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Desert Locust Invasion in Uganda: Effects on Household Food Consumption and Effective Control Interventions

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Abstract: Desert locust invasions are still a danger to the well-being of natural and man-made ecosystems in the tropics. This study examined desert locust invasion duration, survival probability, and control as well as their effects on household food item consumption in the drylands of Uganda. Primary socioeconomic data were collected using various methods (household survey, focus group discussion, and key informant interviews) in May/June 2020 to document the perceptions of households regarding locusts. Our findings reveal that the most significant drivers of desert locust invasions were rainfall, surface temperature, strong winds, soil moisture, soil type, and vegetation type ($p \leq 0.05$). The locusts lasted between 3 and 4 weeks. The survival probability of locusts beyond 1 week was 90%. There were significant differences in the day's food items consumed before and after the locust invasion, except for ground nuts and cashew nuts ($p \leq 0.05$). The number of days per month the food items were consumed decreased after the locust invasion. The most effective locust control measure undertaken was the use of ground and aerial pesticide spraying. The major sources of desert locust control information were radio and television. This information is a prerequisite in desert locust invasion preparedness, response, and recovery but can also strengthen sustainable green economy efforts, especially in fragile semi-arid ecosystems.

Keywords: desert locusts; drivers; duration; household food consumption; locust control

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Citation: Barasa, B.; Watsusi, C.W.; Gudoyi, P.M.; Lutaaya, N.; Gumisiriza, L.T.; Magaya, J.P. Desert Locust Invasion in Uganda: Effects on Household Food Consumption and Effective Control Interventions. *Sustainability* **2023**, *15*, 14496. https://doi.org/10.3390/su151914496

Academic Editor: Hariklia D. Skilodimou

Received: 21 August 2023
Revised: 31 August 2023
Accepted: 6 September 2023
Published: 5 October 2023

1. Introduction

Desert locust (*Schistocerca gregaria*) invasions are still a danger to the well-being of natural and man-made ecosystems in the tropics. The invasions are unpredictable; the dryland environment of sandy soils, short trees, and warm temperatures triggers their unwelcome landing. As such, fluctuations in soil moisture are often associated with a locust hatching period [1], and semi-arid areas that receive less than 200 millimetres of annual rainfall provide a suitable habitat [2,3]; in addition, swarms roost for the night in trees or bushes [4]. The locusts have the ability to quickly reproduce and unidirectionally migrate to new and old areas, including the greenness of above-ground biomass [5]. A group of desert locusts can fly 150 km a day with favourable winds [6].

At the global level, locusts are also the biggest hindrance to agricultural production. The periodic invasions have affected farmers' ability to meet home and market demands, thus distablising food supplies and threatening the resilience of food systems. As a consequence, the invasions are partly responsible for re-occurring scenarios of food crises, economic losses, migration, ecological disasters, and farmers permanently ceasing farming activities. Locusts have also caused tremendous imbalances in diet, mainly concerning the consumption of food items by households. For instance, an upsurge in locust swarms of about 80,000 adults can consume the daily food equivalent of 35,000 people [2]. These concerns have left the affected farmers pondering the next steps. The trees and grasslands are not spared from locust invasion in the tropics; the landings lead to the consumption of leaves, stems, and shoots, leaving the trees bare. After the intensive consumption of standing biomass, the results include damaged trees, depleted tree canopies, and ecosystems that are compromised with regard to the sustenance of biodiversity across the landscapes [7].

In East Africa, desert locust invasions were also reported in 2020 to have damaged the livelihoods, food security, and environment of the tropical region [8]. Uganda experienced the largest locust infestation in the last five decades in the same year. This was a result of locust upsurges in the Arabian Peninsula in mid-2018 following the occurrence of two major cyclones that favoured their breeding [9]. In early 2019, the swarms moved north towards Saudi Arabia and Iran and south towards Yemen. By mid-2019, the swarms had crossed into northern Ethiopia and northern Somalia, and by the end of 2019, the swarms had been reported in Kenya. However, when Cyclone Pawan hit the Horn of Africa in the affected area, it again favoured conditions for the locusts, and by February 2020, the locusts had invaded South Sudan, Tanzania, Eritrea, Djibouti, and Uganda. The desert locust swarms entered the country from the north-western part of Kenya through the Kosike sub-county, Amudat District, in 2020. They then spread out to Loroo, Amudat, and Kalita sub-counties to the north, west, and south and eventually ended up in the neighbouring districts of Moroto, Napak, Abim, and Nakapiripiriti looking for green plants, grass, and crops. Their movement was facilitated by strong winds, while the breeding grounds were in sand, especially under the trees and in grasslands. The young locusts (hoppers), after hatching in the sand and grass, would begin to eat the vegetation on the ground, and on maturing, they would fly and anchor on tall plant leaves.

The solutions to desert locust control in Uganda are not immediate. The efforts require extensive mobilization of resources and wide stakeholder consultation nationally and regionally on the best practices to control the pests. When the locusts invaded Uganda, many limitations were evident. Among these were the lack of a response command centre, the unavailability of standard operating procedures, the inadequacy of local-level disaster management structures, the absence of contingency funds and early warning systems, and inadequate awareness levels within the affected communities [10,11]. These limitations led to a delayed response that resulted in devastating impacts from the locusts on the environment and food production systems managed by households, already constrained by the semi-arid conditions.

Besides the presented limitations, this study, when compared with the current literature on locusts, reveals that many studies related to locust investigations have focused on topics such as the economic costs of locusts on agricultural production [12]; the impacts of locusts on crops and vegetation [13]; the impact of desert locust outbreaks on food security and the food supply chain [14]; effective mitigation measures in desert locust management [15]; the influence of climate on the distribution of locusts [16]; the use of remote sensing and geographical information systems to assess the factors that contribute to desert locust upsurges [17]; the prediction of breeding grounds for locusts [8]; locusts as an alternative protein source [18]; how vegetation influences gregarisation [19]. Although these studies appear to further the discussion of the effects of locusts on vegetation and agricultural production, as well as on control measures, they are inadequate to understand the duration of locust invasions, locust survival rates, and the number of days households consume food before and after such invasions in the tropics. The studies also fall short of demonstrating how households adapt to food consumption changes after the invasions as well as the most efficient modes of transmitting locust control information amongst the smallholder farmers in the dryland areas. This study addresses the aforementioned limitations by examining the desert locust invasion duration, survival probability, and effects on household food item consumption among agro-pastoralists and pastoralists. This information is a prerequisite for desert locust preparedness, response, and recovery and can strengthen sustainable green economy efforts, especially in fragile semi-arid ecosystems.

In recognition of the importance of this study in planning and sustainable development, household perception data are widely relied on to document best practices and lessons in the management and control of desert locust invasions [20]. As such, the objectives of this paper were to (1) assess the most significant environmental drivers of desert locust invasions, duration, and survival probability; (2) ascertain the impacts of locust invasions on household consumption of food items; and (3) analyse the effectiveness of pest control measures and sources of information in Uganda.

2. Materials and Methods

2.1. Study Location

The case study of this research is Uganda, located in the tropics of Eastern Africa. The area of study is situated in north-eastern Uganda (3° N and 34° E) (Figure 1). This region was selected because it was the most affected by the two waves of desert locust invasions in March and May of 2020. In terms of climate, the study area experiences a semi-arid type of climate, which influences the unimodal rainfall pattern [21]. The months that experience high rainfall are March and June. Rainfall amounts range between 1000 and 1500 mm per year [22], while the dry months are from August to February. Topographically, the landscape is characterised by undulating hills and flat plains. Mt. Moroto (3083 m), located in the Moroto district, is the highest mountain in the region, followed by Mt. Kadam (3063 m) and Mt. Morungole (2749 m) [23]. The cultivatable soil layer is mainly composed of sandy clay loam soils. These soils are widely spread across the stony landscape. The vegetation, on appearance, comprises savanna grasslands, savanna woodlands, and bushlands.

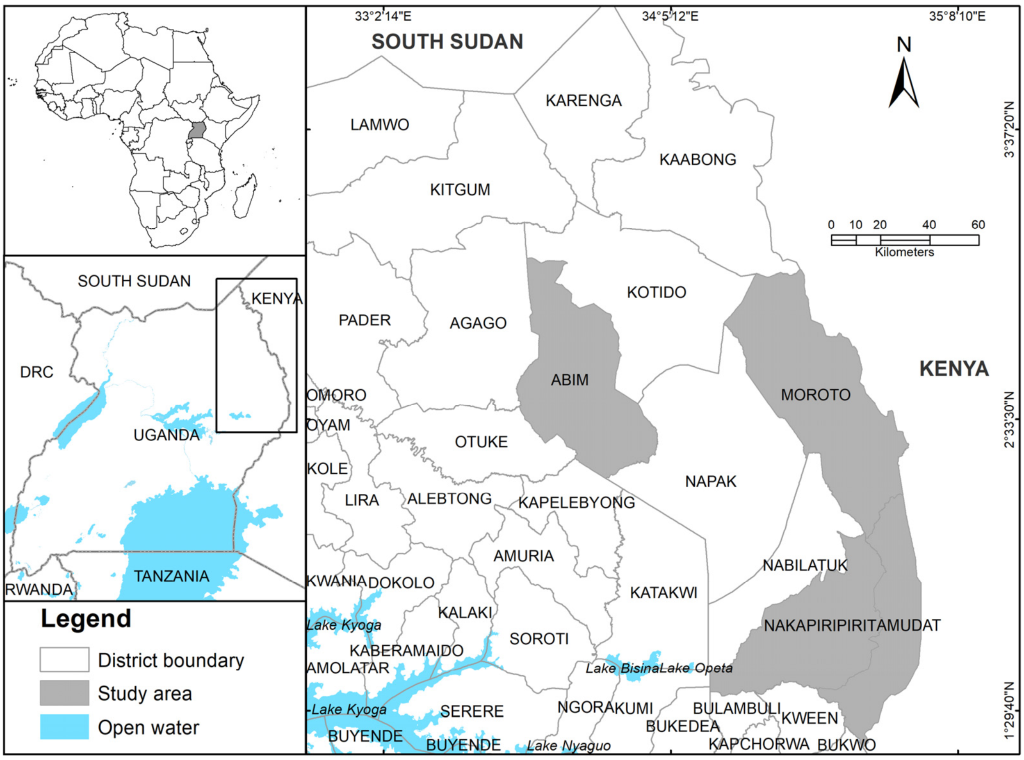

Figure 1. Sampled districts (shaded in light grey), which were purposively selected, in the north-eastern part of Uganda.

2.2. Data and Sources

Primary socioeconomic data were collected using various methods (household survey, focus group discussion, and key informant interviews) to document the perceptions of households in the districts of Moroto, Abim, Nakapiririti, and Amudat. These districts were reported by the interviewed national key informants from the Ministry of Agriculture, Animal Industry, and Fisheries to be the most affected by the two waves of desert locusts that invaded the country. In addition, field visits were made to the desert locust hotspots to observe their scourge on the vegetation and crops, with the guidance of local communities.

2.3. Data Collection Methods

Study Approach: This study adopted a hotspot-based approach to purposively select the districts that were investigated for desert locust invasion in Uganda. This approach provides detailed information on the centralisation of risk, responses, and post-recovery measures. In this approach, the study ensured that only affected households and areas were purposively chosen for oral interviews and validation. Much as the locust invasions were widespread in many districts of north-eastern Uganda, this study only targeted the districts of Moroto, Abim, Nakapiririti, and Amudat, primarily because these were the most severely hit, as reported by the interviewed key informants at the regional level. Secondly, although the locusts entered Uganda through Kenya, the scope of this investigation was limited to Uganda due to logistical constraints. Furthermore, the selection of these districts was therefore based on two elements: security concerns and locust outbreak hotspots. However, in this study, we assumed that the desert locust impacts were widespread in the chosen districts. Thirdly, another criterion that we considered was that the districts selected had experienced the two waves of locusts and were practicing both agro-pastoral and pastoral livelihood systems.

Study Design and Household Sampling: We applied a cross-sectional study design among the communities affected by the desert locusts in May and June 2020. This design facilitated more than one data collection in the same study [24]. The participants targeted in this survey were rural-based smallholder farmers described as either agro-pastoralists or pastoralists and highly dependent on nature. These were also selected in consideration of gender factors and ethical adherence involving human subjects, such as the willingness and informed consent of households to participate in this study. For the selected districts, the participants were selected following the procedures of administrative boundary multistage sampling (district, sub-county, parish, and village). In each district, two sub-counties and four parishes were purposively selected, while at the parish level, eight villages were randomly sampled. At the village level, six households were randomly selected using a developed registration list with the guidance of local leaders on the characterisation of smallholder farmers.

In total, this study targeted 192 households, but due to cattle rustling insecurity [25], only 183 households—including elders, youths, opinion leaders, and local council 1 chairpersons—participated. Secondly, the population in the study area is sparsely distributed and prone to nomadic pastoral practices [26]. The data were collected using face-to-face oral interviews and observations during fieldwork. The sampled households were interviewed using pre-tested and validated semi-structured questionnaires coded using Kobo Toolbox (https://www.kobotoolbox.org/- accessed on 30 March 2020) by well-trained research assistants who were able to translate the questionnaires into the Karamojong language. The minimum academic qualification for the assistants was a diploma. On average, each household was interviewed for about one and a half hours. The contents of the tools included the causes of desert locust invasions and survival, the effects of locusts on agricultural production, locust control, and household food consumption in homes before and after the desert locust invasions in the studied area. A Likert scale was used to examine the drivers of locust invasions and the effectiveness of desert locust control measures. It is worth noting that due to insecurity in the area and the usually scorching sun in the afternoon, our data were collected during the morning hours.

Key informant interviews: In addition to the household survey, key informant interviews were also conducted in this study. The interviews were important for an in-depth understanding of desert locust invasions and their effects on livelihood sources [27]. A total of 28 key informants were purposively selected and interviewed across the studied districts. These were experts in agriculture and natural resource management at the district level.

The key informant interviews were conducted using a key informant guide developed to ensure consistency among the interviewed respondents. These interviews were conducted orally and face-to-face with each expert in their area of jurisdiction. Each interview lasted between 30 and 45 min.

Focus group discussions: Focus group discussions have been widely used in socioeconomic studies. The discussions provide a forum for the households to openly express their views, emotions, and opinions [28]. The main advantage of the focus groups is that they allow much more freedom of speech among participants, encouraging them to interact, debate, and exchange views during the discussion [29]. In this study, 8 focus group discussions were held, two in each district at a centrally agreed-upon venue for accessibility purposes. The discussions were held under the guide of a pre-tested interview guide, and responses were captured using flip charts and audio recorders. The target members (10–15 members) were randomly selected according to gender using the field-generated smallholder farmer registration lists, which included youths, adults, the elderly, and vulnerable groups and were held separately.

The respondents were mobilised, directed, and introduced to this study by their local village leaders. The discussions, on average, lasted for two hours across the sampled districts. However, before the discussions, the participants were informed of the purpose of the discussions, and rules of engagement were established to ensure efficient use of time. In addition, an explanation was provided on how the dataset was going to be processed.

2.4. Data Analysis

Data on the perceptions of smallholders was cleaned in MS Excel and exported to IBM SPSS Statistics version 17.0 for qualitative and quantitative analysis. The descriptive analysis performed included frequencies and Chi-Square test findings presented in graph and table formats, while an inferential paired sample T-test of significance was performed to understand the differences in days of consumption of food items before and after locust invasion (Figure 2). The collected responses from the focus group discussions and key informants were analysed using content and thematic analysis in MS Excel software version 2016.

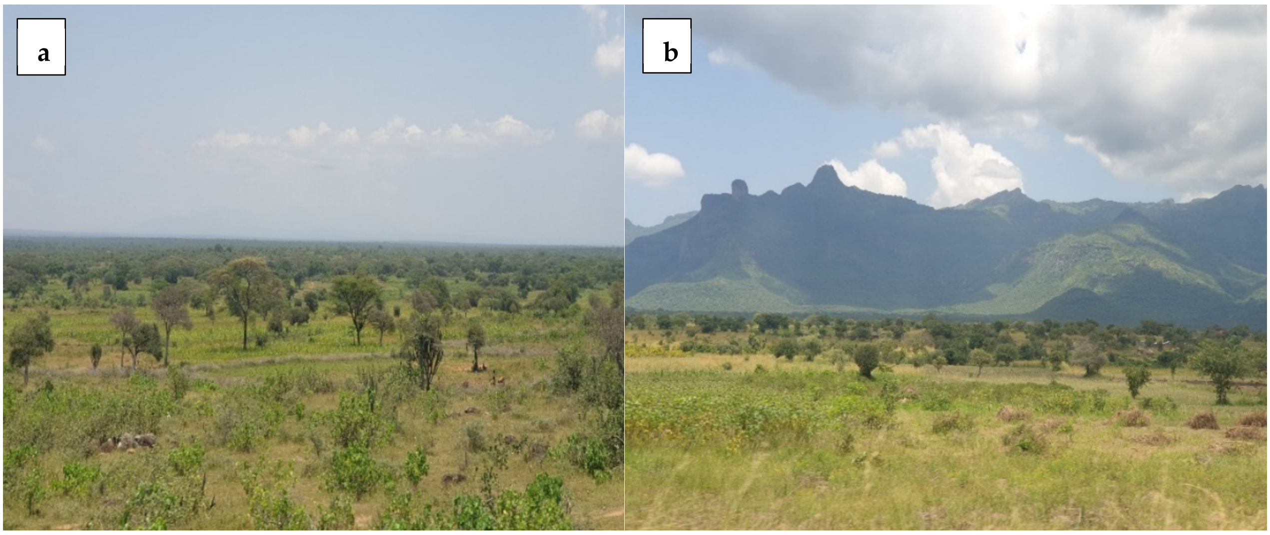

Figure 2. Farmlands (**b**), and woodlots and grassland areas (**a**), across the flat and mountainous landscape, that were invaded by locusts in the study region, north-eastern Uganda.

The most significant environmental drivers of desert locust invasions were determined using the Cox Proportion Hazards Model in Statgraphics Centurion 18 software version 18.1.16. The Cox Proportional Hazards Model was deployed to investigate if the environmental variables (rainfall, temperature, wind, soil moisture, and vegetation) influenced invasion duration and the survival of locusts during their invasions in the studied area. This model is widely used to analyse survival rates and the time it takes for an event to occur [30]. In data preparation, variables were not subjected to multicollinearity testing because it would make variables statistically insignificant [31]. The Cox Proportional Hazards Model is given as follows:

$$h(t \mid x) = h_0\ (t) \exp\left(\beta' x\right) \tag{1}$$

where t is the time, x is the vector of covariates, β is the vector of regression coefficients, and $h_0\ (t)$ is the baseline hazard function, i.e., the hazard function for $x = 0$.

The survival function of the Cox Proportional Hazards Model (1) is given by

$$S(t \mid x) = \exp\left[-H_0\ (t) \exp\left(\beta' x\right)\right] \tag{2}$$

where

$$H_0\ (t) = \int_0^t h_0(u)\mathrm{d}u \tag{3}$$

is the cumulative baseline hazard function.

For this study, the selected combinations of the input factors, x, are multiples of the baseline hazard function h(t∣0), as shown below:

$$\begin{aligned}
\mathrm{h}(\mathrm{t}|x) = \mathrm{h}(\mathrm{t}|0) * \exp(&0.0149941 * \text{ Rainfall} = 2 - 0.0503401 * \text{Rainfall} \\
&= 3 - 1.7816 * \text{Rainfall} = 4 - 0.00170291 * \text{Temperature} \\
&= 2 - 0.284709 * \text{Temperature} \\
&= 3 - 0.0236303 * \text{Temperature} = 4 + 0.604165 * \text{Winds} \\
&= 2 + 0.349329 * \text{Winds} = 3 - 0.42047 * \text{Winds} \\
&= 4 + 0.263795 * \text{Soil moisture} \\
&= 2 + 0.170756 * \text{Soil moisture} \\
&= 3 + 0.0970456 * \text{Soil moisture} \\
&= 4 - 0.038568 * \text{Sandy soils} \\
&= 2 + 0.0331661 * \text{ Sandy soils} \\
&= 3 + 0.491696 * \text{ Sandy soils} \\
&= 4 + 0.839642 * \text{Vegetation type} \\
&= 2 + 0.442093 * \text{ Vegetation type} \\
&= 3 + 0.102656 * \text{ Vegetation type} = 4)
\end{aligned}$$

3. Results

3.1. Drivers, Survival Rates, and Duration of Desert Locust Invasions

3.1.1. Environmental Drivers of Locust Invasions

The desert locust invasions were both on land and air, characterised by both hoppers and adult locusts. Regardless of whether the invasions were primary or secondary, this study shows that the desert locust invasions were significantly determined by environmental parameters such as rainfall, surface temperature, strong winds, soil moisture, soil type, and vegetation type ($p \leq 0.05$). Among these, in reference to the favourable and most favourable factors, vegetation type, strong winds, and soil type were the most important factors in triggering the invasions in the study area (Table 1). The improved health of vegetation and soil due to the onset of the rainy season instead increased their vulnerability to the scourge of locust damage. Whereas the components of climate—rainfall and temperature—had the least impact on igniting the desert locust invasions. The rejuvenation of vegetation growth at the onset of the rainfall season increased the proneness to locust damage, acting as habitat and a source of food, ultimately resulting in the loss and stunted growth of above-ground biomass.

3.1.2. Survival Probability of Desert Locusts

In addition to understanding the factors that triggered the desert locust invasions, this study also investigated the critical factors that influenced the locusts' lifespan in the study area. As such, our findings reveal that the most important parameters were vegetation type and strong winds, as strong winds influenced direction and distance in landing (Table 2). Therefore, the health of crops and pastures was a critical determinant of the locusts' survival. Despite these factors, the lifecycle stages of locusts also influenced their ability to survive and migrate. Furthermore, the size of locust swarms is another key factor that enhanced their survival, as reported by the interviewed key informants. Many members of the focus group discussions also explained that "the locusts were found where the vegetation was green and fresh some weeks after the first rains, and this is evidenced by farmers who found their planted crops like beans and maize eaten after they had sprouted fresh and soft leaves. The locusts would use their abdomens to dig holes in the sand to lay eggs".

Table 1. Environmental drivers of locust outbreaks.

Drivers	Least Favourable		Moderately Favourable		Favourable		Most Favourable		Chi-Square	df	Asymp. Sig.
	Obs. N	Residual	Obs. N	Residual	Obs. N	Residual	Obs. N	Residual			
Rainfall	118	72.3	21	−24.8	43	−2.8	1	−44.8	171.426	3	0.000
Surface temperature	64	18.3	64	18.3	54	8.3	1	−44.8	59.820	3	0.000
Strong winds	39	−6.8	43	−2.8	94	48.3	7	−38.8	84.869	3	0.000
Soil moisture	95	49.3	27	−18.8	59	13.3	2	−43.8	106.377	3	0.000
Soil type (sandy)	84	38.3	33	−12.8	63	17.3	3	−42.8	81.984	3	0.000
Vegetation type	33	−12.8	34	−11.8	107	61.3	9	−36.8	118.093	3	0.000

Table 2. Parameters of an estimated Cox Proportional Regression Model.

Parameter	Estimate	Standard Error	Lower 95.0% Conf. Limit	Upper 95.0% Conf. Limit
Rainfall = 2	0.01	0.09	−0.16	0.19
Rainfall = 3	−0.05	0.07	−0.20	0.09
Rainfall = 4	−1.78	0.35	−2.46	−1.10
Surface temperatures = 2	0.00	0.07	−0.15	0.14
Surface temperatures = 3	−0.28	0.07	−0.43	−0.14
Surface temperatures = 4	−0.02	0.49	−0.98	0.93
Strong winds = 2	0.60	0.08	0.45	0.76
Strong winds = 3	0.35	0.07	0.22	0.48
Strong winds = 4	−0.42	0.14	−0.70	−0.14
Soil moisture = 2	0.26	0.09	0.10	0.43
Soil moisture = 3	0.17	0.07	0.04	0.30
Soil moisture = 4	0.10	0.35	−0.59	0.79
Sandy soil = 2	−0.04	0.07	−0.18	0.11
Sandy soil = 3	0.03	0.06	−0.09	0.16
Sandy soil = 4	0.49	0.20	0.10	0.89
Vegetation type = 2	0.84	0.08	0.68	1.00
Vegetation type = 3	0.44	0.07	0.30	0.58
Vegetation type = 4	0.10	0.14	−0.17	0.38
Likelihood Ratio Tests				
Factors	**Chi-Square**	**Df**	***p*-Value**	
Rainfall	4.41	3	0.2205	
Surface temperatures	2.49	3	0.4767	
Strong winds	9.58	3	0.0225	
Soil moisture	1.10	3	0.7770	
Sandy soils	0.62	3	0.8925	
Vegetation type	10.90	3	0.0123	
Log likelihood = −862.303				

This study further demonstrates that the survival probability of locusts beyond one week was 90% (Figure 3b), while only 40% of locusts were able to survive beyond one month. This meant that the survival of locusts decreased with time. The hazard function graph reveals that the chances of locust death increased with the age of the locusts (Figure 3a). We can therefore conclude that the majority of the locusts that invaded Uganda were characterised by hoppers and adults.

Members of the focus group discussion confirmed that three types of locusts were distinguished according to colour and size. The brown–yellowish and big ones, and the small, green, non-flying ones. The mature ones in yellow and/or brown would land on trees and eat the tree leaves, while the small green ones had not fully developed wings. These would move on the ground, eating grass and crop leaves; these were the most dangerous. Locusts in the maturity stage were the most mobile. These were hard to control because they would be chased from one place and land on another, only to return to the same spot.

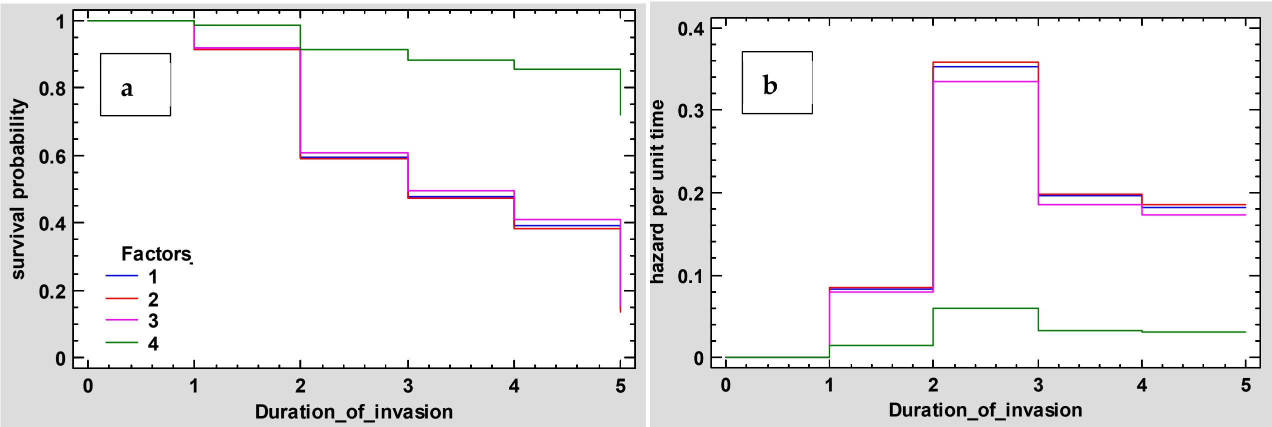

Figure 3. Survival probability (**a**) and hazard per unit time (**b**) as an output of Cox Proportional Regression Model.

3.1.3. Duration of Desert Locust Invasions

The majority of the interviewed respondents (70%) reported that the locusts lasted between 3 and 4 weeks, while a few others (8%) revealed that the locust infestation lasted up to 4 months (Figure 4). This duration was perceived by key informants to be in tandem with the life cycle of locusts (egg, hopper, and adult), in which they mature in two to four months, as well as the structure and composition of the above-ground biomass. Given the observed sizes of desert locust swarms, this period was sufficient for them to cause havoc on vegetation and crops, which are vital in sustaining the supply of ecosystem services. However, in relation to the crop growing calendar, most of the locust arrivals were reported to occur before (67%) and after (21%) the planting season. In a few areas, the invasions were reported to have occurred at the crop maturity and post-harvest stages, while other respondents confirmed that the locusts arrived at the peak of the dry season and that most of the attacks targeted grasslands, trees, and shrubs. At the district level, the districts that experienced invasions throughout the season were the Moroto and Abim districts.

In support of this finding, the members of the focus group discussions (FGDs) explained that they experienced two waves of locusts. The first wave was in March, after they had planted and the crops had sprouted. This was the season of rain. The second wave occurred 3 weeks to 1 month after the first one. It was in April. Probably, the second wave was triggered after the mature first-wave locusts had laid eggs; these hatched and formed the second wave, which affected the seasonal cropping calendar. With regard to the calendar, the respondents revealed that activities of land preparation and planting are undertaken between March and May, weeding starts in April to June, and harvesting takes place between August and October of each year.

3.2. The Impacts of Desert Locust Invasions on Household Consumption of Food Items

This study analysed the availability and household consumption of food items before and after locust invasions using food groups. The findings clearly show that the invasions affected household food consumption patterns (Table 3). In this research, household food consumption inside homes referred to the number of food items consumed by interviewed households during and after locust invasions on days in a month. This was based on either food items purchased or cultivated by the households. For the interviewed households, the majority reported having reduced the number of food items they consumed as well as the frequency of consumption in their homes. There were significant differences in the day's food items consumed before and after the locust invasion, except for ground nuts and cashew nuts ($p \leq 0.05$) (Table 4). The effect was largely negative, as the days the food was consumed generally decreased after the locust invasion. This implied that the locust invasion significantly affected household food security among the affected respondents. Generally, this amount was about half of what was consumed before the invasions. The food items that were affected include cereals like maize, beans and peas; root tubers; vegetables; milk/yoghurt; and beef and poultry products.

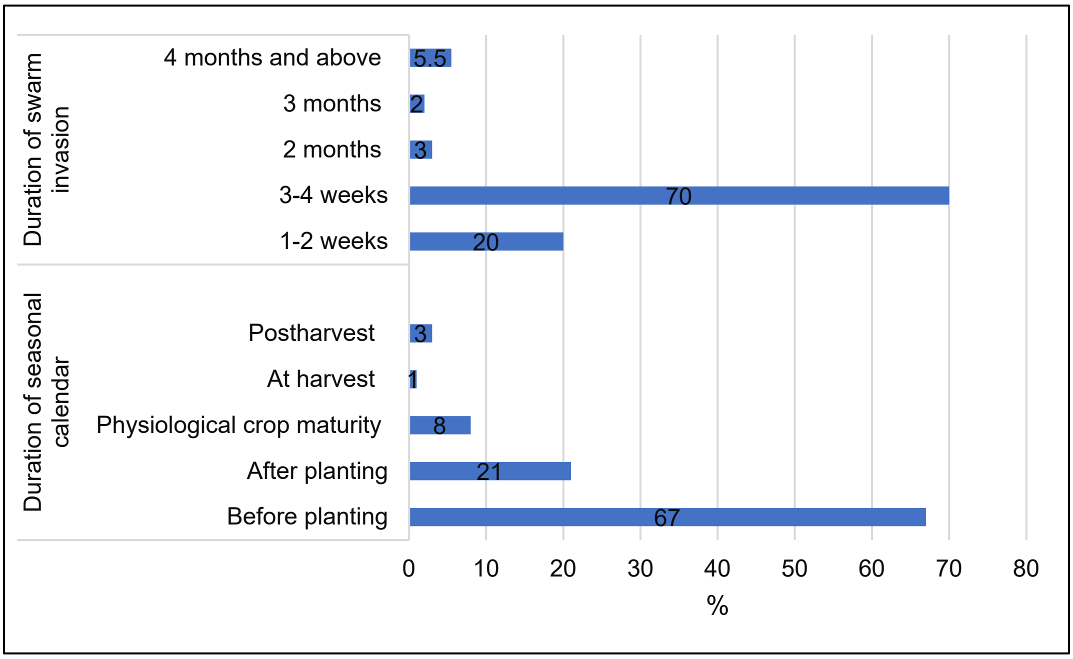

Figure 4. Duration of locust invasions and timing with regard to the crop-growing calendar.

Table 3. Consumption of food items by interviewed households during and after locust invasions by days.

Food Items	Before Invasion Mean No. of Days	After Invasion Mean No. of Days
Maize, maize porridge	15	7
Cereals (rice, sorghum, millet, bread, pasta, etc.)	18	9
Roots and tubers (cassava, Irish potatoes, sweet potatoes)	13	5
Sugar or sugar products	4	7
Beans and peas	15	6
Ground nuts or cashew nuts	4	4
Vegetables	10	3
Fruits	2	1
Beef, goat, or other red meat and pork	3	1
Poultry and eggs	3	2
Milk/yoghurt/other dairy	6	2

One positivity identified during the invasion as reported by the key informant respondents was the ability of farmers to engage in food storage practices through the construction of traditional granaries, the use of indoor baskets and polythene bags, depositing in community stores, and the use of indoor open storage (floors). However, the stored food items were affected by pests/insects, mould growth, and high rates of spoilage, which limited household food consumption. As a result, farmers ended up purchasing more food items to meet household demands.

Table 4. Differences in days of consumption of food items before and after locust invasion.

Number of Days	Mean	Std. Dev.	Std. Error	t	df	Sig. (2-Tailed)
Maize/maize porridge was consumed before and after locust season.	8.5	17.7	1.3	6.5	183	0.000
Other cereals (rice, sorghum, millet, bread, pasta, etc.) were consumed before and after locust season.	9.4	26.9	1.9	4.7	183	0.000
Roots and tubers (cassava, Irish potatoes, sweet potatoes) were consumed before and after locust season.	8.0	20.9	1.5	5.2	183	0.000
Sugar or sugar products were consumed before and after locust season.	−2.8	13.1	0.97	−2.9	183	0.004
Beans and peas were consumed before and after locust season.	8.7	27.9	2	4.2	183	0.000
Ground nuts or cashew nuts were consumed before and after locust season.	−0.13	6.05	0.45	−0.28	183	0.779
Vegetables were consumed before and after locust season.	6.8	16.3	1.2	5.6	183	0.000
Fruits were consumed before and after locust season	0.62	2.9	0.2	2.9	183	0.003
Beef, goat, or other red meat and pork were consumed before and after locust season.	1.4	2.8	0.2	6.9	183	0.000
Poultry and eggs were consumed before and after locust season.	1.3	4.5	0.3	3.9	183	0.000
Milk/yoghurt were consumed before and after locust season	3.9	9.7	0.7	5.6	183	0.000

One member of a focus group discussion gives a clear indication of the effects of the locusts on vegetation and grassland: "Where animals used to graze, there was no longer grass. Grass for cattle was finished in days. They also kept camels that feed on plant leaves, but they failed to get enough to eat because the grasshoppers had eaten all the leaves. The grasshoppers ate the biggest part of the plant leaves and left a small hard part to drop off the tree, and that is what the goats were left with to eat, but it was not enough. Animals failed to access pasture. They destroyed the leaves of crops instead".

Much as subsistence farming is the main source of livelihood, the affected households diversified their sources of income for survival. This study demonstrates that the majority of the households did not diversify their sources of income (63%), and therefore they struggled to sustain themselves and their dependents (Table 5). They simply relied on the provision of casual labour (19%), begging or gifts (15%), and remittances (9.3%), while the rest were engaged in petty trade businesses, formal employment, and beer brewing, among others. This diversity enabled the households to earn income that was used to purchase necessities, such as food, water, clothing, etc., for their sustenance after the outbreak. The studied region heavily relies on humanitarian aid because it is highly susceptible to drought, flooding, and desert locust invasions.

Table 5. Livelihood diversification after desert locust invasion.

Livelihood Diversification	Abim		Amudat		Nakapiripirit		Moroto		Overall	
	N	%	N	%	N	%	N	%	N	%
Remittances	2	5	-		12	25	3	5.9	17	9.3
Casual labour	8	20	4	9.1	12	25	11	21.6	35	19
Begging/gifts	3	7.5	16	36.4	2	4.2	6	11.8	27	14.8
Own business	1	2.5	1	2.3	2	4.2	1	2	5	2.7
Petty trade	3	7.5	2	4.5	-	-	1	2	6	3.3
Pension/social grants	-	-	14	31.8	-	-	1	2	15	8.2
Formal salary/wages	1	2.5	1	2.3	2	4.2	4	7.8	8	4.4
Vegetable/fruit sales	-	-	-	-	1	2.1	-	-	1	.5
Beer brewing/distillation	-	-	-	-	2	4.2	-	-	2	1.1
Not applicable	21	52.5	6	13.6	15	31.2	24	47.1	67	36.7

3.3. Effectiveness of Pest Control Measures and Sources of Information

3.3.1. Perceived Effectiveness of Implemented Locust Control Measures

Although environmental variables can influence the survival of locusts, many integrated risk reduction measures were deployed to control the spread of invasions. The measures employed can be characterised as physical, chemical, and biological. In the studied area, the most utilised measures were chemical and physical interventions (Table 6). In particular, the most commonly deployed locust control measures include pesticide spraying, burning of straw and bushes, making loud noises, trampling locusts, biological control (use of animals and poultry), chasing locusts, and digging out of egg pods. This study further investigated the effectiveness of these measures to control locusts. Effectiveness, in this study, refers to the measures that were able to kill locusts along their life cycle (all the stages) and also reduce their impacts and the possibility of further invasions. The majority of the smallholder farmers interviewed reported that the most effective measure undertaken was the use of ground and aerial pesticide spraying, followed by the chasing of locusts and the use of biological control measures. However, although these measures were reported to be effective, their application was delayed and short-lived due to the high costs of securing an aircraft sprayer and pesticides. The least effective measures applied to control locusts were digging trenches to limit ground movements, trampling hoppers, bush burning, digging up egg pods, and the use of biological control measures. As such, these measures failed to ensure the survival of pastures, crops, and trees in the studied region.

Table 6. Perceived effectiveness of implemented locust control measures by smallholder farmers.

Measures	Not Effective		Somewhat Effective		Effective		Very Effective	
	N	%	N	%	N	%	N	%
Aerial pesticide spraying	14	8	19	10	97	53	53	29
Ground pesticide spraying	4	2	29	16	26	14	124	68
Burning bushes	32	18	118	65	30	16	3	2
Digging trenches	43	24	128	70	9	5	3	2
Making loud noises	17	9	140	77	20	11	6	3
Trampling locusts	40	22	125	68	16	9	2	1
Biological control	20	11	122	67	34	19	7	4
Chasing of locusts	13	7	88	48	38	21	44	24
Digging out egg pods	21	12	135	74	24	13	3	2
Burning of straw	17	9	140	77	20	11	6	3

According to the responses from the FGDs, some of the measures were ineffective, and these included the use of burning as an interventional measure, the drumming of jerrycans, and other loud noises. This was because the locusts were unaffected by these measures, remaining where they were until all the vegetation was eaten. The key informants interviewed revealed that the effectiveness of measures was attributed to the appropriate selection of the areas of intervention, the efficiency of the pesticides used, the methods used to spray the locusts, and the training of community members in locust management and safety measures.

3.3.2. Sources of Desert Locust Control Information

According to the interviewed smallholder farmers, the major sources of desert locust control information were radio and television (Table 7). These were followed by access to information through reading newspapers and the use of extension workers. Other options utilised include the use of mobile phones, neighbours (word of mouth), personal knowledge, non-governmental organisations, and international development partners. Local radio and television stations in the region have a higher regional signal penetration, and they are also able to facilitate high listenership in homes. These resources can increase awareness in the dryland areas characterised by nomads and can be used to strengthen the resilience of households to locust invasions.

Table 7. Sources of desert locust control information.

Sources of Information	No. Cases	Case %	Proportion %
Radio and television	102	55.7	15.9
Direct contact with traders (middle men)	33	18	5.1
Farmers' organisations	39	21.3	6.1
Newspapers	64	35	10
Extension workers	65	35.5	10.1
Mobile phone use of SMS	54	29.5	8.4
Neighbours	51	27.9	8
Agricultural Information Board	44	24	6.9
Personal knowledge	49	26.8	7.6
Food reserve stores and wholesalers	43	23.5	6.7
Non-governmental organisation	47	25.7	7.3
International development organisations	50	27.3	7.8

4. Discussion

The 2020 desert locust invasion in north-eastern Uganda was affected by climate (rainfall) and vegetation conditions. The locust invasion was noticed before and after crop planting and sprouting, which corresponded with the onset of the single rainfall season in the Karamoja region. The invasions lasted for more than two weeks. The first rains in Karamoja dramatically transformed the landscape, as they drove other environmental conditions towards being favourable for desert locust breeding, maturation, gregarisation, concentration, and migration [18]. The locusts were attracted to tall trees and savannah grasslands. The invasions occurred at the onset of the first rainy season, which is characterized by strong blowing winds and high surface temperatures (30–36 °C), as reported elsewhere [32]. Rainfall and soil moisture were reported by the key informants to favour the movement and breeding of locusts in the current study areas. The rainfall season in this way increases soil and sand moisture and vegetation regrowth, favourable for desert locust reproduction, while the winds associated with the season favour migration of the mature swarms. Rainfall and land cover characteristics have provided desert locust outbreak prediction scenarios with high certainty elsewhere, as well as within the East African region [8,33]. These predictions, however, depend on inverse conditions in the initial epicentres. Intense precipitation events in the Arabian Peninsula during 2018 provided suitable soil moisture and lush vegetation, which favoured desert locusts' invasion of the Peninsula; when the conditions shifted to west Asia and north-east Africa the following year, the desert locusts, too, migrated to this region [17]. In Africa, Asia, and Europe, temperature and leaf area index play important roles in shaping the spatial distribution of desert locusts [6].

The locusts that invaded East Africa had their origins in the Arabian Desert [17]. Thus, the conditions that force these pests to migrate from their original breeding areas are usually in tandem with the conditions for inhabitation and breading in the migration destinations. Our study reveals that whereas there were earlier warnings during the 2020 locust invasion, swarms continued to migrate into East Africa from Arabia, and these continued to breed and spread further, especially in farming areas at the start of the planting season, thus causing crop destruction [9]; this was not the case in Karamoja Region of Uganda. Thus, there are intermittent periods of invasion recession in relation to variations in environmental conditions [34]. Desert locust monitoring and surveying efforts should take this into consideration when designing management strategies to both predict invasions and plan for the implementation of preventive strategies before the invasions. This study shows that locust invasion durations were determined by environmental factors and the stage of locust growth. In addition, the duration of locust invasions played a key role in vegetation consumption rates, risks, and reproduction rates, which ultimately affected the health of natural ecosystems and food production systems [35].

Our study revealed that the 2020 locust swarms in north-eastern Uganda had an indirect impact on smallholder farmers' food security. This was expected from a region where crop production forms a very small percentage of the agricultural engagement; instead, the communities rely on pastoralism [36]. More damage was inflicted on natural vegetation cover (grasslands and trees), as also reported by [8]. It should be noted that pastoralists depend on grasslands for livestock production. Reduced grass and tree cover mean limited access to sufficient livestock feed, resulting in decreased meat and milk yields after locust invasions. In addition, reduced vegetation cover forces pastoralists to travel long distances in search of pasture for their livestock, which is often associated with territorial conflicts and movement away from livestock production infrastructure like valley dams and veterinary services centres [37]. As a response, affected communities in the Karamoja region attempted to diversify their livelihood sources into activities such as engaging in casual labour and relying on remittances and petty businesses, which demonstrated some level of community resilience, although the sustainability of the alternatives sought was questionable. There is a need to diversify livelihood sources to build community resilience to desert locust upsurges in the East African region.

Knowledge of desert locust control and management has evolved for those areas that are occasionally invaded by these migratory pests [32]. For the Karamoja region in Uganda, invasion cases have been sporadic and unpredictable; thus, most of the measures implemented were reactive. Consequently, the most widely used control measures proved to be more effective [38,39], and the control methods used in the early stages of development during the 2020 locust invasion included traditional methods involving the use of chemicals and pesticides applied through aerial and ground spraying. Whereas the results from the study show that these were very effective, the measures are associated with adverse environmental effects [35]. As such, there is a need to develop capacity for the near-future and future forecasting of desert invasions and plan for preventive management to minimise the use of spraying with chemicals, which becomes the only reliable measure if invasions are detected only after occurrence as a reactive control measure [38]. Therefore, though this study was conducted in north-eastern Uganda, the findings are of global importance, especially in exploring locust drivers and survival rates, as well as the evaluation of control measures for locust outbreaks.

5. Conclusions

The north-eastern parts of Uganda are highly vulnerable to desert locust invasions beyond the points of entry on the border with Kenya. Our results demonstrate that vegetation type, blowing winds, and soil type triggered locust swarm upsurges, which lasted between 1–2 weeks and 3–4 weeks. Their survival was highly dependent on the type of vegetation and strong winds. Reactive rather than proactive locust control measures were enacted and proved effective in managing the desert locust upsurge in Uganda. The findings are important for both locust disaster preparedness and building the resilience of communities in the locust-affected regions of East Africa to cope with future invasions. Planning for locust swarm management should focus on strengthening community resilience to safeguard livelihood sources and food security. The regional locust control units in East Africa should be strengthened to ensure the ability to conduct ground surveys, access geospatial data, and provide timely reporting of invasions.

Author Contributions: B.B.: conceptualization, methodology, and analysis; P.M.G.: data curation and writing (original draft preparation); N.L.: tool development; L.T.G.: data collection and supervision; J.P.M.: validation; C.W.W.: writing (reviewing and editing). All authors have read and agreed to the published version of the manuscript.

Funding: The study was supported with funding from Kyambogo University Competitive Research Grants Scheme (2019/2020—fourth call).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The field survey data used to support the findings of this study are available from the corresponding author upon request.

Acknowledgments: The authors are grateful to Kyambogo University for funding this research through the Research Competitive Grant (2019/2020—fourth call). We are also thankful to the officials of the visited district's local government for facilitating and guiding this study during the selection of sample districts, sub-counties, parishes, and villages, as well as during mapping exercises.

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

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