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Environmental and Socio-Economic Impacts of Kariba Weed Infestation of Lakes Kyoga and Kwania, Uganda

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Abstract. The objective of this study was to quantify the coverage of Kariba weed (*Salvinia molesta*) on lakes Kyoga and Kwania and document the environmental and socio-economic impacts associated with its infestation. Data on weed infestation status was collected in 2017 and compared with pre-infestation period of 2013. Weed infestations were approximately 15,643 and 13,688 ha on lakes Kyoga and Kwania respectively. The infestation impaired fishing activities, water quality, water abstraction and water transport. They also led to 20.4, 60.1, 7.7, 17.6 and 5.7 kg reduction in catches per day for Tilapia, Mukene, Catfish, Nile perch and Mudfish respectively. The infestations were also associated with a general increase in the prices of the fish. Individual fishermen registered losses in fish revenue. Household spent approximately UGX 108,523 annually as treatment costs for diseases associated with weed infestation. While 32% of the respondents tried to manually control the waterweed at approximately UGX 83,988/year, the mobile nature of the weed rendered these efforts unsuccessful. A strategy to sustainably control the waterweed using specific bio-control agents (*Cyrtobagous salviniae*) is recommended.

Keywords: Kariba weed infestation, Environmental, Socio-Economic Impacts, Kyoga, Kwania.

Introduction

Kariba weed (*Salvinia* molesta D.S. Mitchell), one of the most invasive aquatic weeds in the world (Luque *et al*., 2014), is a free-floating, mat-forming aquatic fern that is native to the Amazon in Latin America (Forno and Harley, 1979; Forno, 1983; Oliver, 1993; Encyclopedia of Biological Invasions, 2011). The plant is primarily found in tropical and sub-tropical regions of the world (McFarland *et al*., 2004; Thomas, 1979) and grows best in still or slow moving waters such as ditches, ponds, lakes, slow flowing rivers and canals. Under ideal conditions of nutrients, optimal temperature and absence of natural enemies, the growth rate of Kariba weed is so high that Creagh (1991) noted that *"A single small plant may grow to form a thick mat covering more than 100 km² in just three months, chocking lakes and waterways, reducing populations of aquatic plants and animals, and in some countries threatening the livelihoods of thousands of people"*. Growth is greatly stimulated by an increase in nutrient levels in water (Cary and Weerts, 1983b). As a consequence, the weed is particularly fast growing in areas where the hydrological regime has been altered by humans, enhancing an increase in nutrient levels (Howard and Harley 1997). Away from its native range, Kariba weed is found in many regions around the world including Asia (Pablico *et al.*, 1989; Room and Fernando, 1992), North America (Jacono *et al.*, 2001), and in Oceania[1]. In Africa, Kariba weed is reported to have been introduced in many countries (Oliver, 1993; Lyons and Miller, 1999).

Although first recorded in Uganda on Lake Kyoga in June 2013 (Unpublished NaFIRRI Report, 2014), it is not exactly known when Kariba weed invaded this lake and Lake Kwania. With its ability to double its biomass and area coverage in 4 to 10 days (Mitchell and Tur, 1975; Harley and Mitchell, 1981), Kariba weed spread over most parts of lakes Kyoga and Kwania within less than two years from the time it was first sighted. Local communities around the two lakes alluded to the devastating effects of infestation by this waterweed such as its interference with fishing activities as it trapped and entangled fishing gears especially gill nets, and its interference with water transport and water abstraction. Kariba weed infestations also impart negative effects on the water environment as it cuts off light that is important for survival of submerged plants and algae; its ability to smother rooted submerged aquatic plants; and its general negative effects on aquatic biodiversity (Creagh, 1991; Oliver, 1993). The formation of mats also lowers the concentration of dissolved oxygen and pH, whilst simultaneously increasing carbon dioxide and hydrogen sulphide in the water beneath them (Mitchell, 1979); this negatively affects survival of most fish species, benthic organisms and other aquatic biota.

This study aimed at documenting the extent of coverage of Kariba weed on lakes Kyoga and Kwania, mapping the weed's infestation hot spots, and establishing the weed's environmental and socio-economic impacts.

Materials and Methods

Field data collection was undertaken on lakes Kyoga and Kwania (Figure 1) in 2017. Lake Kyoga is a shallow lake in central Uganda with a maximum length of approximately 200 km, maximum and mean depths of 5.7 m and 4.0 m, respectively. The lake has a surface area of about 1,720 km^2, and is at an elevation of 1,033 m. Areas that are less than 3 m deep are characterized by extensive mats of water lilies and other aquatic macrophytes, while much of the swampy shoreline is covered with papyrus and water hyacinth. The papyrus also forms floating islands (suds) that drift under the influence of winds and water currents. Extensive wetlands fed by a complex system of streams and rivers surround Lake Kyoga. On the other hand, Lake Kwania with a surface area of approximately 540 km^2, is part of Kyoga Basin lakes and is directly connected to the main Lake Kyoga. On each lake, data collection on cover abundance and distribution of Kariba weed was undertaken on a motorized canoe in the inshore zones, open water and bays where Kariba weed thrived. A line parallel to the shoreline but at the outer Kariba weed fringe was established between two points that were geo-referenced using a hand held GPS (Garmin Extrex–Taiwan) to get the coordinates. The distance between the two points at the outer fringe was considered the length of the weed mat, while the width was similarly established from the outer Kariba weed fringe to the original shoreline. The area of the Kariba weed mats in the open water was similarly determined by establishing the length and width of the mats using the GPS unit. This exercise was repeated along every stretch that had Kariba weed.

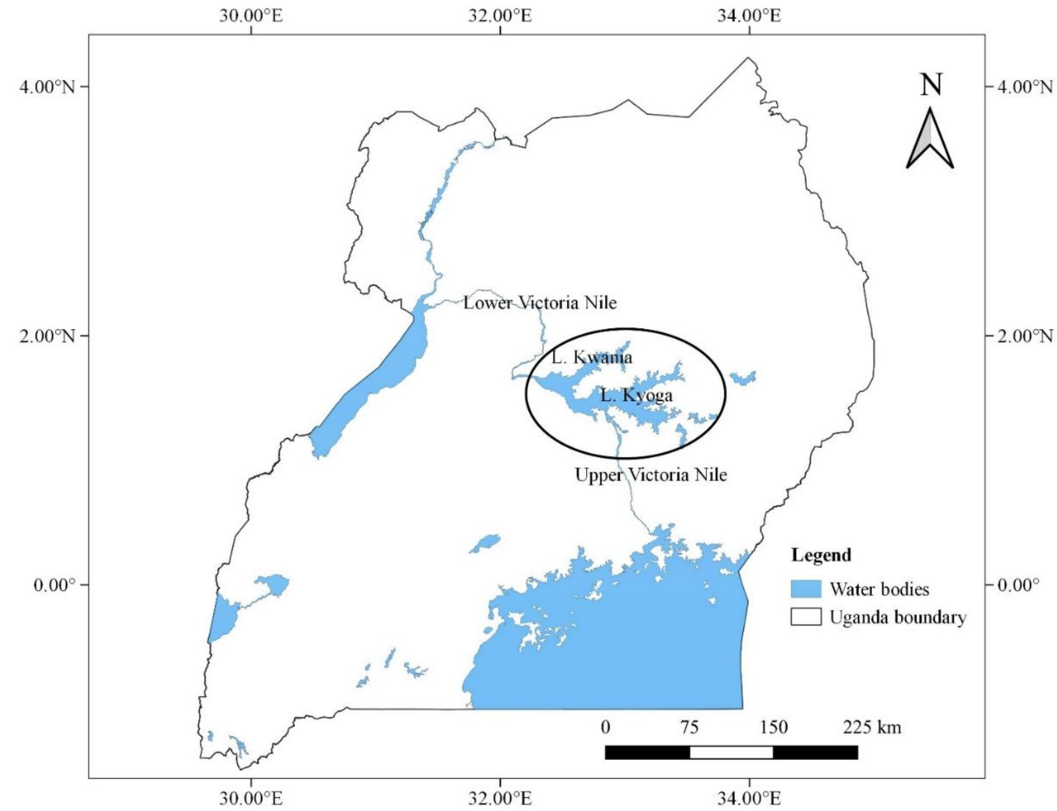

Figure 1. Map of Uganda showing lakes Kyoga and Kwania

The area coverage (m^2) of the Kariba weed mat was therefore a product of the length and width of the sampled area that had the weed mat, and the weed cover abundance (hectares) was calculated from: $A(m^2) = L(m) \times W(m)$, where A = area; L = length; and W = width. Cover abundance (ha) = $A (m^2)/10{,}000$. Cover abundance data was stored in an excel spreadsheet and imported into a GIS software for production of cover abundance geo-referenced maps of the weed on the two lakes. This methodology was based on 'Standard Operating Procedures (SOPs)' developed by NaFIRRI and approved by the Lake Victoria Fisheries Organization (LVFO) (LV 658.562(676.1) LVF, 2004).

Environmental impacts associated with weed infestation were determined based on comparisons of surface water dissolved oxygen concentration and temperature in weed-infested and weed-free zones of the lake. These environmental parameters were determined in triplicate using a Multiprobe Portable Meter (Model HQ40d Hatch). On the other hand, socio-economic impacts of this waterweed infestation on Lake Kyoga were established using a pre-tested questionnaire administered to fishermen at 24 major landing sites (Table 1).

Table 1. Areas identified for the study on Lake Kyoga

Region	District	Landing Site
Southern	Kaliro	Nawampiti
	Nakasongola	Kitaraganya, Zengebbe
	Buyende	Iyingo
	Kayunga	Kambatane
Eastern	Pallisa	Opeta
	Kaberamaido	Bukia, Okile and Muremu
	Soroti	Ongaro, Lale and Abaango
	Serere	Kagwara, Mugarama and Pingire
Northern	Amolatar	Bangaladesh, Naluboyo and Muntu
	Dokolo	Wigudu, Aoa and Agwata
	Apac	Wansolo, Apoi and Wigweng

The survey relied on sampling frames consisting of registered fishermen from the management offices of the Beach Management Units (BMUs). The survey randomly interviewed 300 active fishermen from the 24 major landing sites spread around Lake Kyoga. The fishermen interviewed had been engaged in fishing during both the 'with' (2013) and 'without' (2017) Kariba weed infestation periods. Socio-economics data collected covered the following aspects: periodic fish catches; fish proportions consumed at home; given away for free; lost and sold; local, regional and international prices of fish; socio-economic characteristics of households; household and fishing asset ownership; livestock ownership; access to credit; land ownership; fishing experience; and labor use.

Results

On Lake Kyoga, Kariba weed cover abundance data showed an increasing trend in the infestation magnitude in the east-west direction (Figure 2). On Lake Kwania, the magnitude of Kariba weed infestation indicated an increasing trend in the north-east to south-west direction (Figure 3), with the Kwania-Kyoga confluence being heavily infested. The infestation was higher in the sheltered bays although wave and wind actions would blow these weeds into the open water.

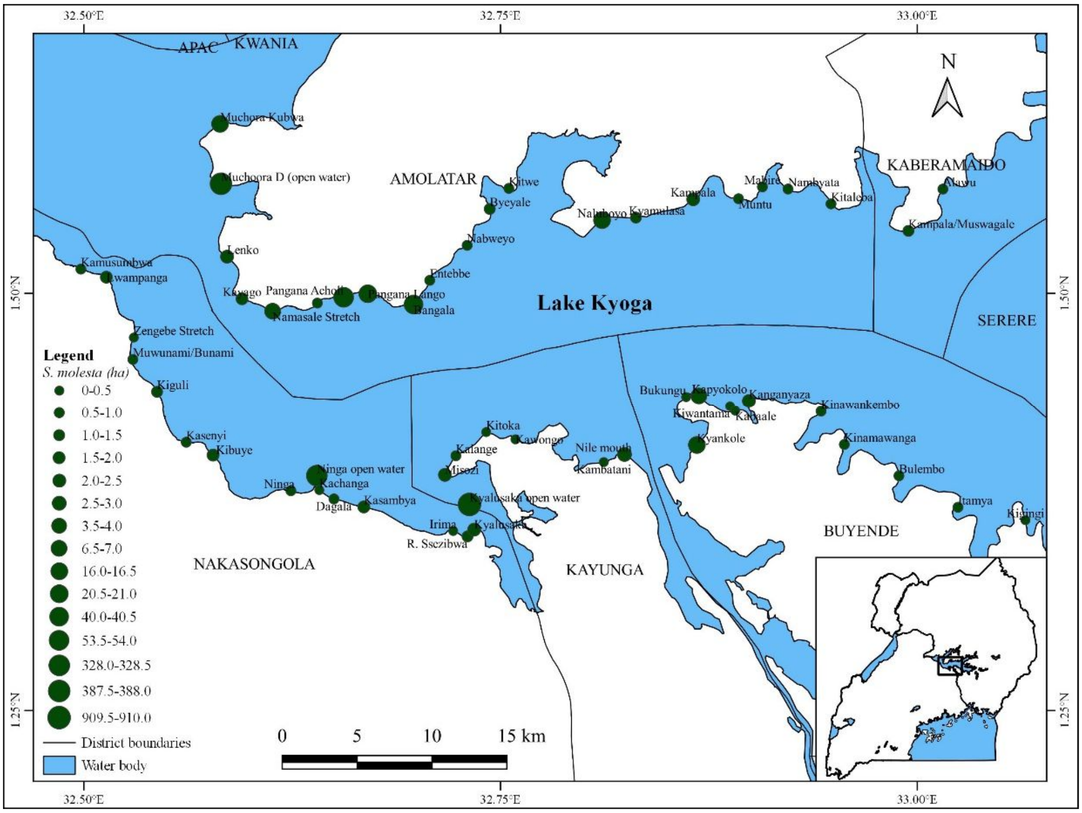

Figure 2. Map of Lake Kyoga showing distribution of Kariba weed hotspots in 2017

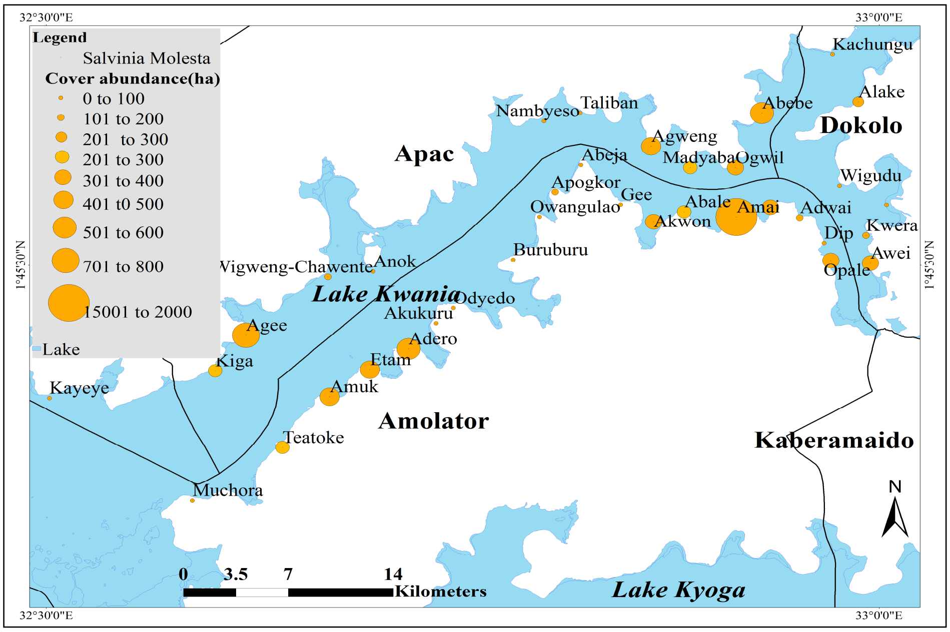

Figure 3. Map of Lake Kwania showing Kariba weed hotspots in 2017

On Lake Kwania, total area covered by Kariba weed was 13,688 ha, and the magnitude of infestation varied greatly from site to site, with major infestations in the bays of Abeja (227 ha), Apogor (149 ha), Owangulawu (20 ha), Buruburu (708 ha), Etam (28 ha), Amuk (71 ha), Teeatoke (32 ha) Ayomi (13 ha), Anok (9 ha), Atuma (192 ha), Abese (158 ha), Ogwil (8 ha), Madyaba (248 ha) and Agweng (166 ha). From Figure 3, it was apparent that the southern stretch of Lake Kwania had the highest weed infestations compared to other zones. Cover abundance of this waterweed in each district stretch of Lake Kwania was such that Amolatar had the highest infestation followed by Dokolo, while Apac had the least coverage (Figure 4).

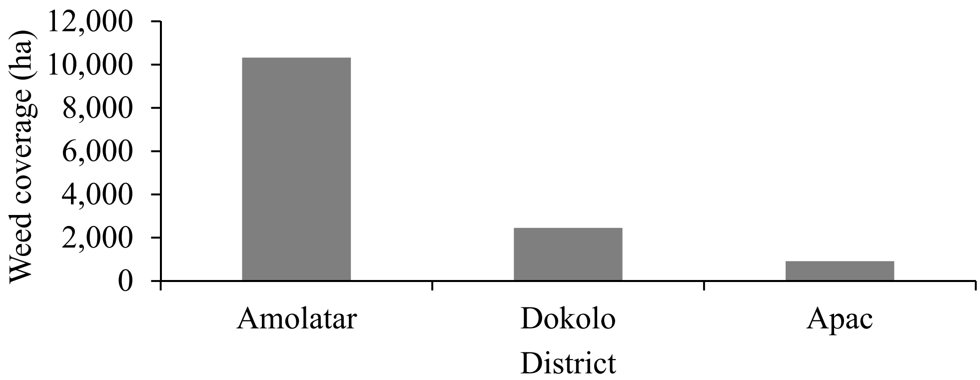

Figure 4. Magnitude of Kariba weed coverage in each district stretch of Lake Kwania in 2017

Fishermen alluded to Kariba weed infestation disrupting fishing activities and impairing water transport. Weed infestations also resulted in the gradual and consistent horizontal reduction in surface water dissolved oxygen from the open water into the weed mat along the shores (Figure 5), while surface water temperature ranged between 22.1 and 33.4 °C.

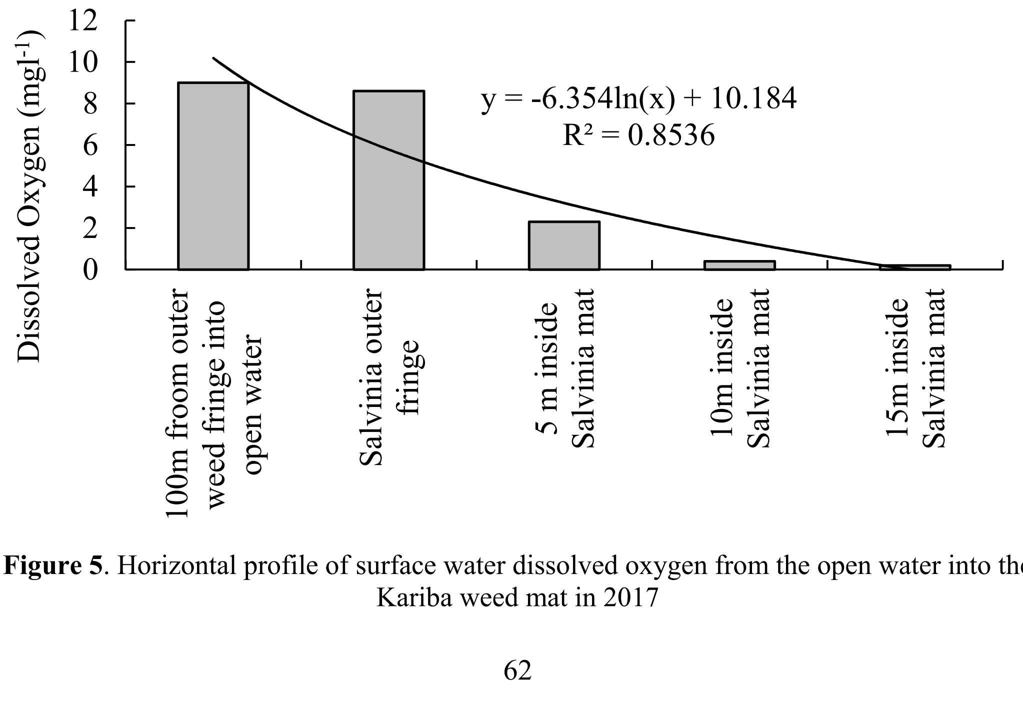

Figure 5. Horizontal profile of surface water dissolved oxygen from the open water into the Kariba weed mat in 2017

Data comparison before and after weed invasion showed some remarkable impacts of Kariba weed infestation on the livelihoods of fishing communities as indicated in Tables 2 to 7.

Table 2. Household characteristics before and after invasion by Kariba weed on Lake Kyoga

Variables	A. Mean before weed invasion (2013)	B. Mean after weed invasion 2017	Difference (A-B)
Number of house rooms	1.70	1.56	0.14
Male headed households	0.98	0.98	0.00
Age of the household head	39.57	36.42	3.15
Number of household members	6.93	6.03	0.90
Number of males in a household	3.37	2.98	0.39
Number of females	3.57	3.20	0.36
Below 15 years	3.13	2.75	0.38
Between 15 and 64	3.71	3.41	0.30
Above 64 years	0.45	0.46	-0.02
Number of household members involved in fishing	1.44	1.33	0.11
Fishermen that accessed credit	0.24	0.26	-0.03
Fishermen that received extension services	0.48	0.54	-0.06
Number of times they received extension in a year	3.34	3.09	0.25
Fishermen that belong to a group	0.36	0.37	-0.01

n = 301

Majority of the fishing households were male headed and fishermen were largely below 40 years of age in both situations of "with" and "without" the weed. The mean age of fishermen together with the average household size of 6 corresponded with the prevailing national statistics which lends credence to the study findings. Institutional support services like access to credit, group membership, and access to education and extension were found to be insufficient and largely lacking. This partly explained the general relative poverty situations prevailing in the study communities. Table 3 shows data on the extent of Kariba weed infestation on lakes Kyoga and Kwania. Fishing grounds in inshore zones of both lakes were 99% infested with Kariba weed.

Table 3. Kariba weed infestation on lakes Kyoga and Kwania

		Pooled data		Kyoga		Kwania		t-tests
		Mean	*SD*	*Mean (A)*	*SD*	*Mean (B)*	*SD*	*(A-B)*
Respondent's education level	Proportion with no education	0.10	0.30	0.10	0.30	0.09	0.29	0.01
	Proportion with Primary Education	0.55	0.50	0.56	0.50	0.49	0.50	0.07
	Proportion with Secondary Education	0.32	0.47	0.31	0.46	0.34	0.48	-0.03
	Proportion with Tertiary Education	0.04	0.19	0.03	0.16	0.07	0.26	-0.05*
Information regarding Kariba weed infestation	If area is infected with the weed	0.99	0.10	0.99	0.09	0.99	0.12	0.01
	Years the area has been weed infested	5.54	2.96	5.51	3.08	5.65	2.54	-0.14
	Percentage of fishing areas covered with Kariba weed	70.43	21.44	72.48	20.25	63.43	23.96	9.06***
Trends in Kariba weed infestation since the first sighting	Had reduced	0.21	0.41	0.20	0.40	0.24	0.43	-0.04
	Had Increased	0.76	0.43	0.76	0.43	0.74	0.44	0.03
	Remained constant	0.04	0.19	0.04	0.19	0.03	0.17	0.01
Variation of Kariba weed infestation over time (i.e. drifts in and out or it was constant)	Weed rotates	0.97	0.18	0.96	0.19	0.99	0.12	-0.02
	Weed was fixed	0.03	0.18	0.04	0.19	0.01	0.12	0.02
	Number of years Kariba weed was at its peak	2.58	1.37	2.57	1.47	2.62	0.98	-0.05
Attempts by fishermen to fight Kariba weed	Proportion that have tried to fight the weed	0.32	0.47	0.36	0.48	0.19	0.39	0.17***
	Years since they started fighting the weed	2.79	1.86	2.79	1.84	2.80	2.04	-0.01
	Number of times in a year they had tried remove weed	18.83	49.51	19.00	51.64	17.50	30.49	1.50
	Amount spent to remove weed in a year	83,988	178,448	76,452	182,079	165,000	120,692	-88548***

While these fishing grounds of Lake Kyoga were more infested (72%) than Kwania (63%), both lakes were reported to have been infested for more than 5 years with peak infestation of approximately 3 years. A majority of respondents (76%) and (74%) reported that the aquatic weed infestation was on an increasing trend on both lakes, with a rotating and shifting colonization pattern. On average, 32% of the respondents had tried to remove the weed from the lake for a period of about 2 years, and each respondent had tried 19 times to remove the weed with an average annual expenditure of UGX 83,988 only.

Kariba weed infestation caused severe fish catch losses across the different fish types (Table 4). For instance, weed infestation was associated with a 20.4 kg, 60.1kg, 7.7kg, 17.6 kg and 5.7kg loss per day for Tilapia, Mukene, Cat Fish, Nile Perch and Mud Fish respectively.

Table 4. Fish catch with and without Kariba weed infestation on Lake Kyoga

Fish type	Without infestation (2013)		With infestation (2017)		Difference
	Kgs Caught/Day (A)	*Fishermen*	*Kgs Caught/Day (B)*	*Fishermen*	*(A-B)*
Tilapia	28.8	217	8.4	198	20.4
Mukene	84.6	40	24.5	32	60.1
Cat Fish	10.6	56	3.0	47	7.7
Nile Perch	25.5	153	7.9	153	17.6
Mud Fish	10.4	64	4.7	63	5.7

From Table 5, it was noted that Kariba weed infestation was associated with a general increase in fish prices probably as a result of reduced fish catches across all fish types except Mukene and mud fish. It was also noted that an individual fisherman registered UGX 56,158, UGX 1,684,753.65 and UGX 20,497,836.10 as lost fish revenue per day, per month and per year, respectively (Table 5).

Table 5. Fish price and revenue with and without Kariba weed Infestation on Lake Kyoga

Fish type	Before weed invasion in 2013		After weed invasion in 2017		Difference
	Price UGX Per Kg (A)	*Number of fishermen*	*Price UGX Per Kg (B)*	*Number of fishermen*	*(A-B)*
Tilapia	3,784	204	4,911	184	-1,127
Mukene	1,089	28	526	23	563
Cat Fish	3,325	52	3,955	44	-630
Nile Perch	5,129	150	5,737	148	-608
Mud Fish	3,185	62	3,105	60	80
Revenue losses due to Kariba weed invasion					
Fish Type	Fish loss (Kgs/Day)	Fish Price per Kg	Total loss/ day	Total loss/month	Total loss/ Year
Tilapia	20.43	4,911	100,345	3,010,354.20	36,625,976.14
Mukene	60.05	526	31,593	947,794.97	11,531,505.50
Cat Fish	7.65	3,955	30,288	908,648.52	11,055,223.64
Nile Perch	17.598043	5,737	100,963	3,028,884.71	36,851,430.60
Mud Fish	5.668651	3,105	17,603	528,085.86	6,425,044.61
Average Revenue loss across fish types			56,158	1,684,753.65	20,497,836.10

Table 6. Other losses due to Kariba weed infestation

Variable	Before weed invasion (2013)		After weed invasion (2017)		Difference
	UGX (A)	*No. of fishermen*	*UGX(B)*	*No. of fishermen*	*(A-B)*
Days spent fishing in a week	2.50	301	5.83	301	-3.33
Hours spent fishing per day	6.53	301	6.66	301	-0.13
Fishing expenses per day	625,873	301	851,122	301	-225,249
Total expenditure on labor	22,733	301	39,562	301	-16,829
Value of Fishing Gear	353,288	301	341,324	301	11,964
Fishing Gear Lifespan	44	301	18	301	25

Fishermen also spent more fishing days in a week and more fishing hours in a day during Kariba weed infestation than before the weed invaded the lakes (Table 6). Other losses associated with weed infestation included increase in fishing expenses per day and increased labor costs, in addition to a reduction in the value of fishing gears and their lifespan due to weed infestation (Table 6).

Approximately 77% of the respondents confirmed they had had health problems which affected more than half the household members (3.43%) when the weed was present (Table 7).

Table 7. Health impacts of Kariba weed infestation in 2017

Diseases that affected people	Mean
Malaria	0.24
Bilharzia	0.17
Typhoid	0.10
Diarrhea	0.19
Dysentery	0.01
Skin Rush	0.28
Stomach ache	0.11
Physical injury	0.03
Cough	0.09
Other diseases	0.18
Number of household members affected per year	3.43
Amount (UGX) spent on treatment per year in a household	108,523.30

The diseases people suffered from included malaria, bilharzia, typhoid, diarrhea, dysentery, skin rush, stomach ache, physical injury, cough and other minor health conditions (Table 7). Additionally, each household spent on average UGX 108,523 annually as treatment costs for health ailments that were associated with Kariba weed infestation.

Discussion

On Lake Kyoga, water flows are in the east-west direction, a factor that likely influenced the increasing magnitude of Kariba weed infestation in the same direction. On Lake Kwania, cover abundance of this waterweed increased towards its south-western end that forms a confluence with Lake Kyoga. Thus, the far north-eastern reaches of Lake Kwania were relatively free of

Kariba weed, while the open water zones were periodically covered with the weed due to the influence of diurnal winds that blew and dislodged the inshore weed mats into the open water. On both lakes, the width of the weed mats at the shoreline stretches varied between less than 0.5 m and more than 1 km, and some of the sheltered bays were periodically covered by varying sizes of the weed mats. Thus, some infestations were composed of small scattered weed clusters, while others had extensive mats.

Growth of Kariba weed is promoted by relatively high water temperatures, a rich supply of macro-nutrients (Mitchell and Tur, 1975), and water currents that aid its dispersal. Room and Kerr (1983) reported optimal weed growth for temperatures between 10 and 40 °C, while Forno and Bourne (1986) reported optimal weed growth in the water temperature range of 16 to 30°C. These water temperature ranges are characteristic of most water bodies in the tropics in general and in Uganda in particular (Wanda, unpublished data). For Lakes Kyoga and Kwania, mean surface water temperature ranged between 22.1 and 33.4 °C hence likely contributed to enhanced growth of Kariba weed. Additionally, the high proliferation rate of Kariba weed on the two lakes was naturally aided by the plant's buoyant nature that allowed it to easily float hence facilitated easy dispersal by winds, waves and water currents.

On lakes Kyoga and Kwania, Kariba weed had become established as a nuisance waterweed and occupied extensive areas of open water and sheltered bays, caused navigation problems, and interfered with fishing activities. The weed also damaged outboard engines of motor boats, and impaired operation of wagon ferries thus increased maintenance costs of such machines. These impacts point to the urgent need to effectively control further spread of this waterweed to avoid similar scenarios.

On the two lakes, Kariba weed formed extensive mats on the water surface that resulted into reduced dissolved oxygen in the water beneath the mats. Under extensive cover, this waterweed therefore impairs opportunities for various water uses including fishing, water transport and domestic water abstraction by local communities. Though innocuous in its native range in Latin America, elsewhere this waterweed is a menace that has had devastating ecological and socio-economic impacts (McFarland *et al.*, 2004; Thomas, 1979), and in 2013 it was elected as one of the 100 of the World's Worst Invasive Alien Species' to replace the Rinderpest virus which was declared eradicated in the wild (Encyclopedia of Biological Invasions, 2011).

The Kyoga basin largely serves the region inhabited by people who were just recovering from a more than 20 year civil war that left their livelihoods severely affected. Just when these communities were beginning to recover through fishing as one of the major economic activities, the invasive Kariba weed covered much of the fishing grounds, thus reversing the little gains these local fishing communities had made. The weed invasion led to several fishermen abandon their boats and fishing gears to rot away in the infestation. For example, it was established that extensive Kariba weed infestations caused severe fish catch losses across the different fish types. While this led to increased fish prices, the dwindled fish catches resulted into increased costs of fishing in terms of direct fishing expenses, and time spent fishing resulted into reduced profitability. Based on this, fishermen had to diversify their investments and sought alternative income sources such as crop and animal agribusinesses as well as running retail kiosks. This was necessary to mitigate financial shocks that arose from the dwindled fish stocks due to Kariba weed infestation. Fishermen also reported fishing for fewer days when the weed was present compared to when it was absent; this was attributed mainly to blockage of canoe routes making it difficult to navigate through the weed mats. This led to reduced fish catches and hence income from fish sales. Fishermen took more hours fishing in the presence of the weed as a lot of time was lost trying to navigate through the weed mats to reach fishing grounds. Additionally, fish catches had greatly reduced hence fishermen would take more hours fishing to compensate for the dwindled catches. Further, fishing gears especially gill nets would get entangled in the weed mass, leading to more time spent cleaning the nets. Kariba weed infestation was also associated with increased fishing durations on the lakes by an average of extra 8 minutes per day and 3.3 days per week. Kariba weed presence also increased total fishing expenses per day by an average of UGX 225,249/- per fisherman. Relatedly, fishing labor expenses increased by UGX 16,829/- per fisherman per day. Both Mud fish and Mukene were easily imported from neighboring communities which probably explained their relative price stability across seasons.

Furthermore, the frequent entanglement of the main fishing gear package (i.e. gill nets, canoes and rowing sticks) in the weed mats resultantly reduced their lifespan by 25 months and its value by UGX 11,964/-. Fishermen also lost a number of fishing gears when the weed was present e.g. the rowing sticks usually broke when trying to navigate through the weed mats. This reduced on the lifespan of rowing sticks, nets and boats and further made it costly for the fishermen to keep purchasing new fishing gears to replace the broken ones. Gill nets would get completely entangled in the weed to the extent that retrieving them became impossible leading to abandonment.

The reduction in the lifespan and value of the main fishing gear kit (nets, boat and rowing sticks) as a result of Kariba weed infestation, coupled with the weed shifting infestation nature, called for phased fishing plans. It was advised that fishermen plan to maximize fishing during the periods when the weed was away and take breaks when the weed invaded. This would serve the dual purpose of saving their gear package from weed destruction and also allow the fish chance to reproduce and increase stocks for more profitable and efficient fishing during the fishing no-invasion season. Thus, fishermen would concentrate on their alternative income generating activities during the invasion days.

Since respondents from several households confirmed they had had health problems associated with Kariba weed infestation, the costs incurred treating these ailments negatively impacted on their ability to meet other household requirements. Due to sickness from some diseases notably malaria, bilharzia, typhoid, diarrhea, dysentery, skin rush, stomach ache, physical injury, cough and other minor health conditions, productivity of affected households reduced remarkably. Based on this, the ministry of health and other concerned non-state actors were advised to provide drugs and health support services specific to the identified diseases in the affected communities.

Conclusions and Recommendations

i. Kariba weed is a relatively new waterweed in Uganda but has spread widely and is well established on lakes Kyoga and Kwania.
ii. Its proliferation is associated with several negative environmental and socio-economic impacts.
iii. A detailed study to establish the extent of the weed's infestation status on all Uganda's aquatic systems and document in detail the environmental and socio-economic impacts is critical in guiding management interventions.
iv. An environmentally friendly and sustainable way of controlling Kariba weed is by use the globally known and proven Salvinia weevil (*Cyrtobagous salviniae*) with remarkable success (Colette *et al.*, 2001).

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