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Original Article

Vachellia kirkii forest cover shrinkage and plant diversity in the Muvumba wetland, Nyagatare, Rwanda

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ABSTRACT

Vachellia kirkii naturally grows along the Muvumba River near Nyagatare Township, north-eastern Rwanda, where irrigated rice cultivation thrives. In Rwanda, irrigated rice farming in wetlands is expanding to ensure the rapidly growing population's food security. Deforestation and the loss of biodiversity are among the most critical consequences of rice farming expansion. This study aimed to evaluate *V. kirkii* forest cover and plant diversity and their changes over time in the Muvumba wetland and the surrounding savannah. High-resolution imagery and remote sensing techniques were used to generate land-use maps for 2008 and 2018 and to detect temporal changes. Random sampling was done to study vegetation structure and floristic composition. Thirty circular plots of 16 m diameter were established randomly in the *V. kirkii* forest, and fifteen 500 m long transects spaced at 50 m apart in the savannah. Trees and shrubs in both vegetation types were identified and counted. Grass and herbaceous species were identified in 1×1 m quadrants established at the center of each of the main plots. *Vachellia kirkii* individuals dominated as a monoculture near the river, and 49 other plant species were identified in the study area. During one decade (2008-2018), *V. kirkii* cover shrank by approximately 70%. Rice farming threatens *V. kirkii* forest and its associated plant species. There is a need for urgent, environmentally sustainable development measures to save *V. kirkii* forests and their associated biodiversity from extinction in this east-central African region.

Keywords: Biodiversity, deforestation, forest fragmentation, land cover/use change, vegetation studies

Introduction

The importance of forest ecosystems to humans and the environment cannot be overemphasized. However, land-use changes resulting from increasing human population and induced activities have led to land-use changes and an ever-increasing shrinkage in forest cover. Tropical forests are among the most diverse ecosystems on earth (Ewers et al., 2008; FAO, 2010), sequester large amounts of carbon (Millennium Ecosystem Assessment, 2005a), and provide additional ecosystem services such as regulating water supplies (Bruijnzeel, 2004), mitigating the impact of floods (Bradshaw et al., 2007), and support for vital pollination services for agroecosystems (Ricketts et al., 2004). Despite their very high economic value (Ricketts et al., 2004; Secretariat of the Convention on Biological Diversity, 2001) and the potential for economic loss from deforestation (Otum et al., 2017), tropical forests are predicted to experience the most significant proportional reduction in extent of all major biomes in the future (Millennium Ecosystem Assessment, 2005b).

Over 50% of new agricultural land in Africa comes from forest encroachment, and in East Africa, cropland has increased by 50% since 1980 (Gibbs et al., 2010). For example, in the eastern and central African highlands, wood demand long bypassed forests' capacity to supply wood several years back and has resulted in the degradation of many natural forests (Burnett, 1985; Thorhaug and Miller, 1986). Rwanda, although a small country, has remarkable ecosystem diversity (REMA, 2009). It harbors very diverse flora, including approximately 3,000 vascular plant species due to a considerable geologic diversity and a climatic gradient from west to east (REMA, 2009). However, about 30% of its forest cover has been cleared, and a further 20% has been degraded (MINIRENA, 2014), leading to significant reductions in biomass, biodiversity, and ecosystem services from forests. Deforestation and associated losses of diversity are irreversible (https://pdfs.semanticscholar.org/).

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Vachellia kirkii subsp. *mildbraedii* (Harms) Brenan is one of the seven indigenous *Vachellia* species identified in Rwanda (Mugunga & Sahinkuye, 2020). The species naturally grow in water-logged areas. It is found in the Muvumba wetland along the Muvumba River in the Tabagwe and Rwempasha sectors of Nyagatare district, north-eastern Rwanda. A few individuals of the species are also scattered along the river up to where it joins the Akagera River near the Rwanda-Tanzania-Uganda border. *V. kirkii* is very rare in Africa (Brands, 1989). It is reported to occur only in Bukoba along the Kagera River in Tanzania-but has not been recollected in the area since 1906 (Ross, 1979), in Mengo district in Uganda and the eastern Democratic Republic of Congo (Rico, 1994).

The Muvumba wetland is surrounded by savannah grassland mainly used for livestock grazing by the local communities. *V. kirkii* trees tolerate seasonal flooding and maintain a humid microclimate year-round enabling several undergrowth species to survive (http://tropical.theferns.info/viewtropical.php?id=*Vachellia+kirkii*). This riparian vegetation provides a habitat for several birds, amphibians, and small mammals. The vegetation also serves to support the associated wetland ecosystem, especially by protecting the Muvumba River.

However, this ecosystem is very fragile and is highly threatened by ongoing rice farming and associated dam and irrigation scheme construction by the Rural Sector Support Project (RSSP II) since 2012. The construction spreads over 27 km aiming to irrigate a 1,500 ha perimeter (http://www2.canadianconsultingengineer.com/). The associated development activities are very likely to cause irreversible damage to this forest ecosystem. On the one hand, the local authorities are concerned about conserving the forest as indicated by the local communities' restrictions against collecting firewood and charcoal and free-range livestock grazing. On the other hand, the local authorities also support paddy rice production to combat hunger, undermining the conservation efforts since the associated deforestation rate may leave a very small *V. kirkii* stand that may be smaller than the critical size needed for perpetuity. The objectives of this study were (i) to assess the extent of the *V. kirkii* forest in this region of Rwanda and to identify changes over the recent past and the associated effects on floral diversity, (ii) to determine the plant diversity in the *V. Kirkii* forest and the surrounding savannah vegetation. Our ultimate goal was to suggest appropriate measures to rescue this species and its habitat from likely extinction in Rwandan territory.

Methods

Study Site

According to the NDDP (2013), Nyagatare, Rwanda is located at 1°18′ 0.00″ S, 30°19′30.00″ E. It is characterized by two main seasons, including a long dry season that varies between 3–5 months with an annual average temperature varying between 25.3–27.7°C. The monthly rain distribution varies across the years, with an annual average of 827 mm. The average altitude is 1,513 m.

The study area comprises two distinct vegetation types: the *V. kirkii* forest found on both sides of the Muvumba River in the wetland and the savannah wooded grassland lying on the forest's eastern side of the river.

Land-Use Changes

Land-use and its changes were identified for the period between 2008 and 2018. The period was selected for two reasons: (i) up to 2009, the Muvumba wetland ecosystem was not converted to intensified agriculture; wetland conversion to agriculture started after 2012; (ii) the availability of high-resolution imagery to detect land-use and change at a small spatial scale was not available before 2008. We used aerial photographs from 2008–2009 from the last nationwide aerial mission (Swedesurvey, 2010) to generate a detailed land-use map of 2008. Using quite closer resolution imagery from digital globe 2018, we produced a land-use map of 2018 for the same areas. Local knowledge and direct, ground-based observations were also made to map vegetation types (Adam et al., 2010) (Esri software). *Vahellia Kirkii* cover change was detected using spatial overlay under spatial analysis tools of ArcMap 10.6, which was also used to visualize the selected land-use types.

Plant Diversity Assessment

In the Muvumba wetland, sampling was done in two distinct habitats, *Vachellia kirkii* forest stand, and savannah grassland. The study area was spatially stratified, considering the vegetation structure and floristic composition. Tree and shrub populations in the *V. kirkii* forest were estimated in 30 circular sample plots of 16 cm diameter established randomly. In the savannah grassland, 15 transects, 500 m long spaced at 50 m apart, were established from the *V. kirkii* forest edge radiating to the surrounding savannah land. Circular plots of 16 cm diameter each were established along each transect at an interval of 100 m, providing an additional 75 plots in all transects (Figure 1). Trees and shrubs found in each plot were recorded by species and number. Grass and herbaceous plants in the area were assessed based on the Buell and Cantlon (1950) approach, where 1 × 1 m quadrants established at the center of the circular plots considered in enumerating trees and shrubs were used.

The vegetation surveys were done toward the end of the rainy season when most plants were flowering, had aerial shoots of geophytes, and grasses still had inflorescences to facilitate species identification. Plant specimens difficult to identify were collected and taken to the national herbarium in Huye town for further identification.

Results

Land Cover Changes

The primary land-use types and forest cover changes in the study area in 2008 and 2018 are illustrated in Figure 1. The 2008 and 2018 imagery interpretation reveals that the Muvumba wetland covered 2,236 ha and was mainly composed of *V. kirkii* forest, savannah pastureland, and a small settlement. In 2008, livestock husbandry activities, natural vegetation (mostly *V. kirkii* forest), and the settlement respectively covered 760, 1,200, and 10 ha. Ten years later, the forest along the Muvumba River had been reduced by over three-fold to approximately 230 ha in 2018 (Figure 2), implying that 69% of the *V. kirkii* forest was lost due to conversion of the wetland to rice farming.

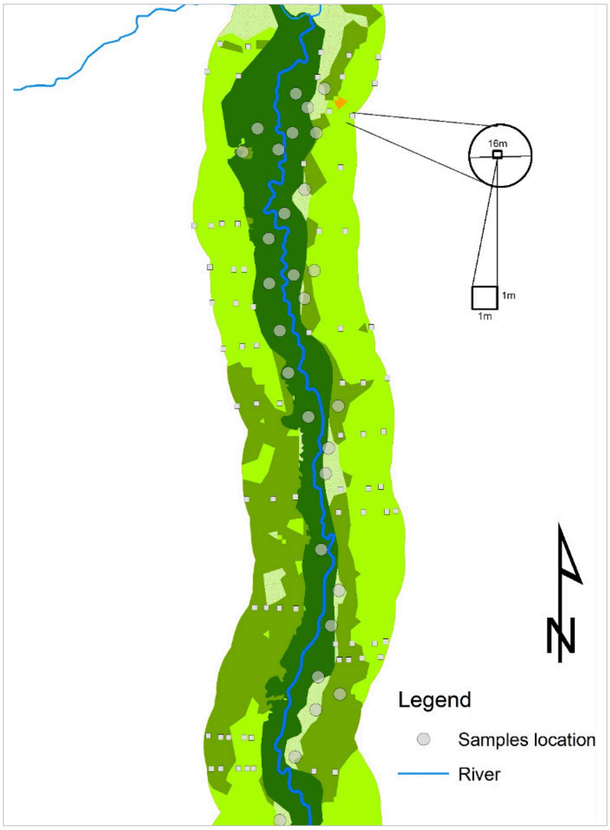


Figure 1
Transect and Sample Plot Layout in a Vegetation Study in Vachellia Kirkii Forest in Muvumba Wetland and the Surrounding Savannah, Nyagatare, Rwanda

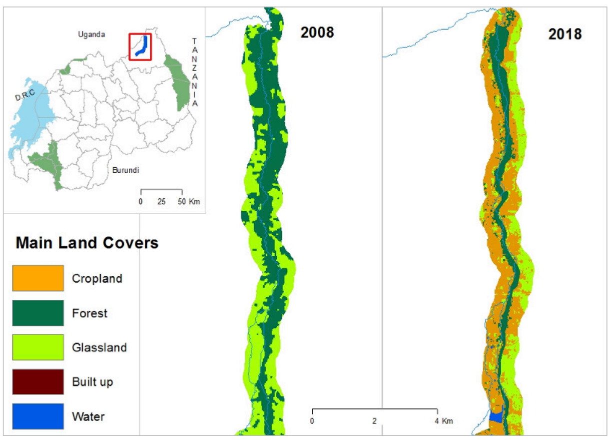


Figure 2
Land Covers Maps of Muvumba Wetland, Nyagatare, Rwanda for the Years 2008 and 2018

Plant Diversity in the *V. kirkii* Forest and Adjoining Savannah Land

Plant species identified in the area are presented in Table 1 with their respective niche preferences (ecosystem category where they were observed), life form, and stocking. A total of 60 plant species and 22 families were observed in the study area (Table 1). A tree density of 1,450 and 150 stems/ha was observed in the forest and savannah, respectively, while 450 and 1,000 stems/h shrubs belonging to 12 families were counted in the forest and savannah, respectively (Figure 3). Among these species, only

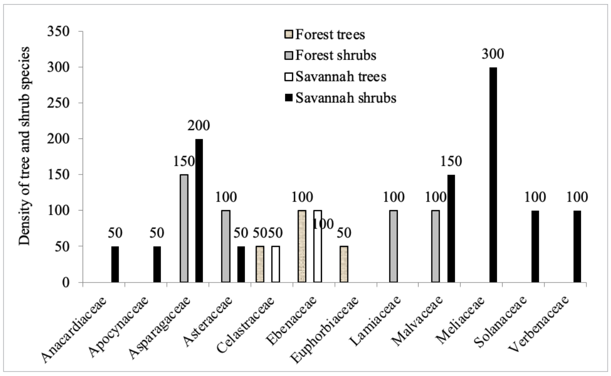


Figure 3
The Number of Trees and Shrubs per Hectare in the Vachellia Kirkii Forest and the Savannah Vegetation in Nyagatare, Rwanda

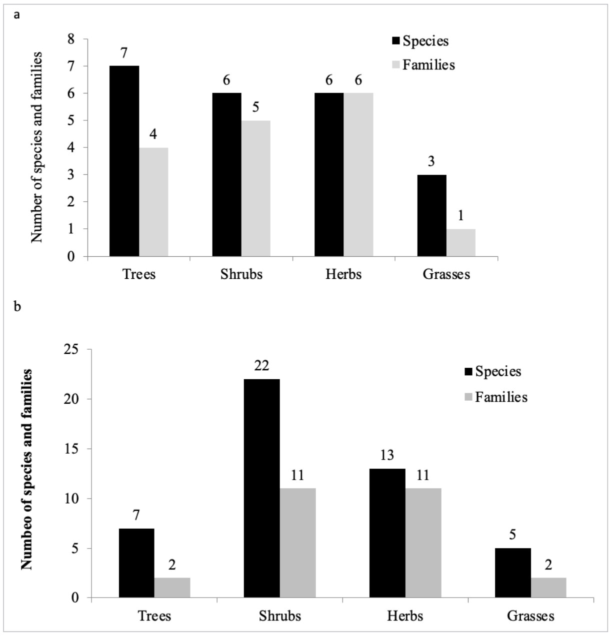


Figure 4. a, b
Number of Species (Dark Bars) and Families (Grey Bars) of Different Life Forms in Vachellia Kirkii Forest in Muvumba Wetland, Nyagatare, Rwanda (a). Number of Species (Dark Bars) and Families (Grey Bars) of Different Life Forms in the Savannah Surrounding Muvumba Wetland, Nyagatare, Rwanda (b)

Table 1
Life Forms and Plant Densities of Different Species Identified in the Vachellia Kirkii Forest and the Surrounding Savannah in Nyagatare, North-Eastern Rwanda

Habitat/*Family*	Botanical name	Life form	Plant density (No./ha)*
***VACHELLIA KIRKII* FOREST**			
Fabaceae	*Vachellia kirkii* subsp. *Mildbraedii* (Harms) Brenan	Tree	25 (1250)
Ebenaceae	*Euclea schimperi* subsp. *Racemosa* (Hem.)	Tree	2 (100)
Fabaceae	*V. sieberiana var woodii* (DC.)	Tree	2 (100)
Fabaceae	*V. gerrardii* (Benth.)	Tree	1 (50)
Celastraceae	*Elaeodendron Schlechteianum* (Loes.)	Tree	1 (50)
Fabaceae	Erythrina abyssinica (Lam. ex DC.)	Tree	1 (50)
Euphorbiaceae	Sapium ellipticum (Hochst.)	Tree	1 (50)
Asparagaceae	*Asparagus flagellaris* (Kunth) Bak.	Shrub	3 (150)
Verbenaceae	*Clerodendrum johnstonii* (Oliv.)	Shrub	3 (150)
Malvaceae	*Pavonia patens* (DC.)	Shrub	2 (100)
Asteraceae	*Tagetes minuta* (L.)	Shrub	2 (100)
Malvaceae	*Triumfeta rhombifolia* (Jacq.)	Shrub	2 (100)
Amaranthaceae	*Achyranthes aspera* (L.)	Herb	0.212 [2120]
Euphorbiaceae	*Tragia brevipes* (Pax)	Herb	0.115 [1150]
Solanaceae	*Physalis peruviana* (L.)	Herb	0.154 [1540]
Commelinaceae	*Commelina africana* (L.)	Herb	0.144 [1437]
Cucurbitaceae	*Cucumis aculeatus* (Cogn.)	Herb	0.131 [1311]
Apocynaceae	*Sarcostema viminale* (L.)	Herb	0.130 [1296]
Poaceae	*Setaria pumila* (Poir.) Roem. & Schult.	Grass	3 [30.000]
SAVANNAH			
Fabaceae	*Vachellia gerrardii* (Benth.)	Tree	8 (400)
Euphorbiaceae	*Euphorbia candelabrum* (Tremaux ex Kotschy.)	Tree	3 (150)
Euphorbiaceae	*Euphorbia tirucallii* (L.)	Tree	1.3 (65)
Fabaceae	*Ormocarpum trachycarpum* (Taub.) Harms	Tree	1 (50)
Fabaceae	*Senna didymobotrya* (Fresen.)	Tree	1 (50)
Verbenaceae	*Lantana camara* (L.)	Shrub	3 (150)
Malvaceae	*Abutilon mauritianum* (Jacq.) Medic.	Shrub	2 (100)
Malvaceae	*Hibiscus fiscus* (L.)	Shrub	2 (100)
Lamiaceae	*Ocimum americanum* (L.)	Shrub	2 (100)
Lamiaceae	*Ocimum sauve* (Wild.)	Shrub	2 (100)
Lamiaceae	*Ricinus communis*	Shrub	2 (100)
Fabaceae	*Senna occidentalis* (L.)	Shrub	2 (100)
Malvaceae	*Sida cordifolia* (L.)	Shrub	2 (100)
Compositae	*Microgrossa pylifolia* (Lam.) O. Kuntze	Shrub	1.5 (75)
Asparagaceae	*Asparagus africana* (L.)	Shrub	1 (50)
Apocynaceae	*Carissa spinarum* (L.)	Shrub	1 (50)
Solanaceae	*Datura stramonium* (L.)	Shrub	1 (50)

Table 1
Life Forms and Plant Densities of Different Species Identified in the Vachellia Kirkii Forest and the Surrounding Savannah in Nyagatare, North-Eastern Rwanda (Continued)

Habitat/*Family*	Botanical name	Life form	Plant density (No./ha)*
Malvaceae	*Grewia similis* (K. Schum.)	Shrub	1 (50)
Malvaceae	*Hibiscus diversifolia* (Jacq.)	Shrub	1 (50)
Lamiaceae	*Hoslundia opposite* (Vahl.)	Shrub	1 (50)
Celastraceae	*Maytenus senegalensis* (Lam.) Excell	Shrub	1 (50)
Anacardiaceae	*Rhus natalensis* (Bernh. Ex Krauss)	Shrub	1 (50)
Solanaceae	*Solanum incanum* (L.)	Shrub	1 (50)
Solanaceae	*Solanum nigrum* (L.)	Shrub	1 (50)
Asteraceae	*Ageratum conizoides* (L.)	Herb	.12 [1200]
Amaranthaceae	*Amaranthus hybridus* (L.)	Herb	.11 [1180]
Amaranthaceae	*Amaranthus spinosus* (L.)	Herb	.10 [1025]
Vitaceae	*Cyphostema adenocaule* (Steud. ex A. Rich.)	Herb	.12 [1215]
Fabaceae	*Dolichos sinensis* (Forssk.)	Herb	.15 [1538]
Acanthaceae	*Hygrophila auriculata* (Schumach.)	Herb	.1 [979]
Phytolaccaceae	*Phytolacca dodecandra* (L'Herit.)	Herb	.76 [763]
Menispermaceae	*Stephania abyssinica* (Dill. & Rich.) Walp.	Herb	.56 [557]
Asphodelaceae	*Aloe lateritia* (Engl.)	Herb	.46 [455]
Vitaceae	*Cissus quadrangularis* (L.)	Herb	.35 [350]
Lamiaceae	*Leonitis nepetaefolia* (L.)	Herb	.3 [297]
Lamiaceae	*Leucas aspera* (Wild.) Linn.	Herb	.23 [279]
Poaceae	*Eleusine indica* (L.)	Grass	4.7 [47,000]
Poaceae	*Setaria homonyma* (Steud.)	Grass	4.5 [45,000]
Poaceae	*Sporobolis pyramidalis* (P. Beauv.)	Grass	4.4 [44,000]
Poaceae	*Cynodon dactylon* (L.)	Grass	3.4 [34,000]
Poaceae	*Panicum maximum* (Jacq.)	Grass	2.5 [25,000]

Note. *Number of tree and shrub species per 200 m^2 plot and figures in round brackets denote stems ha^{-1}); herbaceous and grass species populations were estimated in a 1 m^2 plot, and figures in square brackets stand for plants ha^{-1}).

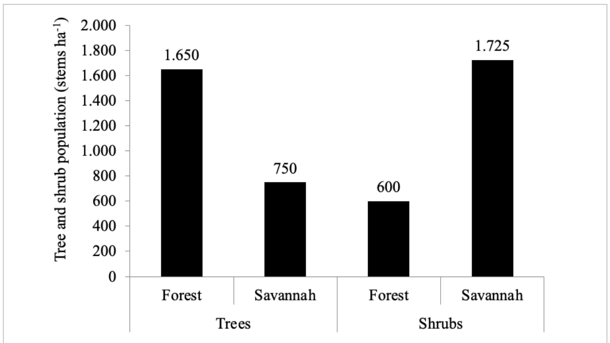
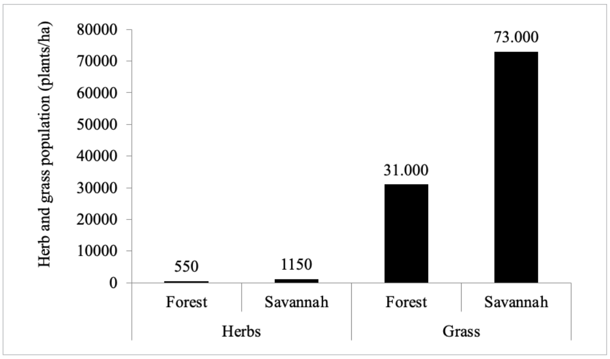


Figure 5
Frequency of Trees and Shrubs in Vachellia Kirkii Forest and the Surrounding Savannah Land Along Muvumba River, Nyagatare District, North-Eastern Rwanda



Figue 6
Number of Herbaeous and Grass Species in Vachellia Kirkii Forest and the Surounding Savannah along Muvumba River, Nyagatare District, Northern Rwanda

V. kirkii had the most localized distribution, clustered into a thin, riverine forest adjacent to the Muvumba River where the species' individuals occurred in an almost pure, monospecific stand. Six other tree species were identified in the forest, but their densities were 12.5–25 times lower than *V. kirkii* in the same niche. Even when their numbers were combined, *V. kirkii* outnumbered them by over three-fold.

The different life forms observed in the *V. kirkii* forest and those from the savannah vegetation are shown in terms of species and family numbers in Figure 4a and Figure 4b, respectively. *Vachellia gerrardii* had the widest distribution among the tree species, with a few individuals observed in the *V. kirkii* forest near the river and an abundance of four times higher in the surrounding savannah land. Five tree species were identified in the savannah grassland, where the densities were far much lower than the density in the comparatively wetter *V. kirkii* forest.

The number of trees in the forest was two times higher than that of trees in the savannah, while the savannah had a shrub population exceeding that of the same life form in the forest by approximately three times (Figure 5). Herb and grass species' frequency were respectively higher in the savannah by about two and five times the numbers observed in the forest (Figure 6).

Discussion, and Conclusion and Recommendations

Land Cover Changes in the Study Area

Rwanda is among the countries with the highest population density in Africa (MINECOFIN, 2014). The country is constrained by a fast-growing population density, having grown from 121 persons km^{-2} in the 1960s to 262 in 1990, and 380 persons km^{-2} in 2010 (MINECOFIN, 2014). Consequently, the average per capita land declined from 3 ha per household in the 1960s to less than 1 ha today (Verdoodt & van Ranst, 2006).

The response of Rwandan farmers to the pressure on land and the associated decline in productivity has been to expand their agricultural activities into the fragile wetlands (Nsharwasi, 2012). The total area of wetlands in Rwanda was approximately 278,000 ha, of which, in 2009, 53% was used for cultivation (REMA, 2009). Conversion of natural forests to agriculture is a significant threat to biodiversity and plant genetic resources (MINIRENA, 2014). The decline of about 70% of the *V. kirkii* forest in only one decade due to wetland conversion to rice production observed in this study is evident in only a small area. A similar ecosystem shrinkage has been observed in the gallery forests of eastern Rwanda following the resettlement of immigrants after the genocide, clearing of woodlands for settlement, crop production, pastures, and wood supply for domestic energy (REMA, 2015). Conversion of part of the Muvumba wetland for rice production also occurred in this period.

Agricultural expansion is one of the biggest causes of deforestation in tropical forests. Rice agriculture has recently been a significant cause of deforestation of Mangrove forests in Southeast Asia (Richards & Freiss, 2012; Webb et al., 2014). Tropical forests are incredibly biodiverse. Their prospects and the biodiversity they contain are becoming increasingly bleak due to unabated deforestation and forest alteration (Millennium Ecosystem Assessment, 2005a) that stem from human activities, including agricultural expansion and human settlement (Matthews et al., 2000). Deforestation depletes biodiversity by destroying habitats, separating contiguous areas of rainforest from each other, interfering with plant reproduction, and exposing organisms of the deep forest to "edge" effects (http://www.rainforestconservation.org/…/3-loss-of-biodiversity-including-genetic-dive-rsity/).

Plant Diversity

The occurrence of *V. kirkii* individuals clustered near the river conforms to the species' characteristics. It is known to grow in riverine woodlands, grasslands, and the lower highlands, especially in seasonal waterlogging areas (Dharani, 2019). The smaller number of plant species in the *V. kirkii* dominated forest than in the savannah is not unexpected. The niche is wetter, capable of supporting perennial plants-the trees, than would a relatively drier environment of the savannah grassland (https://www.wiley.com/college/sc/selby/c05.pdf). Another reason for a higher tree population adjacent to the river than further away might be because the river and the surrounding niche receive some degree of protection from the local authorities.

Unlike near the river, little or no protection might explain the higher number of shrub, herb, and grass species observed in the savannah grassland. In addition to dry conditions, the grassland experienced occasional tree cutting for firewood collection, charcoal-burning bush clearing, and tree cutting as range management interventions by livestock farmers. When done for the purpose of rangeland management, the operation is termed "*kweza*" by the locals, meaning to cleanse. The pastures are "cleansed" by clear-felling all or most of the trees growing in them. Land clearance was reported to be a significant deforestation activity in pasture management in the Amazon forest (Graesser, 2015), where pastureland increased by 96.9 million hectares between 2001–2013, corresponding to a 57% increase resulting in forest cover loss. Reducing tree densities in rangelands also creates more room for grass growth, favoring grasses for fodder availability (https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1312&context=extensin_curall).

A result of forest clearing is a modified environment allowing for light-demanding species (grasses, herbs, etc.) to emerge (Pearson et al., 2003). The observed higher tree and shrub density in the forest than in the savannah in this study might also result from high recruitment rates following disturbances. As expected, tree density usually becomes higher when forests are disturbed to have higher canopy openness (Salm, 2005).

Livestock farming and crop production land-use types are prevalent in the area surrounding the study site, and smallholder dairy farmers own pastures of <1 to >5 ha. Settling of refugee returnees was experienced at a high rate during the post-genocide period (from 1994 onwards) as returnees were allocated land for agriculture formerly reserved for forests. Warfare development is reported to interact with land-use activities to influence the transformation of the landscape and severity of forest conversion (Ordway, 2015). Tree cutting is one of the common activities done on pastures in the study area to promote grass dominance.

In Rwanda, *V. kirkii*, solely found along the Muvumba River near Nyagatare Township, is associated with *Sapium ellipticum* (Hochst.), which is also a rare species. *Sapium ellipticum* has been recorded in the Muvumba wetland (Nyagatare) and in the Nyabarongo wetland (Kigali), where very few individuals of this species were recorded. These two essential species represent many that are endangered as a result of conversion to agricultural land. Being a small population, *V. kirkii* forests are likely to suffer more with slight declines in population size. Small populations are susceptible to any change in their respective habitats (Terborgh et al., 1990; Thiollay, 1994).

Natural forest ecosystems' exploitation has been selective and holistic, leaving an unknown number of species extinct or endangered. The consequence of this is far-reaching. We might have lost or currently losing species that might be potentially economic or adapted to the anticipated climate change.

Rice farming in the study area has emerged as a significant cause of land-use change, where in a single decade, forest cover shrinkage of approximately 70% was observed in the *V. kirkii* dominated forest in the Muvumba wetland, north-eastern Rwanda. Rice farming and the consequent shrinkage of the *V. kirkii* forest threatens its existence, leaving it on the brink of extinction. Adapted to the water-logged sites, *V. kirkii* may probably be important for wetland and riverbank protection against soil erosion, a severe constraint existing throughout the country. Therefore, it would be worthwhile to test its adaptation beyond its natural range in Rwanda to explore its potential in protecting soil erosion and siltation in wetlands. Advocacy needs to be made for urgent conservation of the *V. kirkii* forest. Since the species naturally occur in the Democratic Republic of Congo, Rwanda, Tanzania, and Uganda, a trans-boundary joint effort is recommended to understand the species' conservation status in the region to establish its conservation strategy.

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Conflict of Interest: The authors have no conflicts of interest to declare.

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