

Article

Impact of Abandoned Maasai Bomas on the Spread of *Urtica massaica* and Plant Species Diversity in the Ngorongoro Conservation Area, Tanzania

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Abstract

Abandoned pastoral settlements can create disturbed and nutrient-enriched microsites that favor the dominance of native expansive plant species. Yet limited empirical evidence exists on how abandoned Maasai bomas influence the spread of *Urtica massaica* and associated plant community changes in the Ngorongoro Conservation Area, a UNESCO World Heritage Site in Tanzania. This study assessed the influence of abandoned bomas on plant species abundance, richness, diversity, soil seedbank status, and the spatial distribution of *U. massaica*. A multistage stratified random sampling design was used, whereby Ngorongoro and Nainokanoka zones were selected from the designated management zones of the conservation area. Vegetation data, soil samples, and geographic coordinates of abandoned bomas were collected from abandoned boma sites and adjacent control sites. Plant species abundance, richness, and diversity were compared between abandoned bomas and control sites after testing data normality using the Shapiro–Wilk test. Independent-sample *t*-tests were used for normally distributed data, while Wilcoxon rank-sum tests were used for non-normally distributed data. Spatial distribution of *U. massaica* was assessed using GIS-based heatmap and kernel density estimation. Results showed that native plant species abundance was significantly higher in control sites than in abandoned bomas. Plant species richness and diversity also differed significantly between sites in both Ngorongoro and Nainokanoka, with control sites supporting higher richness and diversity. However, soil seedbank results showed no significant differences in species richness and diversity between soils collected from abandoned bomas and control sites, although slightly higher values were observed in control soils. Spatial analysis revealed that *U. massaica* hotspots were concentrated mainly in highland areas with high densities of abandoned bomas. These findings suggest that abandoned bomas may act as focal points for *U. massaica* establishment and dominance, reducing aboveground plant diversity while retaining some potential for natural regeneration through the soil seedbank. Management interventions should prioritize abandoned bomas as key sites for controlling *U. massaica* spread and supporting vegetation recovery in the Ngorongoro Conservation Area.

Keywords: *Urtica massaica*; Maasai bomas; native species; seedbank; relocation



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1. Introduction

While the prevailing dialogue around invasive species typically centers on alien or non-native organisms that cause ecological or economic harm [1], it is crucial to recognize that native species can also exhibit invasive characteristics when environmental conditions are significantly altered [2]; such species are termed as native expansive species or native “super-dominant” species. Pivello et al. have explicitly defined them as natives which become extremely abundant, transforming communities often after anthropogenic disturbances. These species are characterized by their aggressive ability in colonizing habitats, monopolizing critical resources such as light, nutrients, water, and space [3]. This competitive advantage allows them to outcompete and detrimentally affect other species, leading to a reduction in native plant species diversity and hence the formulation of a homogeneous landscape [3].

Shifting settlements and other human activities increase the spread of these species in protected areas that have been under human occupancy [4]. Increase in human population and the need for settlements has increased human and livestock bomas in the Ngorongoro Conservation Area (NCA) [5], and this is likely to pose a threat to its ecological integrity in ways such as altered forage availability and structural heterogeneity. However, despite the evidence, it is still not known to what extent abandoned bomas contribute to the spread and distribution of some increasingly expansive species such as the native *Urtica massaica*.

A native plant is fundamentally a species that has evolved and adapted to the local environmental conditions of a specific region, forming an integral part of its natural community. However, a crucial ecological phenomenon occurs when a native species, under altered environmental conditions, begins to behave aggressively, outcompeting other native species for resources and causing damage to its own ecosystem, much like an invasive species [6]. Dispersal, and consequently domination, usually begins from disturbed areas and those rich in nutrients such as abandoned fields and meadows [2]. This transformation, where a native species outcompetes others and becomes dominant within its natural geographic range, is predominantly linked to anthropogenic disturbances such as trampling and nutrient inputs that alter existing environmental conditions [7]. Studies have shown that some native species such as *Calamagrostis epigejos*, *Phalaris arundinacea*, and *Urtica dioica* are more likely to spread quickly thanks to underground rhizomes which make them capable of rapid colonization of new sites. They then persist in these colonized areas, and their juveniles grow quickly, thus rapidly pre-empting the available space [2].

In the Ngorongoro Conservation Area, *Urtica massaica*, a native expansive plant, is noted to occupy areas that once had Maasai settlements, i.e., bomas (personal observation). This spatial association with human presence suggests that its ecological niche is expanding into anthropogenically modified environments. Maasai bomas and cattle kraals are areas of concentrated human and animal activity, characterized by the accumulation of animal waste (personal observation). Research indicates that abandoned cattle kraals often develop into “nutrient islands” with significantly higher concentrations of soil nutrients, alongside increased herbaceous biomass [8]. Given that *U. massaica* is known to thrive in nitrogen-enriched habitats [9], these nutrient-rich hotspots around current and former Maasai bomas likely act as primary colonization points and effective dispersal hotspots for *U. massaica*.

As dedicated reports specifically detailing *U. massaica*’s colonization status within the NCA are not as prominent as those of recognized alien invasive species [10], there is a need to assess *U. massaica*’s status, its association with abandoned bomas, and its overall impact on the plant species diversity within the NCA. This study intended to bridge this gap by establishing a relation between abandoned bomas and *U. massaica*’s distribution, its soil seedbank load density in abandoned bomas, and its impacts on the native plants.

2. Methods

2.1. Study Site

The Ngorongoro Conservation Area (Figure 1) is located in northern Tanzania in Ngorongoro District, within the Arusha Region (longitude $36^{\circ}1'38.7466''$ and $36^{\circ}1.645776''$ E and latitude $3^{\circ}9'44.8399''$ and $3^{\circ}9.747332''$ S). Its establishment dates back to 1959 through the NCA Ordinance No. 413 of 1959, defining it as a multipurpose land-use area, and it was officially recognized as a UNESCO World Heritage Site in 1979. It spans approximately 8300 km², with elevation of 1000 to 2500 m from the sea level. The NCA is an integral part of the Serengeti-Mara ecosystem, sharing borders with the Serengeti National Park (SNP) to the northwest, bounded by the rim of the East African Rift Valley wall on the southern and eastern sides, and surrounded by volcanic highlands to the south and west [3]. The region experiences diverse rainfall patterns, ranging from 200–500 mm in the semi-arid lowland areas to 750–1200 mm in the highlands [11]. It serves as a crucial habitat for East African savanna and forest mammal species, including elephants, giraffes, zebras, buffaloes, wildebeests, and eland [12]. The landscape is characterized by *Vachellia* woodlands, highland forest, shrubland, and open grassland [13].

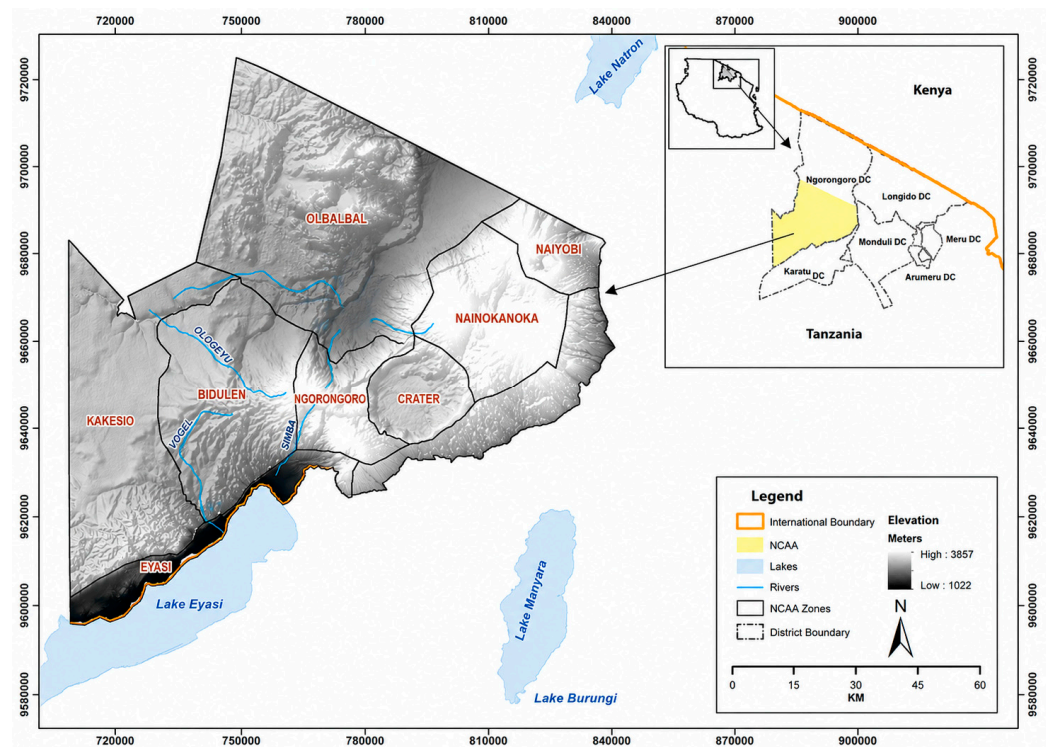


Figure 1. Map showing the study area, the Ngorongoro Conservation Area (NCA).

2.2. Study Species

Urtica massaica (Figure 2) is a distinct species of flowering plant within the Urticaceae family, commonly known as the Maasai stinging nettle or forest nettle [14]. Its native range is exclusively Africa, spanning several countries including the Democratic Republic of the Congo, Burundi, Rwanda, Kenya, Uganda, and Tanzania [15]. The broader genus *Urtica* has a global distribution, having originated in Eurasia and subsequently dispersed across continents, leading to a diversification of species adapted to various regional conditions [15].



Figure 2. *Urtica massaica* within the Ngorongoro Crater.

Urtica massaica is known to thrive in nitrogen-enriched habitats and Maasai bomas within the Ngorongoro Conservation Area (Figure 3), especially in the highland zones [16], most of which are now abandoned, developing into “nutrient islands” with significantly higher concentrations of soil nutrients, including nitrogen, phosphorus, potassium, and calcium [8], which in turn act as primary *U. massaica* colonization points [9].



Figure 3. Typical Maasai bomas within the Ngorongoro Conservation Area.

2.3. Study Design

A multistage stratified random sampling technique was employed in this study. The stratification was based on the seven designated management zones [17] within the Ngorongoro Conservation Area, which served as sampling strata. From these strata, two zones, namely Ngorongoro and Nainokanoka, representing 30% of the management zones, were randomly selected for inclusion in the study. The total numbers of abandoned bomas in the selected zones were 486 in Ngorongoro and 596 in Nainokanoka. In each zone, 10% of the abandoned bomas, i.e., those with boma or *U. massaica* (i.e., 49 at Ngorongoro and 60 at Nainokanoka), were randomly selected, each with an adjacent control point (i.e., without boma or *U. massaica*) positioned 500 m from the abandoned boma. In each of the abandoned boma and control sites, three 1×1 m quadrats were established diagonally ($N = 254$ and $N = 360$ for Ngorongoro and Nainokanoka, respectively).

2.4. Plant Species Richness and Abundance

In each quadrat (see Section 2.3), plant species were identified, grouped into specific families, and then counted [18]. The species' diversity and richness at all points (field and greenhouse) were analyzed using JAMOV version 2.6.44 (2025). The data were first tested for normality using the Shapiro–Wilk test. Whether or not they passed the test, an independent-sample *t*-test and Wilcoxon rank-sum test were then performed to determine whether there were significant differences in plant species diversity, abundance,

and richness between the areas with *Urtica massaica* (abandoned bomas) and those without (control sites). The level of significance was set at $p < 0.05$.

2.5. Soil Sample Collection

Soil samples of at least 40 g were collected to a depth of 20 cm from the three quadrats of the abandoned bomas in Ngorongoro, Nainokanoka, and control sites, respectively, and were later mixed to form a composite sample [19] of 6 kg for each and were used in soil seedbank status assessment.

2.6. Soil Seedbank Status Assessment

From initial composite soil samples of 6 kg each from Ngorongoro, Nainokanoka, and control sites, six (6) replicates of 1 kg each were made for each of the three sampling areas ($N = 18$). The experimental soil samples (replicates) from each sampling area were air-dried for two weeks [12] and set up using 1 kg pots of 10 cm diameter $\times$ 12 cm depth [19]. The pots were perforated with holes at the bottom for drainage and then placed in a screenhouse established away from full sunlight and exposure to environmental changes. Each was irrigated with at least 750 mL of water every morning and evening, mimicking the rainfall patterns of the study area [20]. The experiment lasted for four (4) months (i.e., May–August 2025) [21]. In assessing soil seedbank density, emerging seedlings in each pot were identified to species or genus level, counted and recorded every four weeks. The identified seedlings were then uprooted to reduce the competitive effect, hence allowing other seedlings to germinate.

2.7. Mapping the Distribution of *Urtica massaica* Within the NCA

Mapping the distribution of *U. massaica* was done by associating it with the presence of abandoned bomas. In order to visualize the spatial distribution and intensity of *U. massaica* in the NCA, a heatmap was generated, using GIS version 3.44 software whereby the base layers including boundaries were obtained from the official Ngorongoro Conservation Area Authority (NCAA) spatial data repository. The coordinates of the vacated bomas within the three highland zones were first compiled and geo-referenced and then overlaid on the base map [22]. These points were then subjected to a kernel density estimation technique within the GIS environment [22], which calculated the concentration of abandoned bomas and/or cattle kraal occurrences across the NCA, which in turn depicted the concentration of *Urtica massaica*.

3. Results

3.1. General Observations

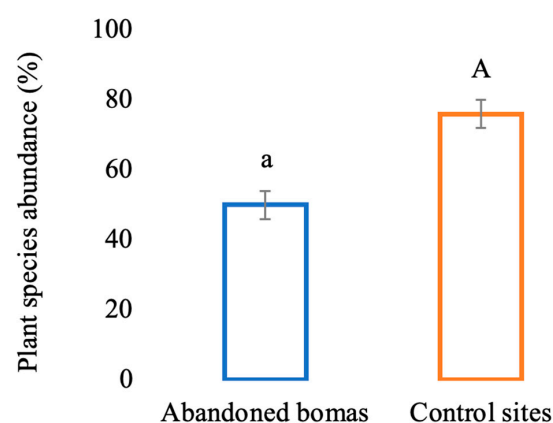
A total of eight dominant plant families were recorded across the Ngorongoro and Nainokanoka zones (Table 1). Poaceae was the most frequently occurring family in both zones, with a frequency of 20 in each zone, followed by Asteraceae with a frequency of 18 in both zones. Fabaceae was also common, although its frequency was higher in Ngorongoro than in Nainokanoka. Acanthaceae showed a similar pattern, with higher occurrence in Ngorongoro. Lamiaceae and Amaranthaceae occurred equally in both zones, while Rubiaceae and Solanaceae were slightly more frequent in Nainokanoka. Largely, the results indicate that Poaceae and Asteraceae were the dominant plant families in both zones.

Generally, native plant species abundance was observed to be significantly higher in areas with no bomas/control sites compared to those with abandoned bomas ($W = 0.984$; $p < 0.001$; Figure 4).

Urtica massaica was observed to dominate in areas with abandoned Maasai bomas (Figure 5).

Table 1. Frequency of occurrence of dominant plant families recorded in the Ngorongoro and Nainokanoka zones within the Ngorongoro Conservation Area.

Family	Frequency of Occurrence	
	Ngorongoro Zone	Nainokanoka Zone
Poaceae	20	20
Asteraceae	18	18
Fabaceae	14	11
Acanthaceae	10	6
Lamiaceae	7	7
Amaranthaceae	5	5
Rubiaceae	3	5
Solanaceae	4	5

**Figure 4.** Percentage plant species abundance along surveyed plots in Ngorongoro Conservation Area. Bars with dissimilar letters are significantly different by Fisher LSD at $p = 0.05$.**Figure 5.** *Urtica massaica* (a) early growth and (b) overgrowth around abandoned Maasai boma in Ngorongoro Conservation Area.

3.2. Plant Species Richness Between Areas with *U. massaica* (Abandoned Bomas) and Without *U. massaica* (Control Sites) in the NCA

Significant differences in plant species richness were observed between plots with and without *U. massaica* in both Nainokanoka and Ngorongoro ($W = 0.947$, $p < 0.001$; $W = 0.986$, $p < 0.001$, respectively). Control sites (c) were observed to have higher plant species richness compared to abandoned bomas (b) (Figure 6; Appendix A).

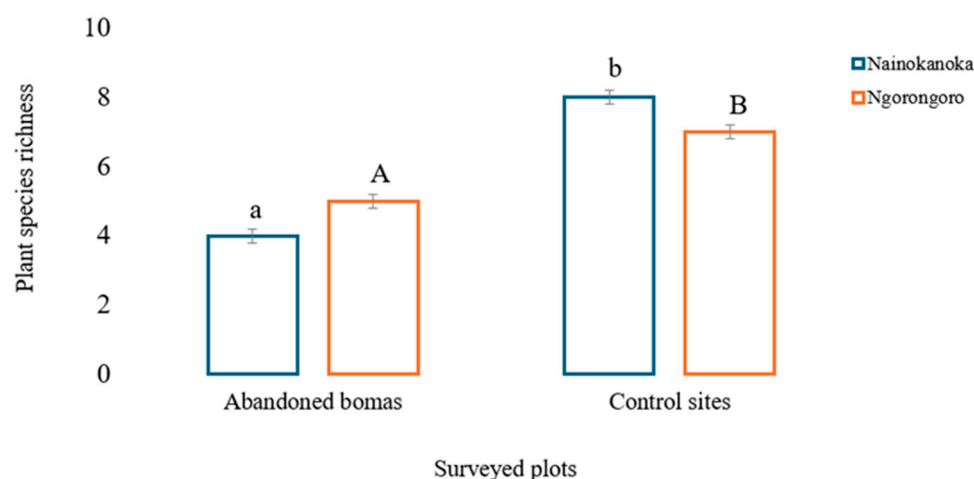


Figure 6. Plant species richness along surveyed plots in Ngorongoro Conservation Area. Bars with dissimilar letters are significantly different by Fisher LSD at $p = 0.05$.

3.3. Plant Species Diversity Between Areas with *U. massaica* (Abandoned Bomas) and Without *U. massaica* (Control Sites) in the NCA

Plants species diversity was generally higher in Ngorongoro in areas both with and without *U. massaica* compared to Nainokanoka (Figure 7). Significant differences in plant species diversity were observed between plots with and without *U. massaica* in both Nainokanoka and Ngorongoro ($W = 0.445$, $p < 0.001$; $W = 0.995$, $p < 0.001$, respectively). Plots without *U. massaica* (control sites) were observed to have higher plant species diversity compared to those with *U. massaica* (abandoned bomas) (Figure 7).

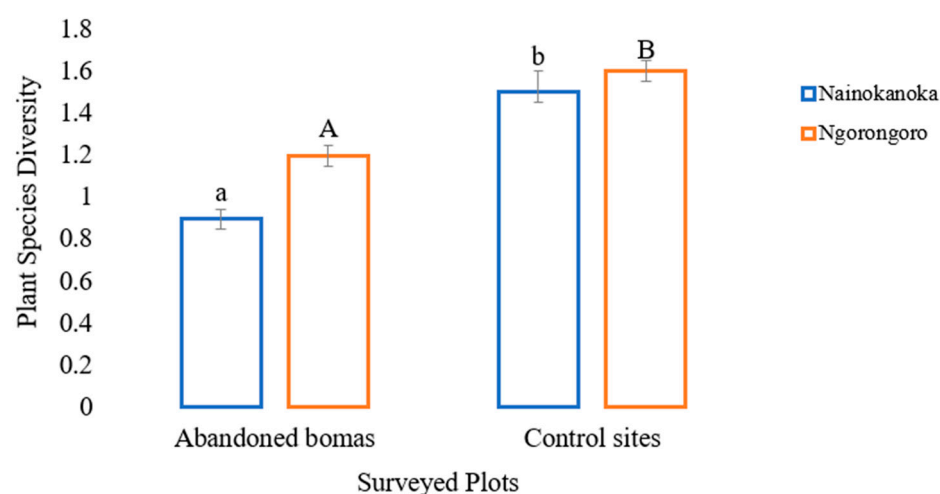


Figure 7. Plant species diversity along surveyed plots in Ngorongoro Conservation Area. Bars with dissimilar letters are significantly different by Fisher LSD at $p = 0.05$.

3.4. Plant Species Diversity and Richness in Soils from Abandoned Bomas and Control Sites in the NCA

There were no significant differences in plant species diversity ($W = 0.936$, $p = 0.936$; $W = 0.970$, $p = 1.000$) and richness ($W = 0.891$, $p = 0.934$; $W = 0.777$, $p = 1.000$) observed in soils that were collected from abandoned bomas and undisturbed areas of both Ngorongoro and Nainokanoka, respectively. However, a slightly higher plant species diversity and richness were observed in undisturbed areas compared to the abandoned bomas.

3.5. Distribution of *Urtica massaica* Within the NCA

The heatmap revealed a clear spatial association between *U. massaica* dominance and areas with high concentrations of abandoned bomas, particularly in the highland areas of the Ngorongoro Conservation Area (Figure 8). This pattern suggests that abandoned bomas may act as focal points for *U. massaica* establishment and spread, possibly due to historical nutrient enrichment and disturbance associated with former settlement activities. Thus, the heatmap helps identify *U. massaica* hotspots and priority areas where management interventions should be targeted.

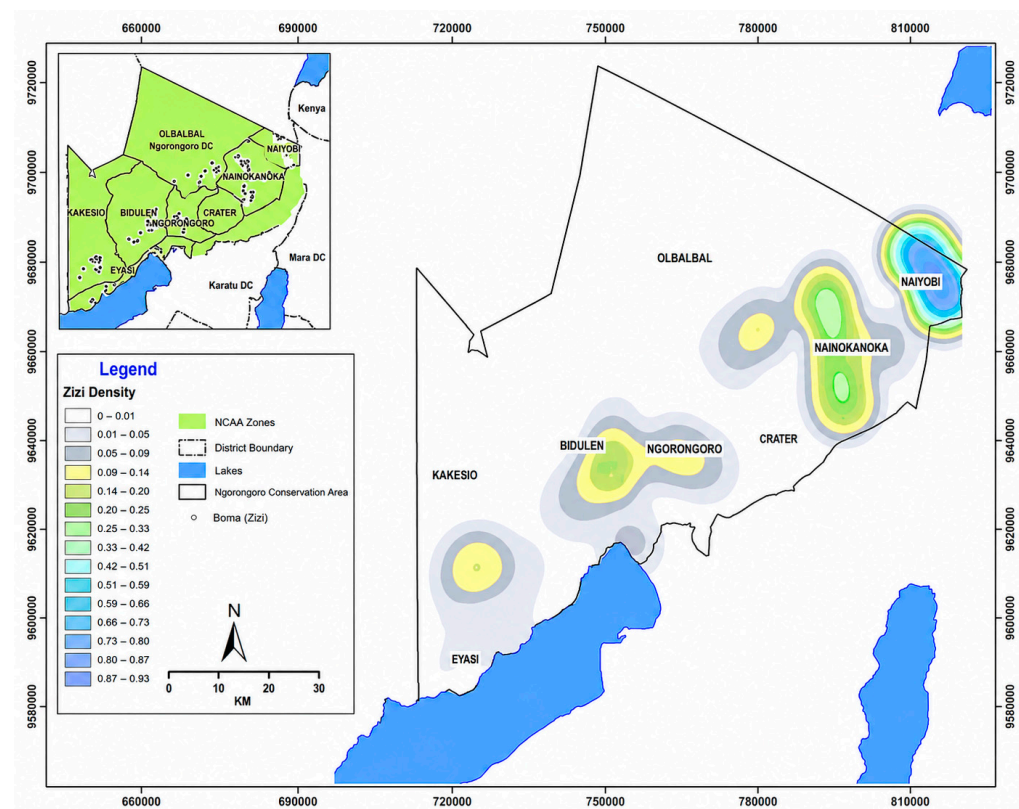


Figure 8. Heatmap showing densities of abandoned Maasai bomas and associated densities of *Urtica massaica* within the NCA.

4. Discussion

This study shows that abandoned bomas may favor the establishment and dominance of *U. massaica* within the Ngorongoro Conservation Area. Field results indicated reduced plant species richness and diversity in areas dominated by *U. massaica*, while soil seedbank results suggested that natural regeneration potential may still exist under favorable conditions. The spatial distribution further showed that *U. massaica* hotspots were concentrated in highland areas with high densities of abandoned bomas. These findings suggest that abandoned bomas are important ecological disturbance points that should be prioritized in *U. massaica* management and vegetation restoration planning.

4.1. The Impacts of *Urtica massaica* on Plant Species Richness and Diversity in Relation to Abandoned Bombs in the NCA

We observed a significant reduction in plant species richness and diversity in plots that were dominated by *Urtica massaica*. These were areas where human disturbance was already in play (abandoned bomas). A similar observation was previously noted by [23], who reported that dominance of species from the Fabaceae family reduced plant species richness and diversity in southwestern Nigeria through factors such as alteration of soil porosity and

organic carbon. Soil porosity in disturbed areas is decreased through human and/or animal trampling, which in turn reduces plants' seed germination and development [24]. However, a paper by [25] revealed that while dominant alien species are known to affect an area's biodiversity by reducing species richness, native dominant species or native expansive species tend to have a greater impact in comparison. The reduction in plant species richness and diversity in areas that were dominated by *Urtica massaica* might be due to some of the plant's traits [26]. *Urtica massaica* has been observed to have large leaves which normally have a shading effect on understory species, suppressing the germination of light-loving grass species such as *Cynodon dactylon* [27]. Moreover, the species has been reported to grow quickly and possess dense and deep-rooted systems, granting it a competitive advantage in terms of both light and nutrients over other species [28], leaving them weak and easily destroyed by various means, such as livestock or other animal trampling [27]. The presence of abandoned bomas in the NCA should therefore be closely observed, as these seem to facilitate outgrowth of unpalatable *U. massaica*. The aggressive spread of *U. massaica* in the NCA presents a serious threat to its biodiversity and the area's sustainability.

4.2. The Soil Seedbank Status in the NCA in Relation to Abandoned Bomas

This study found no significant differences in plant species diversity or richness between seeds that germinated from soil that was collected from abandoned bomas and those from areas with no bomas. This observation was contrary to previous findings [29] that reported that disturbed areas normally hold fewer viable seeds than undisturbed ones. Besides this contradiction, the findings highlight the potential for these areas to be restored should efforts be made to do so. The lower diversity and richness observed in abandoned bomas (in situ), as discussed earlier, can be due among other factors to reduced seed germination caused by increased soil compaction in these areas [30]. Activities such as tillage, grazing, and human disturbances may lead to suppression of seeds in the field. On the other hand, the observed representation of soil seedbank levels within the two areas could be due to the fact that the soil that was collected from abandoned bomas was not compacted as that in the field, therefore allowing for the majority of seeds contained in them to germinate [30]. Ex situ germination, like that produced during the study in the greenhouse, tests how well seeds germinate under controlled and protective conditions, as corroborated by [31]. Therefore, the results of the seedbank experiments suggest that there is potential for natural recovery in these areas which is being suppressed by compaction and *Urtica massaica*. Efforts should therefore be directed towards managing Maasai abandoned bomas to ensure that *U. massaica* is effectively managed to minimize its impact on other plant species within the NCA. This will ensure sufficiency in pasture that can positively influence wild animals' abundance and maximize tourist satisfaction.

4.3. The Distribution of *Urtica massaica* in Relation to Abandoned Bomas Within the NCA

The generated *U. massaica* distribution heatmap shows distinct hotspots that correspond directly to areas with a high density of abandoned bomas. It also reveals that *U. massaica* is highly concentrated in the highland zones of the NCA, Ngorongoro, Nainokanoka, and Naiyobi (personal observation). This may be due to the fact that *U. massaica* requires high moisture and humidity to germinate and thrives in abandoned fields, as reported by [14]. The highland forested areas in the eastern parts of the NCA receive between 1000 and 1200 mm/year, which is significantly higher than the 400 to 600 mm/year in the semi-arid lowland plains in the west [32]. This causes these areas to have the moisture, cool temperatures, and fertile volcanic soils perfect for the germination and thriving of *U. massaica* [14]. Moreover, the regions of dense shade in the generated heatmap correspond also to the areas with high densities of abandoned bomas where human and animal ac-

tivities were concentrated (personal observation). Such areas are normally characterized by the accumulation of animal waste, which increases soil nutrition [33] and supports *U. massaica* overgrowth. This means that with the nomadic nature of the Maasai [34,35] among others, and the current ongoing voluntary relocation of Maasai to Tanga [36], large numbers of bomas in the NCA are abandoned, and each serves as a potential hotspot for the establishment and spread of *U. massaica*. This observation therefore serves as a wake-up call for management to prioritize abandoned bomas as areas that need immediate intervention in managing *U. massaica*.

5. Conclusions

This study concludes that abandoned bomas play an important role in influencing the establishment and dominance of *U. massaica* within the Ngorongoro Conservation Area. Areas dominated by *U. massaica*, particularly abandoned bomas, showed reduced plant species richness and diversity, indicating that the species may suppress native vegetation and alter plant community structure. However, the soil seedbank results suggest that these areas still have potential for natural regeneration when favorable conditions are provided. The spatial analysis further showed that *U. massaica* hotspots are concentrated mainly in highland zones with high densities of abandoned bomas, suggesting a strong link between former settlement activities and the current distribution of the species. Therefore, management interventions should prioritize abandoned bomas as key restoration and control sites. Reducing *U. massaica* dominance, improving soil conditions, and promoting native species regeneration will be important for maintaining pasture availability, biodiversity conservation, and ecological sustainability within the Ngorongoro Conservation Area.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

NCA	Ngorongoro Conservation Area
NCAA	Ngorongoro Conservation Area Authority
IUCN	International Union for Conservation of Nature
GIS	Geographical Information System
SNP	Serengeti National Park
TAWIRI	Tanzania Wildlife Research Institute

Appendix A

Table A1. Plant species that were observed at the Ngorongoro study habitat during field survey.

Control Sites Only	Abandoned Bomas Only	Control Sites and Abandoned Bomas
<i>Acacia tortilis</i>	<i>Amaranthus hybridus</i>	<i>Acalypha racemosa</i>
<i>Asparagus</i> sp.	<i>Artemisia caffra</i>	<i>Achyranthes aspera</i>
<i>Asystasia gangetica</i>	<i>Bersama abyssinica</i>	<i>Aerva lanata</i>
<i>Cadaba abyssinica</i>	<i>Bidens pilosa</i>	<i>Ageratum conyzoides</i>
<i>Caylusea abyssinica</i>	<i>Chenopodium album</i>	<i>Alternanthera pungens</i>
<i>Chloris pycnothrix</i>	<i>Clutia abyssinica</i>	<i>Anagallis arvensis</i>
<i>Cirsium buchwaldii</i>	<i>Commicarpus plumbagineus</i>	<i>Anthriscus sylvestris</i>
<i>Cynium tubulosum</i>	<i>Cynoglossum lanceolatum</i>	<i>Chamaecrista mimosoides</i>
<i>Desmodium repandum</i>	<i>Galinsoga parviflora</i>	<i>Clematis hirsuta</i>
<i>Dychoriste radicans</i>	<i>Gutenbergia cordifolia</i>	<i>Commelina benghalensis</i>
<i>Erigeron bonariensis</i>	<i>Haplocarpha rueppelii</i>	<i>Cucumis dipsaceus</i>
<i>Euphorbia heterophylla</i>	<i>Leonotis nepetifolia</i>	<i>Cyathula cylindrica</i>
<i>Heteropogon contortus</i>	<i>Ocimum grandicimum</i>	<i>Cynodon dactylon</i>
<i>Hypericum peplidifolium</i>	<i>Oxygonum sinuatum</i>	<i>Cyperus tenax</i>
<i>Hypoestes verticillaris</i>	<i>Phytolacca dodecandra</i>	<i>Cyphostemma cyphopetalum</i>
<i>Indigofera</i> sp.	<i>Ricinus communis</i>	<i>Digitaria abyssinica</i>
<i>Justicia calculata</i>	<i>Setaria pumila</i>	<i>Dregea somalensis</i>
<i>Justicia elliotii</i>	<i>Sphaeranthus</i> sp.	<i>Eleusine jaegeri</i>
<i>Lactuca tatarica</i>	<i>Sporobolus spicatus</i>	<i>Eleusine multiflora</i>
<i>Lippia javanica</i>	<i>Stephania abyssinica</i>	<i>Eragrostis tenuifolia</i>
<i>Ocimum philamentosum</i>	<i>Vinca major</i>	<i>Euphorbia inaequilatera</i>
<i>Panicum trichocladum</i>	<i>Zantedeschia aethiopica</i>	<i>Geophila repens</i>
<i>Polygala sphenoptera</i>	<i>Zehneria scabra</i>	<i>Geranium arabicum</i>
<i>Portulaca oleracea</i>		<i>Heliotropium steudnerii</i>
<i>Pteridium aquilinum</i>		<i>Hypoestes forskalii</i>
<i>Ruellia prostrata</i>		<i>Indigofera arecta</i>
<i>Rumex usambarensis</i>		<i>Indigofera volkensii</i>
<i>Rhynchosia hirta</i>		<i>Justicia exigua</i>
<i>Rhynchosia minima</i>		<i>Kalanchoe lateritia</i>
<i>Satureja punctata</i>		<i>Kyllinga odorata</i>
<i>Solanum aculeastrum</i>		<i>Lagenaria sphaerica</i>
<i>Sporobolus iocladius</i>		<i>Medicago laciniata</i>
<i>Tagetes minuta</i>		<i>Neonotonia wightii</i>
<i>Thapsia villosa</i>		<i>Nepeta azurea</i>
<i>Themeda triandra</i>		<i>Ocimum obovatum</i>
<i>Vernonia wightii</i>		<i>Oxalis corniculata</i>
<i>Vicia hirsuta</i>		<i>Pavonia urens</i>
<i>Vigna luteola</i>		<i>Pennisetum sphacelatum</i>
		<i>Peponium vogelii</i>
		<i>Pychnostachia meyerii</i>
		<i>Rubia peregrina</i>
		<i>Salvia nilotica</i>
		<i>Senna didymobotria</i>
		<i>Solanum incanum</i>
		<i>Solanum nigrum</i>
		<i>Sonchus oleraceus</i>
		<i>Sporobolus africanus</i>
		<i>Stenotaphrum dimidiatum</i>
		<i>Urtica massaica</i>
		<i>Verbena officinalis</i>
		<i>Vernonia auriculifera</i>
		<i>Veronica abyssinica</i>

Table A2. Plant species that were observed at the Nainokanoka study habitat during field survey.

Control Sites Only	Abandoned Bomas Only	Control Sites & Abandoned Bomas
<i>Abutilon longicuspes</i>	<i>Acmella caulirhiza</i>	<i>Acalypha racemosa</i>
<i>Agrocharis</i> sp.	<i>Argeratum conozoides</i>	<i>Achyranthes aspera</i>
<i>Ajuga integrifolia</i>	<i>Cronopus didymus</i>	<i>Ageratum conozoides</i>
<i>Altenanthera pungens</i>	<i>Crotalaria agatiflora</i>	<i>Amaranthus hybridus</i>
<i>Anthriscus fischeri</i>	<i>Eleusine jaegeri</i>	<i>Anagallis arvensis</i>
Apocynaceae	<i>Erigerom bonariensis</i>	<i>Anthriscus sylvestris</i>
<i>Artemisia afra</i>	<i>Erucastum arabica</i>	<i>Carnopus didymus</i>
<i>Asparagus africanus</i>	<i>Hibiscus</i> sp.	<i>Chenopodium album</i>
<i>Asparagus</i> sp.	<i>Kohautia virgata</i>	<i>Cirsium buchwaldii</i>
<i>Aspila mossambicensis</i>	<i>Malva versitilata</i>	<i>Clutia abyssinica</i>
<i>Asystasia gangetica</i>	<i>Malva vertisilata</i>	<i>Commelina africana</i>
<i>Bidens pilosa</i>	<i>Neurium oleander</i>	<i>Commelina benghalensis</i>
<i>Bothroclaoa inclupta</i>	<i>Salvia nilotica</i>	<i>Cotula abyssinica</i>
<i>Calanchoe lateritia</i>	<i>Senna didymobotria</i>	<i>Crasocephalum montuosum</i>
<i>Calyusea abyssinica</i>	<i>Setaria sphacelatum</i>	<i>Cyathula cylindrica</i>
<i>Cenesis maranguensis</i>		<i>Cynodon dactylon</i>
<i>Chamaecrista mimosoides</i>		<i>Cynoglossum lanceolatum</i>
<i>Clematis hirsuta</i>		<i>Cyperus tenax</i>
<i>Clotalaria agatiflora</i>		<i>Digitaria abyssinica</i>
<i>Clotalaria alata</i>		<i>Drek-Brockmania somalensis</i>
<i>Codia cordifolia</i>		<i>Eragrostis racemosa</i>
<i>Conyza pyrrhoppapa</i>		<i>Euphorbia inaequilatera</i>
<i>Cynium tubulosum</i>		<i>Galensoga parviflora</i>
<i>Cyphostema cyphopetelum</i>		<i>Geophila repens</i>
<i>Desmodium repandum</i>		<i>Geranium arabicum</i>
<i>Dicliptera albicaulis</i>		<i>Gnidia glauca</i>
<i>Digitaria</i> sp.		<i>Hypoestes forskoolii</i>
<i>Dychoriste radicans</i>		<i>Indigofera volkensii</i>
<i>Eleusine jaegerii</i>		<i>Kyllinga odorata</i>
<i>Eragrostis tenuifolia</i>		<i>Lagenaria sphaerica</i>
<i>Euphorbia corniculata</i>		<i>Medicago lanciniata</i>
<i>Euphorbia heterophylla</i>		<i>Oxalis corniculata</i>
<i>Geranium arabicum</i>		<i>Oxygonum sinuatum</i>
<i>Gerbera</i> sp.		<i>Panicum repundum</i>
<i>Guternbergia cordifolia</i>		<i>Pennisetum sphacelatum</i>
<i>Haplocarpha rueppelii</i>		<i>Physalis peruviana</i>
<i>Heteropogon contortus</i>		<i>Rubia peregrina</i>
<i>Hygrophila auriculata</i>		<i>Slavia nilotica</i>
<i>Hypomoea mombasana</i>		<i>Solanum incanum</i>
<i>Ipomoea mombasana</i>		<i>Sonchus oleraceus</i>
<i>Justicia exigua</i>		<i>Sonchus</i> sp.
<i>Kalanchoe lateritia</i>		<i>Spermacoce princea</i>
<i>Lepidotrichilia volkensii</i>		<i>Sporobolus africanus</i>
<i>Leucas aspera</i>		<i>Stenotaphrum dimidiatum</i>
<i>Melilotus</i> sp.		<i>Stephania abyssinica</i>
<i>Mytenus senegalensis</i>		<i>Trifolium lanceolatum</i>
<i>Neonotonia wightii</i>		<i>Urtica massaica</i>
<i>Nepeta azurea</i>		<i>Venonia auliculifera</i>
<i>Ocimum philamentosum</i>		<i>Veronica abyssinica</i>
<i>Orobancha minor</i>		<i>Zeheneria scabra</i>
<i>Panicum trichocladium</i>		
<i>Pavonia urens</i>		
<i>Phyllanthus</i> sp.		
<i>Pichnostachia meyerii</i>		
<i>Plantago palmata</i>		
<i>Polygala sphenoptera</i>		
<i>Portulaca oleraceus</i>		
<i>Pychnostachya meyeri</i>		
<i>Rubia cordifolia</i>		
<i>Rumex acetosa</i>		
<i>Rumex usambarensis</i>		
<i>Satureja punctata</i>		
<i>Senecio maranguensis</i>		
<i>Sochus oleraceus</i>		
<i>Solanum anguivi</i>		
<i>Solanum nigrum</i>		
<i>Solanum terminale</i>		
<i>Sonchus oleraseus</i>		
<i>Sopubia ramosa</i>		
<i>Sporobolus iocladus</i>		
<i>Sporobolus spicatus</i>		
<i>Targetes minuta</i>		
<i>Themeda trianda</i>		
<i>Tragus berteronianus</i>		
<i>Tribulus terrestris</i>		
<i>Urochloa panichoides</i>		
<i>Verbescus</i>		
<i>brevipedicellatum</i>		
<i>Vigna luteola</i>		

References

1. IPBES. *Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and Their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; Roy, H.E., Pauchard, A., Stoett, P., Renard Truong, T., Bacher, S., Galil, B.S., Hulme, P.E., Ikeda, T., Sankaran, K.V., McGeoch, M.A., et al., Eds.; IPBES Secretariat: Bonn, Germany, 2023.
2. Hejda, M.; Sádlo, J.; Kutlvašr, J.; Petřík, P.; Vítková, M.; Vojík, M.; Pyšek, P.; Pergl, J. Impact of invasive and native dominants on species richness and diversity of plant communities. *Preslia* **2021**, *93*, 181–201. [\[CrossRef\]](#)
3. Natural World Heritage Sites. *Ngorongoro Conservation Area*; Inscribed; UNESCO Natural World Heritage Site: Paris, France, 1979.
4. Bukombe, J.; Smith, S.; Kija, H.; Loishooki, A.; Sumay, G.; Mwita, M.; Mwakalebe, G.; Kihwele, E. Fire regulates the abundance of alien plant species around roads and settlements in the Serengeti National Park. *Manag. Biol. Invasions* **2018**, *9*, 357–367. [\[CrossRef\]](#)
5. Homewood, K.M.; Rodgers, W.A. Pastoralism and conservation. *Hum. Ecol.* **1984**, *12*, 431–441. [\[CrossRef\]](#)
6. Andrews, P.; Bamford, M.K.; Njau, E.F.; Leliyo, G. The Ecology and Biogeography of the Endulen-Laetoli Area in Northern Tanzania. In *Paleontology and Geology of Laetoli: Human Evolution in Context: Volume 1: Geology, Geochronology, Paleoecology and Paleoenvironment*; Springer: Dordrecht, The Netherlands, 2011.
7. Centre for Environmental Excellence. *Invasive Species Overview*; Centre for Environmental Excellence: Singapore, 2024.
8. Muvengwi, J.; Chikorowondo, G.; Gandiwa, E.; Mbiba, M. Diversity and abundance of macro-invertebrates on abandoned cattle kraals in a semi-arid savanna. *Ecol. Evol.* **2018**, *8*, 8477–8489. [\[PubMed\]](#)
9. Maundu, P.; Berger, D.; Saitabau, C.O.; Nasieku, J.; Kipelian, M.; Mathenge, S.; Morimoto, Y.; Höft, R. *Ethnobotany of the Loita Maasai*; People and Plants Working Paper 8; UNESCO: Paris, France, 2001.
10. Ngondya, I.B.; Munishi, L.K.; Treydte, A.C.; Ndakidemi, P.A. A nature-based approach for managing the invasive weed species *Gutenbergia cordifolia* for sustainable rangeland management. *SpringerPlus* **2016**, *5*, 1787. [\[CrossRef\]](#) [\[PubMed\]](#)
11. Masao, C.; Makoba, R.; Sosovele, H. Will Ngorongoro Conservation Area remain a world heritage site amidst increasing human footprint. *Int. J. Biodivers. Conserv.* **2015**, *7*, 394–407. [\[CrossRef\]](#)
12. Ngondya, I.B.; Munishi, L.K. Impact of invasive alien plants *Gutenbergia cordifolia* and *Tagetes minuta* on native taxa in the Ngorongoro crater, Tanzania. *Sci. Afr.* **2021**, *13*, e00946. [\[CrossRef\]](#)
13. Niboye, E.P. Vegetation Cover Changes in Ngorongoro Conservation Area from 1975 to 2000: The Importance of Remote Sensing Images. *Open Geogr. J.* **2010**, *3*, 15–27. [\[CrossRef\]](#)
14. Allan, K. The Effect of Soil and Climatic Factors on Antimicrobial and Phytochemical Composition of Stinging Nettle (*Urtica massaica*). Master's Thesis, University of Eldoret, Eldoret, Kenya, 2019.
15. Grubben, G.J.H. (Ed.) *Plant Resources of Tropical Africa: Vegetables*; PROTA: Ankara, Turkey, 2004; p. 540.
16. Tanzania Wildlife Research Institute (Tawiri). *Mapping Settlement and Livestock Bomas in the Ngorongoro Conservation Area and Its Management Implications*; Tanzania Wildlife Research Institute: Arusha, Tanzania, 2020.
17. Ngorongoro Conservation Area Authority (NCAA). *Ngorongoro Management Plan*; NCAA: Ngorongoro, Tanzania, 2024.
18. Mbinile, S.D.; Munishi, L.K.; Ngondya, I.B.; Ndakidemi, P.A. Conservation and Management Challenges Facing a Medicinal Plant *Zanthoxylum chalybeum* in Simanjiro Area, Northern Tanzania. *Sustainability* **2020**, *12*, 4140. [\[CrossRef\]](#)
19. Sanou, L.; Savadogo, P.; Zida, D.; Thiombiano, A. Variation in soil seed bank and relationship with aboveground vegetation across microhabitats in a savanna-woodland of West Africa. *Nord. J. Bot.* **2022**, *2022*, e03304. [\[CrossRef\]](#)
20. Ngondya, I.B.; Treydte, A.C.; Ndakidemi, P.A.; Munishi, L.K. Can *Cynodon dactylon* Suppress the Growth and Development of the Invasive Weeds *Tagetes minuta* and *Gutenbergia cordifolia*? *Plants* **2019**, *8*, 576. [\[CrossRef\]](#) [\[PubMed\]](#)
21. Adams, C.R.; Nancy, M.S. *Methodology for Wetland Seedbank Assays*; University of Florida Extension: Gainesville, FL, USA, 2018.
22. Wala, K.; Woegan, A.Y.; Borozi, W.; Dourma, M.; Atato, A.; Batawila, K.; Akpagana, K. Assessment of vegetation structure and human impacts in the protected area of Alédjo (Togo). *Afr. J. Ecol.* **2012**, *50*, 355–366. [\[CrossRef\]](#)
23. Dada, A.D.; Olusola, A.J.; Awotoye, O.O.; Odiwe, A.I. A comparative assessment of species diversity and structural characteristics in undisturbed forest reserve and protected forest in the humid tropical rainforests of Southwestern Nigeria. *Discov. For.* **2025**, *1*, 41. [\[CrossRef\]](#)
24. Bisht, M.; Chandra Sekar, K.; Mukherjee, S.; Thapliyal, N.; Bahukhandi, A.; Singh, D.; Bhojak, P.; Mehta, P.; Upadhyay, S.; Dey, D. Influence of Anthropogenic Pressure on the Plant Species Richness and Diversity Along the Elevation Gradients of Indian Himalayan High-Altitude Protected Areas. *Front. Ecol. Evol.* **2022**, *10*, 751989. [\[CrossRef\]](#)
25. Czarniecka-Wiera, M.; Kački, Z.; Chytrý, M.; Palpurina, S. Diversity loss in grasslands due to the increasing dominance of alien and native competitive herbs. *Biodivers. Conserv.* **2019**, *28*, 2781–2796. [\[CrossRef\]](#)
26. Njoroge, G. Utilization of weed species as source of traditional medicines in central Kenya. *Lyonia* **2004**, *7*, 71–80.
27. Bond, W.; Davies, G.; Turner, R.H. *The Biology and Non-Chemical Control of Common Nettle (Urtica dioica L.)*; Ryton Organic Gardens: Coventry, UK, 2007.
28. Martz, F.; Kankaanpää, S. Stinging Nettle (*Urtica dioica*) Roots: The Power Underground—A Review. *Plants* **2025**, *14*, 279. [\[CrossRef\]](#) [\[PubMed\]](#)

29. Vačkář, D.; Harmáčková, Z.V.; Kaňková, H.; Stupková, K. Human transformation of ecosystems: Comparing protected and unprotected areas with natural baselines. *Ecol. Indic.* **2016**, *66*, 321–328. [[CrossRef](#)]
30. Douh, C.; Dainou, K.; Loumeto, J.; Moutsambote, J.-M.; Fayolle, A.; Tosso, F.; Forni, E.; Gourlet-Fleury, S.; Doucet, J.-L. Soil seed bank characteristics in two central African forest types and implications for forest restoration. *For. Ecol. Manag.* **2018**, *409*, 766–776. [[CrossRef](#)]
31. Yankova-Tsvetkova, E.; Petrova, M.; Grigorova, I.; Traykova, B.; Stanilova, M. The Establishment of an Ex-Situ Collection of *Primula veris* in Bulgaria. *Plants* **2022**, *11*, 3018. [[CrossRef](#)] [[PubMed](#)]
32. Mwabumba, M.; Yadav, B.K.; Rwiza, M.J.; Larbi, I.; Dotse, S.-Q.; Limantol, A.M.; Sarpong, S.; Kwawuvi, D. Rainfall and temperature changes under different climate scenarios at the watersheds surrounding the Ngorongoro Conservation Area in Tanzania. *Environ. Chall.* **2022**, *7*, 100446. [[CrossRef](#)]
33. Muchiru, A.N.; Western, D.; Reid, R.S. The impact of abandoned pastoral settlements on plant and nutrient succession in an African savanna ecosystem. *J. Arid. Environ.* **2009**, *73*, 322–331. [[CrossRef](#)]
34. Butt, B.; Shortridge, A.; WinklerPrins, A.M.G.A. Pastoral Herd Management, Drought Coping Strategies, and Cattle Mobility in Southern Kenya. *Ann. Assoc. Am. Geogr.* **2009**, *99*, 309–334. [[CrossRef](#)]
35. Miller, B.W.; Leslie, P.W.; McCabe, J.T. Coping with Natural Hazards in a Conservation Context: Resource-Use Decisions of Maasai Households During Recent and Historical Droughts. *Hum. Ecol.* **2014**, *42*, 753–768. [[CrossRef](#)] [[PubMed](#)]
36. Franco, P.M. Perspective Chapter: A Perspective on the Resettlement of Maasai Communities from the Ngorongoro Landscape in Tanzania. In *New Insights into Protected Area Management and Conservation Biology*; IntechOpen: London, UK, 2022.

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