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Parthenium hysterophorus Linn: Soil Seed Bank Analysis and Impact on Agricultural Production in Nyando Sub-County, Kisumu County, Kenya

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Abstract

Parthenium hysterophorus L. (Parthenium weed) has been classified as one of the world's most serious invasive plants. The extent of severity of Parthenium invasion can be predicted from the condition of the weeds' seed bank in the soil. In addition, data from perception survey of the local people can be used to estimate the impact of Parthenium weed on agricultural production. Thus, the objectives of this study were to analyze soil seed banks of Parthenium weed across different land use types and to evaluate the perception of farmers on the impact of this weed on agricultural production in Nyando Sub-County, Kisumu County, Kenya. A total of fifteen transects measuring 100m were established in the selected areas and soil samples collected for seed bank study. The sites selected for data collection included Rabuor, Nyamware and Bwanda regions while land use types included river bank, residential area, pastureland, roadside and cropland. A total of 210 respondents were interviewed using semi-structured, open-ended questionnaires to assess the impact of Parthenium weed invasion on agricultural production. Most respondents (72.0%) reported negative effects of Parthenium weed on livestock and crop production while the remaining 28% felt that the weed was useful. There was significant difference in the number of

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Parthenium seedlings that germinated in the soil from the different land use types ($F = 3.88$, $df = 14$, $p \leq 0.05$). The seedlings were notably abundant in the roadside (21±2.08) and cropland (19±3.67) than in soil from river bank (11.67±1.67) and residential area (9.33±1.20). This study recommends the need to minimize further spread of Parthenium weed by creating awareness on its impacts on agricultural production to the local people, researchers, extension workers and other relevant stakeholders.

Keywords: *Parthenium hysterophorus*, invasive plants, land use types, seed bank, agricultural production

1. INTRODUCTION

Soil seed bank is the totality of viable seeds present within a soil profile and on the surface [1]. According to Wanga *et al.* [2], all living seeds available in the soil or mixed with debris constitute the soil seed bank. Seeds in the soil bank may exist in or on the surface but on numerous instances; there is progression or continuity between seeds at the surface, partly buried and those completely buried in the soil [3]. Seed banks comprise of both dormant and non-dormant seeds which enhances the probability of persistence of a species at a particular area when germination conditions are unfavourable or in absence of additional seed rain [1]. Given the variety of stresses that ecosystems experience *viz.,* wild fire, cold, drought and disturbance, seed banks are generally a critical survival mechanism for several plants and maintain the long term stability of ecosystems [4]. Seed banks are also useful in conservation of genetic diversity of non-crop plants threatened by ecosystem and land use changes, invasive alien species, pollution, over exploitation and climate change [5].

Increased number of invasive seeds to the seed bank may have major consequences since natural or anthropogenic disturbances may probably promote the germination of seeds of

the invader, resulting in the rapid dominance of the invader in the seed bank and vegetation [6, 7]. Furthermore, elevated densities of invasive seeds may alter the viability and germination patterns of seeds of native species, consequently influencing the susceptibility of invaded communities to secondary invasions [8]. Alien plant invasions normally lower the density of the seed bank of plants in the invaded communities, although the effect on species richness may be insignificant [9]. Among many invasive species with expansive and persistent seed bank is Parthenium; which is widely distributed and belongs to the family Asteraceae or Compositae (tribe: Heliantheae) [10]. Parthenium is an aggressive, annual or transient herbaceous weed of tropical and subtropical regions. This invasive plant is a native to the regions around Gulf of Mexico and has spread to more than forty countries across five continents [11].

Dormancy mechanism and persistent seed bank has implication many years after the reduction in Parthenium weed populations. Besides a persistent seed bank, Parthenium generates a high yield of viable seeds with high regenerative potential and disseminative capacity [12]. Parthenium has invaded the natural ecosystems throughout the world and in so doing, contributed to losses in agricultural productivity. Due to its allelopathic property, the weed has strong potential to spread and has since invaded a range of habitats in Kenya [13]. Parthenium is assumed to have been introduced in Kenya in the 1970s in coffee plantations in Kiambu County [14, 15]. The negative consequences of this invasive plant species in environment and agriculture have been extensively documented [16, 17]. Parthenium has been listed in the weeds of global importance responsible for severe animal and human health issues, agricultural losses and great problem to biodiversity thus research on its impact is of national significance [18]. Hence, the objectives of this study were to

analyze soil seed banks of Parthenium weed and to investigate the effect of this invasive plant species on agricultural production in Nyando Sub-County, Kisumu County, Kenya.

2. MATERIALS AND METHODS

2.1. Study area

This research was carried out in western part of Nyando Sub-County (previously referred to as Kadibo Division) of Kisumu County (Figure 1). Nyando Sub-County is found between longitude 33° 20' - 35° 20' East and latitude 0° 20' – 0° 50' South. The area has a population of approximately 73,227 persons and covers a total of about 163km^2 [20]. Nyando Sub-County experiences mean annual temperature and mean annual rainfall of 20°C and 1000mm, respectively [21]. River Nyando and River Obuso are the main drainage river channels in this region. Nyando Sub-County is predominated by black cotton soil which develops deep cracks in dry seasons and allows most of the rain water to penetrate during the onset of the rainy season. In the beginning of rainy seasons, the soils expand, cracks close and water cannot further penetrate the soil leading to flooding of the plain terrain. Moreover, Nyando Sub-County is situated on the low ridges where rivers occasionally break into Lake Victoria; where they cause loss of human life and property due to flooding [22].

In this research, three sites were chosen for data collection, namely Rabuor, Bwanda and Nyamware (Figure 1). Rabuor is situated near the Nairobi-Kisumu highway and has numerous shopping centers. Most residents of Rabuor are business persons while a few are engaged in small scale agricultural activities and other economic ventures. Bwanda is found far away from the highway and encounters less flooding than Nyamware; which is located on the shores of Lake Victoria. Small scale agriculture and trade are the main

economic activities among the residents of Bwanda. Several farmers from Rabuor and Bwanda graze their livestock in Nyamware because of the expansive pastureland, rivers and closeness to Lake Victoria. Residents of Nyamware carry out livestock grazing and crop farming as the mainstay economic activities. As a result of low amounts of rainfall, many farmers in Nyamware practice irrigation farming. The area encounters flooding due to its proximity to Lake Victoria.

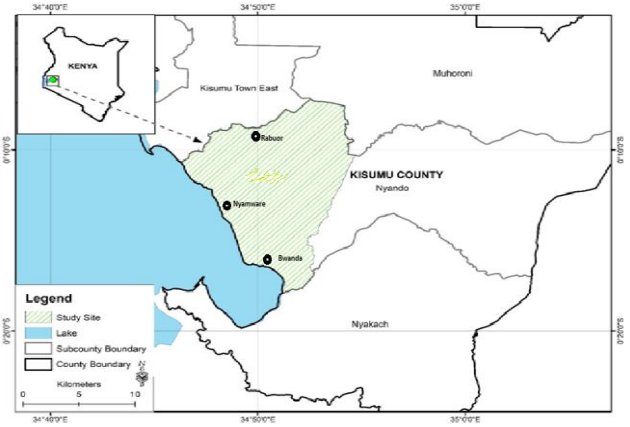

Figure 1: **Map of Nyando Sub-County. Source: Murono *et al.* [19]**

2.2. Sampling method

The research was carried out from 1st November 2016 to 31st February 2017 in the three sampling sites. These sites were chosen on the basis of variation in location, accessibility and area available for invasion by Parthenium weed. This study consisted of two stages: soil seed bank analysis and perception survey of local people to assess the impact of Parthenium weed on agricultural production in the above mentioned sites.

2.2.1. Determination of soil seed bank across the land use types

Based on visual observation, five major land use types were selected using stratified random sampling method [23]. The

land use types included river bank, residential area, pastureland, roadside and cropland. The soil seed banks were investigated by the seedling emergence method [24]. A hundred meter (100m) long transect was established in each sampling site and along it, ten quadrats systematically laid where soil samples were collected. In each site, two kilograms (2kg) of soil was taken i.e. two hundred grams (200g) of soil sample was taken from each of the ten quadrats along each transect at a depth of 15cm using a soil auger. The soil samples from each site were mixed in plastic bags to form a composite sample in order to capture the spatial heterogeneity of the seed distribution in the soil. From the 2kg of soil collected from each site, 500g of soil sample was measured and later transported to a greenhouse in Rabuor for germination experiment. In the green house, soil samples were spread thinly on shallow trays (20 × 25 × 6cm; width/length/height) that were distributed randomly on a bench. All the trays were watered daily to maintain the soil moisture content close to field capacity. The trays were observed regularly and newly emerging Parthenium seedlings recorded by date as they germinated after every two weeks and discarded. Each month, the soil samples were stirred to provide optimum conditions for seed germination. The experiment took three months with the assumption that some seeds might take long to germinate.

2.2.2. Survey of farmers' perception on the impact of Parthenium weed

A single visit formal survey was used to gather information on the impact of Parthenium weed on livestock and crop production. With the aid of a semi-structured, open-ended questionnaire, information was collected on the overall impact of Parthenium using purposive sampling procedure [25]. Respondents were selected based on their awareness of

Parthenium weed invasion and its effect on their livestock and crops. Selection of informants was based on:

(i) Informants' length of stay in the study area i.e. residents who had stayed in the area for more than ten years.
(ii) Willingness of the local inhabitant to participate in the study.
(iii) Informants' age; preferably to be above 30 years.

The questionnaire was prepared in English and verbally translated in Kiswahili and Luo languages where necessary. Farmers were shown live samples of the Parthenium weed and asked for information regarding its invasion in the area. A pretest of the prepared questionnaire was practiced before the start of the actual survey to achieve effective communication of the needed information by the selected farmers. Data gained from interviewing the farmers was used to evaluate the impact of Parthenium weed invasion on crops and livestock.

2.3. Data management and analysis

One-way ANOVA was used to analyze the difference in abundance of Parthenium seeds in soil from various land use types and sites. Tukey's HSD test was employed to investigate significant differences among the means of different sites ($p \leq 0.05$). Data from perception survey was summarized using descriptive statistics. Statistical Package for Social Sciences (IBM-SPSS) version 20 was used for all statistical analyses.

3. RESULTS

3.1. The size of Parthenium soil seed bank in the various land use types

The analysis of mean seed abundance showed that there was a statistical significant difference in the number of seedlings that germinated in the soil from the various land use types (F =

3.88, df = 14, p = 0.017). Parthenium seedlings were notably abundant in the roadside (21.00±2.08) and cropland (19.33±3.67) than in soil from the river bank (11.67±1.67) and residential area (9.33±1.20) (Table 1). Similarly, there was a significant variation in the mean density of the seeds that germinated from the three sampling sites ($p \leq 0.05$). For instance, Rabuor recorded the highest seed density along the road while Nyamware had the highest seed density in the cropland. Bwanda had the lowest seed germination in all the land use types.

Table 1: Mean seed abundance (density) in the land use types and sites

Sites	Abundance (density) of Parthenium / m^2				
	Roadside	Pastureland	Cropland	Residential area	River bank
Bwanda	14.67 ± 2.16^{aD}	17.33 ± 2.67^{cC}	16.00 ± 1.18^{aA}	7.33 ± 2.10^{bD}	9.00 ± 3.68^{bC}
Nyamware	22.00 ± 1.42^{bD}	20.33 ± 2.39^{aA}	24.33 ± 3.76^{bC}	9.67 ± 1.21^{aB}	16.33 ± 2.42^{aC}
Rabuor	28.00 ± 0.57^{aC}	13.67 ± 1.34^{bA}	18.33 ± 2.45^{cB}	10.67 ± 2.71^{aD}	10.00 ± 3.31^{cE}

Results were expressed as Mean±Standard Eror of Mean (SEM). Means followed by different lowercase and uppercase superscripts within the same column and row, respectively are statistically different at $p < 0.05$ by one way ANOVA and Tukey's HSD post hoc test

3.2. Perception of local people on the impacts of Parthenium invasion on crop and livestock productivity

All the respondents were aware of the presence of the weed. However, larger proportion (84%) did not know the name of the weed in their local language while a few (16%) knew the local name of the weed (Figure 2). Some call it 'Mafuwa' (flowers), 'Akech' (bitter) or Buya' (troublesome weed). Forty five percent (45.5%) of the respondents first noted this weed in cropland, 33% by the roadside, 10.5% noted it in pastureland, 6.5% in the residential area while 4.5% first noted it in other land use types (fallow land, abandoned buildings, along rivers, in markets

areas and dump sites) (Table 2). All the respondents felt that the weed was rapidly expanding in its range in the area. Most of the respondents (72%) did not see the value of the weed and were of the opinion that Parthenium was not useful in anyway. Only 28% of the respondents felt that the weed was useful (Figure 3). Some of the uses of the weed stated by the residents were improvement of soil moisture retention and fodder for animals. Other uses of Parthenium according to the respondents include sweeping (brooms), mulching, herbal medicine for stomachache and as a "carpet" in market grounds (yards) during muddy days.

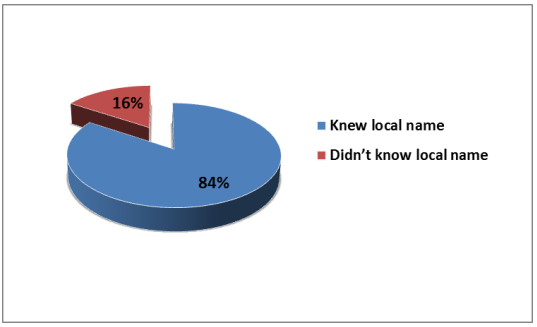

Figure 2: Respondents aware of the local name of Parthenium weed

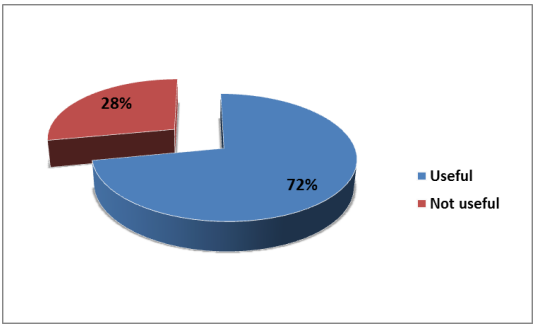

Figure 3: Respondents' views on the usefulness of Parthenium weed

Table 2: Land use type in which the respondents noted the weed for the first time

Land use type	Frequency (N = 210)	Percent (%)
Residential area	15	6.5
Pastureland	23	10.5
Roadside	68	33.0
Cropland	93	45.5
Others	11	4.5

Sorghum, maize, rice, beans and other crops were cultivated by 47.5%, 25%, 12.5%, 8.5% and 6.5% of the respondents, respectively (Figure 4). The study established that Parthenium was most common in sorghum cropland (49.5%) (Table 3). Due to the presence of Parthenium weed, some respondents (48%) experienced increased demand for farm labour especially management of the weed which is done through weeding, slashing, burning and uprooting. Forty percent (40%) noted yield reduction whereas 12% of the respondents experienced health problems (Table 4). Most of the residents (89%) reported that crop production per unit area had declined during the preceding 10 years due to the expansion of Parthenium range in the area. Eleven percent (11%) of the respondents however had not realized the decline in crop production (Figure 5). Residents stated that the presence of Parthenium weed in their village and in their farmland had an impact on the quantity of crops (43.5%), quality (18.5%), income level (35%) and welfare of the society as well as on the movement of the people (3%) (Table 5).

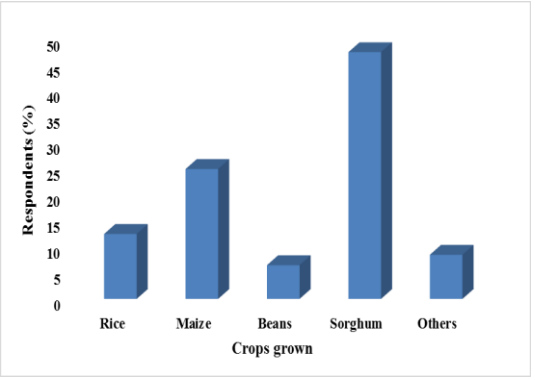

Figure 4: Crops grown by the respondents

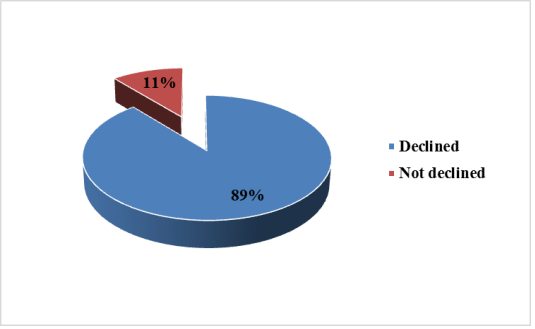

Figure 5: Effect of crop production by expansion of Parthenium since the last 10 years

Table 3: **Cropland in which Parthenium weed is common**

Cropland	Frequency (N = 210)	Percent (%)
Rice	12	5.0
Maize	60	29.0
Beans	13	5.5
Sorghum	101	49.5
Others	24	11.0

Table 4: **Major impacts observed due to presence of Parthenium weed**

Impacts	Frequency (N = 210)	Percent (%)
Intensive labour	98	48.0
Yield reduction	82	40.0
Health problem	25	12.0

Table 5: Impact of the presence of Parthenium weed in the farmland

Impact of Parthenium on crop	Frequency (N = 210)	Percent (%)
Quality of crop	42	18.5
Quantity of crop	90	43.5
Income level and welfare of society	68	35.0
Welfare and movement of people	10	3.0

Apart from Parthenium weed, a number of other weed species were found dominating the grazing land. These included *Gomphrena celosioides, Xanthium strumarium, Datura stramonium, Amaranthus spinosus* and *Alternanthera pungens*. Most respondents (56%) stated that other weeds dominated their grazing land while 44% stated that their grazing land is dominated by Parthenium weed (Figure 6). A larger portion of the respondents (76.5%) stated that the weed is not consumed by livestock whereas 23.5% reported that the weed is consumed by livestock especially goats (Figure 7). Some of the respondents (35.7%) attributed the decline in cattle productivity to the presence of Parthenium weed. Moreover, 24.3% of the respondents reported a decline in their income level, 22.9% complained of a lot of time and cost of labour consumed while weeding out the weed whereas 17.1% realized a decline in the quantity and quality of cattle products especially in the amount and taste of meat and milk, respectively (Table 6).

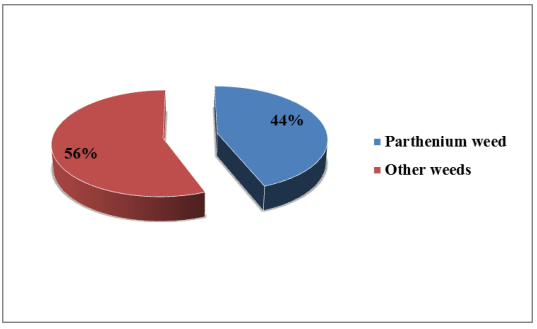

Figure 6: Weed dominating grazing land

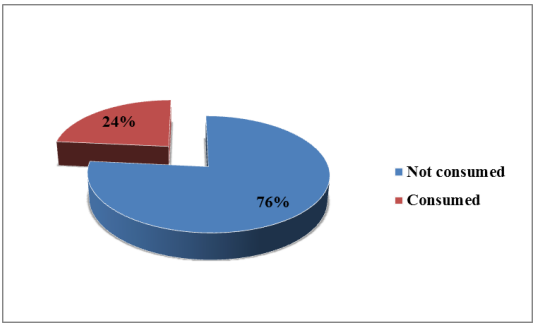

Figure 7: Number of livestock that feed on Parthenium weed

Table 6: Negative impact of Parthenium weed on livestock and human

Impact on livestock	Frequency (N = 210)	Percent (%)
Decline in cattle productivity	75	35.7
Decline in quality of cattle products	36	17.1
Decline in income level of the family	51	24.3
Taking too much time and labour	48	22.9

4. DISCUSSION

The soil seed bank study was conducted for the purpose of gaining information that would assist in determining the land use type that is more vulnerable to Parthenium weed invasion. Data obtained showed that Nyando Sub-County is highly invaded by Parthenium weed. The dominance of Parthenium in Nyando Sub-County may be attributed to frequent drought, flooding during the rainy season and presence of alkaline clay loam soil which is suitable for Parthenium growth [18]. The highest Parthenium seed abundance was recorded in roadside, followed by cropland, pastureland, river banks and finally residential areas. High invasion of Parthenium in different land use types in Nyando Sub-County could be due to its ecological and morphological characteristics which enable it to adapt to a wide climatic and soil conditions, photo insensitivity and drought tolerance [26]. Moreover, the weed produces large number of seeds of up to 25,000 which are small in size and

light in weight [27]; thus the seeds can spread easily over long distances through moving water, wind, animal and human dispersal [28].

Of the five land use types, road side had the highest seed densities and this could be accredited to soil disturbance due to road construction and movement of vehicles. Initial occurrence of Parthenium in a new area usually occurs along roadsides and it's from this foothold that it spreads to other habitats [29]. Blackmore and Charlton [30] reported that roadsides are more commonly invaded and established by Parthenium weed than open spaces and farm lands. Thus, high densities of Parthenium along roadsides may have contributed to the dispersal and spread of this invasive plant to other land use types in Nyando Sub-County. Similarly, cropland recorded high densities of Parthenium seeds. This could be linked to farming activities that involve a greater number of people and vehicles which provide a significant increase to the possible number of invasive plant species and their coverage. Furthermore, farming activities such as irrigation and harvesting may contribute to further spread of the invasive plants. Residential areas recorded the lowest seed bank density and this could be ascribed to frequent management of the weed through anthropogenic activities such as slashing and burning [26, 31].

Densities of Parthenium weed varied significantly among the sites. The possible reason for this could the different ecological conditions among the three sampling sites [32]. For instance, Nyamware had the highest seed bank densities while Bwanda had the least. The highest seed bank densities at Nyamware (in cropland) may be associated with soil disturbance due to flooding, uncontrolled movement of livestock, movement of farm implements and irrigation system. This is because Nyamware lies along the shores of Lake Victoria where many rivers break into and it is also linked with increased farming activities and grazing. In addition,

subsequent reduction in pasture cover due to over grazing has created ideal conditions for Parthenium to establish itself [18].

Rabuor which lies along the Kisumu-Nairobi highway had a high seed bank of Parthenium (along the road). This can be attributed to soil disturbance from road maintenance activities which facilitate establishment of Parthenium weed. According to Fumanal *et al.* [33], disturbing the soil surface not only stimulate the germination of weeds but also increase the number of leaves, stem biomass and the seed production emerging individuals or species. Roads function as prime habitats and corridors for invasive plant species. This is because roads are usually well drained, open habitats that are frequently disturbed by maintenance activities [34]. They are also polluted by heavy metals and fertilizers [35]. Bwanda an area located away from the highway and the lake had low seed bank densities. This could be linked to reduced agricultural activities and less flooding.

Parthenium may therefore attain the status of most dominating weeds in Nyando Sub-County and the surrounding areas in the near future. This is because once it invades; the weed dominates after a few years and continues to persist as pure stand until its managed [35]. In addition, invasion of different land use by an exotic weed Parthenium is a phenomenon which could lead to permanent changes in the structure of indigenous plant community around Nyando Sub-County as observed in other studies [37]. Therefore, there is an urgent need to integrate Parthenium weed management strategy to stop further spread of this alien plant species in the region.

The impacts of Parthenium weed on agriculture have been documented by several authors [12, 38, 39]. Socio-economic survey in Nyando Sub-County established that Parthenium was a common weed since all respondents recognized it. Most respondents reported the use of physical

methods to control the weed through weeding, slashing, and uprooting. These require frequent operations on a single crop field in each season therefore expensive to the farmers [40]. Furthermore, weeding is a time-consuming activity and exposes the farmers to the detrimental health effect of Parthenium weed namely contact dermatitis, hay fever, bronchitis and asthma [41]. Studies show that no single method have been satisfactory in the control of Parthenium weed (mechanical, chemical and biological) thus integrated approaches are warranted to restrict the invasion of this weed by combining more than one option [42].

This research has also established that Parthenium weed invasion negatively affect crop production in Nyando Sub-County. Most respondents revealed that due to Parthenium weed, there is intensive labour since the farms have to be weeded severally. Furthermore, reduction in crop yield especially maize and sorghum was noted. These results are in agreement with the findings of Muli [25] who reported that Parthenium weed invasion reduced the yield of maize, beans and sorghum in Nyando Sub-County of Kisumu County. The same author also reported increased farm labour expenditure in Nyando Sub-County by 6,253 Kenya shillings per year per acre. Crop losses are mainly due to allelopathatic effects [43] and high competitive ability of Parthenium weed [44].

The effect of Parthenium on livestock production is similarly diverse, affecting grazing land, animal health, meat and milk quality. The current study reported a perceived decline in livestock production and quality of milk and meat. This can be explained by the fact that Parthenium releases chemicals that inhibit the germination and growth of pasture grasses and other plants [45] thus reduces feed supply for animals. Besides, Parthenium weed causes reduction in milk and reduces milk quality by tainting it with parthenin toxin; a sesquiterpene lactone abundant in this plant species [32, 46].

This research supports the work of Muli [25] who reported a decline in milk production in Nyando Sub-County of Kisumu County. Furthermore, presence of other weeds like *Xanthium strumarium, Alternanthera pungens* and *Gomphrena celosiodes* which are thorny have reduced the animal feeds since most animals tend to avoid areas dominated by these weeds. Parthenium weed invasion and dominance in grazing land was also reported to cause heavy loses to cattle industry in the Queensland [46].

Although majority of the respondents reported negative impacts from Parthenium, some found it useful in sweeping, mulching and as a mud "carpet" in market grounds (yards) during muddy days. These three uses are detrimental as they contribute to the propagation of Parthenium seeds thus increasing dispersal from one place to another. This demonstrates the need for awareness campaigns in Nyando Sub-County to sensitize the residents on the adverse effects of Parthenium weed. Research by Strathie *et al.* [47] showed that developing countries lack knowledge of the impeding threat of Parthenium weed despite the weed's rapid spread in Africa and globally. Therefore, there is need to initiate awareness campaigns about Parthenium weed in Nyando Sub-County and in Kenya as a whole.

5. CONCLUSIONS

Knowledge of distribution pattern of seed bank across various land use types is essential as it helps one to predict the land use that is vulnerable to invasion. This is because soil seed banks are sources of new individuals (species) for many plant populations and contribute to future genetic variability. The density of Parthenium weed was dependent on the land use type: roadside had the highest seed bank density while residential areas had the least density. This may imply that

roadside is highly vulnerable to Parthenium invasion and it's from here that the weed spreads to other land use types as a result of proximity to dispersal agents such as vehicles and movement of people. This study also established that among the sampling sites, Nyamware had the highest seed bank density and this could be attributed to flooding. Parthenium weed was found to reduce the grazing area and leads to reduction in the quality and quantity of milk and meat products. Furthermore, the weed has reduced the crop yield and increased labour expenses. Thus, the outcome of this study includes the realization of Parthenium weed as a problem of national significance for Kenya; which concurs with the reports of it as a major weed globally.

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