The ecological relationship between the time of the day, environmental conditions and cattle predation by African lions (*Panthera leo*)

Ol Pejeta Conservancy, Kenya

Emma Berglund

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Swedish University of Agricultural Sciences, SLU
Department of Applied Animal Science and Welfare
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The ecological relationship between the time of the day, environmental conditions and cattle predation by African lions (Panthera leo) - Ol Pejeta Conservancy, Kenya

Den ekologiska relationen mellan tiden på dagen, miljöfaktorer och boskapspredation av afrikanska lejon (Panthera leo) - Ol Pejeta Conservancy, Kenya

Emma Berglund

Supervisor:	**Jens Jung, Swedish University of Agricultural Sciences Department of Applied Animal Science and Welfare**
Assistant supervisor:	Maria Andersson, Swedish University of Agricultural Sciences Department of Applied Animal Science and Welfare
Examiner:	Jenny Yngvesson, Swedish University of Agricultural Sciences Department of Applied Animal Science and Welfare

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Keywords: African lions, predation, livestock, moonlight, grass, rainfall, cattle, cover, wildlife-conservation and conservation

Swedish University of Agricultural Sciences
Faculty of Veterinary Medicine and Animal Science
Department of Applied Animal Science and Welfare

Abstract

This study examined the relationship between environmental conditions, the time of the day and cattle predation by African lions (*Panthera leo*) at Ol Pejeta Conservancy, in Kenya, from February 2017 to October 2023. The African lion is classified as vulnerable due to ongoing population decline following losses of habitats and conflicts with humans over livestock. Human-wildlife conflicts constitute a significant challenge to biodiversity conservation and human livelihoods.

Predation patterns were investigated by using incident reports of cattle predation at Ol Pejeta Conservancy during the night, day and in total combined with environmental data of (1) daily rainfall, (2) rainfall for the preceding 90-, 60-, 30- and 7-days, (3) cloud cover, (4) moon phases and (5) remotely sensed estimates of grassland biomass (MSAVI2) as a proxy for grass heights.

Overall, no difference in cattle predation was found between the night and day. The results further revealed that tall grass was associated with a higher number of cattle killed during nights and in total, whereas shorter grass was associated with a higher number of cattle killed during daytime. Furthermore, heavier daily rainfall was associated with more cattle killed during nights and in total. Nights with higher rainfall levels for the preceding 90-days was associated with a higher number of cattle killed. This pattern was also found with higher rainfall levels for the preceding 60-days during night and in total. Contrariwise, lower rainfall levels for the preceding 60-days, resulted in a higher number of cattle killed during the day. Lastly, first quarter moon resulted in more killed cattle during nights, whereas lighter moonlight levels, specifically full moon, was associated with more cattle killed during the day.

Cattle predation is reported to increase during rainier conditions, denser vegetation and darker conditions, most likely as lions can stay undetected from prey or that wild prey is more dispersed, causing lions to switch to domestic prey. However, the findings of this study suggest that it is of importance of taking the time of the day into consideration, as the impact of the environmental conditions on cattle predation varied during the night, day and in total. By including the time of the day, a better insight of how especially different moon phases influence predation was captured. Around days with full moon, increased predation was observed during the day, most likely as lion are unsuccessful hunting with more luminosity during the night. Thus, by including the time of the day, a more nuanced understanding of how environmental conditions influence predation may be obtained. Importantly, variations in climatic conditions due to climate change is expected to intensify human-wildlife conflicts. Understanding the ecological part of human-wildlife conflicts is therefore highly important. The findings of this study can be used by farmers, conservation practitioners or other involved parts into tailoring mitigation strategies and promote long-term co-existence of lions and humans.

Keywords: African lions, predation, livestock, moonlight, grass, rainfall, cattle, cloud cover, wildlife-conservation and conflicts

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Abbreviations

DMR	Daily Mortality Reports
HWC	Human- wildlife conflicts
SLU	Swedish University of Agricultural Sciences
OPC	Ol Pejeta Conservancy
MSAVI2	Modified Soil-Adjusted Vegetation Index
NDVI	Normalised Difference Vegetation Index

1. Introduction

The importance of top-order predators, such as the African Lion (*Panthera leo*), is highlighted through their key functional role in regulating trophic cascades and by their competitive and predatory interactions with other species (Letnic *et al*., 2011). Reductions or disturbances in these interactions can have ecosystem-wide consequences (Letnic *et al*., 2011). However, the African lion (hereafter: lion) has lost a significant proportion of its population size and range, and the remaining individuals has been estimated to approximately 23.000 according to IUCN Redlist (Redlist assessment; Nicholson *et al*., 2023). The decline is largely driven by fragmentation and loss of habitats, over-exploitation and conflicts with humans due to predation on livestock (Woodroffe, 2000, Ripple *et al*., 2014, Kenya Wildlife Service, 2020; Abrahams *et al*., 2023). Such conflicts are commonly referred to as human-wildlife conflicts (HWC) and are generally defined as negative interactions that occurs between people and wildlife (Nyhus, 2016). Predation on livestock by lions is associated with adverse socio-economic impacts on people's livelihood, leading to frequent cases of retaliatory persecution of lions (Lindsey *et al*., 2017; Di Minin *et al*., 2021). Conservation efforts of lions are therefore significantly challenged by these conflicts (Lindsey *et al*., 2017; Di Minin *et al*., 2021).

A considerable percentage of human-wildlife conflicts are observed in East African countries, such as Kenya (Beck *et al*., 2019), commonly outside protected areas in arid and semi-arid lands, where there is a predominance of agriculture and pastoralism, which depend heavily on livestock production with cattle as their main source of income (Kissui, 2008; Ontiri *et al*., 2019; Beck *et al*., 2019; Becker *et al*., 2022). Protected areas, including natural reserves and wildlife sanctuaries, has been established in effort to protect lions and other wildlife (Lindsey *et al*., 2017; Long *et al*., 2020). However, because of the rapid growth of human populations outside these protected areas, has led to encroachment with reduced effectiveness of protected areas and increased risk of conflicts with humans over livestock (Wittenmyer *et al*., 2008; Balme *et al*., 2010; Blackburn *et al*., 2016). Facilitating long term co-existence between humans and wildlife has therefore become a growing priority to prevent wildlife extinctions and sustain rural communities (Killion *et al*., 2021). To achieve this, implementing effective mitigation strategies that reduce these conflicts is crucial (Di Minin *et al*., 2021).

1.1 Current and future mitigation strategies for human-wildlife conflicts

Several mitigation strategies exist globally and can be classified into lethal versus non-lethal strategies (Nyhus, 2016). Lethal control, commonly unregulated, has been widely used for managing damages resulting from lions, since it is considered cost-efficient and effective at limiting losses of livestock (Nyhus, 2016; van Eeden *et al*., 2018). This is often manifested as retaliatory persecution, by using poison, traps or weapons (Acha & Temesgen, 2015; Sibanda *et al*., 2022). A significant issue associated with this strategy does not only include the killing of lions, but also by the non-specific or indiscriminate killing of lions, where all ages and sexes are being killed (Palmer *et al*., 2023). This may cause social disturbances within prides, leading to negative impacts on the lions themselves and on the broader environment through negative impacts on natural predator-prey relationships (Palmer *et al*., 2023). In addition, using poison have a detrimental effect on other animals and on the environment in general, since it is not a targeted mitigation strategy (Nattrass & Conradie, 2018). Regulated lethal control on the other hand, include controlled targeted persecution combined with monitoring of animals (Nyhus, 2016). These control methods are nowadays mostly used on abundant wildlife populations or to remove specific aggressive individual animals that has been directly threatening human life (Treves & Karanth, 2003; Nyhus, 2016).

Non-lethal control efforts are often preferred from a wildlife and conservation perspective (Nyhus, 2016). These efforts include translocation of animals, establishments of predator proof barriers, guarding and economic incentives to increase tolerance for predators (Nyhus, 2016). The effectiveness of translocating wild animals to other areas is however debated (Fontúr & Simonetti, 2011). Moving animals long distances is often impractical and expensive (Fontúr & Simonetti, 2011). Furthermore, several translocated animals have not been able to acclimatise in their new environment or have been involved with new conflicts with humans over livestock, which questions the efficacy of translocation as a non-lethal method (Treves & Karanth, 2003; Goodrich & Miquelle, 2005; Stamps & Swaisgood, 2007; Fontúrbel & Simonetti, 2011; Nyhus, 2016; Morapedi *et al*., 2021).

Evidence stress that mitigation strategies need to generate benefits for both wildlife and humans to achieve long term co-existence (Killion *et al*., 2021). In regards of producing benefits for both wildlife and humans, improved livestock husbandry practices including attentive herding, guarding dogs and barriers, has proven to be most successful although these strategies expose people to danger (Ogada *et al*., 2003; Patterson *et al*., 2004; Woodroffe *et al*., 2007; Killion *et al*., 2021). Particularly attentive livestock herding and guarding dogs have been found to reduce conflicts with lions, both when livestock have been quartered in predator proof- enclosures called bomas or kraals and when they have been out grazing (Ogada *et al*., 2004; Woodroffe *et al*., 2007; Mkonyi *et al*., 2017; Chaka *et al*., 2021). For livestock husbandry practices to be a successful mitigation strategy, understanding of predation patterns of lions is needed as these patterns both vary spatially and temporally.

1.2 Ecology of the African lion

Lions are considered opportunistic and flexible predators, as their diet shows a large variation of prey (Hayward & Kerley, 2005; Barnardo *et al*., 2020). They primarily prey on medium- to large-sized ungulates (zebra *Hippotigris*, wildebeest *Connochaetes* and antelopes) and buffalos *Syncerus caffer* (Hayward & Kerley, 2005). However, hunts on other prey may be utilized if preferred prey are scarce (Eloff, 1984 in Hayward & Kerley, 2005; Sheel & Packer, 1991; Stander, 1992). Within prides, hunting is predominantly performed by female lions through cooperation (Funston *et al*., 2001; Loarie *et al*., 2013). By cooperating during hunts, lions are more likely to catch their prey and thereby sustaining their metabolic needs (Scheel & Packer, 1991; Stander, 1992). Male lions obtain their food from scavenging on killed prey obtained by female lions but may assist if hunting is performed on larger prey (Funston *et al*., 1998). Yet, solitary hunting by males may be observed in relation to the dispersal from their natal pride to form a new one (Hanby & Bygott, 1987; VanderWaal *et al*., 2009).

The term predation could be defined as "*The process by which an animal spends some effort to locate a live prey and, in addition, spends another effort to mutilate or kill it*"- Curio (1976). When and where predation by lions occur, may vary through space and time, influenced by factors as prey availability, catchability or vulnerability (Hopcraft *et al*., 2005; Owen-Smith, 2019; Beattie *et al*., 2020; Kittle *et al*., 2022; Mills *et al*., 2024). Prey catchability commonly refers to how environmental features may support lions while hunting (Beattie *et al*., 2020). Since lions are considered stalk-and ambush hunters, environmental features that provide cover or concealment while hunting, may result in increased prey catchability and hunting success (Funston *et al*., 2001; Hopcraft *et al*., 2005; Davies *et al*., 2016; Beattie *et al*., 2020). Equally, these environmental features may increase prey vulnerability (Hopcraft *et al*., 2005; Kittle *et al*., 2022). However, the vulnerability of prey may also be influenced by its' own body condition, prey group size and defence mechanisms expressed (Owen-Smith, 2015). Other factors as prey activity patterns and metabolic needs of the lion could also influence where and when predation may occur (Palmer *et al*., 2017).

Especially in arid savannah ecosystems (relevant for the current study), prey availability, catchability and vulnerability, are influenced by the highly variable precipitation, through its effect on available drinking water, high-quality forage and vegetation cover (Western, 1975; Riggio *et al*., 2013; Owen-Smith, 2015; Kittle *et al*., 2016). Migrations of wild prey usually follow seasonal patterns of rainfall (Patterson *et al*., 2004). During rainier conditions, forage and the availability of drinking water is normally greater, and prey are usually more abundant and have a greater body condition compared to drier conditions (Western, 1975; Patterson *et al*., 2004; Owen-Smith, 2015). In addition, with a more abundant vegetation, the catchability and vulnerability of prey may be increased as it may provide cover while lions are hunting. Yet, other variables may also influence prey availability, catchability or vulnerability. Importantly, the amount of light reflected by the moon, has been found to affect foraging behaviours of several species during the night (Preston *et al*., 2019; Botts *et al*., 2020). At night, the moon represents the brightest natural source of light and higher percentage of the moon disk illuminated normally generate brighter nights, while less percentage give darker nights (Pusching *et al*., 2014; Huck *et al*., 2017; Kyba *et al*., 2017). Animal response to the moon is likely a trade-off between enhanced vision with improved resource and predator detection through increased moonlight, and by using the darkness for concealment of predators (Pusching *et al*., 2014; Trail *et al*., 2016; Śmielak, 2023). Therefore, the catchability and vulnerability of prey may also vary depending on light levels. Furthermore, cloud cover may also influence light levels through its effect on moonlight (Krieg, 2021) and therefore the catchability and vulnerability of prey. A higher percentage of cloud cover during the night can supress the light provided by the moon and make it darker (Krieg, 2021). Following the influence of environmental conditions on prey availability, catchability and vulnerability, changes in these environmental conditions, are likely having impacts on predation patterns. Since lions are opportunistic stalk-and ambush hunters, reduced densities of preferred prey or because preferred prey are harder to catch, may cause lions to hunt livestock instead (Packer *et al*., 2004; Holmern *et al*., 2007; Beattie *et al*., 2020; Oliver *et al*., 2023). In turn, the risk of human-wildlife conflicts is heightened. Especially, cattle (*Bos Taurus*), are highly susceptible as an alternative source of prey for lions, as cattle are within lions preferred prey weight range (Hayward & Kerley, 2005).

Despite the significant progress in understanding how environmental conditions influence predation on livestock, there are still some uncertainties remaining. Earlier research has addressed seasonally variable livestock predation and found attacks to increase during either rainier or drier conditions (Butler, 2000; Patterson *et al*., 2004, Woodroffe & Frank, 2005; Kissu, 2008; Loveridge *et al*., 2017; Western *et al*. 2021). Increased or decreased livestock predation during these conditions, is likely related to local wild prey availability (Kissui, 2008). Rainier conditions may also generate greater vegetation cover which could potentially increase catchability of livestock by helping lions to be concealed (Beattie *et al*., 2020). On the other hand, the body condition of wild prey may increase during the conditions, leading to decreased hunting success (Owen-Smith, 2015), causing lions to hunt livestock instead. However, the effect of rainfall in arid and semi-arid lands is rather cumulative due to soil properties (Western, 1975; Shinoda, 1995). Furthermore, the establishment of artificial waterholes (as this study area Ol Pejeta Conservancy have several of) can interrupt the typical seasonal migration patterns of wild prey, that occur during rainy season versus dry season (Smit *et al*., 2007; Holdo *et al*., 2009; Bennit *et al*., 2022; Mills *et al*., 2024). Thus, rather than rain seasons, investigating the impact of preceding rainfall is therefore significant in these lands. In addition, daily rainfall events may also influence predation patterns through its effect on visibility, olfactory and auditory ques. Studies analysing daily rainfall events on carnivores are limited, since most studies have focused on the effect of seasons or preceding periods of rainfall (Patterson *et al*., 2004; Robertson *et al*., 2020; Oliver *et al*., 2023). Furthermore, it is plausible that grass heights could trigger changes in predation patterns, since many prey species feed on grass and because the height of the grass could generate cover for predators (McNaughton, 1983 in Hopcraft *et al*., 2005; Owen-Smith *et al*., 2010; Owen-Smith, 2015). Earlier research analysing lion attacks on livestock, have investigated the overall effect of vegetative productivity or quality using the normalized difference vegetation index (NDVI) and have not specifically focused on grass heights (Beattie *et al*., 2020; Oliver *et al*., 2023). For instance, Beattie *et al*. (2020), found that greater vegetive productivity increased the risk of lion attacks on livestock in Botswana. On the contrary, Oliver *et al*. (2023) found no association between livestock lost and vegetative quality in southern Kenya. The impact of environmental conditions may, however, differ locally depending on the ecogeographical properties in a specific habitat (Patterson *et al*., 2004; Kissui, 2008; Chege *et al*., 2024) thus why it is important to further analyse these variables in different ecosystem. Furthermore, although several studies have found darker nights, specifically moonless nights or when the moon has been partly concealed by clouds, to increase wild prey catchability (Van Orsdal, 1984; Funston *et al*. 2001; Preston *et al*. 2019) and fuller bellies on lions (Packer *et al*., 2011), less is investigated on livestock predation relative to these environmental conditions. In Oriol-Cotterill *et al*. (2015), lions travelled closer to enclosures with livestock at lower moonlight levels during the night, whereas Robertson *et al*. (2020) found increased risk of livestock predation at nights around new moon. Regarding cloud cover, the impact is unclear. However, following the impact of cloud cover on wild prey, cloud cover is likely having impacts on livestock predation as well. Lastly, while lions are considered nocturnal predators, they are frequently observed to hunt during the day (Schaller, 1972;

Ogada *et al*., 2003; Kissui, 2008). While the night most likely produces the most benefits for lions, earlier research has addressed both increased rates of livestock predation to occur during the day when cattle are out grazing, as well as during the night the most cattle are quartered in kraals (Ogada *et al*., 2003, Kissui, 2008).

1.3 Main objective

Considering these uncertainties and to create mitigation strategies that produce benefits for both wildlife and humans, this study aims to examine how environmental conditions and the time of the day influence cattle predation by lions. This is done by using nearly 7 years (2017-2023) of reported predation events by lions during the night, day and in total at Ol Pejeta Conservancy in Kenya, combined with environmental data of (1) daily rainfall, (2) rainfall for the preceding 90-, 60-, 30- and 7-days, (3) cloud cover, (4) moon phases and (5) remotely sensed estimates of grassland biomass (MSAVI2) as a proxy for grass heights. By analysing these factors, this study seeks to contribute to a more detailed understanding in when potential human-wildlife conflicts may occur and facilitating long term co-existence between lions and humans.

To address the aim of this study, the following research questions was formulated:

- When does predation on cattle take place during the day?
- Are there any effects of different levels of daily rainfall, rainfall for the preceding 90-, 60-, 30- or 7-days, cloud cover, moon phases or grass heights on cattle predation during night, day or in total?
- Does the effect of each or any environmental predictor vary depending on the time of the day?

Based on these questions, it was hypothesized that**:** (H1) a higher occurrence of predation on cattle takes place during the night compared to the day; (H2) higher rates of predation on cattle occur with heavier daily rainfall during the night, day and in total; (H3) higher rates of predation on cattle occur with higher average rainfall levels for the preceding 90 days during the night, day and in total; (H4) higher rates of predation on cattle occur with higher average rainfall levels for the preceding 60 days during the night, day and in total; (H5) higher rates of predation on cattle occur with higher average rainfall levels for the preceding 30 days during the night, day and in total; (H6) higher rates of predation on cattle occur with higher average rainfall levels for the preceding 7 days during the night, day and in total; (H7) higher rates of predation on cattle occur with higher percentage of cloud cover on the sky during the night, day and in total; (H8) higher rates of predation on cattle occur with darker moon light levels during the night and total; (H9) higher rates of predation on cattle occur with taller grass heights during the night, day and in total; (H10) the effect of moon phases of predation on cattle vary depending on the time of the day, whereas the effect of the remaining environmental conditions will not.

Importantly, although this study focuses on environmental conditions, it is important to acknowledge that other factors such as husbandry practices may also influence the risk of livestock predation. For instance, guardian dogs, human activity and construction of bomas (kraals) has been reported to be associated with livestock predation (Ogada *et al*., 2003; Kolowski & Holekamp,2006; Kissui, 2008; Woodroffe *et al*., 2007; Loveridge *et al*., 2017). These factors will not be examined in the analysis but will be addressed in the discussion.

2. Material and Methods

2.1 Study site

This study was conducted at the not-for-profit wildlife reserve Ol Pejeta Conservancy (OPC), covering about 400 km^2 in Laikipia County, Kenya. The conservancy is considered to contain with one of the highest densities of wildlife in Kenya and engages in an integrated system of wildlife conservation and livestock production with cattle (Ol Pejeta Conservancy, 2024a). The cattle herds consist of a smaller Ankole cattle herd and a larger herd of approximately 7000 Boran cattle (*Bos primigenius indicus*), managed with traditional livestock husbandry techniques. Each herd, of approximately 100 to 150 animals, is normally herded by two guards to grazing areas and water points during the day and return to metal-fenced mobile-bomas (corrals or kraals) at night. Typically, the herds leave around 7 A.M and return 6 P.M (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-01-03). During the night, cattle are guarded by two people that also sleeps next to the boma. Bomas are relocated based upon resource availability, normally after 7-10 days during dry season and after 3-5 days during rainy season (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-01-03). The 50 herds of Boran cattle are divided after age and stage in lactation or reproduction cycle (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-01-03).

The border around OPC is electrical fenced except for the wildlife corridors that allows migration of wildlife in and out of the conservancy (Ol Pejeta Conservancy, 2023a). The conservancy support more than 100 lions divided into six or nine prides, which are closely monitored by the Ecological Monitoring Unit (EMU) in OPC. The unit engages in controlling and maintaining a dynamic wildlife population in the conservancy (Ol Pejeta Conservancy, 2023b). Apart from conserving wildlife, the property provides a sanctuary for the only two remaining northern white rhinos (*Ceratotherium simum cottoni*) (Ol Pejeta Conservancy, 2024b).

The conservancy receives an average mean annual rainfall of 750 mm (Kavwele *et al*., 2017) which typically occur during the two rainy seasons in March-May and October-November (Nicholson, 2017). Habitat cover is characterized by semi-arid savannah grass-and woodland, with dense bush covering most of the land of specie *Euclea divinorum* (Ol Pejeta Concervancy, 2023c). Open bushlands cover approximately 25% of the reserve with *Acacia drepanolobium* (Ol Pejeta Concervancy, 2023c). Grasslands are dominated by the grass species *Penisetum mezianum, Themeda triandra* and *Penisetum strimineum* (Ol Pejeta Conservancy, 2023e). The rest of the conservancy (2%) consists of riverine and swamp/marsh areas (Ol Pejeta Conservancy, 2023c). Artificial waterholes are distributed across the reserve with only a few kilometres in between, acting as supplements for the one permanent river flowing through the reserve (Kavwele *et al*., 2017; Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-01-03).

2.2 Data collection and sorting

All data used in this study was collected between February 18^{ths} 2017 and October 22th 2023. The precise data collection period comprised 2330 days due to 108 days of missing predation data.

2.2.1 Predation

Within this study, the term predation refers to an occurrence where lions had killed cattle. Cattle predation was obtained using data from "Daily Mortality Reports" (DMR) which contained daily reports of dead cattle observed in Ol Pejeta Conservancy. The DMR file included the date (year, month, day) and time of the day of when cattle were killed, cattle category (calf, heifer, steer, cow, bull), ID/dam number, chip number of cattle, location of dead cattle, responsible herder, predator responsible for the attack and reported by. Data were mainly collected and verified by rangers and herders taking care of the cattle. Based on the objective of this study, only data of when (date and time of the day) cattle were killed and predator responsible of the attack was included the analysis. Cattle category and location were therefore not considered.

Observing an ongoing predation event by a lion was rare. Therefore, predation data consisted mostly of cattle that was already found dead. Predator responsible for the attack were determined through post-mortem analysis and visual inspection, by identifying predator-specific injuries on the carcass. Classification regarding at what time the cattle was killed by a lion, was based on a combination of missing cattle observed by the herders and the condition of the carcass found (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-07-02).

Cattle are continuously tracked and checked by the herders, both in the morning when cattle leave for grazing and when cattle return to bomas during the night (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-07-02). This enables detection of missing cattle that have accidentally been left behind. Rangers and herders will then search for the missing cattle and if found dead, determine if the killing took place during the day or night. The killing was categorised as unknown if the timing of the killing was uncertain. However, on several occasions, lions have jumped into the boma during the night and killed cattle. Roaming lions outside the boma have also caused cattle to break through the boma and as a result got killed. On these occasions, the classification of what time the killing took place and predator response of the killing could be determined immediately (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-07-02). However, the exact number of these specific causes of death were not available but is mentioned for awareness. Furthermore, as mentioned above, cattle in Ol Pejeta Conservancy are herded to grazing areas at 7 A.M and return 6 P.M to bomas, therefore, the time between 7 A.M and 6 P.M was classified as day while the remaining hours of the day were classified as night in this study. Thus, nighttime was defined as 13 hours and daytime as 11 hours.

All predation data relating to lions within the "Daily Mortality Reports" file, were transferred to a spreadsheet (Microsoft Excel) with all dates from February 18^{ths} 2017 until October 22th 2023. Predation events were then summarized per day, month and year, resulting in a dataset of both predation and non-predation events (when zero predation took place). The data were further organised into columns as predation during the night, predation during the day, predation during unknown time of the day and total predation. Total predation comprised all predation by lions. In this study, three response variables were explored: cattle predation during night, day and in total.

2.2.2 Grass height

To measure grassland biomass, satellite remote sensing technology was used. Remote sensing is the use of reflected or emitted energy to measure the physical properties of distant objects, making it possible to identify and estimate earth surface features and the corresponding geo-biophysical properties (Moore, 1979; Roy *et al.*, 2017) such as grassland biomass.

Satellite images were obtained from Sentinel- 2 (ESA, EU), which is a multispectral imaging mission consisting of two identical satellites Sentinel - 2A and Sentinel – 2B (Phiri *et al.*, 2020). They operate simultaneously, every day and cover all continental land surfaces between latitudes 56° South and 82.8° North (Phiri *et al.*, 2020). Images were used to estimate grass biomass content using the Modified Soil-

Adjusted Vegetation Index (MSAVI2). MSAVI2 was chosen since it is considered a more sensitive indicator of vegetation productivity in areas containing bare soil (Qi *et al*., 1994), commonly in arid and semi-arid lands. The MSAVI2 formula is as follows;

$$MSAVI2 = \frac{(2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)}}{2}$$

where NIR is the reflectance in the near-infrared band of a sensor, RED is the reflectance in the near-infrared bands of a sensor and L is a soil brightness correction factor (Qi *et al*., 1994). The calculation of the MSAVI2 was performed by Mats Söderström, Swedish University of Agricultural Sciences, Skara.

Grasslands biomass content was recorded for total 13 areas (Figure 1) once every week on cloud free days. However, only the 10 areas within Ol Pejeta Conservancy were used in this study, since cattle herds of the conservancy generally do no stay outside of the borders. An average grassland biomass content was made from these 10 measurements, with the purpose to generate a general estimation of the grassland biomass content inside the borders of the conservancy. Since satellite images were not provided each day, an estimated average daily grassland biomass content was calculated between each measurement following a straight-line equation, covering all days from February 18th 2017 until October 22th 2023.

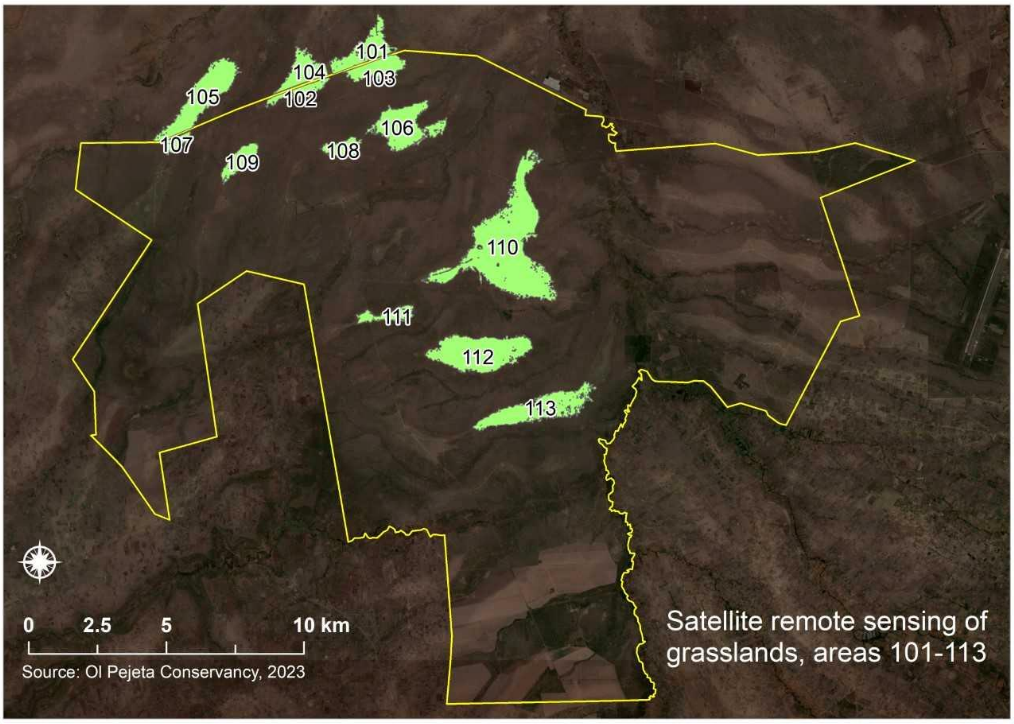


Figure 1. Map of Ol Pejeta Conservancy indicating the different regions of grasslands measured using satellite remote sensing, with 10 points inside the conservancy and 3 points outside (Map:Mats Söderström, Swedish Agricultural University (SLU), Skara

Since MSAVI2 act as an indicator of grassland biomass or vegetation characteristics (Qi *et al*., 1994) and because grass biomass most likely correlates with grass heights (Dusseux *et al*., 2022), the predicted grassland biomass content was used as a proxy for grass height in this study. Three levels of grass heights were defined according to the size of the MSAVI2 index (Table 1). These levels were obtained by sorting the MSAVI2 values in size order and then dividing them into three approximately equal groups based on the number of days in this study.

Table 1. Levels of grass height (MSAVI2) with corresponding days (n) in each level.

Grass height	**MSAVI2 index values**
Short grass	0.2300-0.3779 (n=775)
Medium high grass	0.3780-0.5104 (n=777)
Tall grass	0.5105- 0.8153 (n=778)

2.2.3 Moon phase

Daily percentage of the moon disk illuminated was downloaded from Timeanddate.com (timeanddate 2024). According to Timeanddate, illumination is calculated based on when the moon is the highest on the sky, so called "lunar noon". During days when the moon did not pass the meridian (lunar noon), illumination was therefore added manually. These values were obtained by calculating the average illumination value based on the day before and after the specific day. These values were then compared with moon data from Mooncalc.org (mooncalc.org, 2024). The illumination value was then used as proxy for illumination levels across the entire day (24hours).

Earlier studies analysing lion behaviour in relation to the moon, have categorised the moon phases commonly into two or three phases, or as a continuous variable (Funston *et al*., 2001; Oriol-Cotterill et al., 2015; Palmer *et al*., 2017; Preston, 2019; Robertson *et al*., 2020). However, to sustain the darkest and brightest periods of the moon, as well as the period before and after respective full moon and new moon, four moon phases was formulated in this study, based on the percentage of the moon disk illuminated (Table 2). Initially, eight moon phases were considered, since eight phases include all intermediate phases of the moon (waxing crescent, waxing gibbous, waning gibbous, waning crescent) (Śmielak, 2023). However, prior to the model formulation, the overall fit of the models including eight moon phases was poor, though why four phases were chosen instead.

To sustain the spike of brightness close to full moon (Śmielak, 2023) days with illumination levels between 84-100% was categorized as full moon. Consequently, when defining the four phases, it was not possible to rank all four groups into approximately equal group sizes, see table 2.

Table 2. Classification of moon phases based on illumination levels, with number of days (n) in each phase.

Moon phase	% of the moon disk illuminated
New moon	0-16.4% (n=591)
First quarter moon	16.5-83.9% (n=534)
Full moon	84-100% (n=660)
Third quarter moon	16.8-83.9% (n=545)

2.2.4 Rainfall and cloud coverage

Total daily rainfall was obtained from VisualCrossing (VisualCrossing, 2024), with data collected from two weather stations located in Nanyuki City, approximately 20 kilometres away from Ol Pejeta Conservancy. To investigate the impact of daily rainfall, three levels of total daily rainfall were defined according to the categorisation of Ongoma *et al*. (2018); low rainfall: <1 mm (n=1613), heavy rainfall: >1 - <10 mm (n= 824), and very heavy rainfall: <10 – 110 mm (n=276).

Moreover, since the effect of rainfall in arid- and semi-arid lands is rather cumulative (Shinoda, 1995), the average rainfall for the preceding 90-, 60-, 30- and 7-days was also analysed in this study. Within each group of days, three levels of rainfall were defined, based on the amount of rainfall (Table 3). These levels were obtained by sorting the rain data in size order and then dividing it into three approximately equal groups based on the number of days in this study.

Table 3. Levels of the average rainfall (mm) for the preceding 7-,30-,60- and 90-days, with the number of days (n) in each level.

Level	7 days	30 days	60 days	90 days
Low rainfall	0-0.737 (n=768)	0-1.2176 (n=756)	0- 1.385 (n=758)	0-1.884 (n=805)

Medium high rainfall	0.739-3,064 (n=769)	1.2177-3.509 (n=775)	1.392-4.053 (n=812)	1.887-4.169 (n=751)
High rainfall	3.065- 32.4 (n=793)	3.510- 20.1 (n=799)	4.057-14.186 (n=760)	4.170-12.0 (n=774)

The average daily cloud cover data was downloaded from Visual Crossing (VisualCrossing, 2024). Three levels of cloud cover were defined based on the average daily amount of cloud cover in percentage (Table 4). Each level was obtained by sorting the cloud cover data in size order and then dividing it into three approximately equal groups based on the number of days in this study.

Table 4. Levels of average daily cloud coverage in percentage with the number of days (n) in each level.

Level	**Cloud coverage (%)**
Clear skies	4.3- 56.7% (n= 775)
Partly cloudy	56.8- 75.6% (n=776)
Cloudy/Overcast	75.7- 98.6% (n=779)

2.3 Model formulation and data analysis

Each explanatory variable and response variable were sorted by date and time in Excel (Microsoft Excel) and statistical procedures were conducted in Minitab software, version 19.2020.1.0. Normality of the three response variables; cattle predation during the night, day and in total - each expressed on a daily scale, was analysed ocularly with histograms and showed a non-normal distribution with an excessive zero-inflation. The zero-inflation resulted from many days with zero predation in Ol Pejeta.

Poisson regression models are widely used for identifying what variables that predict the rate or frequency of an event and are considered the simplest count regression model (Elhai *et al.*, 2008; Wu & Little, 2011). Compared to linear regression models, which assumes normal distribution, the Poisson regression model fit data better that are not normally distributed (Hutchinson & Holtman, 2005; Elhai *et al.*, 2008; Sellers & Scmueli, 2010). Thus, a Poisson regression model was fitted to test whether the ranked effect of each environmental variable together influence predation rates (the number of cattle killed) during the night, day and in total. The same test was also used to identify whether the ranked effect of the environmental variable on the response variables, varied depending on the time of the day. However, a Goodness-of-Fit test for Poisson indicated that the data of each response variable do not follow a Poisson distribution perfectly (night= $p<0.001$; day=$p<0.0001$; total= $p<0.001$), most likely because of the zero-inflated dataset. Consequently, overdispersion is prevalent, resulting in biased parameter estimation and underestimated standard errors. Alternative models, such as Quasi-Poisson regression, negative binomial regression, zero-inflated or hurdle models (Hoef & Boveng, 2007; Feng, 2021) was considered to account for the overdispersion and zero-inflation. However, these models could not be performed due to limitations in Minitab Software. Poisson regression was therefore kept as model for analysing the relationship between environmental conditions and cattle predation.

Before the final Poisson regression model analysis, multicollinearity was checked. Explanatory variables with variance inflation factor (VIF) <2 were excluded. Furthermore, a Pearson Pairwise comparisons was used to investigate whether the environmental variables was correlated. The Peason Pairwise comparison showed a high correlation between the average rainfall for the preceding days 90-days and grassland biomass (r_p=0.68, $p<0.001$) as well as for the average rainfall for the preceding days 60-days and grassland biomass (r_p=0.71, $p<0.001$). Because of the aim of this study, regarding whether grass heights and preceding days of rainfall influence the response variables, each of these variables were kept with caution when included in the same model.

To test the hypothesis whether the occurrence of predation is higher during the night compared to the day, a non-parametric analysis, chi-square "χ^2 test was fitted. Only predation data during the night and the day was considered in the chi-square test analysis, not days with unknown timing of predation.

Model analysis

Four final multivariable Poisson regression models (1-4) were formulated to test whether the ranked environmental variables influence the response variables. Four models were formulated to separate and investigate the average rainfall for the preceding 90-,60-,30- and 7 days in relation to the other explanatory variables.

1 $$Y' = Intercept + 90days\ rain + daily\ rainfall + moon\ phases + grass\ heights + cloud\ cover$$

2. $$Y' = Intercept + 60days\ rain + daily\ rainfall + moon\ phases + grass\ heights + cloud\ cover$$

3. $$Y' = Intercept + 30days\ rain + daily\ rainfall + moon\ phases + grass\ heights + cloud\ cover$$

$$\mathbf{4}.\quad Y' = Intercept + 7days\ rain + daily\ rainfall + moon\ phases + grass\ heights + cloud\ cover$$

If the explanatory variable was found to significantly affect the response variable, while holding the other explanatory variables constant in the model, a subsequent Poisson Regression test was made to investigate if the variable alone affected the response variable and to assess for differences between each level. The subsequent test was also performed to test the hypothesis whether the effect of each environmental variable varied depending on the time of the day. Initially, a Kruskal-Wallis test was considered. Kruskal-Wallis test is a non-parametric test that is suitable for analysing and comparing more than two groups or rank data (Ostertagová *et al*., 2014). However, since the test compares the median of each rank, the test was not suitable in this study, because the median of the response variables was zero, following the zero-inflated dataset. Instead, since the interpretation of the results from the Poisson regression is relative to the reference level of the explanatory variable, the reference level (intercept) of the environmental variable was changed, to change the interpretation of the model, without changing the overall fit (Winter & Bürkner, 2021). By doing this, an indication of how each level influence the response variable level was obtained. Thus, no formal post hoc test was made.

Alpha levels for the Poisson Regression test and the chi-square test were set to $p \leq 0.05$. To interpret the regression coefficients from the Poisson Regression output, the coefficients estimates was transformed into incidence rate ratios (IRR). Furthermore, the predicted mean of predation rates obtained from the Poisson regression was visualised in graphs, where error bars were based on the confidence intervals. Descriptive statistics, specifically the observed mean of predation rates (raw data), standard mean error, relative to the environmental variables are visualised in pivot tables to give the reader an overview of the dataset.

3. Results

3.1 General predation patterns by lions

Totally, 323 cattle were killed by lions in Ol Pejeta Conservancy within the study period (2017-2023), where 168 individuals were killed during the night, 109 individuals during the day and 46 individuals during unknown time of the day. Number of cattle killed per predation event, varied from 1 to 10, where one predation event was most common while 10 was extremely rare. The results further revealed that out of the data collection period of 2330 days, zero predation took place for 2101 days (90.3 %). Additionally, 114 nights and 90 days were registered with at least one predation event, whereas 25 days were registered with at least one predation event during unknown time of the day. The chi-square test revealed a statistical tendency towards a difference between the occurrence of predation between the night and day, with p=0.085 and χ^2 =2.95.

3.2 Cattle predation in total

3.2.1 Descriptive statistics and multivariable Poisson regression analysis

Descriptive information of the data is presented in table 5. The four multivariable Poisson regression models (see Table 6) found associations between the number of cattle killed in total and the average rainfall for the preceding 60-days, daily rainfall and grass heights respectively. The average rainfall for the preceding 7-, 30- and 90-days, moon phases and cloud cover had no effect on the number of cattle killed in total.

Table 5. Descriptive statistics of explanatory variables of cattle predation in total. (N)= number of days in each level of the explanatory variable. (SE mean)= standard error of the mean.

Environmental variable	**N**	**Observed mean of cattle killed in total**	**SE mean**

90-days rain	Low	805	0.106	0.015
	Medium	751	0.133	0.018
	High	774	0.177	0.023
60-days rain	Low	758	0.124	0.015
	Medium	812	0.102	0.014
	High	760	0.191	0.026
30-days rain	Low	756	0.124	0.013
	Medium	775	0.107	0.016
	High	799	0.182	0.025
7-days rain	Low	768	0.127	0.015
	Medium	769	0.117	0.014
	High	793	0.170	0.025
Daily rainfall	Low	1385	0.124	0.011
	Medium	707	0.127	0.018
	High	238	0.256	0.067
Cloud cover	No clouds	775	0.112	0.014
	Partly cloudy	776	0.144	0.019
	Overcast	779	0.159	0.023
Grass height	Short	775	0.125	0.015
	Medium high	777	0.095	0.014
	Full moon	778	0.195	0.026
Moon phases	New moon	534	0.137	0.020
	First quarter	660	0.127	0.026
	Full moon	591	0.122	0.016
	Third quarter	545	0.170	0.026

Table 6. The four multivariable Poisson Regression models examining the overall ranked effect of the average rainfall for the preceding 90-,60-,30- and 7-days, daily rainfall, moon phases, cloud cover and grass height on cattle killed in total, while holding the other predictors constant in the model. Significant p-values are indicated with bold text. (DF)= degrees of freedom.

		Wald test		
Model	**Source**	**Chi-square**	**P-value**	**DF**
(1)	Regression	59.34	**0.000**	11
	90-days	3.90	0.142	2
	Daily rainfall	15.19	**0.001**	2
	Moon phases	5.21	0.157	3
	Cloud cover	1.38	0.501	2
	Grass height	15.69	**0.001**	2
(2)	Regression	64.34	**0.000**	11
	60-days	8.19	**0.017**	2
	Daily rainfall	13.55	**0.001**	2
	Moon phases	4.75	0.191	3

	Cloud cover	0.95	0.622	2
	Grass height	14.53	**0.001**	2
(3)	Regression	59.24	**0.000**	11
	30-days	3.63	0.163	2
	Daily rainfall	12.96	**0.002**	2
	Moon phases	4.80	0.187	3
	Cloud cover	0.79	0.674	2
	Grass height	17.36	**0.000**	2
(4)	Regression	57.04	**0.000**	11
	7-days	1.29	0.524	2
	Daily rainfall	13.45	**0.001**	2
	Moon phases	4.88	0.181	3
	Cloud cover	0.74	0.690	2
	Grass height	21.90	**0.001**	2

3.2.2 Univariable Poisson regression analysis

Rainfall

The Poisson regression revealed an overall significant effect of daily rainfall as a single variable on the total number of cattle killed (χ^2=25.41; DF= 2; p<0.001). Very heavy rainfall resulted in 2.06 times higher number of cattle killed compared to low rainfall as intercept (p<0.001), while no significant relationship was found between heavy rainfall and low rainfall (intercept) (IRR= 1.02; p=0.849; Appendix 1) see figure 2. Furthermore, very heavy rainfall was linked with 2.01 times higher number of cattle killed compared to heavy rainfall as intercept (p<0.001).

An overall significant effect was also found between the average rainfall for the preceding 60-days and the total number of cattle killed (χ^2=23.98; DF= 2; p<0.001). High levels of rainfall resulted in 1.5 times higher number of cattle killed compared to low rainfall as intercept (p=0.001), whereas no relationship was found between medium high rainfall compared to low rainfall (intercept) (IRR=0.82; p=0.199; Appendix 1) see figure 2. High levels of rainfall were further associated with 1.8 times higher rates of cattle killed compared to medium rainfall as intercept (p<0.001).

Grass height

An overall significant effect was also found between grass height and the total number of cattle killed (χ^2=28.69; DF=2; p<0.001). Tall grass gave 1.5 times higher number of cattle killed compared to short grass as intercept (p=0.001; Appendix 1) see figure 2. A statistical tendency was found between medium grass and short grass (intercept) (p=0.077), where medium high grass was associated with 0.76 times lower rates of cattle killed compared to short grass (intercept). Tall grass was associated with 2.05 times higher rates cattle killed compared to medium high grass as intercept (p<0.000).

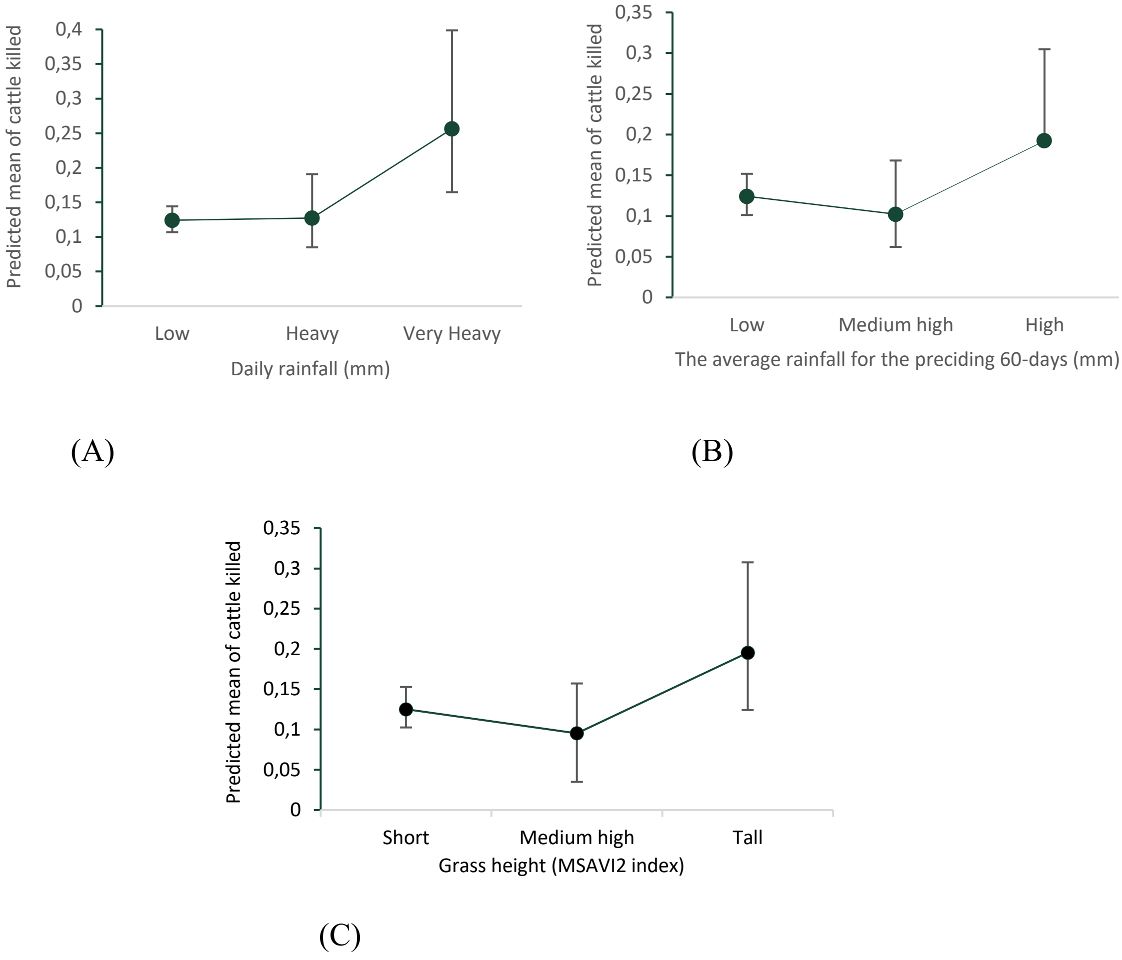


Figure 2. Predicted mean of cattle killed relative to (A) daily rainfall (B) the average rainfall for the preceding 60-days (mm) (C) grass height. Error bars are based on the confidence intervals.

3.3 Cattle predation during the night

3.3.1 Descriptive statistics and multivariable Poisson regression analysis

Descriptive information of the data is presented in table 7. The four multivariable Poisson regression models (see Table 8) found associations between the number of cattle killed during the night and the average rainfall for the preceding 60- and 90-

days, daily rainfall, grass heights and moon phases respectively. The average rainfall for the preceding 7- and 30-days and cloud cover had no effect on the number of cattle killed during the night.

Table 7. Descriptive statistics of explanatory variables of cattle predation during the night. (N)= number of days in each level of the explanatory variable. (SE mean)= standard error of the mean.

Environmental variable		**N**	**Observed mean of cattle killed during the night**	**SE Mean**
90-days rain	Low	805	0.037	0.009
	Medium	751	0.079	0.015
	High	774	0.100	0.019
60-days rain	Low	758	0.046	0.010
	Medium	812	0.057	0.010
	High	760	0.113	0.021
30-days rain	Low	756	0.048	0.009
	Medium	775	0.063	0.013
	High	799	0.102	0.019
7-days rain	Low	768	0.061	0.011
	Medium	769	0.062	0.011
	High	793	0.092	0.019
Daily rainfall	Low	1385	0.062	0.008
	Medium	707	0.063	0.014
	High	238	0.156	0.053
Cloud cover	No clouds	775	0.058	0.011
	Partly cloudy	776	0.067	0.012
	Overcast	779	0.091	0.019
Grass height	Short	775	0.050	0.009
	Medium high	777	0.061	0.011
	Full moon	778	0.104	0.021
Moon phases	New moon	534	0.082	0.017
	First quarter	660	0.088	0.023
	Full moon	591	0.043	0.011
	Third quarter	545	0.078	0.017

Table 8. Table 8. The four multivariable Poisson Regression models examining the overall ranked effect of the average rainfall for the preceding 90-,60-,30- and 7-days, daily rainfall, moon phases, cloud cover and grass height on cattle predation during the night, while holding the other predictors constant in the model. Significant p-values are indicated with bold text. (DF)= degrees of freedom.

		Wald test		
Model	**Source**	**Chi-square**	**P-value**	**DF**
(1)	Regression	54.35	**0.000**	11
	90-days	10.24	**0.006**	2

	Daily rainfall	10.18	**0.006**	2
	Moon phases	9.62	**0.022**	3
	Cloud cover	1.40	0.497	2
	Grass height	2.98	0.226	2
(2)	Regression	54.69	**0.000**	11
	60-days	8.53	**0.014**	2
	Daily rainfall	8.23	**0.016**	2
	Moon phases	10.17	**0.017**	3
	Cloud cover	1.39	0.498	2
	Grass height	2.35	0.309	2
(3)	Regression	48.06	**0.000**	11
	30-days	1.83	0.401	2
	Daily rainfall	9.21	**0.010**	2
	Moon phases	9.83	**0.020**	3
	Cloud cover	1.32	0.517	2
	Grass height	4.83	0.089	2
(4)	Regression	47.24	**0.000**	11
	7-days	0.59	0.746	2
	Daily rainfall	11.31	**0.003**	2
	Moon phases	9.95	**0.019**	3
	Cloud cover	0.91	0.636	2
	Grass height	11.33	**0.003**	2

3.3.2 Univariable Poisson regression analysis

Rainfall

The Poisson regression revealed an overall significant effect of daily rainfall as a single variable on the number of cattle killed during the night (χ^2=23.88; DF= 2; p<0.001). Very heavy rainfall gave 2.5 times higher number of cattle killed compared to low rainfall as intercept (p<0.001), whereas no relationship was found between heavy rainfall and low rainfall (intercept) (IRR= 1.02; p=0.893; Appendix 2). Very heavy rainfall gave 2.4 times higher number of cattle killed compared to heavy rainfall as intercept (p<0.001) see figure 3.

A significant relationship was also found between the average rainfall for the preceding 60-days and cattle killed during the night (χ^2= 25.71; DF=2; p<0.001). High levels of rainfall were linked with 2.4 times higher number of cattle killed compared to low rainfall as intercept (p<0.001), whereas no effect was found between medium rainfall and low rainfall (intercept) (IRR=1.2; p=0.311). High levels of rainfall gave 1.9 times higher number of cattle killed compared to medium rainfall as intercept (p<0.001; Appendix 2; see Figure 3).

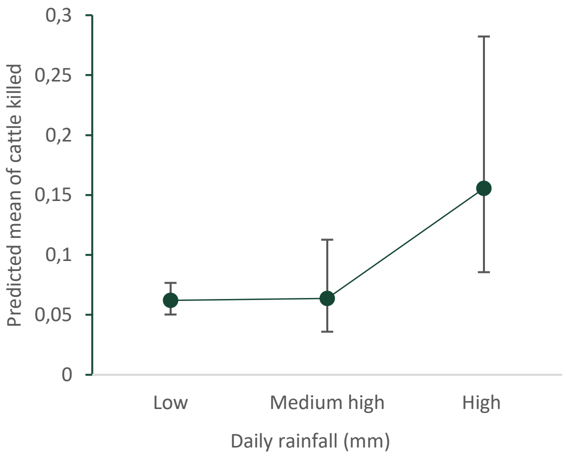
An overall significant effect of the average rainfall for the preceding 90-days as a single variable on the number of cattle killed during the night was found (χ^2=21.52: DF=2; p<0.001). Medium rainfall levels gave 2.1 times more killed cattle compared to low rainfall as intercept (p=0.001), whereas high levels of rainfall gave 2.7 times higher rates of cattle killed compared to low rainfall (p<0.001; Appendix 2), see figure 3. No effect was found between high levels of rainfall compared to medium rainfall as intercept (IRR=1.2; p=0.176).

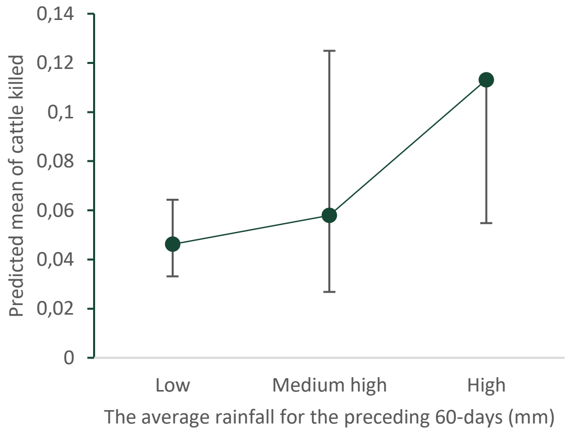
Grass heights

An overall significant association between grass height and cattle killed during the night was found (χ^2=16.71; DF=2; p<0.001). Tall grass was linked with 2.06 times higher number of cattle killed compared to short grass as intercept (p<0.001), whereas no significant effect was found between tall grass and short grass as intercept (IRR=1.2; p=0.341; Appendix 2). Tall grass was associated with 1.6 times higher rates of cattle killed compared to medium grass as intercept (p=0.004), see figure 3.

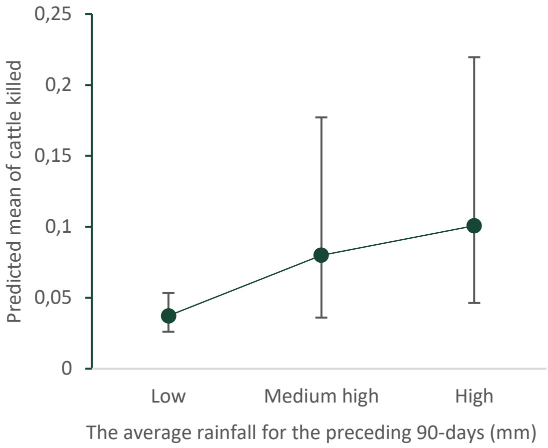
Moon phase

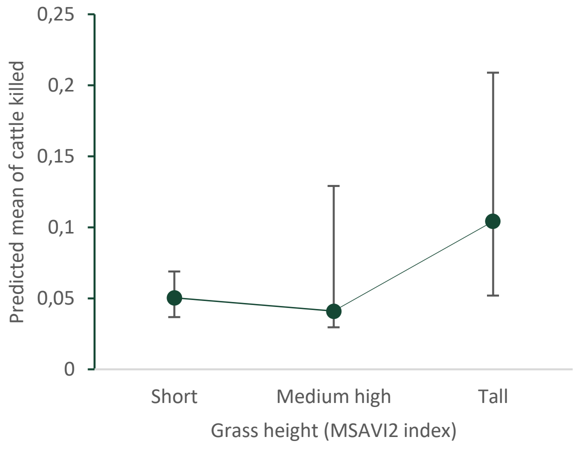
The Poisson regression revealed an overall significant association between moon phases and cattle killed during the night (χ^2=10.09; DF=3; p=0.018). New moon, first quarter moon and third quarter moon was associated with respective 1.8-, 2- and 1.74-times higher number of cattle killed compared to full moon as intercept (p=0.007; p=0.003; 0.015), see Appendix 2 and figure 3. No effect was found between new moon and first quarter as intercept (IRR=0.94; p=0.770). No association was either found between third quarter moon and first quarter moon as intercept (IRR=0.33; p=0.604). Lastly, no significant relationship was found between new moon and third quarter moon (IRR=1.05; p=0.812; Appendix 2; Figure 3).



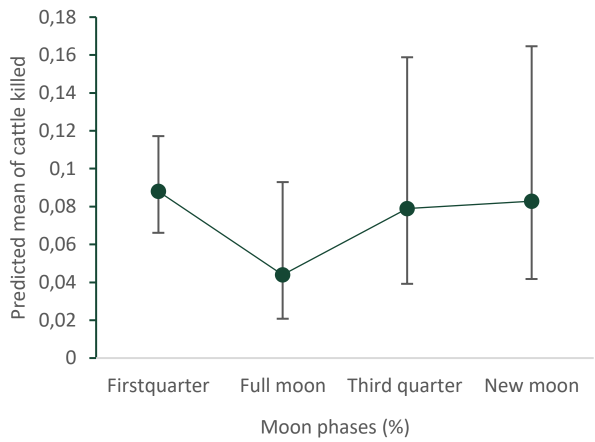


(A) (B)





(C) (D)



(E)

Figure 3. Predicted mean of cattle killed relative to (A) daily rainfall (B) the average rainfall for the preceding 60-days (mm) (C) the average rainfall for the preceding 90-days (D) grass height (E) moon phases. Error bars are based on the confidence intervals.

3.4 Cattle predation during the day

3.4.1 Descriptive statistics and multivariable Poisson regression analysis and

Descriptive information of the overall data is presented in table 9. The four multivariable Poisson regression models (see Table 10) found associations between the number of cattle killed during the day and the average rainfall for the preceding

60-days, grass height and moon phase respectively. The average rainfall for the preceding 90-,30- and 7 days, daily rainfall and cloud cover had no effect on cattle killed during the day.

Table 9. Descriptive statistics of explanatory variables of cattle predation during the day. (N)= number of days in each level of the explanatory variable. (SE mean)= standard error of the mean.

Environmental variable		N	Observed mean of cattle killed during the day	SE Mean
90-days rain	Low	805	0.055	0.009
	Medium	751	0.037	0.007
	High	774	0.046	0.009
60-days rain	Low	758	0.066	0.011
	Medium	812	0.028	0.006
	High	760	0.047	0.010
30-days rain	Low	756	0.062	0.009
	Medium	775	0.033	0.008
	High	799	0.045	0.009
7-days rain	Low	768	0.059	0.010
	Medium	769	0.039	0.007
	High	793	0.041	0.009
Daily rainfall	Low	1385	0.048	0.006
	Medium	707	0.041	0.009
	High	238	0.054	0.019
Cloud cover	No clouds	775	0.042	0.007
	Partly cloudy	776	0.045	0.009
	Overcast	779	0.052	0.010
Grass height	Short	775	0.058	0.009
	Medium high	777	0.028	0.007
	Full moon	778	0.054	0.010
Moon phases	New moon	534	0.037	0.009
	First quarter	660	0.029	0.009
	Full moon	591	0.062	0.010
	Third quarter	545	0.055	0.012

Table 10. The four multivariable Poisson Regression models examining the overall ranked effect of the average rainfall for the preceding 90-,60-,30- and 7-days, daily rainfall, moonlight, cloud cover and grass height on cattle predation during the day, while holding the other predictors constant in the model. Significant p-values are indicated with bold text.(DF)= degrees of freedom.

		Wald test		
Model	Source	Chi-square	P-value	DF
(1)	Regression	19.90	**0.047**	11
	90-days	1.83	0.401	2
	Daily rainfall	1.05	0.590	2
	Moon phases	7.97	**0.047**	3
	Cloud cover	0.63	0.731	2

	Grass height	7.21	**0.027**	2
(2)	Regression	27.42	**0.004**	11
	60-days	9.61	**0.008**	2
	Daily rainfall	1.21	0.546	2
	Moon phases	8.40	**0.038**	3
	Cloud cover	0.39	0.822	2
	Grass height	6.15	**0.046**	2
(3)	Regression	22.81	**0.000**	11
	30-days	4.65	0.401	2
	Daily rainfall	1.03	**0.010**	2
	Moon phases	8.43	**0.020**	3
	Cloud cover	0.50	0.517	2
	Grass height	6.58	0.089	2
(4)	Regression	21.22	**0.019**	11
	7-days	3.20	0.084	2
	Daily rainfall	1.15	0.599	2
	Moon phases	8.00	**0.038**	3
	Cloud cover	0.91	0.780	2
	Grass height	6.74	**0.037**	2

3.4.2 Univariable Poisson regression

Rainfall

The Poisson regression revealed an overall significant effect of the average rainfall for the preceding 60-days as a single variable on cattle killed during the day (χ^2=11.36; DF=2; p=0.003). Medium rainfall levels were linked with 0.42 times lower number cattle killed compared to low rainfall as intercept (p=0.001), while no effect was found between high levels of rainfall and low rainfall (IRR=0.71; p=0.130; Appendix 3) see figure 4. A statistical tendency between high levels of rainfall and medium rainfall as intercept was found (p=0.054), where high levels of rainfall gave 1.6 times more cattle killed compared to medium rainfall.

Grass height

An overall significant association of grass heights as a single variable on cattle killed during the day was found (χ^2=8.31; DF=2; p=0.016). Medium grass gave 0.48 times lower number of cattle killed compared to short grass as intercept (p=0.006), while no significant association was found between tall grass and short grass (IRR=0.92; p=0.734; Appendix 3), see figure 4. However, tall grass was associated with 1.9 times higher number of cattle killed compared to medium grass as intercept (p=0.014).

Moon phase

An overall significant association of moon phases as a single variable on the number of cattle killed during the day was found (χ^2=8.24; DF=3; p=0.041). Full moon was associated with 2.0 times higher number of cattle killed compared to first quarter moon (p=0.013) and third quarter moon was associated with 1.8 times higher number of cattle killed compared to first quarter moon (p=0.049; Appendix 3), see figure 4. No association was found between new moon and first quarter moon (intercept) (IRR=1.2; p=0.509). A statistical tendency was found between new moon and full moon as intercept (IRR=0.59; p=0.053), while no significant relationship was found between third quarter moon and full moon (IRR=0.88; p=0.615). No significant association was found between third quarter moon and new moon (IRR=1.4 ;p=0.163)

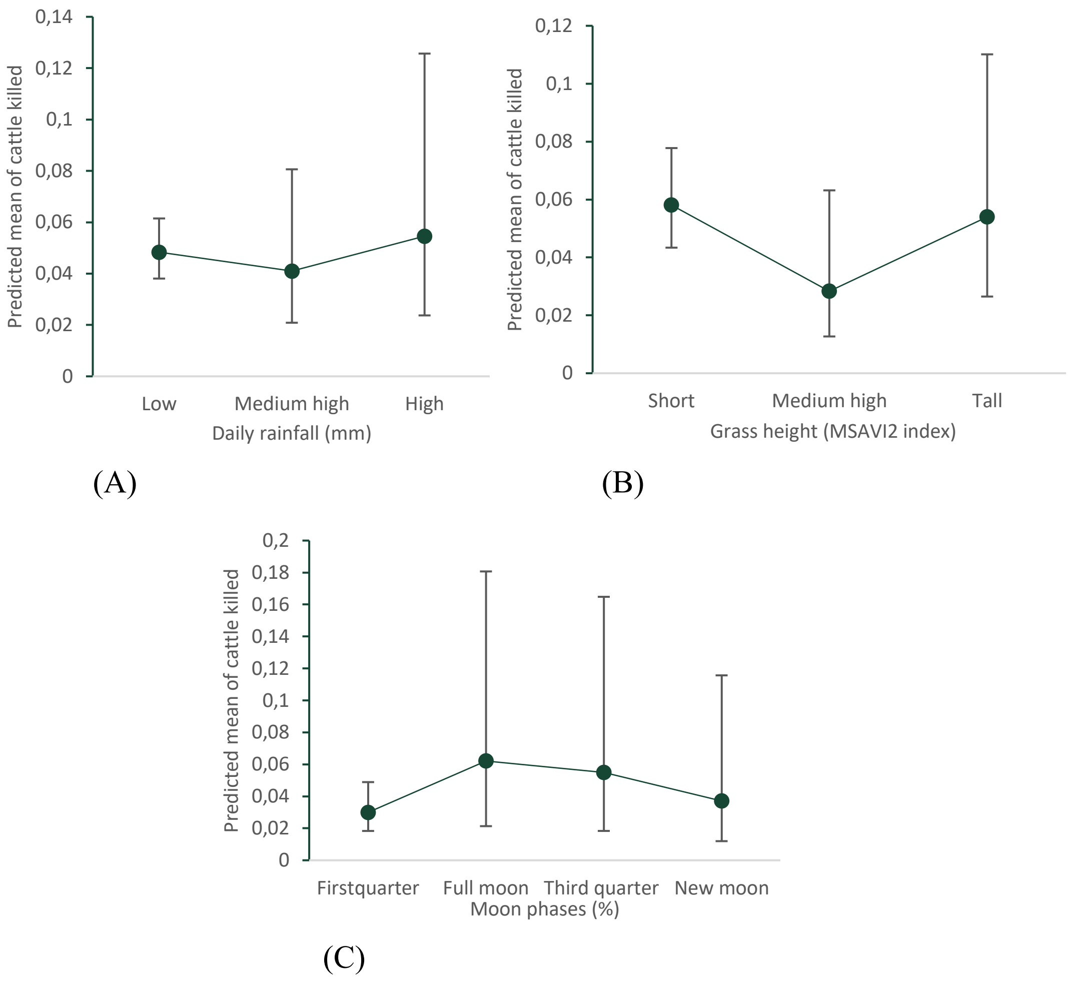


Figure 4. Predicted mean of cattle killed relative to (A) the average rainfall for the preceding 60-days (mm) (B) grass height (C) moon phases. Error bars are based on the confidence intervals.

4. Discussion

The aim of this study was to investigate how the time of the day and environmental conditions influence cattle predation by lions, and thus further understand when higher rates of human-wildlife conflicts might be expected. Interestingly, overall, predation on cattle showed no difference between night and day. However, the findings in this study illustrate a complex ecological relationship between cattle predation, the time of the day and environmental predictors. Significant variations of cattle predation relative to rainfall, grass heights (MSAVI2) and moon phases were found, whereas cloud cover showed no impact. While the results partially align with earlier research, it also reports differences.

4.1 General predation pattern by lions

The hypothesis that a higher occurrence of predation would occur during night compared to the day, was not supported in this study. This is in contrast with research indicating that lions are nocturnal hunters (Hayward & Slotow, 2009; Packer *et al*., 2011). Generally, the darkness provided from the night, is thought to produce greater concealment opportunities for lions compared to the day (Owen-Smith, 2019), with increased catchability and vulnerability of prey. Additionally, felid predators generally have better night vision compared to their prey (Veilleux & Kirk, 2014). By this reason, it is very surprising with no observed difference. Yet, it cannot be fully ruled out that lions prefer hunt livestock during the night, since the results showed a statistical tendency towards having a difference between the night and day.

Earlier research on livestock predation have reported differences in when predation on livestock occurred. For instance, Patterson *et al*. (2004) observed more killed and injured cattle during the night at Tsavo National Park in Kenya. In contrast, Kissui (2008) reported more lion attacks on cattle to occur during the day, while cattle were grazing at the Maasai Steppe in northern Tanzania. As discussed later, the contrasting results of those in Patterson *et al*. (2004) Kissui (2008) and in Ol Pejeta, might be explained by spatial-temporal variations. However, other variables, such as husbandry practices may also influence (Ogada *et al*., 2003; Robertson *et al*., 2020) and might differ in Ol Pejeta compared to Patterson *et al*.

(2004) and Kissui (2008). Notably, cattle in Ol Pejeta are quartered in metal-fenced bomas during the night, which is considered effective when protecting cattle from predators (Loveridge *et al*., 2017; Wakoli *et al*., 2023). Still, herders in Ol Pejeta observe lions jumping into to the bomas and kill cattle. Furthermore, roaming lions outside the boma causes cattle to break through the bomas. Interestingly, bomas in Ol Pejeta Conservancy are reported to be located mostly in areas of grassland and open bush habitats (Ekholm, 2024). Open habitats are generally associated with decreased risk of lion attacks, as it is easier for people and prey to detect predators (Kavwele *et al*., 2017). However, following the results of no difference of predation between the night and day in Ol Pejeta, suggest that further measures can be taken. For instance, as shown in Ogada *et al*. (2003), lions were less likely kill cattle enclosed in bomas at nights with more humans present. Carnivores generally avoid human encounters (Oriol-Cotterill *et al*., 2015; Davoli *et al*., 2022). In Ol Pejeta cattle are guarded by only two people, whereas in Kissui (2008) bomas were surrounded with several homesteads, which likely explain the lower rate of lion attacks on livestock in Kissui (2008). Furthermore, the presence of dogs has been shown by Woodroffe *et al*. (2007) to reduce lion predation. Specifically, presence of guardian dogs minimized cattle lost to lion predation with 59% at bomas and 67% during day while cattle were grazing. By employing more herders combined with guarding dogs, predation rates may therefore be minimized. Also, notably, Radford *et al*. (2020) showed that cattle lost to lion predation, were significantly reduced with artificial eyespots and cross marks painted on cattle rumps. Radford *et al*. (2020) indicated that these elements, most likely are perceived as being novel and intimidating for lions, which represent a cost-effective measure that could be taken as well to minimize predation by lions.

4.2 Effects of grass heights

The findings in this study showed that the grass height significantly influence cattle predation in Ol Pejeta Conservancy. Since lions are known to ambush and stalk their prey, it is expected that lions seek cover in taller grass or dense vegetation before proceeding. This is supported by Funston *et al*. (2001), who made continuous direct observations on lions in South Africa, where tall grass (>60 cm) and dense shrub cover resulted in increased hunting success on wild prey during the night (Funston *et al*., 2001). Similarly, as hypothesized, the results in Ol Pejeta showed that cattle predation tend to increase with taller grass at night and in total. These results support the catchability theory (Schaller, 1972; Hopcraft *et al*., 2005) that certain environmental factors, such as taller grass, increase the hunting success by helping lions to stay undetected. In support of the results in Ol Pejeta, although grass heights were not measured explicitly, a similar relationship between higher vegetation productivity (NDVI) and increased risk of lion attacks on livestock by lions was found in northern Tanzania at Manyara Ranch Conservancy by Beattie *et al*. (2020). Contrariwise, Oliver *et al*. (2023) found vegetation quality (NDVI) to have little impact on cattle lost to lion attacks in southern Kenya. The contrasting results compared to Ol Pejeta, might be explained by the normalised difference vegetation index (NDVI) used in Oliver *et al*. (2023). The index may come with some limitations in areas containing bare soil, which the Modified Soil-Adjusted Vegetation Index (MSAVI2) used in this study is adjusted for (Qi *et al*., 1994). On the other hand, the contrasting result may be explained by the productivity of vegetation in southern Kenya. According to Oliver *et al*. (2023), it did not change during the study period.

In contrast to the hypothesis that taller grass produces higher predation rates during all times of the day, the results in Ol Pejeta Conservancy showed that cattle predation tends to increase with shorter grass during daytime. This is surprising as taller grass likely produce more benefits for lions, such as increased cover. The inconsistency between grass height and cattle predation during the day, night and in total, suggest that the relationship with environmental conditions is complex, and its influence tends to vary depending on the time of the day. There are a few explanations for this pattern. For instance, based on that tall grass increases the hunting success of wild prey during nights (Funston *et al*., 2001), days with shorter grass may encourage lions to hunt opportunistically on livestock, as the hunting success on wild prey is likely decreased during these conditions. Lions may compensate for their lower food intake followed by the decreased hunting success of wild prey. On the other hand, higher predation rates with shorter grass may relate to a combination of husbandry practices, livestock abundance and the foraging behaviour of wild prey. As mentioned earlier, carnivores usually try to avoid contact with humans and make behavioural adjustments when entering areas dominated by humans (Oriol-Cotterill *et al*., 2015; Davoli *et al*., 2022). In Kupier *et al*. (2024), attacks on livestock resulting in losses or injuries, increased in areas of lower woody cover and closer to homesteads in Zimbabwe, which are areas in which lions can be detected more easily. Kupier *et al*. (2024) indicated that livestock abundance likely explains these results and that lions, as mentioned above, make a trade-off between sustaining their metabolic needs and by being seen by humans. In Ol Pejeta, cattle are herded to grazing areas during the day. Although cattle prefer grazing in certain areas, movement patterns and distances walked by livestock tend to be more influenced by the herders rather than their livestock (Turner & Hiernaux, 2002; Raizman *et al*., 2013). Although unlikely, some herdsmen might choose to move their cattle to areas with shorter grass since these areas provide the advantage of detecting predators more easily (Kavwele *et al*., 2017). As cattle become easier to detect as well together with the fact that they are more abundant, lion may be willing to risk detection to sustain their metabolic needs. However, a more reasonable theory might relate to that in terms of food scarcity, such as shorter grass, cattle may be herded to areas closer nearby water sources, since vegetation around these areas are usually more abundant (Hirata *et al*., 2010; Ogutu *et al*., 2010; Owen-Smith *et al*., 2010). Consequently, with a more abundant vegetation as well as cattle are more abundant, cattle become more susceptible to predation by lions (Hopcraft *et al*., 2005; Beattie *et al*., 2020; Kupier *et al*., 2024), thus explaining the results of increased predation with shorter grass. Additionally, in Ol Pejeta and elsewhere in Kenya, grazing ungulates quite frequently overlap with grazing cattle (Odadi *et al*., 2011). Wild ungulates graze both in open landscapes of shorter nutrient grass (McNaughton, 1983 in Hopcraft *et al*., 2005) as well as in areas of taller grass of less nutrient quality (Owen-Smith *et al*., 2010). In turn, while preferring wild ungulates, lions might hunt opportunistic on cattle, since cattle may not require the same energetic expenditure as when hunting wild prey. Not only might lions need to travel long distances before finding wild prey (Eloff, 1984 in Hayward & Kerley, 2005), quite frequently, attacks become unsuccessful due to several anti-predator behaviours expressed by the wild prey. For instance, although lions generally have an initial acceleration advantage, the evasion speed of Thomson´s gazelle (*Gazella Thomsoni*), zebras (*Hippotigris*) and wildebeest (*Connochaetes taurinus or gnou*) will eventually outpace the lions (J.P Elliot *et al*., 1977 in Hayward & Kerley, 2005). Further to this, by defending and having horns, wild prey is likely to cause damages on lions, which in turn can have negative impacts on lions' further survival (Hayward & Kerley, 2005). It is highly plausible that through domestication, in favour of husbandry practices, livestock species have lost anti-predator behaviours and morphological characteristics of their ancestors and wild counterparts (Prince, 1984; Van Vuure, 2002). These include, heighten aggression, large horns and presumably camouflaged pelage colouration (Van Vuure, 2002). Therefore, cattle may become more vulnerable to predation by lions. Interestingly, in a study on predation on Tswana cattle in Botswana by Weise *et al*. (2020), it was reported that cattle with no horns, calves and bulls were preferentially targeted by lions, whereas cattle with uniform colour patterns as well as long horned cattle, were highly avoided. Furthermore, preferences were shown to be context-specific, where enclosure attacks comprised of calves, while bulls or oxen were attacked when free-roaming. In Ol Pejeta Conservancy, the Borana cattle (*Bos indicus*) have no or small horns and are either completely white or brown in their pelage, while the Ankole cattle (*Bos primigenius taurus*) have large horns and brown pelage. Based on the findings shown in Weise *et al*. (2020), especially calves and adult Borana cattle in Ol Pejeta, may be more vulnerable to predation by lions. Additionally, if cattle have been lost by wandered away from their herd, although the cattle itself is large and have larger horns, will increase their risk of predation as demonstrated in Weise *et al*. (2020). Thus, the potential danger arising from guarding herders, might be outweighed, since cattle are an easier target and lions can spend less energetic expenditure when hunting cattle. This emphasizes the importance of having a vigilant herding strategy in regards of reducing predation risk by lions since cattle have lost features that enables them to co-exist with lions. Cattle characteristics were not examined in this study but is an aspect important in understanding predation patterns of lions, that could be analysed further in future studies.

As indicated by Kupier *et al*. (2024), this raises the question whether areas considered dangerous of livestock predation is truly dangerous, or it is in fact dependent on the abundance of livestock. However, recently Mills *et al*. (2024) indicated that predation on livestock is likely influenced by a combination of both wild prey and livestock availability influenced by fluctuations in primary production and water availability. Considering all these factors and their interactions in future studies in Ol Pejeta Conservancy will likely provide a broader understanding of livestock predation.

4.3 Effects of rainfall

The findings in Ol Pejeta indicate that rainfall is important when predicting livestock predation by lions. However, the impact showed great variability. Contrary to the hypothesis, only preceding rainfall from the longer time scales, specifically 90-days and 60-days, influenced cattle predation. Additionally, contrary to the hypothesis, their influence did vary depending on the time of the day. A generally higher rate of predation was observed during higher rainfall levels for the preceding 90-days at nights, compared to lower rainfall levels. This pattern was also found with higher rainfall levels for the preceding 60-days during night and in total. Surprisingly, a general higher rate of predation was observed with lower rainfall for the preceding 60-days during the day. The inconsistency, as observed for grass height, suggest again that the relationship with environmental conditions is complex, and their influence tends to vary depending on the time of the day. The pattern may partly be explained by the correlation with grass height in this study. As observed prior to the model formulation in this study, preceding 90- and 60-days of rainfall showed a strong correlation with grass biomass (MSAVI2), which is itself was a variable predictable of cattle predation, as discussed above. When modelling cattle predation as a function of grass heights, taller grass increased predation during the night and in total, whereas shorter grass increased predation during the day, which is a similar pattern observed for preceding 90-and 60-days of rainfall. Due to the correlation, especially grass heights could be used as an indicator of livestock predation. However, this overlap raises the question whether it is truly the preceding days of rainfall or grass height that influenced predation in Ol Pejeta Conservancy. Compared to grass height (MSAVI2), the rains might contain additional information important when predicting cattle predation, such as more available drinking water and growth of important bushes or trees. It is therefore reasonable to consider that grass height and preceding rainfall influence predation differently.

For instance, in previous research on radio-collared lions in southern Kenya (Oliver *et al*., 2023), cattle lost to lion attacks was found to increase with increased levels of rainfall in the preceding 3 months. Similarly, the findings in Ol Pejeta generally align with Oliver *et al*. (2023) showing how increased levels of rainfall in the preceding period of days (90 and 60-days) led to increased cattle predation. The findings can be explained by the theory that lions may hunt opportunistically on livestock during wetter conditions, when wild prey may have dispersed and have a greater body condition in response to a more abundant vegetation and drinking water availability following rainfall (Patterson *et al*., 2004; Woodroffe and Frank, 2005; Kissu, 2008; Loveridge *et al*., 2017). Finding and catching wild prey might become difficult, causing lions to select domestic prey instead (Patterson *et al*., 2004; Ng´weno *et al*., 2019). A further explanation for why higher rainfall levels from the longer time scales influenced predation during the night and in total, might relate to the increased hunting success with a denser vegetation following rainfall. As previously explained, with a denser vegetation, lions may be better concealed, which in turn could help them from staying undetected by both cattle and human while hunting, resulting in increased hunting success (Oriol-Cotterill *et al*., 2015; Beattie *et al*., 2020). Based on these theories, may explain why the shorter time scales of rainfall were non-significant, specifically 30-days and 7-days. Perhaps these time scales may not be enough to trigger vegetation growth in Ol Pejeta Conservancy. On the contrary, in a study by Robertson *et al*. (2020) in Botswana, higher levels of rainfall in the previous month were found to decrease the likelihood of predation in the subsequent month. A similar pattern was found in Zimbabwe, where livestock losses occurred more frequently in drier conditions compared to wetter ones (Butler, 2001). The contrasting results demonstrated by Butler (2001) and Robertson *et al*. (2020) compared to Ol Pejeta Conservancy, might reflect the different landscape features as well as wild prey densities in Botswana and Zimbabwe, compared to Kenya. However, notably, in Patterson *et al*. (2004), no relationship between preceding rainfall of 1-6 months and cattle killed or injured was found in southern Kenya at Tsavo National Park. Instead, months representing rainy season had higher rates of attacks. The discrepancy between the results of Ol Pejeta and those by Patterson *et al*. (2004), might instead of wild prey densities, be explained by the provision of artificial water points at Ol Pejeta. Since there are no artificial water points provided in Tsavo National Park (Patterson *et al*., 2004), wild prey is likely more dependent on the provision of rainfall and respond more quickly to rainfall during rainy season as the ephemeral pools will be filled. In turn, increased risk of lion attacks on livestock is expected during rainy season in Tsavo National Park.

Lastly, unlike earlier research, for instance Robertson *et al*. (2020), the results in Ol Pejeta suggest that daily rainfall events influence livestock predation. In addition, the impact tends to be influenced by the time of the day, underpinning again the complex relationship between the time of the day and environmental conditions. Generally, higher rates of predation were observed during very heavy daily rainfall at nights and in total, while no relationship was found during the day. When it comes to studies analysing daily rainfall events on carnivores, Theuerkauf *et al*. (2003) found that the daily activity patterns of wolves (*Canis lupus*) were reduced with heavy rainfall, but the reason why was not specified. However, since vegetation productivity in arid- and semiarid landscapes usually do not respond immediately to daily rainfall events (Shinoda, 1995) the theory of dispersion of wild prey or increased vegetation cover (Patterson *et al*., 2004), is unlikely to relate with the impact of daily rainfall events. Though, since animals rely heavily on olfactory, visual and auditory ques to communicate and avoid dangers (Ruzicka & Conover, 2011; Wijers *et al*., 2021), the increased rate of cattle predation in response to heavy daily rainfall, might relate to reduced hearing or visibility induced by the rainfall. Studies investigating the impact of noise created by rainfall is extremely rare. Yet, strong winds have been reported to increase the hunting success of wild prey explained by the noise induced by the winds, which potentially concealed the lions while approaching prey (Leuthold, 1977 in Wijers *et al*., 2022). When rainfall make contact on a surface, a noise is generated (Schmid *et al*., 2021), and in the same way as the noise from the wind might have concealed lions, the sound created by heavy rainfall might conceal lions while approaching cattle during the night. Alternatively, or a combination of both, increased number of killed cattle in relation to heavier daily rainfall, might relate to reduced visibility at night. During darker periods at night, increased hunting success on both wild and domestic prey has been reported, explained by the reduced detection by prey and humans (Funston *et al*., 2001; Van Orsdal, 1984; Oriol-Cotterill *et al*., 2015; Robertson *et al*., 2020). During night, the rain itself as well as the cloud cover induced following rainfall, may result in greater darkness (Krieg, 2021). In turn, lions can stay unnoticed by humans and prey more easily. Based on that rainfall reduces hearing or visibility, may explain why no significant influence was observed during the day, since the impact from daylight outweigh these factors. In turn, prey and humans are still able to detect lion during the day although it is raining.

4.4 Effects of moonlight and cloud cover

The results in Ol Pejeta showed that the moon does not only influence cattle predation at night, but also during the day. Interestingly, no relationship was found between the moon and total cattle predation in Ol Pejeta, which contrast with the hypothesis. The result in Ol Pejeta further contrasts with the findings in Robertson *et al*. (2020), where the overall likelihood of cattle predation in Botswana, was increased with decreasing moonlight levels, specifically at times around new moon. Yet, as hypothesized, during the night in Ol Pejeta, higher rates of predation were observed with darker moon illuminations. The differences might relate to that Robertson *et al*. (2020), had no data of when predation occurred during the day. However, notably, the results in Ol Pejeta showed that first quarter moon followed by new moon, had the highest rates of predation when compared to full moon. This is surprising as new moon is considered the darker period during the night (Kyba *et al*., 2017; Śmielak, 2023). Generally, prey is likely more susceptible to predation in darker conditions by lions having greater hunting success due to better concealment from the darkness while stalking, which has been reported on wild prey in South Africa, Uganda and Zimbabwe (van Orsdal, 1984; Funston *et al*., 2001; Preston *et al*., 2019). In addition, increased predation in darker conditions might be explained by the fact that lions can stay undetected from humans. This is supported by Oriol-Cotterill *et al*. (2015) who found lions remained closer to bomas at nights with lower moon lights levels. Nevertheless, the pattern of increased cattle predation during first quarter moon may relate to a spillover effect. Although new moon is favourable to hunt in (Van Orsdal, 1984; Preston *et al*., 2019) it is possible that hunts may be unsuccessful since humans and wild prey species are more vigilant of their surroundings in these conditions (Embar *et al*., 2001; Packer *et al*., 2011). In turn, more attacks in the phase after the new moon is observed, although the light provided from first quarter moon might expose the lion. This pattern is in contrast with earlier findings indicating that the influence of the moon is the same regardless of the phases before and after full moon (Packer *et al*., 2011). Nevertheless, the pattern of higher predation rates in the phase after new moon resemble those reported by Preston *et al*. (2019). Although predation on domestic prey was not investigated, Preston *et al*. (2019) indicate that lions may hunt successfully during the intermediate phases of the moon. By assessing the belly distension of lions in Zimbabwe, Preston *et al*. (2019) found that lions had larger bellies across other illumination levels than just the darkest, indicating recent food intake and hunting success in other moon phases. Therefore, the pattern showed in Ol Pejeta, constitute a potential novel insight into predation on cattle, that may be considered further in future studies.

Higher rates of predation were shown at full moon during daytime in Ol Pejeta, when compared to other moon phases. Since the light arising from the moon does not typically influence light levels during the day, indicate that other factors associated with the moon may influence the results. Importantly, Packer *et al.* (2011) indicated that scavenging by lions during daytime, largely reflects unsuccessful hunts during the night. In the same study, by analysing lions feeding behaviour through recordings of lions´ belly sizes, Packer *et al.* (2011) found a higher probability of scavenging by lions to occur during daytime around days with full moon. Generally, the luminosity provided at nights with full moon enhances the vision for many prey species (Prugh & Golden, 2014; Trail *et al*., 2016). Prey species has therefore likely greater ability to detect predators, in the same way as predators can detect prey more easily (Trail *et al*., 2016). Yet, as discussed above, lions may not be as successful hunting wild prey, as wild prey most likely express additional anti-predator manoeuvres (Boiseau *et al*., 2024) making them harder to catch compared to livestock. In turn, lions switch to cattle. Additionally, Funston *et al*. (2001) showed that increased hunting success on wild prey was only observed for medium-sized ungulates under darker conditions, whereas no difference in the hunting success on smaller prey was found in relation to the lunar cycle. This suggests, in addition to unsuccessful hunts in general, that lions may also hunt cattle in Ol Pejeta during day, due to an insufficient energy intake from hunting smaller prey. Overall, these findings suggest that the phases before and after full moon is of importance when predicting livestock predation, although the phases may provide the same luminosity.

However, although the moon´s phase may affect cattle predation directly through increased hunting success, it may not entirely explain why lions choose to hunt cattle during these circumstances. Other underlying factors such as landscape features might interact as well (Funston *et al*., 2001). As mentioned earlier, cattle are within the preferred prey weight of lions (Hayward & Kerley, 2005), making them highly vulnerable to predation. Yet, when both are available, lions generally prefer wild ungulates over domestic prey (Patterson *et al*., 2004; Tumenta *et al*., 2014). As discussed in earlier section, with high quality forage and drinking water available, wild prey may become harder to find or catch due to greater body condition (Patterson *et al*. 2004). Thus, although the hunting success may be increased during darker conditions at night (van Orsdal, 1984; Funston *et al*., 2001) finding or catching wild prey may be difficult if wild prey have a greater body condition or are dispersed over the area. In turn, lions may choose to hunt cattle instead (Valeix *et al*., 2012). The interaction between the moon and grass height or preceding rainfall were not investigated in this study but could be considered in future research.

In addition, although light levels may vary depending on how much of the moon is illuminated during the night, the light reaching the ground may be in turn be affected by the extent of cloud cover (Śmielak, 2023). Recently, Krieg (2021) showed that the night illumination was profoundly decreased when the sky was overcast (large amount of cloud cover), which resulted in elevated darkness. Prior research on cloud cover have mostly been done at night together with the moon illumination (van Orsdal, 1984; Funston *et al*., 2001; Prugh *et al*., 2014; Preston *et al*., 2019; Botts *et al*., 2020). In van Orsdal (1984) and Funston *et al*. (2001), cloud cover was observed to increase the hunting success on wild prey by having impacts on the moon, specifically when the moon was obscured by clouds. By this, it was expected that cloud cover would have had impacts on cattle predation in Ol Pejeta. However, contrary to the hypothesis that cloud cover would influence predation, it showed no impacts on neither the night, the day or in total. This is surprising since daily rainfall events was a significant predictor of cattle predation during the night and in total. One theory why cloud cover showed no impact during the day, may be explained by the non-influence of daily rainfall during the day. As discussed earlier, lions may respond more strongly to other predictors during the day. However, the result is more likely explained by the fact that cloud cover alone does not influence predation, but together with the moon (Funston *et al*., 2001; Krieg, 2021). In this study cloud cover was analysed as a single variable, and not the interaction with the moon, which potentially introduces bias to the analysis. Future research should therefore consider their interaction to gain a better understanding of how cloud cover influence livestock predation.

4.5 Research implications and relevance

Understanding predation patterns of lions is critical in the context of facilitating co-existence between humans and wildlife, as well as for a sustainable biodiversity conservation and livestock production. As an apex predator, the African lion play a significant ecological role by regulating trophic cascades and hold great cultural and economic value (Ripple *et al*., 2014; Lindsey *et al*., 2017). Lions are among the top five species in wildlife viewing preferences (Lindsey *et al*., 2007). Extinction or population declines of lions, have large ecological impact and affect national economies who depend upon revenue generated from sustainable utilization and wildlife-based tourism (Lindsey *et al*., 2017; Di Minin *et al*., 2021).

Analysing predation patterns of lions becomes more evident following the impact of climate change on human-wildlife conflicts. In Kenya, conflicts are expected to intensify through unpredictable rainfall patterns with increased rainfall during the short rains (October- December) and reduced rainfall during the long rains (March-May) (Wainwright *et al*., 2021; Abrahams *et al*., 2023; Funk *et al*., 2023; Oliver *et al*., 2023; Palmer *et al*., 2023). Climate change may also change resource availability through intensified droughts and higher temperatures (Tucker *et al*., 2018; Kogo *et al*., 2021; Abrahams *et al*., 2023). With changes in resources, the movement of not only wild animals, but also livestock, may change as they seek more suitable habitats (Tucker *et al*., 2018; Abrahams *et al*., 2023; Mills *et al*., 2024). Consequently, shifted distributions and densities of wildlife populations will be prevalent, with the potential to overlap with human activities (Tucker *et al*., 2018; Abrahams *et al*., 2023). As a result, the risk of livestock predation will be increased. This thesis has shown a complex ecological relationship of how both environmental conditions and the time of the day influence predation patterns of lions. In long term, environmental changes related to climate change are therefore predictable to have impacts on human-lion conflicts in Ol Pejeta Conservancy. This study, therefore, provides important insights into proactively mitigate these conflicts under changing climate conditions. For instance, with increased preceding rainfall from the short rains together with the longer rains in Kenya, imply increased risk of livestock predation during these occasions, influenced by the time of the day. The rains will in turn influence grass heights. Altogether, with the impact of the moon, these conditions increase the risk of predation. It is imperative that farmers and managers anticipate the environmental changes related to climate changes, since ecosystems vary and local conditions might impact lion movements differently (Tuqa *et al*., 2014; Turner *et al*., 2022) and in turn lion predation patterns.

Mitigating the conflicts is highly important in regards of protecting livelihoods of affected communities, who already live under poverty and food insecurity. People in Kenya, as well as other sub- Saharan African countries, are experiencing high levels of poverty and food insecurity (Amwata *et al*., 2016; Bedasa & Deksisa, 2024; Moses, 2024). Food security refers to having the availability of adequate quantities of high- quality food as well as having economic, social and physical access to nutritious and safe food (Amwata *et al*., 2016). The situation in Kenya has gotten more critical by climate changes. In the context of this severe situation, tourism and agricultural practices are highly important and has proven to generate substantial employment opportunities and economic progress in Kenya and other African nations (Kogo *et al*., 2021; Seraj *et al*., 2025). Thus, the economic consequences of human-wildlife conflicts, such as loss of livestock, intensify the already severe situation, creating a significant welfare issue, as well as an ethical one. Importantly, by not mitigating these conflicts, the tolerance and support by affected communities in biodiversity conservation may be diminished. Successful biodiversity conservation relies heavily on the support of local communities (Measham & Lumbasi *et al*., 2013). Thus, by using the findings in this study together with compensation schemes, the tolerance for conservation may be increased, as both wildlife and humans are benefited (Ravenelle & Nyhus, 2017; Killion *et al*., 2021; Chepkwony *et al*., 2025). Nevertheless, economic incentives through conservation and ecotourism employment are also vital in gaining conservation support (Wunder, 2000; Sabuhoro *et al*., 2021). Specifically, people neighbouring protected areas in which many human-wildlife conflicts occur, often experience limited livelihood options (Kissui, 2008; Ontiri *et al*., 2019; Beck *et al*., 2019; Becker *et al*., 2022), making income from conservation or eco-touristic activities important sources of support to biodiversity conservation. Overall, both social and ecological aspects of these conflicts need to be considered, in order to achieve successful conservation of lions and mitigate human-wildlife conflicts (Lischka *et al.,* 2018; Montgomery *et al*., 2018; Robertson *et al*., 2020).

Importantly, by using these strategies, not only the conflicts may be mitigated, but the animal welfare of both livestock and wild animals is likely to be increased (Allen & Hamptom *et al*., 2020). Animal welfare issues related to predation is often overlooked, both in the context of extensive production systems (Allen & Hamptom *et al*., 2020; Temple & Manteca, 2020) as well as in wildlife conservation (Paquet & Darimont, 2010). Carnivores may not only cause animal welfare issues when killing livestock, but also indirectly by scaring them (Temple & Manteca, 2020). Exposure to repeated fearful situations can lead to chronic stress with negative implications on the immune system, reproduction and production on livestock (Dwyer and Bornett, 2004). Furthermore, the killing of lions with traps, weapons or poison, as well as translocating lions or introducing fences, are methods likely to create pain, fear, suffering, anxiety, helplessness and stress for lions themselves and other animals in the ecosystem (Mellor, 2012; Nunny, 2020; Smith *et al*., 2020; Treves & Karanth, 2003; Goodrich & Miquelle, 2005; Stamps & Swaisgood, 2007; Fontúrbel & Simonetti, 2011; Nyhus, 2016; Nattrass & Conradie, 2018; Morapedi *et al*., 2021). Thus, by using non-lethal strategies, a more sustainable, economic and ethical livestock production and wildlife conservation may be achieved as well as better livelihoods for affected communities. While the results of this study are of particular interest in East Africa, other nations may also have an interest, as human-wildlife conflicts are estimated to increase on a global scale (Anand & Radhakrishna, 2017; Stevens *et al*., 2025).

4.6 Limitations and future directions

4.6.1 General

As already mentioned, many days were registered with no cattle predation, which left a large proportion of zeros in the dataset. Poisson regression models are widely used for count data (Hutchinson & Holtman, 2005; Sellers & Scmueli, 2010), thus, why it was chosen in this study. However, by using this model, introduced potential biased estimated parameters and standard errors. Caution when interpreting the results should therefore be taken and alternative models (see "Material & Method) may be preferred in future studies. Alternative methods may also include using binary or binomial regression models, where the likelihood of an event is investigated rather than the frequency of an occurrence provided from the Poisson regression model. Earlier studies analysing livestock predation have used a combination of Poisson and binomial regression models, such as Robertson *et al*. (2020).

Furthermore, the differences in observation length in hours between night (13h) and day (11h) was not accounted for in this study. This introduces bias into the analysis as the longer observation length create a longer window for predation to be categorised within nighttime and therefore more observations. For a more robust analysis, analysing predation per hour may be considered. Moreover, due to several of variables in in this study, multiple testing was carried out and due to limitations in Minitab software, no formal post hoc test was made to analyse differences across groups of individual environmental variables. Consequently, since no post hoc test was made and that alpha levels (p-values) were not adjusted, the risk of inflation of Type-I errors was prevalent (García-Pérez, 2023).

Also, many days in Ol Pejeta were registered with none to low rainfall levels. Consequently, each level within the daily rainfall predictor had different group size. The low rainfall level was overrepresented while the very heavy rainfall level was underrepresented. Consequently, this may have affected the overall stability of the estimates.

The results in this study should be interpreted with caution. Nevertheless, the findings should be considered investigative or exploratory, and further analysis is needed to confirm the patterns found in this study.

4.6.2 Predation data - daily mortality reports

Within this study, as well as in other research analysing livestock predation by lions, incidents or mortality reports was used (Robertson *et al*., 2020; Oliver *et al*., 2023; Mills *et al*., 2024). Records of mortality data provide the advantage of not needing to restrain any animals, since wild animals are difficult to handle. Additionally, restraining an animal, increase the risks of injuries of the animal itself and people. Overall, using reported incidents of cattle predation provides many ethical advantages. However, a few limitations may be induced when concerning the assessment of cause of death. In one way, it is beneficial to use direct observation by the fact that cause of death can be determined directly. Yet, there is a risk of making wrong assessments since there are other predators residing in Ol Pejeta

Conservancy, such as hyenas and leopards. Furthermore, the exact timing of when cattle was killed during the day may have been misclassified. Consequently, negative impacts on the overall credibility of the findings may be induced. However, the staff working in Ol Pejeta hold great knowledge, expertise and years of experience in this area, which increase the reliability of their assessments. For this reason, this study used daily mortality reports of cattle in Ol Pejeta Conservancy to predict cattle predation.

However, using a combination or alternative methods to incident reports may be considered in future research. In recent years, wildlife camera traps have been widely used to capture movements of animals (Nichols *et al*., 2011). Camera traps offer several advantages that include unlimited photos of animals, minimal cost and that they are non-invasive (Nichols *et al*., 2011). Since movement patterns of lions are largely driven by metabolic needs (Baker, 1996; Loveridge *et al*., 2009; Valeix *et al*., 2012), indicate that their movement, captured by camera traps, can be used as a further source of data to predict livestock predation and to create effective conservation strategies (Chege *et al*., 2024). In addition, although telemetry data (GPS [Global Positioning System] is considered invasive by needing to sedate and restrain an animal, a lion fitted with a GPS collar create the possibility to keep more precise positions and locate areas where lions commonly reside in (see Oriol-Cotterill *et al*., 2015). With this data, in support of environmental conditions, may capture a more comprehensive understanding of cattle predation, creating the possibility to give more effective mitigation strategies. In addition, fitted GPS collars, may be used as an early warning procedure as well. The usage of GPS collars on lions, is currently used and running in Ol Pejeta Conservancy to minimize conflicts (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-01-03)

Nevertheless, although data on solely lions give great indications of when livestock predation might occur, the usage of movement data of wild prey and livestock likely produce a deeper understanding of predation patterns and the risk of human-wildlife conflicts (Schieltz *et al*., 2017; Chege *et al*., 2024; Kupier *et al*., 2024; Mills *et al*., 2024). Currently, there are wildlife camera traps distributed across Ol Pejeta Conservancy and several of cattle are fitted with GPS-collars (Swedish University of Agricultural Sciences n.d.; Jung personal message 2025-01-03). By combining this data would likely generate many advantages in producing effective mitigation strategies as well as in understanding the ecology of respective lions, wild prey and cattle. Knowledge in how animals move can also be used in the process of establishing protected areas.

4.6.3 Environmental data

Since satellite images were not provided for each day in this study, due to cloud cover, a straight-line equation was calculated to cover these days. However, true biomass does not likely follow a linear pattern in nature (Ali *et al.*, 2016). In turn, this data could be considered biased. Future studies might consider having shorter measurement intervals to minimize these issues. Also, to get a more accurate estimation of vegetation cover would be to use a combination of direct observation and satellite remote sensing, which allow satellite images to be related to real features on the ground (Nagai *et al.*, 2020). For direct observations or ground truth observations, grassland biomass or height can be measured by using calibrated rising plate meters at different locations in the study area (Klootwijk *et al.*, 2019). By combining satellite imagining with truth ground observation provide the opportunity to analyse further vegetation characteristics, such as grass species.

Civil twilight was not considered in this study due to time constraints. When the sun is 6 degrees below the horizon, there is still some light arising from the sun, commonly referred to as civil twilight (Palmer *et al.*, 2017; Nakamura-Garcia & Ríos, 2022). Since the moon can be seen during these times, it is not certain if it is the light provided from the moon or the civil twilight that influenced predation in this study. In addition, the amount of light reaching the atmosphere depend on the moon surface brightness, distance between the moon and earth, moon position and angel of incidence (Śmielak, 2023). The distance between the earth and moon may cause fluctuations of perceived brightness from the moon, where closer distance generates increased perceived brightness on earth (Śmielak, 2023). Therefore, a more accurate way of estimating the effect of the moon on livestock predation, would have been to include these factors. Caution should therefore be taken when interpreting the results. However, to estimate the moon position and angel of incidence require specific tools. These tools are often expensive and need training to use. By this reason, only moon surface brightness was included in this study. Also, importantly, in this study, the light versus darkness provided from a specific moon phase was not only of interest, but also the actual moon phase. As observed in this study, higher rates of predation tend to occur in first quarter moon during the night, even though third quarter moon provide the same light intensity. Thus, although civil twilight, the distance between the moon and earth, moon position and angel of incidence can be considered in future studies to provide a more detailed insight into how different light levels affect predation, the results regarding moon phases would likely not change markedly. However, the actual moonlight intensity on the ground is further affected by the extent of cloud cover and vegetation structure (Śmielak, 2023). Thus, as cloud cover and vegetation structure are more easily assessed, future research can therefore consider their interactions rather than solely investigating the moon, cloud cover and vegetation as separate variables.

Lastly, rainfall and cloud cover data were gained from two weather stations situated in Nanyuki, approximately 20 kilometres away from Ol Pejeta Conservancy. In future research, incorporating rainfall and cloud cover measured from inside of Ol Pejeta Conservancy, would increase the reliability and quality of the data.

4.6.4 Specification of variables

Although this study found rainfall, grass height and moon phases to influence lion predation, other environmental conditions might influence as well. For instance, in Robertson *et al*. (2020) temperature was reported to increase predation risk including the severity of predation, with decreasing temperatures in Botswana. Lions are more active and more likely to hunt in cooler conditions, as hunting increases body temperature of lions, increasing the risk of becoming overheated (Hayward & Slotow, 2009; Robertson *et al*., 2020). Temperature has also been found to influence food intake of lions (West & Parker, 2002). Also, as mentioned briefly earlier in the discussion, wind speed and direction were shown in Wijers *et al*. (2021) to influence movement patterns of lions. It is indicated by Wijers *et al*. (2021) that more windy conditions or crosswinds are likely to increase the hunting success of lions through better prey detection. It is also indicated that more windy conditions might increase hunting success by the noise associated with the wind, making lions harder to detect by prey (Wijers *et al*., 2021). Moreover, in Barnardo *et al*. (2020) diet preferences of lions was reported to be sex-specific, including opportunistic. In turn, livestock predation might be influenced by the sex of the lion. Other factors, such as proximity to protected areas, management practices and abundance of livestock are also indicated to influence livestock predation (Singh & Kamboj, 1996; Ogada *et al*. 2003; Patterson *et al*. 2004; Van Bommel *et al*. 2007; Woodroffe *et al*. 2007; Kissui, 2008; Mills et al., 2024). Future studies should therefore consider these factors to better understand patterns of livestock predation.

5. Conclusion

In conclusion, the results in this study indicate that rainfall, grass height and moon phases influence predation on cattle, while cloud cover do not. In addition, their influence varied depending on the time of the day. Overall, no difference in the occurrence of a predation event was found between the night and day. However, taller grass gave higher rates of killed cattle during the night and in total, whereas shorter grass gave higher rates during the day. Higher rates were also observed with higher rainfall levels for the preceding 90-days during the night, as well as for the preceding 60-days during the night and in total. Notably, lower rainfall levels for the preceding 60-days, gave rise to more killed cattle during the day. Also, heavier daily rainfall resulted in more killed cattle during the night and in total. Lastly, higher rates of killed cattle were shown during the night with first quarter moon, while full moon gave higher rates during the day. The findings in this study illustrate a complex ecological relationship between environmental conditions, the time of the day and livestock predation and suggest that it is of importance of considering the time of the day. Nevertheless, future research should consider investigating the interaction between these environmental conditions as well as including movement data on wild prey, livestock and husbandry practices, as this mostly likely provide a more nuanced understanding of when predation on livestock might occur, and in turn human wildlife conflicts. The results of this study provide important insights into produce mitigation strategies of human-wildlife conflicts.

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Popular science summary

The African lion is one of many species that is suffering from population declines and is often involved with conflicts with humans over livestock. Human-wildlife conflicts constitute a global conservation and livelihood challenge as lions are being killed in retaliation for hunting and killing people's livestock, that are of cultural and economic value. Kenya experiences some of the highest conflict rates in East Africa, in which many people depend heavily on livestock production with cattle as their main source of income. Lions play an important role in the ecosystem and are a major source of income through wildlife tourism. Facilitating long-term co-existence between humans and wildlife has therefore become a growing priority to prevent these issues.

Implementing effective mitigation strategies that reduce these conflicts is crucial, where understanding of where and when lions may attack livestock is necessary. In this thesis, cattle predation by lions were investigated at Ol Pejeta Conservancy in Kenya. Predation patterns were examined with regard to the time of the day and to the following environmental conditions; daily rainfall, the average rainfall for the preceding 7-, 30-, 60- and 90-days, grass height (MSAVI2), moon phases and cloud cover. Predation data consisted of reported predation incidents by lions at Ol Pejeta Conservancy. The findings in this study illustrate a complex ecological relationship between predation, the time of the day and environmental conditions. Overall, no difference in the occurrence of a predation event was found between the night and day. The results further revealed that tall grass resulted in more killed cattle during nights, whereas short grass resulted in more killed cattle during the day. More killed cattle were shown with very heavy daily rainfall at night and in total. Higher rainfall levels for the preceding 90-days resulted in more incidents during the night, while higher rainfall levels for the preceding 60-days gave more incidents during nights and in total. Surprisingly, lower rainfall for the preceding 60-days, resulted in more incidents during the day. The study further revealed that first quarter moon resulted in more attacks during the night, whereas lighter moonlight levels, specifically full moon, resulted in more attacks during the day. Lions hunting success is reported to increase during rainier conditions, denser vegetation or taller grass and during darker conditions as this most likely produce advantages when hunting. However, the findings of this study indicate that time of the day influence the impact of these environmental conditions, as their effect

varied during the night, day and in total. Further studies should consider including the time of the day, movement data of wild prey and livestock as well as husbandry practices to gain a deeper understanding of when and where a lion may attack cattle. The findings of this study can be used by farmers, conservation practitioners or other involved parts into tailoring mitigating strategies of human-wildlife conflicts.

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Appendix 1

The univariable Poisson regression models examining the average rainfall for the preceding 60-days, daily rainfall and grass height as a single variable on cattle predation in total. (Coef)= Coefficient. (SE Coef)=Standard error of the coefficient. (95% CI)= 95% Confidence level. Significant values are indicated in bold.

Environmental variable		Coef	SE Coef	95% CI	P-value
60-days rainfall	Low rainfall(intercept)	-2.087	0.103	(-2.290;-1.885)	0.000
	Medium rainfall	-0.193	0.151	(-0.488; 0.102	0.199
	High rainfall	0.438	0.132	(0.178; 0.679)	**0.001**
	Medium rainfall (intercept)	-2.281	0.110	(-2.496;-2.066)	0.000
	Low rainfall	0.193	0.151	(-0.102; 0.488)	0.199
	High rainfall	0.631	0.137	(0.362; 0.900)	**0.000**
Daily rainfall	Low rainfall (intercept)	-2.086	0.0762	(-2.2354;-1.9365)	0.000
	Heavy rainfall	0.025	0.130	(-0.230; 0.280)	0.849
	Very heavy rainfall	0.725	0.149	(0.432; 1.017)	**0.000**
	Heavy rainfall (intercept)	-2.061	0.105	(-2.268; -1.855)	0.000
	Low rainfall	-0.025	0.130	(-0.280; 0.230)	0.849
	Very heavy rainfall	0.700	0.166	(0.375; 1.025)	**0.000**
Grass height	Short grass (intercept)	-2.078	0.102	(-2.277;-1.879)	0.000
	Medium high grass	-0.273	0.154	(-0.576; 0.029)	0.077
	Tall grass	0.445	0.130	(0.191; 0.700)	**0.001**
	Medium high grass (intercept)	-2.351	0.116	(-2.579;-2.124)	0.000
	Short grass	0.273	0.154	(-0.029; 0.576)	0.077
	Tall grass	0.719	0.142	(0.441; 0.996)	**0.000**

Appendix 2

The univariable Poisson regression models examining the average rainfall for the preceding 60-days, daily rainfall and grass height as a single variable on cattle predation during the night. (Coef)= Coefficient. (SE Coef) =Standard error of the coefficient. (95% CI)= 95% Confidence level. Significant p-values are indicated in bold.

Environmental variable		**Coef**	**SE coef**	**95% CI**	**P-value**
90-days rainfall	Low rainfall (intercept)	-3.290	0.183	(-3.647;-2.932)	0.000
	Medium rainfall	0.763	0.224	(0.324; 1.201)	**0.001**
	High rainfall	0.995	0.215	(0.574; 1.416)	**0.000**
	Medium rainfall (intercept)	-2.527	0.129	(-2.780;-2.274)	0.000
	Low rainfall	-0.763	0.224	(-1.201;-0.324)	**0.001**
	High rainfall	0.232	0.172	(-1.104; 0.569)	0.176
60-days rainfall	Low rainfall(intercept)	-3.075	0.169	(-3.407;-2.744)	0.000
	Medium rainfall	0.226	0.223	(-0.212; 0.664)	0.311
	High rainfall	0.896	0.200	(0.503; 1.289)	**0.000**
	Medium rainfall (intercept)	-2.849	0.146	(-3.135;-2.563)	0.000
	Low rainfall	-0.226	0.223	(-0.664; 0.212)	0.311
	High rainfall	0.670	0.181	(0.315; 1.026)	**0.000**
Daily rainfall	Low rainfall (intercept)	-2.779	0.108	(-2.990;-2.568)	0.000
	Heavy rainfall	0.025	0.184	(-0.336; 0.385)	0.893
	Very heavy rainfall	0.918	0.197	(0.532; 1.303)	**0.000**
	Heavy rainfall (intercept)	-2.754	0.149	(-3.047;-2.462)	0.000
	Low rainfall	-0.025	0.184	(-0.385; 0.336)	0.893
	Very heavy rainfall	0.893	0.222	(0.458; 1.328)	**0.000**
Grass height	Short grass (intercept)	-2.989	0.160	(-3.303;-2.675)	0.000
	Medium high grass	0.205	0.216	(-0.217; 0.628)	0.341
	Tall grass	0.727	0.195	(0.345; 1.109)	**0.000**
	Medium high grass (intercept)	-2.784	0.144	(-3.067;-2.501)	0.000
	Short grass	-0.205	0.216	(-0.628; 0.217)	0.341
	Tall grass	0.522	0.182	(0.165; 0.879)	**0.004**

Moon phases	Full moon (intercept)	-3.125	0.186	(-3.489;-2.761)	0.000
	Third quarter	0.585	0.240	(0.114; 1.056)	**0.015**
	First quarter	0.695	0.236	(0.232; 1.158)	**0.003**
	New moon	0.635	0.234	(0.176; 1.094)	**0.007**
	First quarter (intercept)	-2.430	0.146	(-2.716;-2.144)	0.000
	Full moon	-0.695	0.236	(-1.158;-0.232)	**0.003**
	Third quarter	-0.109	0.211	(-0.523; 0.304)	0.604
	New moon	-0.063	0.204	(-0.460; 0.340)	0.770
	Full moon (intercept)	-2.540	0.152	(-2.838; -2.241)	0.000
	Third quarter	0.050	0.209	(-0.360; 0.459)	0.812
	First quarter	0.109	0.211	(-0.304; 0.523)	0.603
	New moon	-0.585	0.240	(-1.056; -0.114)	0.015

Appendix 3

The univariable Poisson regression models examining the average rainfall for the preceding 60-days, daily rainfall and grass height as a single variable on cattle predation during the day. (Coef)= Coefficient. (SE Coef) =Standard error of the coefficient. (95% CI)= 95% Confidence level. Significant p-values are indicated in bold.

Environmental variable		Coef	SE Coef	95% CI	P-value
60-days rainfall	Low rainfall(intercept)	-2.719	0.141	(-2.996;-2.441)	0.000
	Medium rainfall	-0.845	0.252	(-1.339; -0.352)	**0.001**
	High rainfall	-0.331	0.219	(-0.760; 0.097)	0.130
	Medium rainfall (intercept)	-3.564	0.209	(-3.973;-3.155)	0.000
	Low rainfall	0.845	0.252	(0.352; 1.339)	**0.001**
	High rainfall	0.514	0.267	(-0.009; 1.037)	0.054
Grass height	Short grass (intercept)	-2.846	0.149	(-3.138;-2.554)	0.000
	Medium high grass	-0.718	0.260	(-1.228; -0.208)	**0.006**
	Tall grass	-0.073	0.130	(-0.493; 0.348)	0.734
	Medium high grass (intercept)	-3.564	0.213	(-3.982; -3.147)	0.000
	Short grass	0.718	0.260	(0.280; 1.228)	**0.006**
	Tall grass	0.645	0.263	(0.130; 1.161)	**0.014**
Moon phases	First quarter (intercept)	-3.508	0.250	(-3.998;-3.018)	0.000
	Full moon	0.729	0.295	(0.151; 1.307)	**0.013**
	Third quarter	0.608	0.310	(0.001; 1.215)	**0.049**
	New moon	0.217	0.329	(-0.427; 0.861)	0.509
	Full moon (intercept)	-2.779	0.156	(-3.085;-2.473)	0.000
	New moon	-0.512	0.264	(-1.030; 0.006)	0.053
	Third quarter	-0.121	0.240	(-0.592; 0.350)	0.615
	First quarter	-0.729	0.295	(-1.307; -0.151)	**0.013**
	New moon (intercept)	-3.291	0.213	(-3.709; -2.873)	0.000
	Third quarter	0.391	0.281	(-0.159; 0.941)	0.163
	First quarter	-0.217	0.329	(-0.861; 0.427)	0.509
	Full moon	0.512	0.264	(-0.006; 1.030)	0.053

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