different as this tree does not change much in diameter with age, the changes are more with the height. Therefore, the distribution of *P. rabaiensis* was classified into three arbitrary classes based on height as trees (height >2.5 m), poles (height 1–2.5 m), and saplings (height < 1 m). A similar classification was used by Flecks et al. (2012a). The percentage proportion of the stems of *C. odorata* and *P. rabaiensis* trees was calculated at a plot level.
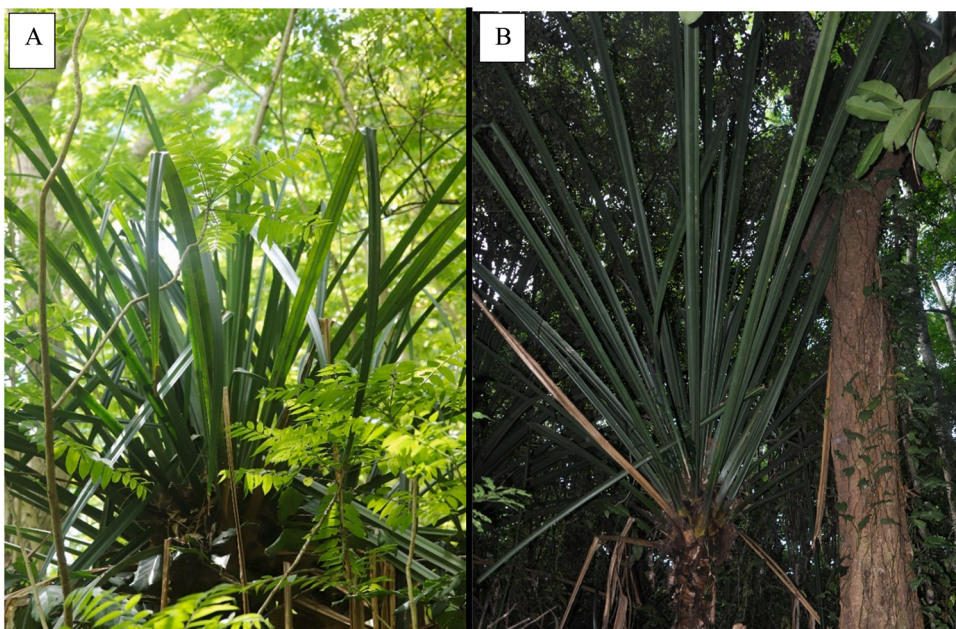
3.2.2. Impact of C. odorata and canopy cover on L. williamsi

Gecko surveys were conducted in January 2017. The forest was stratified into three potential habitats of *L. williamsi* as follows*:* 1) *P. rabaiensis* trees growing in a mixture with dominant native trees, 2) *P. rabaiensis* trees growing in a mixture with dominant *C. odorata* trees, and 3) pure stand of *P. rabaiensis* (Fig. 3). Three replicates were made for each habitat type (Fig. 2). Each vegetation type was further subdivided into three sub-categories based on canopy cover of the dominant vegetation as i) 0–30%; ii) > 30–50%, and iii) > 50%. The canopy cover was determined using a Spherical Crown Densiometer (GeoConnect, India). In each cover category, five *P. rabaiensis* trees were randomly selected making the total number of *P. rabaiensis* trees involved in the study to be 125. The *P. rabaiensis* selected for the study was limited to a height of 3 m as reliable field observations above that height were not deemed to be possible. The Visual Encounter Method (VEM) was conducted by five persons to observe *L. williamsi*. The involvement of multiple observers in each site was considered useful in reducing observer bias. Furthermore, all observers were familiarized with the geckos and how to study them prior to the actual survey. For each vegetation canopy cover category, one person observed and recorded the number of geckos in one *P. rabaiensis* two times a day for one hour starting from 9 to 10 a.m. and 4–5 p.m. The VEM was applied by Flecks et al. (2012a) to estimate the population of *L. williamsi* in the same forest.

4. Data analyses

4.1. Impact of C. odorata on P. rabaiensis

Mean stem density of *C. odorata* and *P. rabaiensis* were computed at a plot level in MS Excel. The Inverse Distance Weighted (IDW) interpolation tool in QGIS software version 3.16 (QGIS Development Team) was used to model the distribution of *C. odorata* and *P. rabaiensis* trees at a forest level. The IDW estimated the abundance of *C. odorata* and *P. rabaiensis* in un-surveyed parts of the forest by averaging the abundance of the trees in the neighborhood of the surveyed plots. The abundance of *C. odorata* and *P. rabaiensis* was not normally distributed. Therefore, parametric tests could not be applied to establish the relationship between the two species. Multi-dimensional Scaling (NMDS) was performed in PC-ORD for Windows (version 6, MjM Software, Gleneden Beach, Oregon, U.S.A) to determine the relationship between the abundance of *C. odorata* trees and various size classes of *P. rabaiensis*. Logarithmic transformation (log10 (x + 1)) was applied to the abundance data of the two tree species to equalize the relative importance of the two species (McCune and Grace, 2002). All plots with zero occurrences of *C. odorata* and *P. rabaiensis* were excluded from the analysis.

Fig. 3. Potential habitats for *L. williamsi; A) P. rabaiensis* trees growing in a mixture with dominant *C. odorata* trees, and B) *P. rabaiensis* trees growing in a mixture with dominant native trees.

4.2. Impact of C. odorata and canopy cover on L. williamsi

One-way analysis of variance in JMP software (version 15, SAS Institute Inc., Cary, NC, 1989–2021) was applied to determine the effect of *C. odorata* and canopy cover on the abundance of *L. williamsi*. Turkey's HD was used to separate the means.

5. Results

5.1. Impact of C. odorata invasion on P. rabaiensis

The summary of the distribution of *C. odorata* and *P. rabaiensis* in the Kimboza forest reserve is shown in Table 1. The density of *C. odorata* increased with a decrease in diameter, typical for a proper regenerating tree species. However, the density of medium-sized *P. rabaiensis* was low compared to small and large trees. This pattern could indicate a regeneration problem. Spatially, the two tree species were widely distributed in the reserve but appear to dominate in different parts of the forest (Fig. 4). The NMDS ordination revealed an inverse relationship between the abundance of *C. odorata* and *P. rabaiensis*. The correlation coefficient between *C. odorata* and ordination axes 1 and 2 were − 0.29 and − 0.81 (Fig. 5 A) whereas the correlation between *P. rabaiensis* trees, poles, and saplings with the axes was 0.59 and 0.41 (Fig. 5 B), 0.34 and − 0.36 (Fig. 5 C), and 0.93 and − 2.1 (Fig. 5 D) respectively. *P. rabaiensis* trees and saplings had lower abundance in plots where *C. odorata* was abundant.

5.2. Impact of C. odorata and canopy cover on L williamsi

The total number of geckos was 196 of which 112 were males and 84 were females. There was no significant (p > 0.05) effect of *C. odorata* on the occurrence of *L. williamsi*. The abundance of the gecko was comparable in all habitat types (Fig. 6A). However, it was found that the canopy cover of the tree growing above the *P. rabaiensis* affects the abundance of *L. williamsi*. The abundance of the gecko in a 0–30% cover was significantly higher than 30–50% (p < 0.001) and > 50% (p < 0.001) (Fig. 6 B). Furthermore, the abundance of *L. williamsi* in 30–50% cover was significantly higher than > 50% (p < 0.001).

6. Discussion

We predicted that the increase in the abundance of *C. odorata* will negatively affect the abundance of *P. rabaiensis*. Our results agrees with hypothesis, which showed an inverse relationship between the abundance of *C. odorata* and *P. rabaiensis* trees, poles, and saplings. Spatially, *C. odorata* and *P. rabaiensis* trees appeared to dominate in different parts of the forest. The two trees did not occur together in large densities. This is likely partly because their performance was affected by different environmental factors (soil moisture and disturbance) found in the forest, in line with the 'join the locals' hypothesis (Tecco et al., 2010; Thompson et al., 1995). Based on our field experience, we speculate that *C. odorata* was able to establish itself in areas disturbed by wildfires, illegal logging, and natural tree falls but it was unable to establish itself in undisturbed and waterlogged parts of the forest. *Cedrela odorata* dispersal in the forest cannot be considered a limitation since the seeds are wind dispersed and could reach every part of the forest. In contrast, *P. rabaiensis* trees were dominant in waterlogged/ swampy areas or limestone rocks where it forms dense stands or 'Pandanus stand' (Flecks et al., 2012b; Rodgers et al., 1983) that could not be invaded by the light demanding *C. odorata*. However, *P. rabaiensis* occurs as single scattered trees in other forest areas (outside 'Pandanus stand') where *C. odorata* could be replacing it. A study conducted in 1982 found that *C. odorata* and *P. rabaiensis* trees occurred on 16% and 58% of sample plots (Rodgers et al., 1983) whereas the present study found that the two tree species occurred on 52.2% and 28% of sample plots respectively. There is an indication that there is an increase in the distribution of *C. odorata* and a decline in *P. rabaiensis*. If the alien tree is left unmanaged it could have detrimental impact on the forest inhabitants. *Cedrela odorata* has been found to have a detrimental effect on forest biodiversity in Ghana (Van der Meersch et al., 2021) and the Galápagos Islands (Trueman et al., 2014; Rivas-Torres et al., 2018b).

We predicted that the presence of *C. odorata* and a dense canopy cover above *P. rabaiensis* reduces the abundance of *L. williamsi*. Our results revealed that the presence of alien and invasive *C. odorata* did not affect the abundance of *L. williamsi*. However, the abundance of the geckos was significantly lower in *P. rabaiensis* growing under dense canopy cover compared to open canopy cover as we predicted. The presence of *C. odorata* probably did not affect the geckos because the tree is deciduous in nature (it loses most of its leaves during dry season), and may thus allow solar radiation which is essential to reptiles. A dense canopy cover cools the habitat's temperature (through blocking thermal radiation) and negatively affects lizards' thermoregulation (Carter et al., 2015; Garcia and

Table 1
Size class distribution of *C. odorata* and *P. rabaiensis* in Kimboza Forest Reserve. *C. odorata:* trees (DBH≥ 10 cm); poles (DBH ≥ 5 cm < 10 cm) and saplings (Diameter < 5 cm). *P. rabaiensis*: trees (height>2.5 m; poles height 1–2.5 m and saplings (height <1 m).

| S/N	Size class	*C. odorata*		*P. rabaiensis*	
		Frequency (%)	Density (N/ha)	Frequency (%)	Density (N/ha)
1	Saplings	73	12,913	34	364
2	Poles	43	774	6	15
3	Trees	52	167	28	130
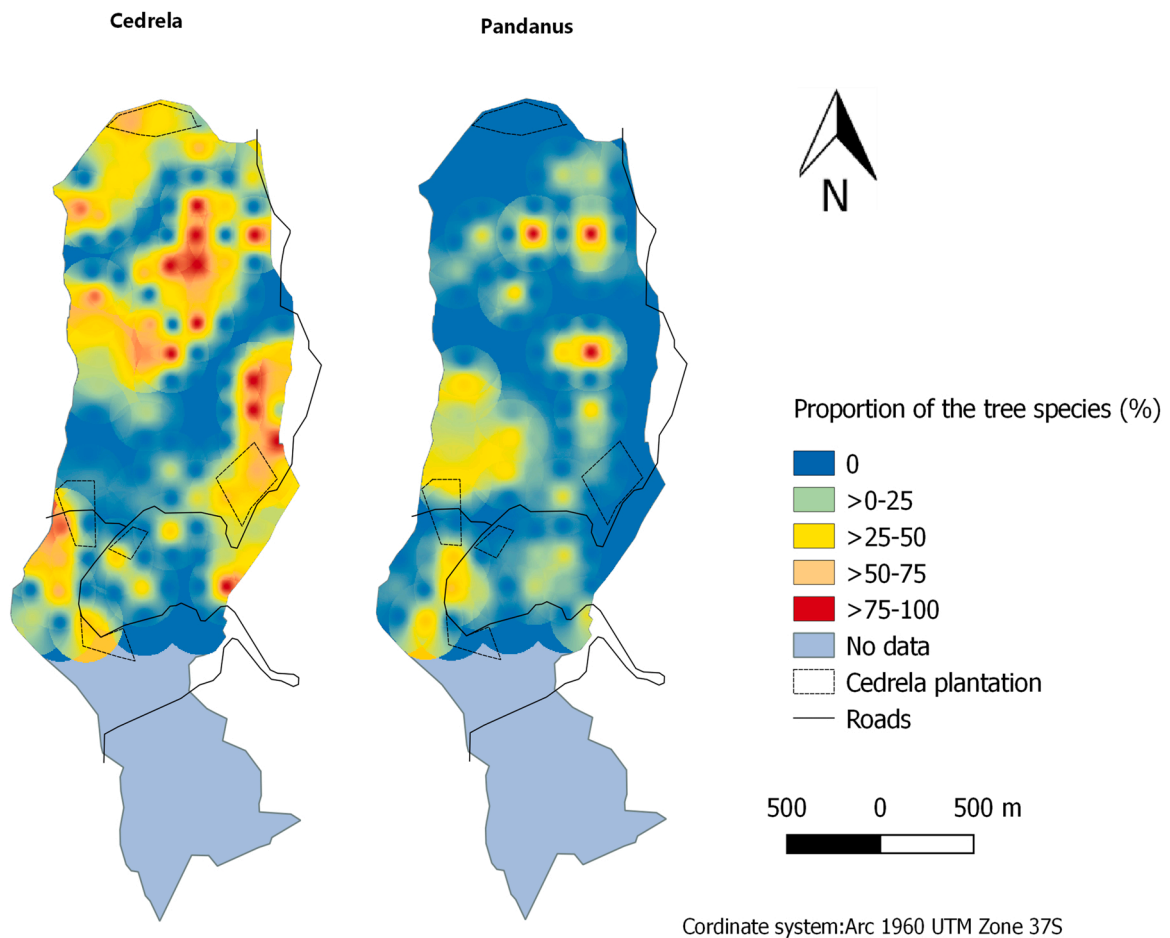
Fig. 4. The percentage proportion of *C. odorata* trees (left) and *P. rabaiensis* trees (right) in Kimboza Forest Reserve. Colors in the map show different severity in the abundance of *C. odorata* and *P. rabaiensis*.

Clusella-Trullas, 2019; Huang et al., 2014; Pike et al., 2011; Row and Blouin-Demers, 2006; Zani and Rollyson, 2011). Dense canopies could also obstruct movement or visibility (Anderson, 2007, 2018).

Another explanation could be that *P. rabaiensis* growing under dense vegetation could collect more litter and debris than those in the open air or slightly open canopy cover, and in particular in the base of the leaf where water gathers. That may affect the quality of the leaf axil as a microhabitat for the gecko. Clean water should be able to collect in the leaf axils for the gecko's thermoregulatory, water balance functions and feeding on insects that congregate to breed in the water-filled leaf axils (Flecks et al., 2012a; Lehtinen, 2002). An experimental study is needed to determine if the removal of litter from *P. rabaiensis* could increase the abundance of the gecko in dense canopies. Furthermore, experiments involving opening up canopy cover (e.g. at interval of 10%) above *P. rabaiensis* and evaluating the gecko's response are needed to identify canopy cover thresholds for the practical management of the geckos' habitat.

6.1. Limitations of the study

The VEM of *L. williamsi* was limited to *P. rabaiensis* with 3 m in height. A survey of all the *P. rabaiensis* could have provided more understanding of the effects of *C. odorata* and canopy cover on the abundance of the gecko. Furthermore, the survey of the gecko was limited to only one season (short rains). Different results could be obtained if the study was conducted during long rains (March-May) or dry and warm seasons (July-November). Change in microclimate has been found to affect the lizards' thermoregulation (Carter et al., 2015; Garcia and Clusella-Trullas, 2019; Huang et al., 2014; Row and Blouin-Demers, 2006; Zani and Rollyson, 2011). Moreover, we used arbitrary classification of *P. rabaiensis* age based on tree height. The relationship between height with age for this tree is not known and should be more investigated. Lastly, based on field observations we have speculated that disturbance caused by wildfires and illegal logging were the drivers for the spread of *C. odorata* in the forest. Empirical evidence from quantitative data would be needed to confirm the hypothesis. Despite of these limitations, this study provides baseline knowledge of the impacts of the invasive tree *C. odorata* on *P. rabaiensis,* a microhabitat of the critically endangered *L. williamsi* which can be used for future conservation planning.
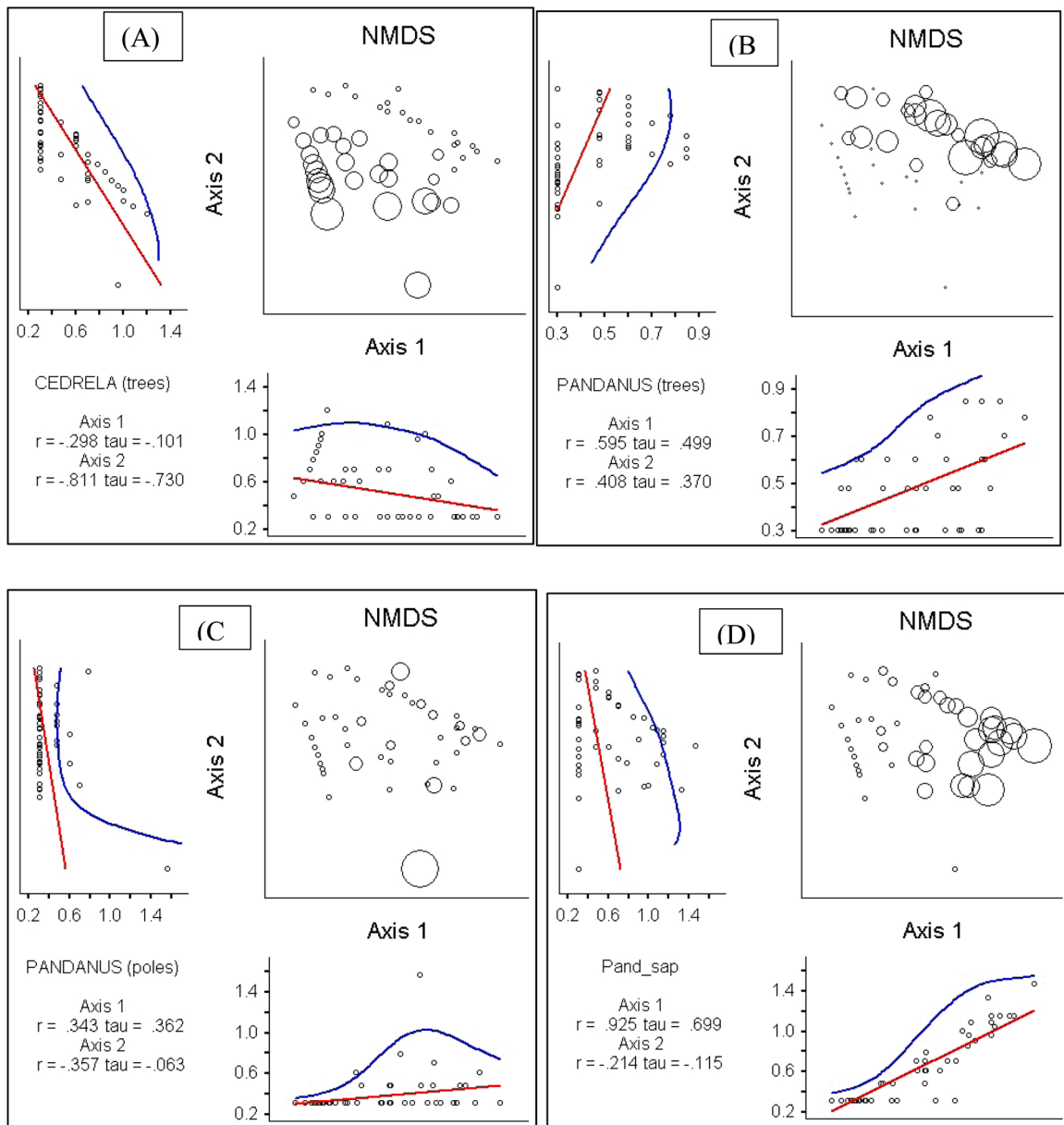
Fig. 5. Scatter plots of abundance (log (x + 1)) of *C. odorata* trees (A) and *P. rabaiensis* trees (B), Poles (C), and Saplings (D) in relation to two NMDS axes. Points represent sample plots and symbol size represents the abundance of the trees.

7. Conclusion

This study is the first published work to show the effect of invasive tree *C. odorata* on a critically endangered electric blue gecko, *L. williamsi,* and its microhabitat, *P. rabaiensis.* The invasion by *C. odorata* does not directly affect the occurrence of *L. williamsi* but indirectly through negative effects on the occurrence of *P. rabaiensis. Cedrela odorata* is taking up the space that could be occupied by *P. rabaiensis* and other native species particularly where it forms monotypic stands in aras with recurrent fires. Restoration actions such as prevention of further spread with a removal of single scattered trees and a regulated removal of monotypic stands of *C. odorata* in areas favaurable to the establishment of *P. rabaiensis* should be implemented.Such actions should benefit L. williamsi by increasing its population size and thus enhance the survval of this econic gecko.

The study also demonstrate that a decrease in canopy cover of the trees growing above the *P. rabaiensis* significantly increase the abundance of *L. williamsi.* The removal of dense canopy cover of *C. odorata* trees above *P. rabaiensis* can benefit *L. williamsi.* However, such active management should be carefully planned and executed since opening large gaps can lead to more colonization by the invasive species. We suggest against removing dense canopies of native species above *P. rabaiensis* to avoid effects on other forest
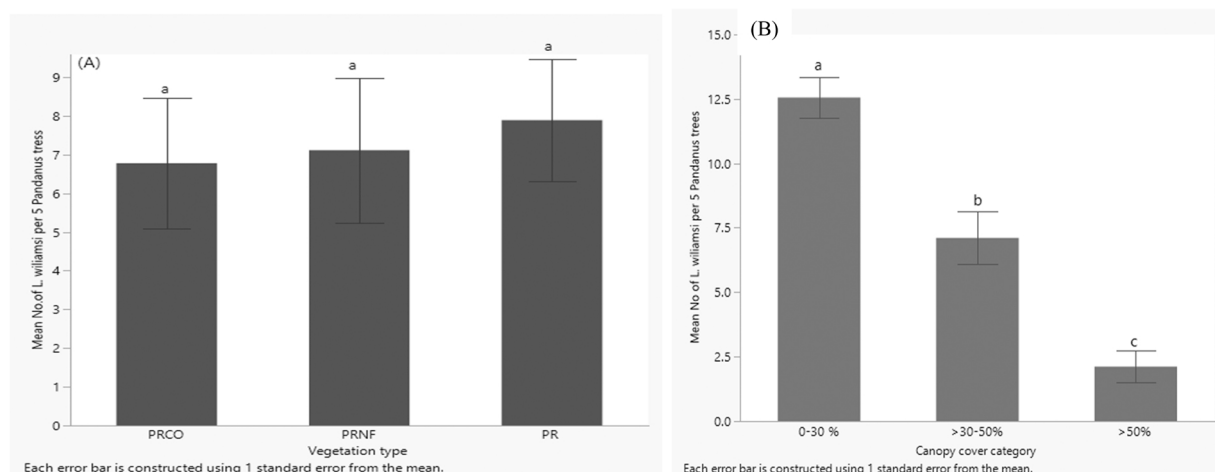
Fig. 6. (A): Mean densities of *L. williamsi* under three potential habitats. PR = pure stand of *Pandanus rabaiensis*; PRCO = *P. rabaiensis* tree growing in mixture with dominant *C. odorata* and PRNF = *P. rabaiensis* tree growing in mixture with dominant native tree species. Similar letter (a-a) above error bars indicate that there was no significant difference (p < 0.05) in the abundance of *L. williamsi* among treatments (habitat types, Tukey's post-hoc test). **(B):** Mean densities of *L. williamsi* under three tree canopy cover categories. Different letters above error bars 'a-b' and 'b-c' indicate slight significant differences (p < 0.05), and 'a-c' the most significant difference (p < 0.01), in the abundance of *L. williamsi* among treatments (canopy cover categories, Tukey's post-hoc test).

inhabitants.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data included in the supplementary materials submitted with this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02225.

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