2021-09

Impact of invasive alien plants Gutenbergia cordifolia and Tagetes minuta on native taxa in the Ngorongoro crater, Tanzania

Ngondya, Issakwisa

Elsevier

https://doi.org/10.1016/j.sciaf.2021.e00946

Scientific African 13 (2021) e00946

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Impact of invasive alien plants *Gutenbergia cordifolia* and *Tagetes minuta* on native taxa in the Ngorongoro crater, Tanzania ☆

Issakwisa B. Ngondya*, Linus K. Munishi

Department of Sustainable Agriculture, Biodiversity Conservation and Ecosystem Management, School of Life Sciences and Bio-Engineering, The Nelson Mandela African Institution of Science and Technology, P O Box 447, Nelson Mandela Road, Arusha, Tanzania

ARTICLE INFO

Article history:
Received 6 July 2020
Revised 15 August 2021
Accepted 16 August 2021

Editor: DR B Gyampoh

Keywords:
Daisy
Herbivore
Invasion
Marigold
Rangeland
Weed

ABSTRACT

Understanding the ecological impacts of invasive plant species on the native communities and identifying native plant species that co-exist with invasive plants are important for planning the effective control and restoration of invaded rangelands. Systematic random sampling technique was applied to assess the effect of the two invasive plants (*Gutenbergia cordifolia* and *Tagetes minuta)* on native vascular plant species' cover and diversity as well as identification of native grasses that co-exist well with the two invasive plants in the Ngorongoro crater, Tanzania. Native species ground cover in lowly invaded quadrats doubled that of medium and highly invaded quadrats. The mean height of native plants in highly invaded areas doubled the height of native plants in lowly invaded areas. While species richness was higher in both *G. cordifolia* and *T. minuta* lowly invaded quadrats compared to quadrats that were under medium and high invasion similarly, lowly invaded quadrats had higher species evenness than both medium and highly invaded quadrats. *Cynodon dactylon* was the most co-existing native grass with both *G. cordifolia* and *T. minuta* followed by *Chloris pycnothrix*. The results highlights how invasive plants *G. cordifolia* and *T. minuta* drastically changed the abundance and richness of the native vascular plant community within the Ngorongoro crater. It also highlighted on presence of native grasses that are capable of co-existing with the two invasive plants. This study further generated a baseline information for long term research to elucidate mechanisms associated with the two invasive plants interactions, while at the same time informing the management authorities on the threats to native plant species associated with invasive plants *G. cordifolia* and *T. minuta*.

☆ Editor by: B. Gyampoh

* Corresponding author.
E-mail address: issakwisa.ngondya@nm-aist.ac.tz (I.B. Ngondya).

https://doi.org/10.1016/j.sciaf.2021.e00946

Introduction

Invasive species have been declared as one of the biggest threats to biodiversity [1,2]. These species have been reported not only to affect ecosystems through suppression of native species and, hence, resulting in the extinction of the latter [2–4] but also altering ecological processes and, therefore, reducing overall ecosystem yields [5]. As human population and people's movement increases, so does dispersal of invasive plants such as *Gutenbergia cordifolia* Benth. ex Oliv. var. *cordifolia* and *Tagetes minuta* L. from one locality to another [6]. Although various attempts have been made to control the invasives and mitigate their impacts particularly in conservation areas [7], the cost-effective approaches that are eco-friendly to address this are largely lacking in the literature.

Gutenbergia cordifolia and *Tagetes minuta* have been reported as invasive weed species across the tropics, subtropics and several temperate countries [8–10]. In Tanzania, these species have recently invaded the Ngorongoro Conservation Area (NCA) [9], likely impacting the native plant and herbivore communities in this highly renowned protected area. The Ngorongoro crater floor as it is mostly grassland [11,12] is at greater risk as invasion within it is over half of the entire crater [13] and majority of ungulates within it depends on its forage species for grazing. Like other invasive species, *G. cordifolia* and *T. minuta* are not edible by animals [14] and, hence, grow more leaves, roots and flowers than their native counterparts. They, therefore, may have an increased competitive ability to suppress the native plant species [15]. The two species, as most invasives, spread supposedly through a complex interaction of human and animal movement patterns [16]. However, their ecological effect on native vascular plants has never been quantified in the herbivore-rich NCA.

While considerable research has been done on woody invasive weeds [17–21], studies are lacking on herbaceous invasive plant species and their effects in grassland systems. Quantification of the impact of herbaceous invasive plant species on the native plant species and habitat transformation as well as their consequences on ecosystem services is still rudimentary and sometimes lacking particularly in protected areas. The lack of such information hinders appropriate and timely management decisions to prevent further establishment and spread. In this case, information on impacts of such species is needed for enhancing the implementation of the management actions in the appropriate time as well as assisting the future prediction of the invasive species.

There is a need to determine the ecological impacts of invasive plants *G. cordifolia* and *T. minuta,* particularly in a fragile ecosystem like Ngorongoro crater, where the survival of animals strongly depends on the vigor of native grasses within the crater that might be easily suppressed by the invasives. Identifying the ecological impacts of the two invasive plants and native grasses that co-exist with the two invasives will therefore, contribute to formulation of intervention and mechanisms for invasive plants management purposes and will add to the efforts as per Strategy for Managing Invasive Species in Africa (2021–2030) which will help in realizing the Africa we want (African Union Agenda 2063; goals 1,3,4 and 7). This study therefore aimed at assessing the impacts of invasive plants *G. cordifolia* and *T. minuta* on the diversity (abundance, richness and evenness) of native plant species in the Ngorongoro crater and identifying native grass species that co-exist well with the two invasive plant species. It therefore, hypothesized that highly invaded plots would have lower native plant species (including forage grasses) diversity. Further, it was expected that native plants' vigor (height and percentage ground cover) would be poor in plots under medium and high invasion levels of *G. cordifolia* and *T. minuta* compared to those under low invasion level.

Materials and methods

Study site

Ngorongoro Conservation Area (NCA) is located in the northern part of Tanzania (2°30′-3°30′S, 34°50′-35°55′E), bordering the Serengeti National Park to the North-West, Lake Eyasi to the South and the Loliondo Game Controlled Area and village lands in the South-East [12]. The NCA covers an area of 8300 km^2 with the main crater (Ngorongoro crater) descending to a depth of 610 m with a basin that covers an area of 260 km^2. The crater floor soil is mostly of colluvial deposits with wet and dry seasons diurnal temperatures ranging from 7.4 °C–14.5 °C and from 10.6 °C–19.6 °C, respectively and an annual rainfall ranging from 300–630 [11].The crater floor is mainly grassland composed of various species including *Sporobolus* spp, *Themeda triandra* and *Cynodon dactylon* [22] with a small woodland and shrubs on the Western side. The area provides a habitat to over 30 African elephants (*Loxodonta africana*), 7000 wildebeests (*Connochaetes taurinus*), 4000 zebras (*Equus quagga*), 3000 common elands (*Taurotragus oryx*), 4000 African buffalos (*Syncerus caffer*), 3000 Grant's (*Nanger granti*), 3000 Thomson's gazelles (*Eudorcas thomsonii*), 6000 Spotted hyenas (*Crocuta crocuta*) and over 55 lions (*Panthera leo*) [9].

Study species

While both *T. minuta* and *G. cordifolia* (Fig. 1) belongs to family Asteraceae, *T. minuta* originated from South America and has escaped cultivation in most nations and is considered a noxious weed in parts of southern Africa [24]. *Gutenbergia cordifolia* on the other hand is an annual plant native to Sudan, Kenya, Democratic Republic of Congo, Rwanda, Burundi, Zambia, Malawi and Zimbabwe [25]. Both species have recently been reported as among problematic plants that have invaded the Ngorongoro Conservation Area [9].

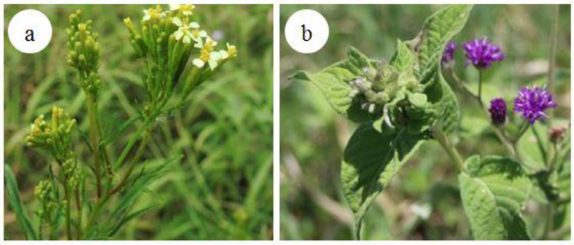

Fig. 1.. Study species (a) *T. minuta* and (b) *G. cordifolia* (source: field survey).

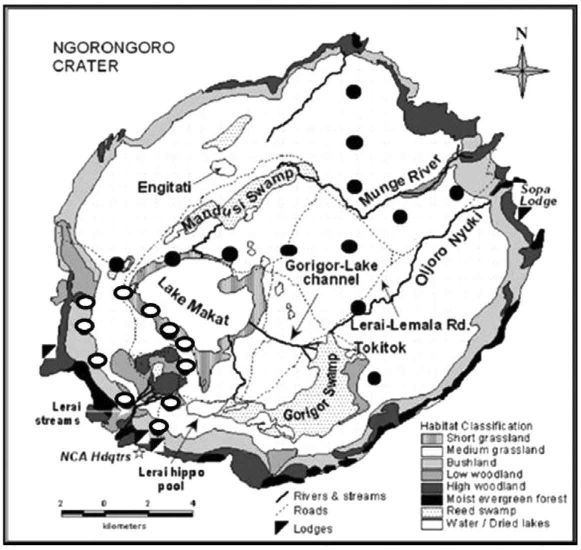

Fig. 2.. A map of Ngorongoro crater modified from [23] black and white circles indicate areas where *G. cordifolia* and *T. minuta* invasion sampling was done, respectively.

Sampling design

Quadrats of 1 m^2 were established along a continuum of the two species' invasion cover [18]. Each quadrat was used as a unit of observation. Invasion density at a site was grouped based on invasive plant's percentage ground cover as; "low invasion" (1–24% invasion cover), "medium invasion" (25–49% invasion cover) and "high invasion" ($\geq$ 50% invasion cover) with two replicates. The quadrats were systematically laid out and placed at 20 m apart from each other at a site. For *G. cordifolia,* which was mostly all over the crater floor and thus covering mainly the grassland vegetation; each site was placed with six quadrats after every 3 km along two crossing transects running from South to North (18 km long, 0.1 km wide) and East to West (21 km long, 0.1 km wide) of the Ngorongoro crater (Fig. 2). For *T. minuta*, that was covering most of the western parts and the crater rim and thus bush land vegetation; each site was placed after every 600 m and 300 m along a 3.6 km long, 0.1 km wide and 2.4 km long, 0.1 km wide transects, respectively (Fig. 2).

Data collection

The study assessed native vascular plant species richness, ground cover and vegetation height along invasion gradients of *G. cordifolia* and *T. minuta* from early July to late August, 2019. Each native vascular plant species was identified using literature [26], recorded and its number estimated after consensus by a team of three experts. Native vascular plants height was measured in each quadrat at four random points using a ruler. Invasive and native species percentage ground cover was visually estimated [27].

Statistical analysis

One way Analysis of Variance (ANOVA) was performed to compare native vegetation height while a Kruskal-Wallis test was performed to compare native species evenness ($J^/$), percentage ground cover, richness (S) and abundance along the invasion gradient for both *T. minuta* and *G. cordifolia* separately [18]. The percentage occurrence (presence) of each native grass was calculated to identify the native grass with the highest presence along the invasion gradient. Correlation between

Table 1.
Plant species observations per invasion category in the Ngorongoro crater.

Observations	Invasion category					
	T. minuta			*G. cordifolia*		
	L	M	H	L	M	H
No. of plant species observed	42	22	14	48	22	16
No. of families observed	16	10	8	14	6	6
No. of grass species (Poaceae) observed	13	8	5	24	12	9
No. of native plant species observed	41	21	13	45	21	15
No. of non-native plant species observed	1	1	1	3	1	1
No. of invasive plant species observed	1	1	1	1	1	1

*L = lowly invaded, M = medium invaded and H = highly invaded.

Table 2.
One-way ANOVA and Kruskal-Wallis test for; Shannon-Wiener's diversity index, evenness, vegetation height (cm) and ground cover (%) of native plants in both *T. minuta* and *G. cordifolia* quadrats ($H = H_{(2,24)}, F = F_{(2,24)}$).

Index	*T. minuta*				*G. cordifolia*			
	MS	*F*	*H*	*P*	MS	*F*	*H*	*P*
SWD Index			7.4	< 0.01	-	-	3.8	0.02
Evenness (J/)	-	-	2.3	0.03	-	-	3.1	0.04
Vegetation height	901.2	9.0	-	< 0.01	1949.6	24.2	-	< 0.01
Ground cover	-	-	17.3	< 0.01	-	-	19.1	< 0.01

*SWD = Shannon-Wiener's Diversity, MS = mean square, F = F-value, H = H-value, P = P = value.

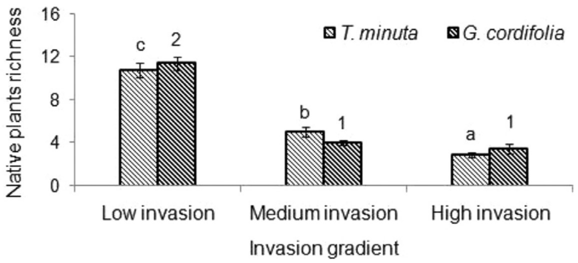

Fig. 3.. Native plant species richness per quadrat under *T. minuta* and *G. cordifolia* invasions.

the impact of *G. cordifolia* and *T. minuta* on native vascular plant species composition (expressed as Sorensen similarity between highly invaded and lowly invaded plots) and native species richness were performed using Pearson's product-moment correlation analysis and Spearman's rank-order correlation analysis, respectively. The statistical software used was STATISTICA version 8 [28] with the level of significance set at $\alpha < 0.05$.

Results

Impacts of invasive plants G. cordifolia and T. minuta *on native plant species diversity in the Ngorongoro crater*

The highest number of native plant species and families were observed in lowly invaded quadrats compared to quadrats that were highly invaded by *G. cordifolia* and *T. minuta* (Table 1; Supplementary materials 1 and 2). *Gutenbergia cordifolia* and *T. minuta* lowly invaded areas had fifteen (15) and eight (8) more grass species (Poaceae), respectively than highly invaded areas (Table 1; Supplementary materials 1 and 2). While over 93% of plant species that were observed in the study area were native plant species less than 6% were non-native plant species (Table 1).

Generally, species diversity differed significantly along invasion gradient for both *T. minuta* and *G. cordifolia* (Table 2). The mean native species richness per quadrat was found to be decreasing along the invasion gradient for both *T. minuta* and *G. cordifolia* (Fig. 3). While species richness differed significantly along the invasion gradient under both *T. minuta* and *G. cordifolia* ($H_{(2,24)} = 15$, $p = 0.0021$ and $H_{(2,24)} = 28$, $p = 0.0004$, respectively), likewise species abundance significantly differed under both *T. minuta* and *G. cordifolia* ($H_{(2,24)} = 4.3$, $p = 0.0021$ and $H_{(2,24)} = 9.6$, $p = 0.0052$, respectively). Species evenness differed significantly along invasion gradient for both *T. minuta* and *G. cordifolia* (Table 2) with lowly invaded quadrats being more evenly distributed ($J^{/}$=0.8) than both medium ($J^{/}$=0.5) and highly ($J^{/}$=0.3) invaded quadrats. Lowly invaded quadrats had three times higher mean native species per quadrat than highly invaded quadrats (Fig. 3).

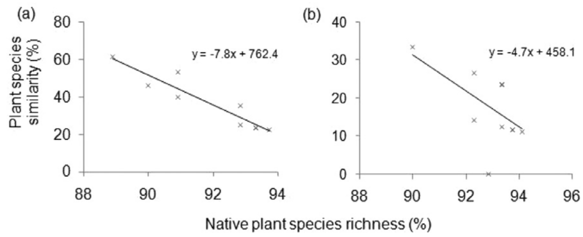

Fig. 4.. Correlation between the impact of (a) *T. minuta* and (b) *G. cordifolia* invasive plant species on native vascular plant species composition (expressed as Sorensen similarity between highly and lowly invaded quadrats in a pair) and native species richness.

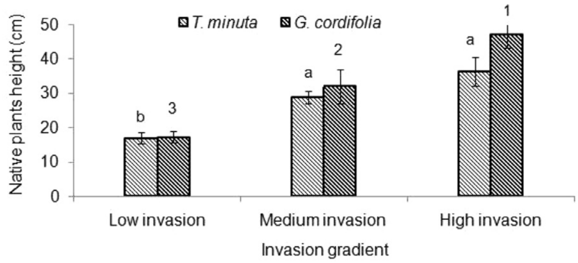

Fig. 5.. Average native plants height under *T. minuta* and *G. cordifolia* invasions. Bars with disimmilar letters and or numbers are significantly different by Fisher LSD at $p = 0.05$.

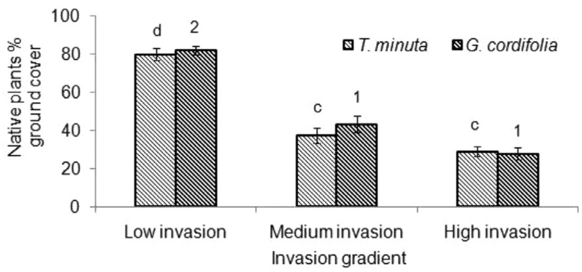

Fig. 6.. Native plant species percentage ground cover under *T. minuta* and *G. cordifolia* invasions. Bars with disimmilar letters and or numbers are significantly different by Fisher LSD at $p = 0.05$.

Native vascular plant species composition similarity was negatively correlated with native species richness under both *T. minuta* and *G. cordifolia* invasions ($r = -0.94$, $p = 0.0001$; $\rho = -0.61$, $p < 0.05$, respectively) (Fig. 4).

Impacts of invasive plants G. cordifolia and T. minuta *on native plant species vigor in the Ngorongoro crater*

Under both *T. minuta* and *G. cordifolia* invasions, the height of native plants in highly invaded quadrats were about double that of lowly invaded quadrats ($p < 0.05$) (Fig. 5).

Native species percentage ground cover in both *T. minuta* and *G. cordifolia* invasions was twice as high in lowly invaded quadrats compared to medium and highly invaded quadrats ($p < 0.05$) (Table 2 and Fig. 6).

Native species observed to co-exist with invasive plants *G. cordifolia* and *T. minuta* in the Ngorongoro crater

Cynodon dactylon was the most dominant plant observed to co-exist with both *G. cordifolia* and *T. minuta* weeds in both medium and highly invaded quadrats with an average occurence of more than 70% and 30%, respectively. The mean number of *C. dactylon* individuals in *G. cordifolia* and *T. minuta* highly invaded quadrats were 53 ± 13 and 42 ± 10, respectively (Table 3). *Chloris pycnothrix* was the second most co-existing local grass species with percentage occurence of ≥ 17% in both medium and highly invaded quadrats. The mean number of *C. pycnothrix* individuals in *G. cordifolia* and *T. minuta* highly invaded quadrats were 19 ± 5 and 3 ± 0, respectively (Table 3).

Discussion

While the two invasive species, *G. cordifolia* and *T. minuta* might not be the only cause of changes in native species diversity observed in this study but rather passengers of change as invasion itself may be due to disturbance and heavy grazing

Table 3
. Mean individual number per quadrat (± SE) of the common native grass species of occurrence of ≥ 15% in both *G. cordifolia* and *T. minuta* quadrats.

Grass species	Measurement	*T. minuta*			*G. cordifolia*		
		L	M	H	L	M	H
C. pycnothrix	Mean #	0 ± 0	1 ± 0	3 ± 0	111 ± 4	1 ± 0	19 ± 5
	% of appearance	0	17	17	18	17	57
C. dactylon	Mean #	15 ± 7	53 ± 17	42 ± 10	21 ± 6	45 ± 8	53 ± 13
	% of appearance	100	50	89	18	33	71

*L = lowly invaded, M = medium invaded and H = highly invaded.

within the crater [16], it is evident that the higher number of both grass species and native plant families in uninvaded quadrats were generally due to lack of competitive effects of the passengers of change i.e. both *G. cordifolia* and *T. minuta* hence allowing the native plants to flourish in these areas than those that were medium and highly invaded [29,30]. The results highlight the potential consequences of invasives *G. cordifolia* and *T. minuta* in reducing grass availability and hence posing an overall imminent impact to the wildlife and their habitat in Ngorongoro crater. While grasses plays an important role in sustaining ecosystem as a source of food for herbivores [31,32] and nutrient flows in the ecosystem, including maintenance of soil fertility [33], their decreased abundance due to invasion of *G. cordifolia* and *T. minuta* poses a threat to fragile ecosystems such as the Ngorongoro crater. The higher number of grass species in lowly invaded areas suggest the impact of invasives *G. cordifolia* and *T. minuta* in reducing the diversity of forage plant species and decline in the range of pasture utilized by non-generalist herbivores. As lowly invaded areas have been observed to contain more palatable plant species (grasses), non-generalist herbivores are likely to move and spend more time in those areas [31,34]. As they do so they initially disperse more propagules of invasive species into these (lowly invaded) areas, hence making those areas more susceptible to further invasion. The net effect of this disproportional habitat use and pasture utilization would be limited forage availability, exacerbating overgrazing that would subject the habitat to secondary invasion [35–37].

The observations that lowly invaded quadrats had three times higher native plants species richness than invaded quadrats is consistent with other previous studies [38,39]. These supressive effects by invasives are likely due to a reduction of reproductive success and pollen deposition of the native species [40]. The lower native species richness in invaded quadrats can also be due to higher competitiveness of *G. cordifolia* and *T. minuta,* which is facilitated by a lack of natural enemies such as herbivores as shown by some invasive plants [41]. Moreover, *G. cordifolia* and *T. minuta,* tend to produce a large number of seeds per plant (Personal observation), which adds to their success in colonising areas rapidly. The negative correlation between native species similarity and richness could be due to an increase in interspecific competition. As many different species occupy an area, interspecific competition increases and, therefore, the number of similar surviving individual species in the community decreases (mixed composition). In contrast, when few species occupy an area interspecific competition decreases, therefore the number of similar surviving individual species increases (mono-composition).

It was observed that the invasion of both *G. cordifolia* and *T. minuta* can be linked to an increase in native vegetation height and a decline in native plant species diversity and cover. These declines are likely due to the high competitive ability of the two invasive plant species and to the latteŕs strong allelopathic potential [42]. In this study, *G. cordifolia* and *T. minuta* strongly suppressed native plant species diversity, these results agree with other studies on the effects of invasive plants in riparian plant communities [18]. Increased competition for both light and nutrients between native species and the two invasive plants could be a reason for a decreased diversity in both medium and highly invaded areas compared with lowly invaded ones. While evidence of the allelopathic potential of *G. cordifolia* is lacking, that of *T. minuta* has been reported to suppress seedling growth of some adjacent plants [42]. Reduced growth of native plants reduces their competitiveness and vigor leading to a reduction in native species diversity (increased homogeneity).

As expected, the results strongly suggest that invasion of *T. minuta* and *G. cordifolia* species facilitated an increase in native plant species height and reduced their sterm strength. This reduction in sterm strength is probably due to an increased competition for light due to shading through the invasives as reported by [43] for crop species. Invasive plants have been shown to encourage native plants to invest more in their growth (elongation) activities as a result of light competition, leading to taller individuals in invaded sites [40,44]. Overall, native vegetation height and ground cover in this study provide evidence that *G. cordifolia* and *T. minuta* invasion can result in a pasture with reduced biomass due to competition [45] and, hence, less productive forage for inhabiting ungulates. Moreover, invaded areas are likely to be avoided by most ungulates as they are possible hideouts for predators due to taller vegetation [46]. Most prey species have been reported to prefer predator-free areas and, hence, spend more time in lowly invaded but nutrient poor areas [47,48].

A percentage ground cover twice as high in lowly invaded quadrats compared to highly invaded ones is likely due to the absence of suppressive effects of invasive species such as allelopathy and competition. Absence of suppression in turn results in healthier native species with higher biomass and horizontal growth (i.e., more ground cover) [49]. Moreover, reduced reproductive success and pollen deposition of the native species in higly invaded sites might have further lead to reduced ground cover [40].

Among the common grass species (Poaceae) surveyed, *Cynodon dactylon* was found to be the most successful grass species that co-existed well with *T. minuta* and *G. cordifolia.* Although *C. dactylon* abundance was lower in highly invaded quadrats compared with lowly invaded ones, its percentage occurrence was higher than other surveyed grasses, suggesting a strong resistance to the suppression by the two invasives. The high occurance of *C. dactylon* could be due to its high competitive ability [50]. For example, with its stoloniferous ability, *C. dactylon* is able to escape from invasion by forming roots away from invaded areas [51] and, hence, will access soil nutrients and light that would have been competed for with *G. cordifolia* and or *T. minuta*. Its drought tolerance tendency, ability to grow on soils with a wide range of pH and survive flooding as reported by [52–54] can be another reason for its successful competition with *G. cordifolia* and or *T. minuta.* The use of Nature based approach i.e ecosystem-based approach that rely on the direct utilization of elements of native biodiversity in addressing not only ecosystem degradation arising from ecological invasions but also other degradation drivers have recently been recommended [13,50], among the recommended approaches is the use of native plants such as *C. dactylon* with the ability to compete and suppress invasive plants. The *C. dactylon* is a native grass species in the savanna rangelands with a known track record as an important fodder for herbivores [55], and a proven ability to compete with both *G. cordifolia* and *T. minuta* [50]. These advantages from *C. dactylon* present a potential to be used in managing the two invasives as alternative to developing eco-friendly control methods that could be a long-term solution to addressing the problem of the two invasive plants in the NCAA. The use of such native plants in managing invasive plants such as *G. cordifolia* and *T. minuta* are likely to contribute in achieving African Union Agenda 2063 goal seven (7) particularly in ensuring sustainable conservation of biodiversity, genetic resources and ecosystems.

Conclusion

As invasive plants pose significant threats to native plant species and their communities; their impacts can result in an overall change of not only plant community structure and composition but also that of associated herbivores [56,57]. It is now evident through this study that areas with invasives *G. cordifolia* and *T. minuta* are prone to loss of native forage plants. This in turn might results in a reduction of Ngorongoro crater's attractiveness as a famous tourist destination, which might result in income loss for government, park authorities and local people who are either directly or indirectly interacting with tourists. This study generated the information that contributes to the understanding of the ecological influence of invasive plant species and is important for incorporation into the management plans of rangelands. Generally, the two invasive plants, changed the ecology of the native plant communities, particularly the native species richness, cover and height. As most rangelands are increasingly threatened by these invasive plant species, this study is therefore timely and has generated a baseline information for long term research to elucidate mechanisms associated with the two invasive plants interactions with natives, while also informing the management authorities on the threats to native plants and animals associated with invasion of the two plant species. Time was a greatest limitation on this study; and therefore we recommend further long term monitoring of the impacts of the two invasive plants to native plant species of the Ngorongoro crater.

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.

CRediT authorship contribution statement

Issakwisa B. Ngondya: Methodology, Investigation, Writing – review & editing, Formal analysis. **Linus K. Munishi:** Methodology, Investigation, Writing – review & editing, Formal analysis.

Acknowledgments

Much appreciation is expressed to all laboratory technicians of the Nelson Mandela African Institution of Science and Technology for facilitating the conduction of the experiments.

Funding

This work was supported by the Government of Tanzania (GoT) through the Nelson Mandela African Institution of Science and Technology (NM-AIST) with grant number 02020811-048-4001-F01503-B02.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2021.e00946.

References

[1] CBDHandbook of the Convention on Biological Diversity Including its Cartagena Protocol on Biosafety, 3rd ed., Montreal, Canada, 2005.
[2] M. Gichua, G. Njoroge, D. Shitanda, D. Ward, Invasive species in East Africa: current status for informed policy decisions and management, J. Agric. Sci. Technol. 15 (1) (2014) 45–55.

[3] M. Clavero, E. Garcia-Berthou, Invasive species are a leading cause of animal extinctions, Trends Ecol. Evol. 20 (3) (2005) 110-110, doi:10.1016/j.tree.2005.01.003.
[4] A.G. Aguilera, P. Alpert, J.S. Dukes, R. Harrington, R. impacts of the invasive plant *Fallopia japonica* (Houtt.) on plant communities and ecosystem processes, Biol. Invasions 12 (5) (2010) 1243–1252, doi:10.1007/s10530-009-9543-z.
[5] E. Vasquez, R. Sheley, T. Svejcar, Creating invasion resistant soils via nitrogen management, Invasive Plant Sci. Manag. 1 (3) (2008) 304–314, doi:10.1614/IPSM-07-059.1.
[6] G. Boy, Invasive alien plants and their management in Africa. Synthesis report of the UNEP/GEF Removing barriers to invasive plant management in Africa (RBIPMA) project, CABI Africa, Nairobi- Kenya, 2013 https://wedocs.unep.org/handle/20.500.11822/240?show=full.
[7] J.S. Dukes, H.A. Mooney, Disruption of ecosystem processes in western North America by invasive species, Rev. Chil. De Hist. Nat. 77 (3) (2004) 411–437, doi:10.4067/S0716-078X2004000300003.
[8] Hulina, Wild marigold-Tagetes minuta L., new weed on the Island of Hvar, and new contribution to the knowledge of its distribution in Dalmatia (Croatia), Agric. Conspec. Sci. (ACS) 73 (1) (2008) 23–26 https://hrcak.srce.hr/22152.
[9] Invasive alien plants strategic management plan in Ngorongoro conservation area, Ministry of Natural Resources and Tourism, United Republic of Tanzania, Dodoma, 2011.
[10] Byers Bruce, et al., Tanzania environmental threats and opportunities assessment, US Department of Agriculture Forest Service- International Programs, 2012 http://www.brucebyersconsulting.com/wp-content/uploads/2013/01/Tanzania-Environmental-Threats-and-Opportunities-Assessment-2012.pdf (Accessed date: 20 May 2020).
[11] G.D. Anderson, D.J. Herlocker, Soil factors affecting the distribution of the vegetation types and their utilization by wild animals in Ngorongoro crater, Tanzania, J. Ecol. 61 (3) (1973) 627–651, doi:10.2307/2258640.
[12] E.P. Niboye, Vegetation cover changes in Ngorongoro conservation area from 1975 to 2000, Open Geogr. J. 3 (2010) 15–27.
[13] I. Ngondya, L. Munishi, A. Treydte, P. Ndakidemi, A nature based approach for managing the invasive weed species Gutenbergia cordifolia for sustainable rangeland management, SpringerPlus 5 (1) (2016) 1787, doi:10.1186/s40064-016-3480-y.
[14] E. Hurst, The Poison Plants of New South Wales, University of Sydney, 1942 N.S.W. Poison plants Comm.
[15] L.M. Wolfe, J.A. Elzinga, A. Biere, Increased susceptibility to enemies following introduction in the invasive plant *Silene latifolia*, Ecol. Lett. 7 (9) (2004) 813–820, doi:10.1111/j.1461-0248.2004.00649.x.
[16] M.E. Dix, M. Buford, A.M. Solomon, J. Slavicek, S.G. Conard, M.E. Dix, K. Britton, Invasive species and disturbances: current and future roles of forest service research and development, in: A Dynamic Invasive Species Research Vision: Opportunities and Priorities 2009-29, U.S. Department of Agriculture, Forest Service, Research and Development, Washington, DC, 2010, pp. 91–102. General Technical Report WO-79/83.
[17] B.W. Van Der Waal, The influence of acacia mearnsii invasion on soil properties in the Kougamountains, Eastern Cape, South Africa (Masters thesis), 2009.
[18] M. Gaertner, F. Tererai, S.M. Jacobs, D.M. Richardson, Eucalyptus invasions in riparian forests: effects on native vegetation community diversity, stand structure and composition, For. Ecol. Manag. 297 (2013) 84–93, doi:10.1016/j.foreco.2013.02.016.
[19] R.T. Shackleton, D.C. Maitre, N.M. Pasiecznik, D.M. Richardson, Prosopis : a global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa, AoB Plants 6 (2014) plu027, doi:10.1093/aobpla/plu027.
[20] R.T. Shackleton, D.C. Le, B.W. Wilgen, D.M. Richardson, The impact of invasive alien Prosopis species (mesquite) on native plants in different environments in South Africa, S. Afr. J. Bot. 97 (2015) 25–31, doi:10.1016/j.sajb.2014.12.008.
[21] A. Reda, F. Tewelde, Impact of invasive alien plants on biodiversity and livelihood of local communities in Tigray, Ethiopia, World Appl. Sci. J. 35 (11) (2017) 2364–2378, doi:10.5829/idosi.wasj.2017.2364.2378.
[22] C. Stuart, T. Stuart, in: T. Ngorongoro Conservation Area, Struik, 2003, p. 24.
[23] R. Estes, J. Atwood, A. Estes, Downward trends in Ngorongoro crater ungulate populations 1986–2005: conservation concerns and the need for ecological research, Biol. Conserv. 131 (1) (2006) 106–120, doi:10.1016/j.biocon.2006.02.009.
[24] J.M. Wells, et al., A catalog of problem plants in Southern Africa: Incorporating the National Weed List of Southern Africa, Mem. Bot. Surv. S. Afr. 53 (1986) 658 pages.
[25] Kewscience. *Gutenbergia cordifolia* Benth. ex. Oliv http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:277825-2 (Accessed 20 May 2020)
[26] E. Van Wyk, F. Van Oudtshoorn, Guide to Grasses of Southern Africa, Briza Publications, Arcadia, South Africa, 1999.
[27] CNRITPlant Cover Estimation for Herbaceous Plants: A Quick Field Method, Center for Natural Resource Information Technology, 2014.
[28] StatSoft-Inc. STATISTICA (data analysis software system), version 8.0 (2007), www.statsoft.com
[29] D.L. Gorchov, D.E. Trisel, Competitive effects of the invasive shrub, Lonicera maackii (Rupr.) Herder (Caprifoliaceae), on the growth and survival of native tree seedlings, Plant Ecol. 166 (2003) 13–24, doi:10.1023/A:1023208215796.
[30] S.L. Flory, K. Clay, Non-native grass invasion alters native plant composition in experimental communities, Biol. Invasions 12 (2010) 1285–1294, doi:10.1007/s10530-009-9546-9.
[31] S.B. Hill, P.M. Kotanen, Evidence that phylogenetically novel non-indigenous plants experience less herbivory, Oecologia 161 (2009) 581–590, doi:10.1007/s00442-009-1403-0.
[32] J.R. Soto-Shoender, R.A. McCleery, A. Monadjem, D.C. Gwinn, The importance of grass cover for mammalian diversity and habitat associations in a bush encroached savannah, Biol. Conserv. 221 (2018) 127–136, doi:10.1016/j.biocon.2018.02.028.
[33] M.O. Gessner, C.M. Swan, C.K. Dang, B.G. McKie, R.D. Bardgett, D.H. Wall, S. Hattenschwiler, Diversity meets decomposition, Trends Ecol. Evol. 25 (6) (2010) 372–380, doi:10.1016/j.tree.2010.01.010.
[34] W.E. Morrison, M.E. Hay, Herbivore preference for native vs. exotic plants: generalist herbivores from multiple continents prefer exotic plants that are evolutionarily naïve, PLoS One 6 (3) (2011) e17227, doi:10.1371/journal.pone.0017227.
[35] J.L. Hierro, D. Villarreal, O. Eren, J.M. Graham, RM. Callaway, Disturbance facilitates invasion: the effects are stronger abroad than at home, Am. Nat. 168 (2) (2006) 144–156, doi:10.1086/505767.
[36] E. Machler, F. Altermatt, Interaction of species traits and environmental disturbance predicts invasion success of aquatic microorganisms, PLoS One 7 (9) (2012) e45400, doi:10.1371/journal.pone.0045400.
[37] L. Tamburello, F. Bulleri, D. Balata, L. Benedetti-Cecchi, The role of overgrazing and anthropogenic disturbance in shaping spatial patterns of distribution of invasive seaweed, J. Appl. Ecol. 52 (2014) 406–414, doi:10.1111/1365-2664.12199.
[38] M.E. Alvarez, J.H. Cushman, Community level consequences of a plant invasion: effects on three habitats on coastal California, Ecol. Appl. 12 (2002) 1434–1444 10.1890/1051-0761(2002)012[1434:CLCOAP]2.0.CO;2.
[39] P.E. Hulme, E.T. Bremner, Assessing the impact of *Impatiens glandulifera* on riparian habitats: partitioning diversity components following species removal, J. Appl. Ecol. 43 (1) (2006) 43–50, doi:10.1111/j.1365-2664.2005.01102.x.
[40] M.A. Martinez-Ghersa, C.M. Ghersa, R.L. Benech-Arnold, R.M. Donough, R.A. Sanchez, Adaptive traits regulating dormancy and germination of invasive species, Plant Species Biol. 15 (2) (2000) 127–137, doi:10.1046/j.1442-1984.2000.00033.x.
[41] JEscarre Cano, K. Vrieling, F. Sans, Palatability to a generalist herbivore, defence and growth of invasive and native senecio species: testing the evolution of increased competitive ability hypothesis, Oecologia 159 (1) (2009) 95–106, doi:10.1007/s00442-008-1182-z.
[42] J. Kil, K. Shim, Allelopathic effects of *Tagetes minuta* L. and *Eupatorium rugosum* Houtt. Aqueous extracts on seedling growth of some plants, Allelopath. J. 18 (2) (2006) 315–321.
[43] Hager A., et al., Weed/crop competition: Factors to consider. The bulletin, pest management and crop development information for illinois, (1998). http://bulletin.ipm.illinois.edu/pastpest/articles/v982h.html. (Accessed 10 May 2020).

[44] M. Hejda, P. Pysek, V. Jarosík, Impact of invasive plants on the species richness, diversity and composition of invaded communities, J. Ecol. 97 (3) (2009) 393–403, doi:10.1111/j.1365-2745.2009.01480.x.
[45] J.M. Levine, M. Vila, C.M. Antonio, J.S. Dukes, K. Grigulis, S. Lavorel, Mechanisms underlying the impacts of exotic plant invasions, Proc. R. Soc. Lond. B Biol. Sci. 270 (1517) (2003) 775–781, doi:10.1098/rspb.2003.2327.
[46] W.J. Ripple, R.L. Beschta, Wolf reintroduction, predation risk, and cottonwood recovery in yellowstone national park, For. Ecol. Manag. 184 (1) (2003) 299–313, doi:10.1016/S0378-1127(03)00154-3.
[47] S.L. Lima, L.M. Dill, Behavioral decisions made under the risk of predation: a review and prospectus, Can. J. Zool. 68 (4) (1990) 619–640, doi:10.1139/z90-092.
[48] W. Cresswell, Non-lethal effects of predation in birds, Ibis 150 (1) (2008) 3–17, doi:10.1111/j.1474-919X.2007.00793.x.
[49] H. Nagashima, K. Hikosaka, Plants in a crowded stand regulate their height growth so as to maintain similar heights to neighbors even when they have potential advantages in height growth, Ann. Bot. (2011) mcr109, doi:10.1093/aob/mcr109.
[50] I.B. Ngondya, A.C. Treydte, P.A. Ndakidemi, L.K. Munishi, Can Cynodon dactylon suppress the growth and development of the invasive weeds Tagetes Minuta and Gutenbergia cordifolia? Plants 8 (12) (2019) 576, doi:10.3390/plants8120576.
[51] M. Horowitz, Competitive effects of *Cynodon dactylon, Sorghum halepense* and *Cyperus rotundus* on cotton and mustard, Exp. Agric. 9 (3) (1973) 263–273, doi:10.1017/S0014479700005792.
[52] D. Zhao, K.R. Reddy, V.G. Kakani, V. Reddy, Nitrogen deficiency effects on plant growth, leaf photosynthesis, and hyperspectral reflectance properties of sorghum, Eur. J. Agron. 22 (4) (2005) 391–403, doi:10.1016/j.eja.2004.06.005.
[53] H. Shi, Y. Wang, Z. Cheng, T. Ye, Z. Chan, Analysis of natural variation in bermudagrass (*Cynodon dactylon)* reveals physiological responses underlying drought tolerance, PLoS One 7 (12) (2012) e53422, doi:10.1371/journal.pone.0053422.
[54] G. Burton, W. Hanna, M. Heath, R. Barnes, D. Metcalfe, Bermuda grass, in: Forages the Science of Grassland Agriculture, Iowa State University Press, Ames, Iowa, 1985, p. 643.
[55] M. Hameed, M. Ashraf, Physiological and biochemical adaptations of cynodon dactylon (L.) pers. from the salt range (Pakistan) to salinity stress, Flora 203 (8) (2008) 683–694, doi:10.1016/j.flora.2007.11.0.
[56] X. Gan, B. Li, J. Chen, Z. Ma, The ecological effects of biological invasions on birds, Biodivers. Sci. 15 (5) (2007) 548–557.
[57] B.E. Johnson, J. Cushman, Influence of a large herbivore reintroduction on plant invasions and community composition in a California grassland, Conserv. Biol. 21 (2) (2007) 515–526, doi:10.1111/j.1523-1739.2006.00610.x.