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Distribution and Impact of Invasive *Parthenium hysterophorus* on Soil Around Arusha National Park, Tanzania

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Abstract: An increase of biological invasion in developing countries is threatening smallholder's livelihoods, biodiversity conservation, agroecosystems and rangeland productivity. In Tanzania, the exotic invasive plant *Parthenium hysterophorus*, which is rapidly spreading in Arusha region, threatens wildlife conservation, human well–being and food security in the country. This study was conducted to assess the current distribution of *P. hysterophorus* and its associated soil properties within the Arusha National Park (ANP) and in adjacent villages at the park's border zones using road surveys. *Parthenium hysterophorus* density was visually estimated as high, medium, and low when the invasive individuals were > 4, 3–4, and 1–2 in 1 m^2 quadrats, respectively. The results showed that albeit some adjacent villages are invaded, ANP is yet not affected. *Parthenium hysterophorus* was observed growing in grazing areas, maize and banana fields in villages, and along road verges, with particularly high densities in maize fields, along roadsides, and at lower altitudes. Moreover, analysis of soil chemical properties showed that *P. hysterophorus* was associated with soils of higher Manganese and cation exchange capacity. We recommend that *P. hysterophorus* surveys within the ANP and other protected areas in Arusha region should be carried out regularly as the rapid expansion of *P. hysterophorus* threatens ANP's ecology and biodiversity.

Keywords: Africa, Alien Plants, Livelihoods, Soil Properties, Weed Biology, Weed Invasion, Weed Survey

1. Introduction

Invasive plants are defined as exotic plant species that when released into novel environments establish, grow, reproduce and sustain self–replacing populations without human intervention [1, 2]. They exert negative effects on intact and semi–intact ecosystems [3]. Invasive species are characterized by a longer life span and fruiting period, greater seed yield, smaller seed size, easy dispersal by wind, human or animals, stronger vitality, and higher biomass than native species [4]. These characteristics facilitate the spread and invasion of many alien species [5]. Movement of people, transportation of goods, and horticulture contribute considerably to the introduction of exotic invasive species.

Anthropogenic activities resulting in alteration of habitats promote invasion and dispersal of invasive plant seeds [6].

Alien invasion causes potentially harmful impact on native biota conservation [7], ecosystem processes (e.g., nutrient cycling) and services (e.g., pollination, [8]), alters indigenous vegetation structure, ecological communities and fire regime [9]. It reduces the abundance, species richness, and diversity of indigenous plant species [10]. Some alien invasives adversely affect trophic structure, food webs and vertebrates [11, 12], as well as invertebrates [8, 13]. In some cases, alien invasion may even lead to biodiversity loss [1]. Rural communities' livelihoods that depend entirely on natural resources or agriculture are also impacted unfavorably by the invasives [14]. Overall, biological invasion is associated with negative impacts on ecology and economy worldwide [3].

An alien invasive plant *Parthenium hysterophorus* L. (Asteraceae) is known for its deleterious impact on biodiversity, agriculture, and livelihoods of local people (Figure 1, [5, 15]). It is indigenous in Central and South America [16], but has become invasive in Africa, Asia, and Australia [7]. Within its invasive range, *P. hysterophorus* causes severe harmful effects on the environment [16]. It suppresses natural flora, reduces quantity and quality of palatable fodders as well as crop production [7, 14]. It also interferes with pollination services of native plant species [5], modifies vegetation community structure and exerts harmful health effects to people, livestock and wildlife [4].

Parthenium hysterophorus is a prolific seed producer i.e. producing about 15,000–28,000 seed on average [4]. Its seeds disperse easily and germinate under wide range of environment condition, i.e., at rainfall of > 500 mm per year, 10–25°C average annual temperatures and a soil pH of (2.5–10 [4]. In addition to withstanding saline, drought and moisture stress [4], *P. hysterophorus* is capable to grow and establish on different soil types i.e. black, clay, alkaline and cracking soils of high fertility [4]. Also, it uses allelopathy to outcompete indigenous plant species [15]. Since in 2010 when *P. hysterophorus* was first reported in Arusha region, Tanzania it has spread in other four regions i.e. Kagera, Kilimanjaro, Geita and Manyara (Figure 1). It has invaded rangelands and agroecosystems in these regions while reducing crop yield and forage for livestock [5, 15]. As a result, it endangers livelihoods of smallholders and pastoralists.

As it is projected that *P. hysterophorus* will spread further into protected areas in Tanzania [17], it is imperative to understand its current distribution [2]. This information is a vital step for managing and preventing its spread, and developing possible management responses [2, 11]. Its current spread also indicates when and where management control such as mechanical removal, biological agents, or bio–herbicides can be applied, effectively (Figure 3, [1]). Efforts to assess the distribution of invasives has been ongoing in Tanzania but little work has been done to document the distribution of *P. hysterophorus* in and around protected areas. The primary objective of this study was to assess *P. hysterophorus* (i) distribution within and at the border zones of Arusha national park (ANP) and (ii) its association with particular soil chemical properties.

Figure 1. *Seedling (A) and mature flowering (B) Parthenium hysterophorus plant in northern Tanzania.*

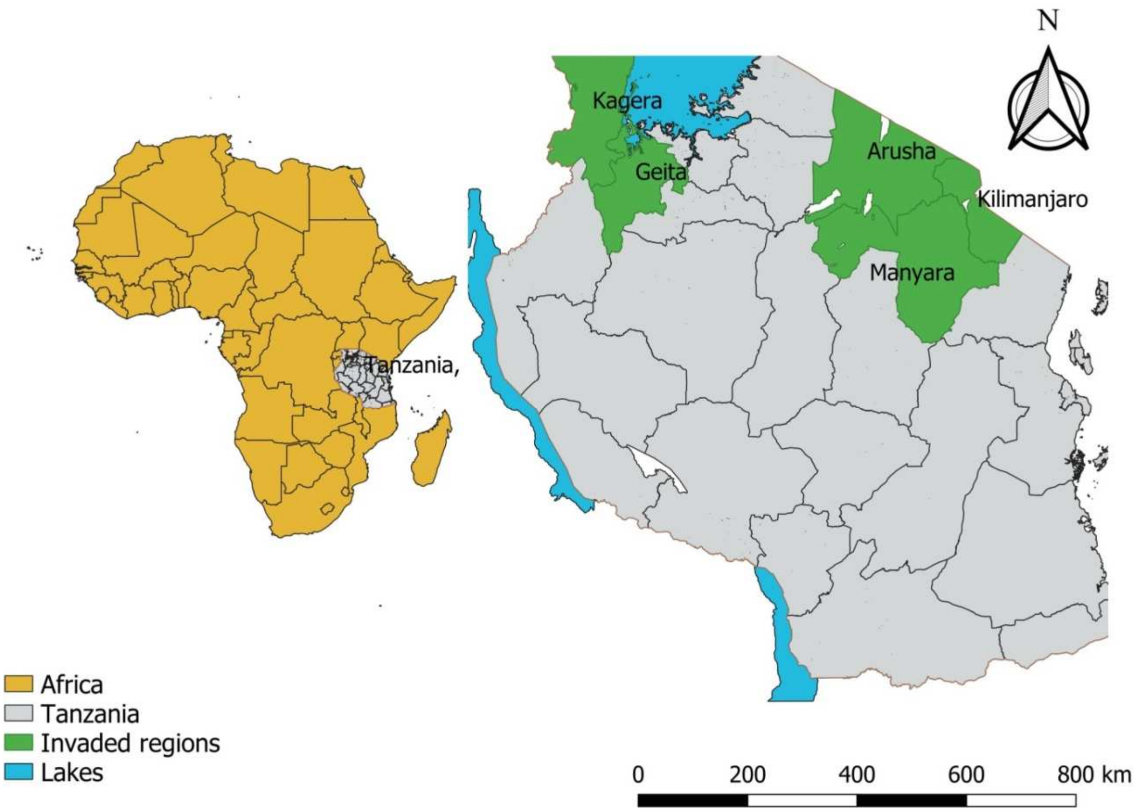

Figure 2. *Regions invaded by Parthenium hysterophorus in Tanzania.*

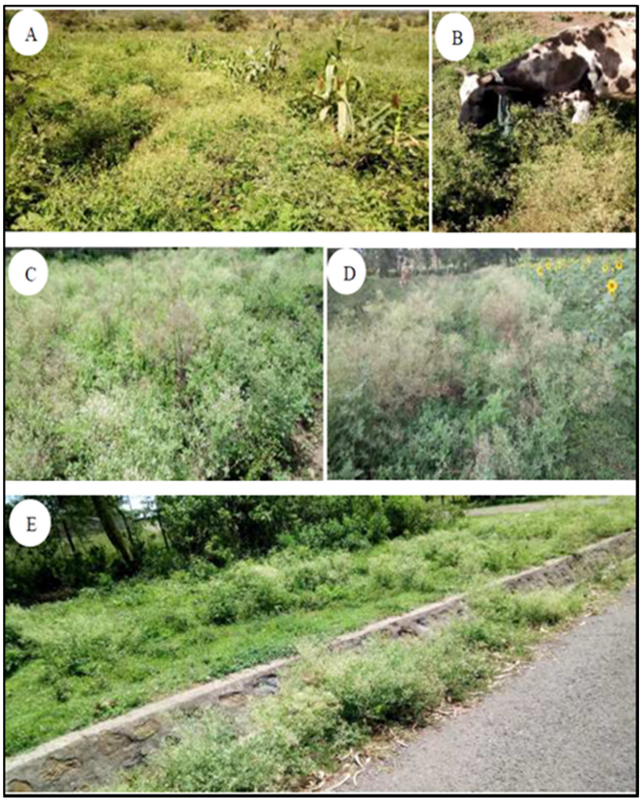

Figure 3. *Maize field (A), grazing area (B), rangeland, (C), sunflower field (D), and (E) Momela road heading to Arusha national park (E) invaded by Parthenium hysterophorus in Arusha, Tanzania.*

2. Materials and Methods

2.1. Study Sites and Field Survey

The study was conducted within ANP and villages nearby the park border zones. Arusha national park is located at 3°15' S and 37°00' E in the Arusha region of Tanzania. The surveys were conducted between January and June, 2018. We used a roadside survey to search for P. *hysterophorus* along roads, both inside and outside ANP using a vehicle and motorcycle. We stopped after every 30 m to 50 m to scan for the presence of *P. hysterophorus* in areas nearby the roads, farms, grazing fields, and settlements and recorded the location of *P. hysterophorus* (Garmin etrex20 GPS). Inside the park, the stops were made at an interval of 1 km as we expected lower occurrence probability. On every *P. hysterophorus* detection, we recorded latitude, longitude, elevation, land use type, and density per square meter. We estimated visually the density of *P. hysterophorus* as high, medium, and low when P. *hysterophorus* plants were > 4, 3–4, and 1–2 individuals in 1 m^2 quadrat, respectively.

The road survey method was used in this study because we were searching for an invasive species that is known to grow along roadsides (or road verges) and in disturbed areas [18]. The road verge environments are suitable for invasions of alien plants (e.g., *P. hysterophorus*) because they offer appropriate microhabitat [19, 20]. The road networks are also known to be a major conduit for dispersal of *P. hysterophorus* seeds at a long distance by vehicles [20, 21]. Previous studies refer road survey method as a suitable method for assessing and early detection of the population of a single or new known invasive species [18, 22]. The method facilitates rapid assessment of the distribution and diversity of the invasive plant species [21, 22].

2.2. Soil Sampling and Analyses

During the survey, we randomly selected patches invaded heavily by *P. hysterophorus* and as control patches without invasion (uninvaded) to collect soil samples. The distance between the invaded and uninvaded patches was 30 m. At each selected patch we established 1 m^2 plot and removed leaf litter before taking soil samples. Five soil samples (one from the center and one from each of the four corners of the plot to a depth of 10 cm) were collected using a garden trowel. The five soil samples were pooled to make a single sample of each plot [16, 23].

In total, we collected 20 soil samples, i.e. 10 samples from invaded and another 10 from uninvaded plots. Each sample was stored in a zip–lock plastic bag and transported to the Ministry of Agriculture Training Institute (33°22'E and 8°55'S, 1798 m a.s.l) soil laboratory in Mbeya, Tanzania, for analyses. Soil was sieved through a 2 mm fine–mesh screen to remove fine rocks and roots, and other unwanted particles. The soil samples were then analyzed for chemical parameters such as total nitrogen (N), phosphorus (P), organic carbon (OC), pH, electrical conductivity (EC), organic matter (OM), calcium (Ca), magnesium (Mg), potassium (K), manganese (Mn), and cation exchange capacity (CEC).

Recommended standard soil analytical procedures were used [16, 23, 24]. Total OC was determined by the Tinsley method; the pH was measured potentiometrically in a soil-distilled water suspension (ratio 1:2.5); EC with a saturated soil paste; OM and total N were determined by the Walkley-black and Kjeldahl methods respectively. Furthermore, 0.5 M $NaHCO_3$ was used to extract the available P and analyzed colourimetrically with the ascorbic acid molybdate method according to Bray and Curtz No 1; $NH_4C_2H_3O_2$ extracted soil cations (Ca^{2+}, Mg^{2+} and K^+) and analyzed on atomic absorption spectrophotometer with flame atomizer (Perkin- Elmer Analyst 100). The Mn was extracted using diethylene triamine pentaacetic acid (DTPA), and CEC was determined with Ammonium Acetate method at pH 7.0.

2.3. Statistical Methods

These soil chemical parameters were then compared statistically between invaded and non-invaded plots using a t-test following normality and homogeneity of variance tests using Shapiro–Wilk's and Levene's test, respectively. The statistical software used was Origin version 9.0 SR1 (Origin Pro, 2013) at a significance level of $\alpha = 0.05$.

3. Results

Parthenium hysterophorus invasion was only observed outside ANP but in villages close by, particularly along the south-eastern boundaries during our field survey (Figure 4). These villages included Ngongongare, King'ori, Oligilai, Maleu, Ngurudoto, and Sakila. *Parthenium hysterophorus* was observed growing in grazing areas, maize and banana fields and along the roadsides. The invasive dominated the road verges and road drainage lines, mainly along the Momela road. A higher density of *P. hysterophorus* was recorded at lower altitude, along roadsides, and in maize fields (Figure 5). It was also observed growing in other disturbed habitats such as landfills or dumping grounds.

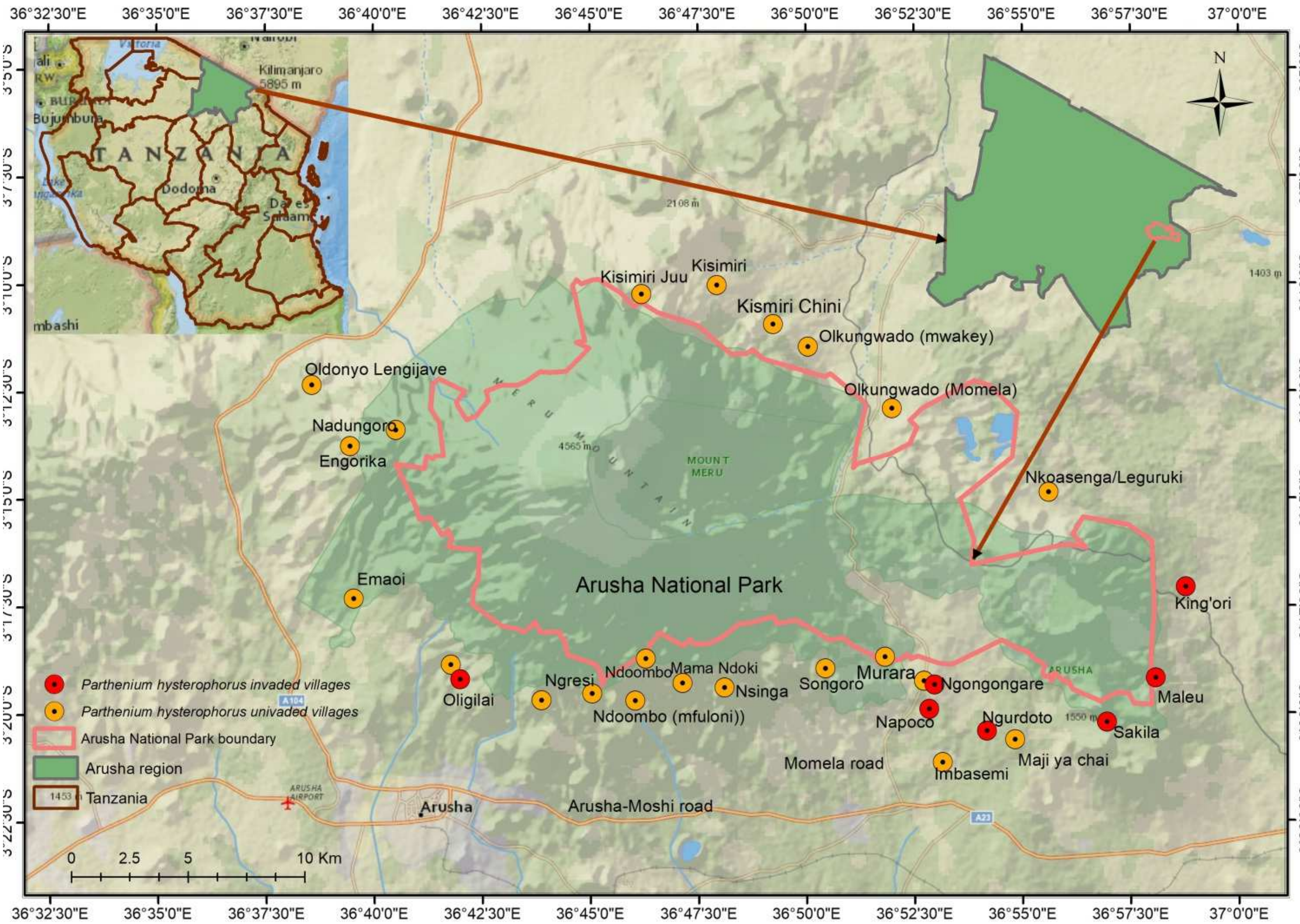

Figure 4. Current spread of P. hysterophorus outside the Arusha national park based on the field survey.

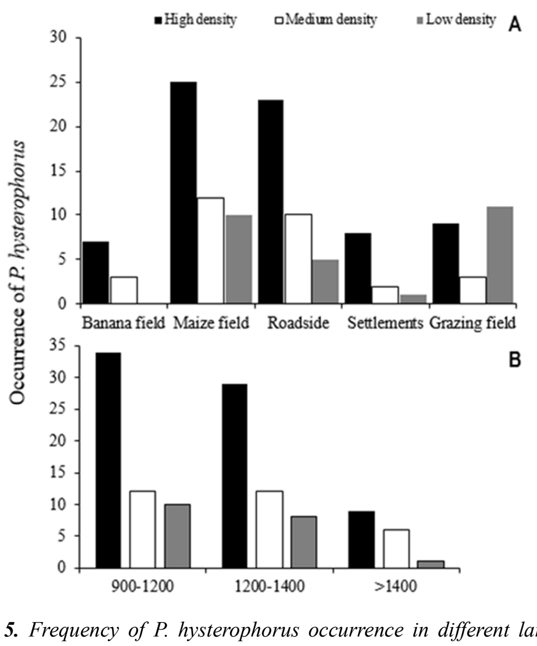

Figure 5. *Frequency of P. hysterophorus occurrence in different land use types (A) and elevation in m.a.s.l (B).*

Our results show that most soil chemical properties did not differ significantly between sites invaded by P. hysterophorus and control sites (Table 1). However, a slightly significant difference was observed between the invaded and uninvaded plots for EC ($p = 0.046$), pH ($p = 0.013$), and Ca ($p = 0.043$) (Table 1). The soil P concentration was by about 10% higher in uninvaded than in invaded plots ($p = 0.003$, Table 1) while soil CEC showed the opposite trend, being about 15% higher in the invaded than in uninvaded plots ($p = 0.015$, Table 1).

4. Discussion

Our study reveals that *P. hysterophorus* is spreading in some villages closest to the border zones of ANP. However, inside the park is not invaded yet. The spread of *P. hysterophorus* in the villages is possibly aided by the number of factors such as vehicles, fodder collection, grazing, and other socio–economic activities which disperse the invasive seeds [7, 25].

These factors were reported to have significant relationships with biological invasions in European and some African countries [26, 27]. Vehicles or motorcycles going to pick harvests from farms or collect remains for livestock may carry *P. hysterophorus* seeds and spread them to other areas i.e. farms, grazing lands, or rangelands. This was also described by Gervilla et al. [26] and Wilson et al. [28] that contaminant seeds in seed lots constitute a pathway for introducing a plant species into new habitats.

As people walk in *P. hysterophorus* invaded areas, the seeds can drop in their shoes or carried on sole to other locations as contaminants. This could be the reason of why maize fields in our study had the greater number of *P. hysterophorus* invasions in total following roadsides. The current *P. hysterophorus* invasions in these villages is an indicator that the weed threatens to invade the ANP. Thus, if it is left uncontrolled, P. hysterophorus can migrate into the ANP and affects its ecological integrity, ecosystem services and function.

Table 1. *A t-test statics of the soil parameters in areas with (invaded) and without (uninvaded) invasion of P. hysterophorus*

	Mean ± SE				
	Uninvaded	**Invaded**	**T**	**df**	***p-value***
pH	6.54±0.06	6.36 ± 0.03	*2.74*	18	0.013
E (CmS/cm)	0.58 ± 0.08	0.44 ± 0.03	2.14	18	0.046
OC (%)	1.79 ± 0.15	1.43 ± 0.22	1.59	18	0.129
Organic matter (%)	3.09 ± 0.25	2.47 ± 0.38	1.60	18	0.128
Total N (%)	0.11 ± 0.01	0.12 ± 0.02	-0.65	18	0.526
P (mg/kg)	68.62±4.65	48.07 ± 3.69	3.46	18	0.003
Ca (Cmol/kg)	19.37±0.35	18.11 ± 0.46	2.18	18	0.043
Mg (Cmol/kg)	2.22 ± 0.01	2.21 ± 0.11	0.44	18	0.668
K (Cmol/kg)	3.68 ± 0.26	2.79 ± 0.37	1.98	18	0.063
Mn (ppm)	49.8 ± 7.01	64 ± 3.23	-1.65	18	0.116
CEC (Cmol/kg)	34.4 ± 1.64	43.2 ± 1.83	-2.69	18	0.015

Bold *p*-values are significant at $p < 0.05$

The invaded Momela road which is used by vehicles going to and from Ngarenanyuki through the ANP is the major route through which *P. hysterophorus* seed can be transported into the park. This road is connected to the Arusha–Moshi road which is highly invaded by *P. hysterophorus*. We suggest that the Arusha–Moshi road to be the main source and starting point for *P. hysterophorus* invasions along the Momela road. Previous studies have reported how roadsides act as preferential migration corridor and starting point for *P. hysterophorus* invasion and other invasive species [18, 20, 22]. In this view, the invaded Momela road increases the chance of spreading *P. hysterophorus* into the park. Vehicles from invaded Arusha and Arumeru areas or those using the Momela road may carry *P. hysterophorus* seeds in mud adhered to the tyres into the ANP. The wind produced by these vehicles can also disperse the seeds further from its location to other areas [19, 21, 29].

Additionally, *P. hysterophorus* seeds can enter into the park as a contaminant of tourists, travelers, or workers' possessions [26, 27]. They may even transport the seeds in mud adhered to their shoes [26]. A study by Vilà and Pujadas [27] claimed that alien plant species introduced in protected areas correlate with the number of visitors. Accordingly, protection of natural habitats or rangelands may not guarantee alien invasive exclusion. So, in order to control alien invasions in natural areas, park ecologists should educate visitors not to releases any seed in protected area; and ensure that neither their belongings nor shoes have seeds contaminants.

Anthropogenic activities associated with change in vegetation structure and composition, as well as fire frequency create a window of opportunity for *P. hysterophorus* invasions in adjacent habitats [27]. Preceding studies unveil that man–made and disturbed areas i.e. agroecosystems, ruderal areas, and roadsides are invaded more compared to pristine areas [6]. Land–use changes, agriculture and livestock in the villages bordering the park are vital means by which *P. hysterophorus* may spread to the ANP's border zones. In our study we found high density of *P. hysterophorus* invasions in maize farms and along road verges. Maize fields are usually left bare without crop or vegetation cover after harvest, and thus, creating a room for *P. hysterophorus* to germinate, colonize and increase in biomass. On the other hand, road verges in our field sites seem to provide suitable conditions for *P. hysterophorus* to flourish. Studies have shown that road verges can increase soil disturbance, soil moisture, sun exposure and nutrient runoff [18, 19, 29] conditions needed for many invasives to establish. But, sites distant from the roads can be resistant to alien invasives due to dissimilar abiotic conditions i.e. reduced resource accessibility and disturbance frequency [29]. Human activities nearby the borders of ANP should be controlled and monitored often to preclude *P. hysterophorus* invasion into the park. Road networks in the park must also be monitored because they promote immigration of *P. hysterophorus* and the dispersal of already existing invasives.

Our results have showed that *P. hysterophorus* is invading areas typically at lower altitudes. The ANP which is located at higher altitude could be the main reason of not being invaded by *P. hysterophorus*. At higher altitudes it is difficult for *P. hysterophorus* seeds to be transported by surface runoff into the park [29]. Our findings conform to that of Etana et al. [24] which showed high *P. hysterophorus* invasions at lower altitudes in Awash national park in Ethiopia. Though high elevation seems to impede *P. hysterophorus* from invading the ANP, when its seeds are released into the park can germinate and establish. This is because *P. hysterophorus* grows virtually on all types of habitats and soil with different pH values [30].

In addition, the ANP and its surrounding outer areas have suitable habitats for *P. hysterophorus* invasions as predicted by Kija et al. [17]. Alien invasives are claimed to modify soil chemical properties of the invaded habitats [16, 23, 30, 31]. But, few studies have studied the impact of *P. hysterophorus* on soil chemical properties [23, 31].

Our study showed that *P. hysterophorus* may have a limited negative impact to some soil chemical parameters. This is because most of our soil parameters did not differ significantly between the invaded and uninvaded plots. Our findings conform in some way with that of Etana et al. [24] who found insignificant impact of *P. hysterophorus* on soil OM, total N, Mg, K, and Mn invaded plots. In contrary, Timsina et al. [31] found that soil N, OM, K, P and pH were highest in the *P. hysterophorus* invaded plots. Furthermore, we found that among the major soil nutrients (N, P and K) only P, and other parameters (pH, EC, and Ca) in our study were lower in the invaded plots. Minor difference in soil OM and N content between the invaded and uninvaded plots perhaps is due to lower decomposition rate and amount of above-ground biomass [31] of *P. hysterophorus* in the study sites. Cation exchange capacity was the highest in the invaded plots implying good soil quality and productivity. However, it is not necessary that a soil with a highest CEC is always more fertile as it may sometimes contain acid cations i.e. aluminium (Al^{3+}) and hydrogen (H^{+}).

Therefore, we suggest that negative impact of *P. hysterophorus* on soil chemical parameters may depend on invasion longevity, intensity, amount of above-ground biomass, and/ or soil type on the invaded habitats. Whether *P. hysterophorus* increases or decreases concentration or content of soil chemical parameters, its invasion is likely to have an overall harmful effect on the functioning of the entire ecosystem or rangeland [31]. Moreover, our results from both survey and soil chemical analysis reiterate the immediate need to control *P. hysterophorus* invasions in protected areas and development of strategies and policy guidelines for managing the invasive.

5. Conclusion and Recommendation

Feasible management of biological invasions require information about the distribution and location of alien invasive beforehand. This information is significant because it enables to plan effective management of alien invasive in protected areas, rangelands and agroecosystems. Although the park is uninvaded now, the invasions in the villages indicate that the ANP's biome is under risk. Our study has provided very important information for the distribution of *P. hysterophorus*. We have shown that currently *P. hysterophorus* is at initial invasion or spread stage towards the borders of ANP. This is the most effective stage for ecologists or invasion biologists to target for managing *P. hysterophorus*. We advise that in order to prevent the immigration of *P. hysterophorus* into the park emphasis must be placed on the control of land-use and socio-economic determinants at the border zones. Policies that integrate local communities in invasive species eradication process should be put in place. We also recommend that *P. hysterophorus* survey within ANP and other protected areas in Tanzania should be conducted, and prevention measure must be prepared beforehand. Besides, appropriate management methods for *P. hysterophorus* are essential to avoid potential negative impact to native biota and economic losses in the country.

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