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Human-giraffe coexistence: Community nature-based enterprises as a basis for Somali giraffe conservation in eastern Kenya

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Abstract

Nature based solution is gaining recognition globally to solve environmental degradation and biodiversity loss. This study examines a nature-based mitigation strategy by assessing the economic viability of lime farming as a deterrent to giraffe crop-raiding in Garissa County, Kenya. We compared lime prices across three market channels (companies, local markets and middlemen) and analyzed the relationship between crop type and giraffe conflict frequency on 101 farms between 2022 and 2024. Statistical analysis showed that lime sold to companies yielded significantly higher returns than to local markets or middlemen. The mean price was 71.25 units (company) versus 43.33 units (local market), with a highly significant t-value of 17.888 ($p < 2.2e-16$). ANOVA confirmed significant price variation across market types ($F(2,105) = 375.5$, $p < 0.0001$). Tukey HSD tests showed that middlemen offered 35.56 units less than companies ($p < 0.001$) and 7.64 units less than local markets ($p < 0.001$). Lime farms generated higher monthly incomes than mango farms, with lime median income around 250,000 units versus 80,000 units for mango. Conflict analysis revealed a strong inverse relationship between lime farm acres and giraffe conflict incidents. Mango farms experienced significantly higher crop-raiding (up to 20

incidents) compared to lime farms (typically 0–3 incidents), suggesting giraffes preferentially raid mango crops.

Introduction

The ongoing global economic expansion has led to the overexploitation of natural resources, degradation of land and increased air pollution (Cohen-Shacham et al., 2019; Nungula et al., 2023). For example, the growth of urban areas has significantly impacted the environment through deforestation, pollution, and a decline in biodiversity (Osaka et al., 2021). Over time, several approaches have emerged as potential remedies to these intensifying human-induced environmental issues (Osaka et al., 2021; Mohamed et al., 2025). Among these, Nature-Based Solutions (NBS) have gained global momentum as strategies that utilize natural processes to strengthen environmental resilience (Nelson et al., 2020). NBS aim to tackle ecological, social, and economic issues through sustainable practices (Nesshöver et al., 2017). In the European context, the European Union (EU) has promoted a sustainable economy by incorporating nature-based solutions to foster innovations in low-carbon technologies (Maes & Jacobs, 2017). The effectiveness of NBS is largely dependent on the extent to which non-renewable energy sources can be replaced without diminishing the overall output of ecosystem services (Maes & Jacobs, 2017). In African nations such as Namibia, nature-based tourism includes both consumptive activities like hunting and non-consumptive activities such as wildlife observation and birdwatching (Gronau et al., 2017).

According to Muller (2018), giraffe populations are experiencing a sharp decline across much of Africa due to factors such as habitat destruction, poaching, political instability and conflicts between humans and wildlife. Although giraffes are crucial to the ecosystem of the African savanna and contribute significantly to the economic and social well-being of local communities, the human aspects of giraffe conservation have frequently been neglected (Koppel et al., 1998; Ali et al., 2024). The reticulated giraffe, which is classified as endangered by the IUCN, has seen a 56% decrease in its population over the past thirty years. A large portion of these giraffes reside in the counties of Garissa, Wajir and Mandera in northeastern Kenya (Muneza et al., 2018). Nature-inspired approaches have emerged as a valuable strategy to implement ecosystem services, aiming to integrate ecological factors alongside traditional planning priorities (Scott et al., 2016; Emmanuely et al., 2024). These nature-based solutions have proven effective in urban settings, addressing complex environmental challenges (Chappa et al., 2024; Zarei & Shahab, 2025). In a similar vein, crop farmers in northeastern Kenya are frequently confronted with the issue of crop raiding, particularly by giraffes that feed on mango flowers. In response, some farmers resort to retaliatory actions, attacking the animals with crude weapons (Ali et al., 2023).

To mitigate this human-wildlife conflict, the Somali Giraffe Project has been actively promoting nature-based solutions. A key initiative involves distributing lime seedlings to farmers each year and facilitating connections with companies that purchase the harvested lime. This study aimed to assess (i) the social enterprise aspect of crop farming by investigating lime prices across three market channels, companies, local markets and middlemen and (ii) to document the frequency and nature of conflict incidents on farms where both lime and mango trees are cultivated. Through this approach, the project seeks to address both the ecological needs of giraffe conservation and the socio-economic challenges faced by farmers.

Materials and methods

Study Area

This study was conducted in Garissa County, located in eastern Kenya along the border with Somalia. Spanning approximately 45,720 square kilometers, Garissa is one of the largest counties in the country. The landscape is predominantly flat, with elevations ranging from 70 to 400 meters above sea level, and lies at coordinates 0.4497° N, 39.6583° E. The region experiences a typically hot and arid climate, characterized by a prolonged dry season from June to October and a shorter rainy season between March and May. Rainfall is highly variable, averaging between 200 and 600 millimeters annually, while temperatures frequently exceed 30°C (Ali et al., 2017). The Tana River, the county's primary water source, is vital for both human and wildlife populations, supporting local ecosystems and livelihoods. The study focused on the crop-farming communities in the Sankuri, Bour Algy and Kamuthe areas, where human-wildlife conflicts, particularly involving giraffes, have become increasingly common. These areas are predominantly inhabited by Somali pastoralists, although many residents living near the Tana River also engage in small-scale farming.

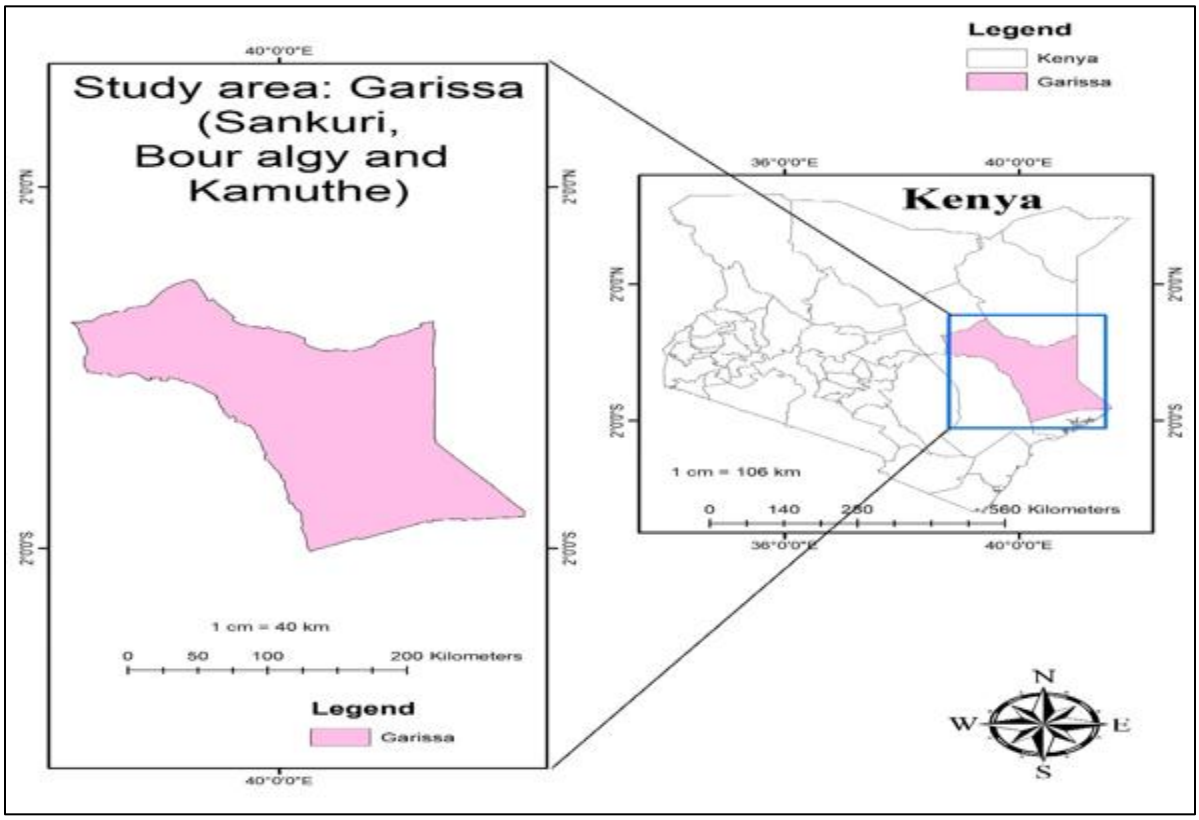

Figure 1: Study area map

Research Design

We used a mixed-methods approach that combined quantitative, qualitative and observational methods to explore the relationship between crop farmers' monthly income and giraffe-related crop-raiding incidents. We recorded monthly lime sales over a three-year period in Excel spreadsheets to evaluate price differences across various market centers. We visited 101 farms to document conflict incidents, including 19 farms in Sankuri, 70 in Bour Algy and 12 in Kamuthe. We systematically selected farms at one-kilometer intervals to ensure broad and representative coverage of the study area. We recorded giraffe footprints and fecal matter found inside farms as direct evidence of giraffe presence and crop-raiding activity. We tallied the total number of crop-raiding incidents for each farm on a monthly basis throughout the years 2022, 2023 and 2024.

Sample size

We selected a sample size of 101 farms distributed across three regions: Sankuri (19 farms), Bour Algy (70 farms) and Kamuthe (12 farms). Bour Algy accounted for the largest portion of the sample, as many farms in the area had received free lime seedlings from the Somali Giraffe Project, leading to a higher adoption rate of lime farming among local farmers.

Data collection methods

We collected data through systematic field observations and market records to capture both quantitative and qualitative aspects of the study. Between 2022 and 2024, we conducted weekly visits to each of the 101 sampled farms to monitor and document giraffe-related crop-raiding incidents. During each visit, we recorded physical evidence of giraffe presence, specifically footprints and fecal matter, within farm boundaries, which we classified as confirmed conflict incidents.

We tallied and recorded the total number of conflict incidences separately for each farm, enabling detailed tracking of crop-raiding frequency over time. To complement the field observations, we compiled monthly lime sales data from various market centers using Excel spreadsheets. This dataset, spanning three consecutive years, enabled us to evaluate price differences between markets and examine potential links between lime farming and giraffe crop-raiding behavior**.**

Consent and Permission

Prior to initiating data collection, we secured all required authorizations. We received clearance from the Garissa County Government, confirming that the study complied with regional policies. On a national level, we obtained a research permit from the National Commission for Science, Technology and Innovation (NACOSTI, Ref No: 412950), which is a legal requirement for any research involving human subjects in Kenya. We clearly explained the purpose and objectives of the study to all participants, including Garissa farmers association chairperson and emphasized that their involvement was entirely voluntary. We also assured them that all information collected would be treated with strict confidentiality.

Data Analysis

All statistical analyses were performed using RStudio (R Core Team, 2023). We first assessed the normality of the data using the Shapiro-Wilk test and checked for homogeneity of variances with Levene's test. Given that the data met the assumptions of normality and homoscedasticity, we proceeded with the following parametric analyses:

i. Comparison between Local Market and Companies: We conducted an independent samples t-test to compare the mean price differences between the local market and the companies.

ii. Comparison across Market Types (Local Market, Middlemen, and Companies): A two-way analysis of variance (ANOVA) was used to assess the main effects of crop type (lime vs. mango) and market type (companies, local market, and middlemen). To explore significant differences between the market types, we performed post-hoc pairwise comparisons using Tukey's Honestly Significant Difference (HSD) test.

iii. Relationship between Acres Under Lime Farming and Conflict Incidents: We analyzed the association between the number of acres under lime cultivation and the incidence of conflicts on the farms. This analysis allowed us to assess whether the extent of lime farming influences the occurrence of conflicts.

iv. Comparison of Conflict Incidents on Lime vs. Mango Farms: We generated a heatmap to visually compare the incidence of conflicts on lime and mango farms across the three locations (Sankuri, Bour Algy and Kamuthe).

We set a significance threshold at $\alpha = 0.05$ for all statistical tests. Data visualizations were produced using the ggplot2 package in RStudio. We recorded the results, including test statistics (F-statistics, t-values, p-values), and 95% confidence intervals where applicable.

Results

Price of lime sold to companies versus local market

The results show a significant difference in the price of lime sold to companies compared to the local market. The mean price when selling to companies is 71.25, while the mean price in the local market is 43.33. A t-test revealed a t-value of 17.888 with 70 degrees of freedom and a p-value < 2.2e-16, indicating that the difference between the two groups is highly statistically significant (Fig 2). The 95% confidence interval for the difference in mean prices ranges from 24.80 to 31.03, meaning we can be confident that, on average, farmers earn between 25 and 31 units more when selling to companies. These findings clearly suggest that farmers receive a much better price for their lime when selling to companies rather than in the local market.

Farmers sell lime to companies at much higher prices. The median price is around 70. However, there are also outliers indicating that in some cases, farmers receive prices even above 80. In contrast, the lime price in the local market is lower, with the median price around 47–48. The price range is also wider and stretches down to around 30, suggesting that farmers often have to sell at significantly lower prices in the local market. Farmers earn better income when they sell lime to companies compared to the local market, where prices are generally lower and more variable. This could encourage farmers to prefer selling to companies if they want higher and more stable returns.

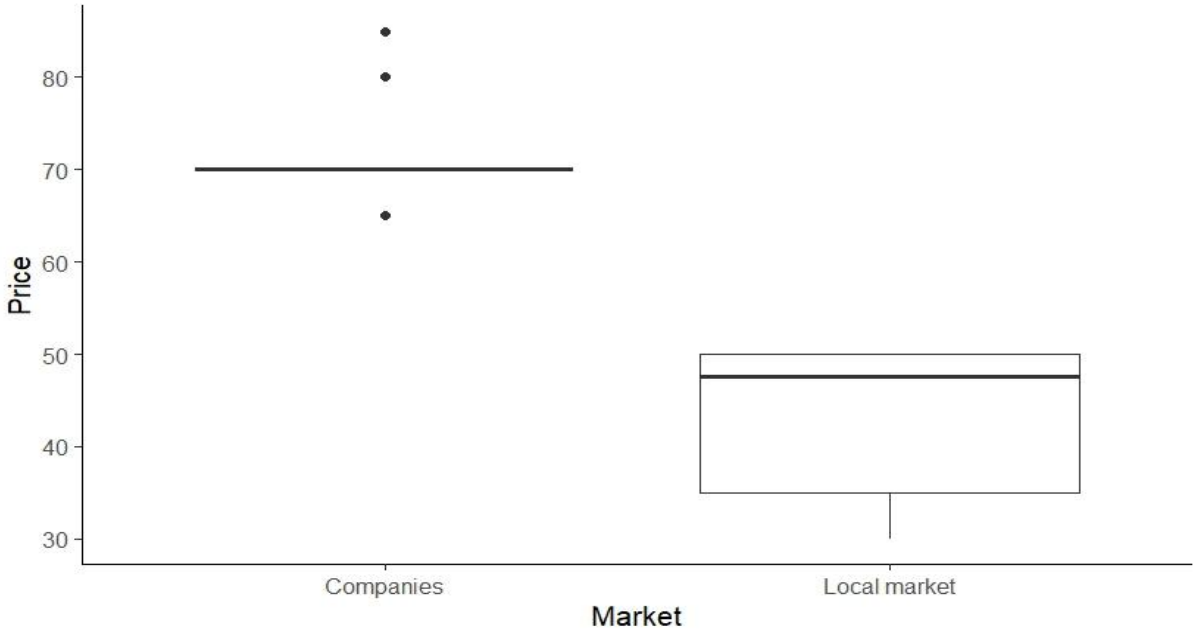

Figure 2: A box plot comparing lime prices between two markets in Garissa Town: companies and the local market. The bold horizontal line represents the median price for the companies, with outlier points above it indicating instances when prices exceeded 70. In contrast, the local market shows a median lime price of approximately 47.5.

Effect of market type on lime sale

The ANOVA results showed that there was a statistically significant effect of market type on lime sale prices ($F(2, 105) = 375.5$, $p < 0.0001$). This indicates that the average sale prices differed significantly across the three market categories: Companies, Local market and Middle men.

Table 1: ANOVA Interpretation

Source	Df	Sum sq	Mean Sq	F value	Pr(>F)
Market	2	25,223	12,611	375.5	< 2e-16
Residuals	105	3,526	34		

To identify which specific groups differed, a Tukey Honest Significant Difference (TukeyHSD) post-hoc test was conducted. The results revealed that lime prices in the Local market were significantly lower than those offered by Companies, with a mean difference of approximately 27.92 units ($p < 0.001$). Similarly, prices offered by Middle men were significantly lower than those from Companies by about 35.56 units ($p < 0.001$). Additionally, Middle men prices were also significantly lower than those in the Local market, with a mean difference of 7.64 units ($p < 0.001$). These findings demonstrate clear price disparities among the market types, with companies offering the highest prices, followed by the Local market and Middle men offering the lowest.

Table2: Tukey HSD Post-hoc Comparison

Comparison	Diff	lwr	upr	P adj
Local market-Companies	-27.916667	-31.16408	-24.669254	0e+00
Middle men-Companies	-35.555556	-38.80297	-32.308143	0e+00
Middle men – Local market	-7.638889	-10.88630	-4.391477	5e-07

Distribution of prices across different markets

The density distribution of prices across different market groups reveals clear differences. Prices offered by middle men are the lowest, predominantly ranging between 30 and 45 units. Their distribution is multimodal, indicating several common pricing points within this lower range. The local market prices fall between those of middle men and companies, mostly ranging from 40 to 55 units, and display a unimodal distribution peaking around 48–50 units. Companies exhibit the highest prices, typically ranging from 60 to 80 units, with a pronounced peak near 70 units. Notably, there is some overlap between middle men and local market prices; however, company prices are distinct and considerably higher, with no overlap with the other groups. This pattern suggests a clear stratification in pricing strategies among the three market sectors, with middle men offering the most affordable options and companies commanding premium prices (Fig 3).

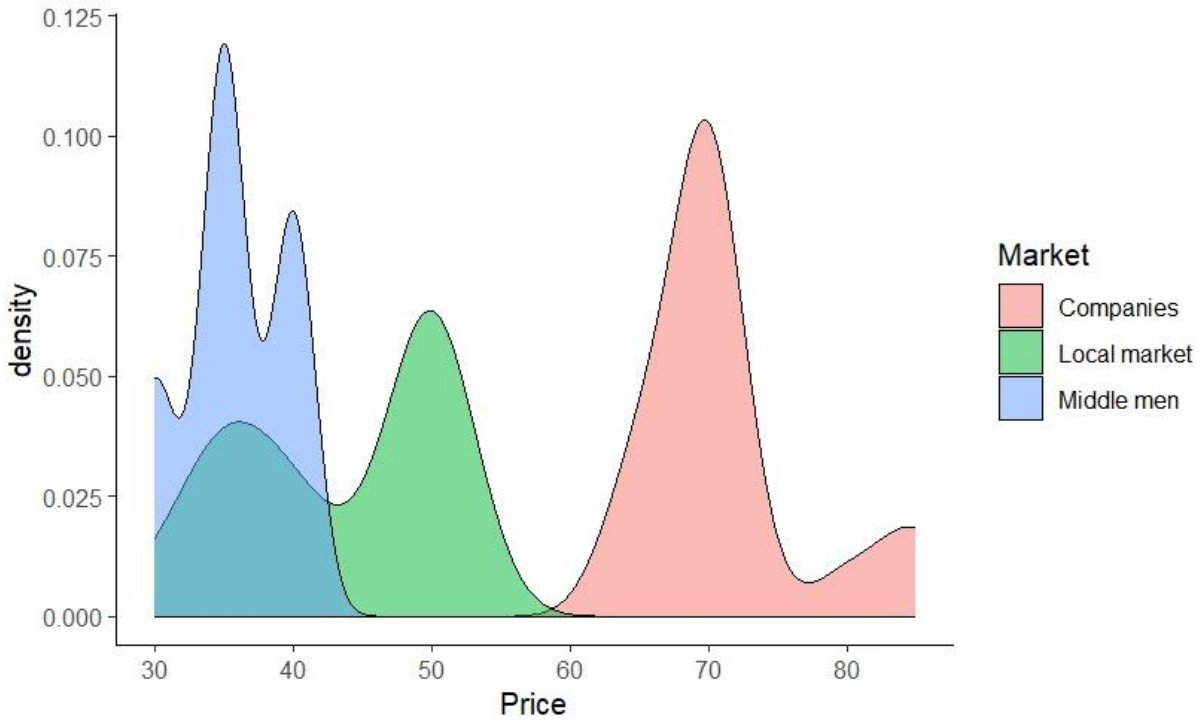

Figure3: Density distribution map of lime prices across different markets shows that middlemen prices range between 30 and 45 units, local market prices fall between 40 and 55 units, while companies exhibit the highest prices, ranging from 60 to 80 units.

Monthly sales and income per crop type

The analysis compared monthly sales (in tons) and corresponding income for two crop types: Lime and Mango. The distribution of monthly income varied substantially between the two crops, as illustrated in Figure 4. Lime crops demonstrated a wider range and higher median income compared to Mango crops. Monthly sales for Lime were typically between 3 and 5 tons, generating a monthly income that ranged from approximately 100,000 to over 400,000 units of currency. The Lime distribution was notably right-skewed, with several instances of exceptionally high income. The median income for Lime was approximately 250,000, as indicated by the central line within the box plot embedded in the violin.

In contrast, Mango crops showed a narrower and lower range of both sales and income. Monthly sales were clustered around 2 tons, with corresponding incomes typically between 0 and 150,000 units of currency. The distribution for Mango was more symmetrical and the median income was significantly lower, at around 80,000 units. Furthermore, the Mango violin plot was more compressed, indicating less variability in income compared to Lime. Overall, Lime cultivation yielded higher and more variable monthly income per crop compared to Mango cultivation. These results suggest that, from an income perspective, Lime may be a more profitable crop choice compared to Mango.

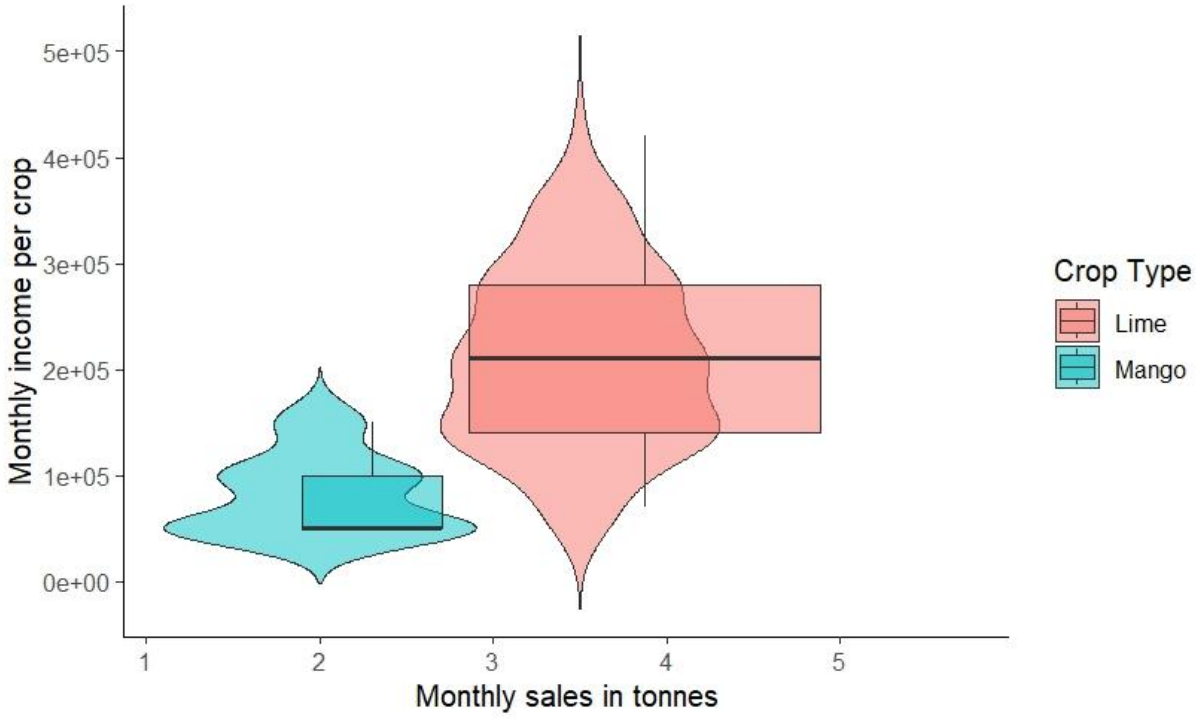

Figure 4: Violin and box plots illustrating monthly sales (in tonnes) and income per crop. Mango income displays a more symmetrical distribution, with a median of approximately 80,000 units. In contrast, lime income is right-skewed, with a higher median of around 250,000 units.

Relationship Between Lime Farming and Giraffe Conflict Incidents

The results reveal an inverse relationship between the area under lime cultivation and the number of giraffe conflict incidents. As the extent of lime farming increases, the frequency of giraffe-related conflicts shows a decreasing trend. Although there is a degree of scatter in the data, the fitted regression line indicates that larger lime farm sizes are associated with fewer conflict incidents. This suggests that lime farming may serve as a deterrent or disincentive for giraffe intrusion, potentially due to the unpalatability of lime trees or structural characteristics of lime farms that restrict giraffe movement (Fig 5a).

To further explore spatial variability in this relationship, the analysis was disaggregated by location (Fig 5b). The data were stratified by three primary sites: Bour Algy, Kamuthe and Sankuri, each represented by a distinct color-coded trendline. A consistent negative association was observed across all three sites, although the strength of the relationship varied. The most substantial decline in conflict incidents with increasing lime farm area was observed in Sankuri, followed by Kamuthe and Bour Algy. Specifically, the slope of the regression line for Sankuri suggests a relatively stronger deterrent effect of lime farming on giraffe conflicts compared to the other two sites.

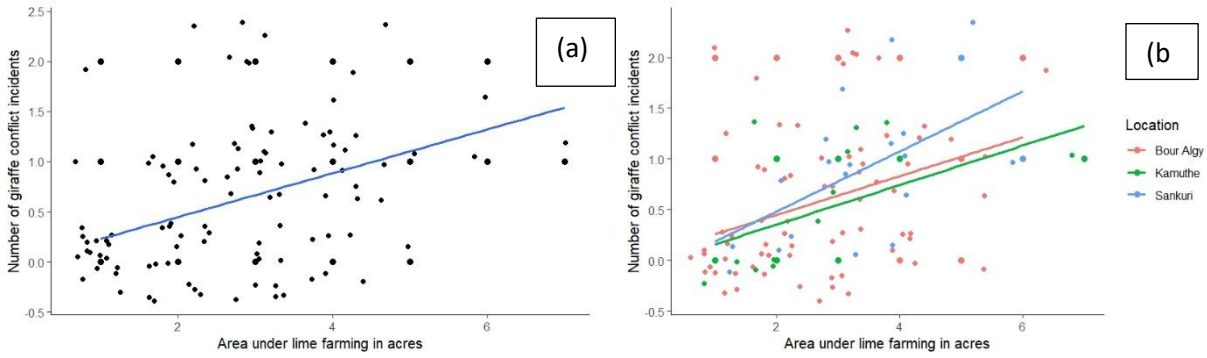

Figure 5: The scatter plot illustrates a negative relationship between lime farm size and the number of conflict incidents reported by farmers, more acres of lime farming are associated with fewer conflicts (Fig. 5a). Fig. (5b) highlights the distribution of conflict incidents across different locations.

Comparison of Giraffe Conflict Incidents Between Lime and Mango Farms

The heat map provides a comparative visualization of giraffe conflict incidents across three study sites, Bour Algy, Kamuthe and Sankuri, based on two crop types: lime and mango. The results reveal a distinct disparity in conflict intensity between the two crops, with mango plantations experiencing significantly higher numbers of conflict incidents compared to lime farms across all locations. In lime farms, conflict levels were consistently low across the three sites, with incident counts ranging from zero to approximately three. Sankuri and Kamuthe recorded minimal conflict levels, while Bour Algy showed slightly elevated but still relatively low conflict frequencies. The corresponding shades of blue on the heat map represent these low levels, reinforcing the pattern

observed in the regression analysis (Figure 5a and 5b), where increasing lime cultivation was associated with fewer conflict events.

In contrast, mango farms exhibited substantially higher levels of conflict, with incident counts reaching up to and above 20 in some instances. Sankuri and Kamuthe recorded the highest number of giraffe conflict incidents associated with mango cultivation, followed by Bour Algy. The heat map clearly reflects this intensity through darker red hues, highlighting the heightened attractiveness or vulnerability of mango crops to giraffe incursions. This suggests that mango farms are likely to be more susceptible to giraffe-related conflict, potentially due to the palatability or accessibility of mango fruits and foliage to giraffes. Overall, the results suggest a crop-specific pattern in conflict dynamics, where mango cultivation poses a significantly greater risk for giraffe conflict than lime farming. These findings underscore the importance of crop selection in conflict-prone regions and provide evidence to support the promotion of less conflict-prone crops such as lime as part of broader human-wildlife conflict mitigation strategies (Fig 6).

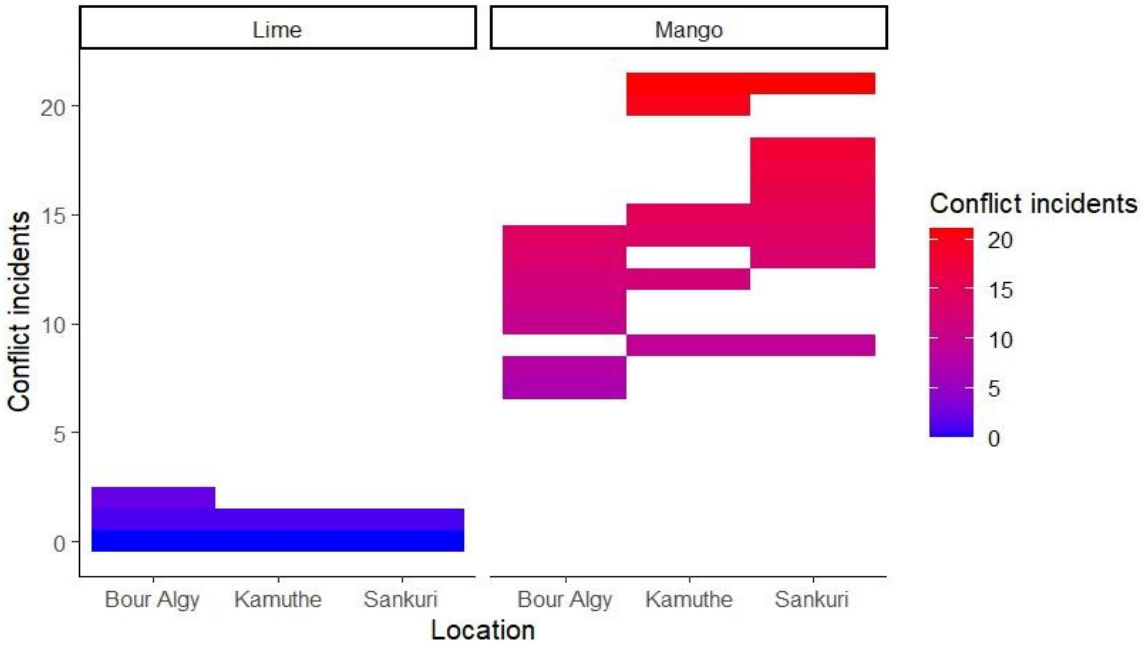

Figure 6: A heat map showing that lime plantations experience fewer conflict incidents compared to mango plantations, which have recorded higher levels of crop invasion across all three locations.

Discussion

The study highlights the potential of lime farming as a dual-benefit intervention in areas prone to giraffe-related crop-raiding. Economically, lime provides a more lucrative and stable source of income for farmers compared to mango, especially when sold to formal company channels. It has been noted that community-based businesses can offer a structure where companies can build mutually beneficial connections with local groups, fostering openness and responsibility within the community (Anyonge-Bashir et al., 2012). Environmentally and socially, lime appears to deter giraffe intrusion, possibly due to its physical characteristics or unpalatability, as shown by consistently lower conflict rates across study sites. The sharp income disparities across market types underscore the importance of structured market access. Farmers linked to companies consistently earned better prices, with fewer price fluctuations than those selling in local markets

or to middlemen. Promoting cooperative structures or direct farmer-company partnerships could thus boost both income and crop security.

Sometimes, positive changes in behavior seem to happen not just because of direct income changes, but because of the overall positive feelings created by the benefits of the business. This includes the belief that the benefits are fairly shared and that they are connected, either directly or indirectly, to a conservation program (Boshoven et al., 2022). From a conservation perspective, redirecting farmers toward less palatable crops like lime can mitigate retaliatory responses toward giraffes, which are sometimes attacked for raiding mango trees. This aligns with the Somali Giraffe Project's approach, which blends conservation goals with livelihood support. Encouraging wider adoption of lime, especially in zones adjacent to giraffe habitats, may help reduce tension between wildlife and local communities while improving household resilience. Future research should assess the long-term ecological effects of widespread lime cultivation and explore whether similar benefits apply to other wildlife species and crops. Overall, this study affirms the role of socially responsible enterprise in bridging human-wildlife coexistence.

In inconclusion, according to Oduor, (2020) community-led natural resource management programs function within intricate social and environmental systems that involve a variety of different stakeholder groups. Lime farming is a profitable enterprise and a conflict-mitigation tool. The crop's lower attractiveness to giraffes, combined with higher and more stable income from company-linked sales, positions lime as a strategic choice for agro-pastoral communities in conflict-prone areas.

Acknowledgments

We would like to express our sincere appreciation for the Somali Giraffe Project's efforts in distributing free lime seedlings to farmers in the region, as part of their commitment to promoting nature-based solutions to the growing conflict between farmers and giraffes. Special thanks are extended to Mr. John Wambua, Director of the Eastern Conservation Area at Kenya Wildlife Service (KWS), and to the KWS Garissa station for their significant contribution to the research. We are also grateful to the Chairperson of the Garissa County Farmers Association for providing valuable information and to the Garissa County Government for granting us permission to collect data at the Garissa lime market.

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