Human-Leopard Conflict and Coexistence in Northern Kenya

Final Report

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Preface

How did a team of five American graduate student researchers come to be studying the issue of human-leopard conflict on the high savannas of Kenya's Laikipia Plateau? As we will show, the answer to this question spans hundreds of years and proves critical to the contextualization of our recommendations for improving regional human-leopard coexistence.

The story of leopard conservation in Laikipia County, Kenya is highly complex. In this report, we will shed light on this narrative by providing a broad overview of the region's historical geography. Though the political and ecological history of Kenya is exceedingly nuanced, overlapping, and generationally connected, we will consider it within three broad historical eras. We draw from discussions of the pre-colonial history of East African pastoralism-- examining the relationship between land, people, livestock and wildlife prior to European/Western occupation. From there, we will examine the colonial era history of Kenya. This was a period marked by changing relationships between people, land, and wildlife brought on by imported colonial values and governance systems. Finally, we contextualize our own positionality within a second wave of shifting human-wildlife dynamics that occurred and continues to occur during this post-colonial era.

This historical overview frames the tangled relationship between the notion of leopard conservation, the role of Loisaba Conservancy and the San Diego Zoo Wildlife Alliance (formerly San Diego Zoo Global), the political economy of Laikipia, and our own relationship to these various actors, ideas, and places. We feel that by considering how we, as student researchers from the University of Michigan, got to where we are, we can provide more effective, just, and viable recommendations for improving human-leopard coexistence in the communities surrounding Loisaba Conservancy.

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Executive Summary

African Leopards are a vulnerable species under threat from habitat disturbance, declining prey abundance, and of greatest concern for our project, retaliatory killings as a result of livestock depredation (Jacobson et al., 2016; Kissui, 2008). Protecting leopard populations in Laikipia County, Kenya from these human conflicts has become an imperative conservation goal as leopards provide both ecosystem benefits (Braczkowski et al., 2018; O'Bryan et al., 2018; SANBI, 2020) and likely add value to the growing community-based tourism economy.

World-wide, the conservation paradigm is increasingly centered around the concerns of local communities where the effects of conservation projects are most acutely felt (Adams & Hulme, 2001; Campbell & Vainio-Mattila, 2003; Sunderland et al., 2008). This is certainly true in Laikipia County, where private and community conservancies are being used as strategies for integrating the livelihood needs of pastoralists with leopard conservation goals.

To maximize the efficacy of these community centered approaches to leopard conservation, SDZWA and Loisaba Conservancy are studying social and ecological dimensions of human-leopard conflict data and mitigation strategies. We assist with this mission by analyzing ecological and sociological data related to human-leopard conflict collected by SDZWA. We also conduct an extensive literature review to contextualize regional human-leopard conflict within the political and ecological landscape and identify important considerations for the design and implementation of human-leopard conflict mitigation strategies. These efforts culminate in our production of a set of recommendations for how SDZWA and their partners at Loisaba Conservancy can improve human-leopard interactions in a viable, just, and effective manner.

Summary of Recommendations:

I. Improving Protective Measures Efficacy
   - A. Support boma operation and reinforcement
   - B. Consider use of guard dogs
   - C. Consider use of noise and light emitting devices
   - D. Focus on protecting shoats
   - E. Focus on protecting larger herds
   - F. Focus on protecting livestock closer to rivers
   - G. Focus on protecting livestock near land cover transition zones

II. Advocating for Long-Term Reform
   - A. Advocate for statewide reformations of wildlife policy
   - B. Increase capacity for pastoral mobility
   - C. Advocate for reformed land governance structures
   - D. Facilitate the elevation of traditional ecological knowledge
   - E. Facilitate the actionability of traditional ecological knowledge
   - F. Engage in public outreach campaigns that discuss the relative threats to community livestock

III. Conducting Future Research

A. Conduct research and expand interviews into further understanding historical human-wildlife interactions and the cultural significance of wildlife in the region
B. Conduct research that collects richer socioeconomic data including poverty and herd sizes
C. Conduct future studies that collect richer ecological data on things like wild prey densities and higher resolution precipitation/seasonal data
D. Standardize collection of leopard conflict data from pastoralists on a non-self reporting basis

StoryMap: Human-Leopard Conflict and Coexistence in Northern Kenya

Introduction

Laikipia County is a warm, semi-arid region in central Kenya and home to many pastoralist communities (Yurco, 2017). Livestock depredation by local carnivores impacts the sustainability of livelihoods in the area. A significant portion of this conflict occurs between pastoralists and the African leopard (*Panthera pardus pardus)*. Recent declines in leopard populations have resulted in the species being uplisted to 'vulnerable' by the International Union for Conservation of Nature. This, combined with a ban on the hunting of wildlife in Kenya, has inhibited pastoralists' abilities to legally eliminate problem leopards in order to protect their livestock. Leopards opportunistically prey on livestock, but are protected from retaliation due to their status as a vulnerable species. Focusing only on contemporary human-leopard interactions in the region would remove the political and historical context that has driven these interactions to the point of conflict. Changes in land use and management due to British colonization, coupled with the rise of the community-based conservation (CBC) model has markedly altered relationships with local wildlife. Additionally, the field of wildlife conservation must confront its ties with the colonial legacies of land dispossession from Indigenous communities.

Leopard populations across the world are on a decline as a result of various anthropogenic actions. The threats include habitat destruction and fragmentation, decrease in prey availability, human-leopard conflicts, trophy hunting, poaching, and indiscriminate killing (Jacobson et al., 2016). Leopards are integral for ecosystems as they are apex predators and help regulate trophic relationships and habitat structure (Braczkowski et al., 2018; SANBI, 2020). Humans also benefit from leopards as they can control prey that can cause crop damage and spread infectious diseases (O'bryan et al.,2018; SANBI, 2020). Leopards are culturally important to many Indigenous communities as they are a symbol of power, courage and wisdom (SANBI, 2020). Many Indigenous communities have utilized leopards as an integral symbol as part of their culture and society. The disappearance of leopards could not only lead to drastic environmental consequences, but also can impact the culture and community of many Indigenous groups in Africa.

The communities of Laikipia County are largely of Maasai, Samburu, and Turkana lineage (Yurco, 2017) and engage in a primarily agro-pastoral economy (Letai, 2011). While these communities still practice a pastoral lifestyle, it cannot be described as one of "traditional" pastoralism. Many of the aspects of the pastoral economy, such as high mobility and common-pool resource governance that made the pastoral livelihoods here "traditional", have eroded since the colonization of Kenya in the late 1800s (Unks et al., 2019). Modern pastoral livelihoods here are defined by a wholly different set of social and ecological dynamics. Though there is a lack of historical documentation of regional pre colonial interactions between pastoralists and leopards specifically, Jacobson et al. (2016) note that the African leopard range was far greater across East Africa immediately prior to colonization, and others point out that traditional pastoralism is one of the most sustainable livelihood strategies for semi-arid lands (Butt, 2010; Ellis, 1999). Together, historical and contemporary research into leopard population ecology and rangeland ecosystem ecology suggests that the empowerment of traditional pastoralism could yield positive outcomes for leopard conservation goals.

Using a political ecology lens we analyze the contemporary human-leopard conflicts occurring in Laikipia County, Kenya. By approaching the issue this way we aim to contextualize human-leopard conflict within the broader histories of pastoralism, colonization, and conservation. As we will show, these historical geographies complicate the narrative of human-leopard interactions, making our recommendations for improving human-leopard interactions all the more difficult to produce. However, without this component, our recommendations would likely prove insufficient at protecting leopards and/or protecting the pastoral communities with which they come into conflict and would certainly perpetuate the colonial ideology that is still entrenched in the conservation of East African wildlife and wildlands (Cockerill & Hagerman, 2020).

In this report, we examine how Uhifadhi wa Chui, a leopard conservation program developed through a partnership between the San Diego Zoo Wildlife Alliance (SDZWA) and Loisaba Conservancy, fits into the overall political and ecological history of the region. We will also analyze the efficacy of current human-leopard conflict mitigation strategies using conflict data reports provided by the program. We begin by characterizing periods of Kenya's history from pre to post-colonization in relation to human interactions with social and environmental conditions. We then delve into the ecology of the African leopard and the Laikipia Plateau. This is followed by the contextualization of the Loisaba Conservancy and San Diego Zoo Wildlife Alliance within the region and the role of our graduate student project. Next, we detail our methods, results, and discussion of the leopard conflict data provided and, finally, propose recommendations for peaceful human-leopard coexistence within a broader historical context.

Political Ecology of Laikipia County

Precolonial Era

The precolonial history of the lands known today as Kenya can be characterized by dynamic and diverse people existing within various intersecting and overlapping ecological niches (Galaty, 1982; Ndege, 2009; Spear, 1993). What is now Laikipia County in central Kenya has a history of high savanna pastoralism practiced among various ethnic groups over several millennia (Boles et al., 2019; Sutton, 1993). Laikipia's pre colonial, pastoral history culminated in what has been referred to as a "perfected" high savannah pastoralism by the Maa speaking peoples approximately 400 years ago (Sutton, 1993). These semi-nomadic pastoral communities reared sheep, cattle, and goats in the semi-arid region alongside wild herbivores and carnivores, developing the knowledge and tools necessary to coexist with competitors and predators alike under ever-changing environmental conditions (Lankester & Davis, 2016).

The pastoralism practiced in East African semi-arid rangelands developed as an economic adaptation to the environmental conditions of unreliable rainfall patterns and prolonged droughts (Gifford-Gonzalez, 2005; Lankester & Davis, 2016). High mobility across communal rangelands, along with an effective herd management system, allowed East African pastoralists to successfully inhabit and make use of the semi-arid savanna landscape (Gifford-Gonzalez, 2005; Lankester & Davis, 2016). By organizing themselves into "small, mobile herding units while at the same time maintaining wide-ranging links throughout the society, based on age-sets that united all the men of a given age in a single comprehensive social institution," pastoralists exhibited a system of social governance that effectively adapted to their environmental conditions (Spear, 1993, *Maa-Speaking People and their Neighbours*).

Ensuring survival throughout challenging times, such as prolonged drought, required complex social and ecological management. By widely dispersing their livestock across rangelands, pastoralists could ensure some of their herd always survived harsh periods (Spear, 1993). Divisions of labor based on age, sex, and social identity facilitated a process of building larger herd sizes during wet seasons to accommodate for livestock losses during periods of drought (Gifford-Gonzalez, 2005; Spear, 1993). These herd management techniques required intricate ecological knowledge and social organization. Typically, a community of families worked together to collectively manage their herds (Spear, 1993). At the same time, individual herders established and maintained links to kin and age-mates outside their immediate community to ensure access to rangelands (Spear, 1993) and councils of elders made decisions regarding the sustainable use of lands for livestock husbandry (Mwangi & Ostrom, 2009). As Galaty (1982) notes, within the Maasai communities of Kenya and Tanzania, through elaborate social interactions emerged broader systems of land governance, resource use, and economic networks that were a defining feature of pre colonial pastoralism.

Though the depiction of Maasai pastoralists as the “archetypal primordial conservationist” is laden with prejudices (Lane, 2015, p. 264), the Maasai did thrive in the semi-arid lands of the Laikipia Plateau for several millennia prior to European colonization in a manner which may be considered ‘sustainable.’ Pastoral communities were shaped by the savanna environments they inhabited, but they also helped shape the savannas. Through their mobility, livestock grazing, and use of fire, pastoralists directly affected the soil composition and nutrients as well as the grass species and tree cover of the rangelands (Lankester & Davis, 2016), which in turn affected wildlife composition, survival, and fecundity (Boles et al., 2019). For pastoral communities and the wildlife with which they shared the savannas, the presence of the other presented an array of advantages and disadvantages. As pastoral communities migrated, their livestock left behind concentrations of wastes that spawned rich plant life for herbivores and hunting wildlife provided a means of survival during periods of scarcity. However, their coexistence also led to competition for grasses during times of drought, transmission of diseases from wildlife to livestock, and livestock predation by carnivores (Lankester & Davis, 2016). Regardless of how we might categorize such interactions today, these exchanges were once inherent aspects of the pastoral economies of East Africa and the Laikipia Plateau. Towards the end of the nineteenth century, however, the interactions between pastoralists, their livestock, wildlife, and rangelands changed drastically as various factors challenged the apparent ecosystem-economy equilibrium that had been developed over thousands of years.

In the late 1800s, diseases decimated both human and livestock populations across East Africa (Shaffer, 1967; Sinclair, 1995). This sparked a series of changes in both plant and animal life in ecosystems with lengthy histories of use as pastoral rangelands (Lankester & Davis, 2016; Sinclair, 1995). These changes occurred just as imperial powers began formally establishing themselves across East Africa following the 1884 Berlin Conference. The ecosystem dynamics observed by incoming colonial administrators were, as Lankester & Davis (2016) describe, assumed “to be the norm rather than a unique historical moment,” and so, colonial administrators set these ecosystem dynamics “as the benchmark against which wildlife conservation has been judged ever since” (p. 475).

Colonial Era

The 1895 British annexation of the East African Protectorate, which later became known as the Kenya Colony, marked the beginning of a nearly 70-year-long period of direct colonial rule (Gjerso, 2015) that resulted in the demonization, victimization, marginalization, and manipulation of Indigenous communities and landscapes across the region. During this period, Colonial administrators encouraged white settlement of historic rangelands and promoted land tenure policies that supported large scale, commercial agriculture and ranching activities (Morgan, 1963). Expanding the agricultural potential of the Kenya Colony was the primary focus of Colonial administrators. It was not until decades after European occupation that Colonial administrators became substantively concerned with the conservation of land or wildlife. By the end of the Colonial era, the European land tenure model had blanketed the Colony. Room for the traditional African land ethos was left only on the margins of society and the increasingly profitable African wildlife became the foreground of Kenya’s international image. The relationships, values, and ideologies distilled into Kenyan society during Colonial rule underlie the physical and narrative context of wildlife conservation today.

For pastoralists of the Laikipia Plateau, Colonial rule meant the imposition of a new set of land governance priorities and systems. In *Moving the Maasai: A Colonial Misadventure* (2006), Lotte Hughes provides a factual recount of the series of early twentieth century events that displaced and marginalized the Kenyan Maasai whose ancestral lands include the semi-arid grasslands of the Laikipia Plateau. Likely due to the severe population declines among the Maasai and their cattle as a result of disease outbreaks in the late 1800s (Shaffer, 1967; Sinclair, 1995) as well as a poor understanding of regional economies and land use patterns, colonial land surveyors initially reported vast tracts of uninhabited and unused lands suitable for agricultural and commercial development in the rangelands of the Laikipia Plateau (Morgan, 1963). These socio-ecological circumstances led to the 1904 Agreement, under which the Maasai of the central Rift-Valley were relocated onto “two reserves in order to make way for white settlement” (Hughes, 2006, p. 8). These reserves were both on lands that were already occupied, governed, and used by other distinct Maasai groups (Mwangi & Ostrom, 2009). One reserve was established on the southern border of Kenya, while the other was established on the north-central Laikipia Plateau (Hughes, 2006).

Just seven years after the 1904 Agreement that promised the reserves would be left to the Maasai indefinitely, the Maasai living in the Laikipia Reserve were forcibly relocated yet again (Hughes, 2006). Colonial administrators justified this second eviction through a 1911 Agreement that they argued effectively nullified the 1904 Agreement (Hughes, 2006). In both instances, colonial officials took advantage of Maasai illiteracy in order to deceive and coerce them into signing the Agreements. Subsequently, Maasai illiteracy made it difficult for them to challenge the Agreements in British courts (Hughes, 2006). Exiled from their lands on the Laikipia Plateau to make room for white settlers, the majority of northern Maasai were forced onto the Southern Maasai Reserve, though some managed to stay behind and others eventually returned with their herds to settle on land that had come under white ownership (Hughes, 2006).

As Colonial administrators redistributed the Maasai rangelands of the Laikipia Plateau to white settlers for commercial farming and ranching following the 1911 Agreement, the lands became known as the ‘White Highlands’ (Hughes, 2006; Morgan, 1963; Unks et al., 2019). Having found the lands to be of superb quality for agricultural development and of strategic location near the Uganda Railway, colonial officials enacted a series of settlement policies that exclusively granted land to white immigrants, overlooking Indigenous people’s land claims and ignoring land applications from Indian migrants (Morgan, 1963). White settlement of the Highlands and surrounding areas reached a crescendo under the Ex-Soldier Settlement Scheme following the end of World War I (Morgan, 1963). During the next twenty years, colonial ordinances and policies would legally open the Highlands to non-whites, but would still privilege the Highlands to European settlers and establish formal boundaries between the “Scheduled Areas” of white settlement and the “African Land Units” and other similar Indigenous African Reserves (Shaffer, 1967; Morgan, 1963). In documenting the colonial involvement on the Laikipia Plateau specifically, Morgan (1963) notes that white “settlers rapidly took up large ranches for extensive grazing on the natural grassland” (p. 150), the legacy of which can be seen in the land ownership of Laikipia today (Letai, 2011).

Heading into the 1920s and ‘30s, Colonial administration goals of commercializing Kenya’s agricultural outputs were on full display. However, concerns over land and soil conservation began to emerge as perceptions of declining farm productivity and overgrazed rangelands increased (Anderson, 1984). Herskovits’ 1926 work, “The Cattle-Complex In East Africa,” which suggested that a compulsive and unsustainable attachment to cattle among East African pastoralists led them to strain environmental resources, became popularized by Colonial administrators and white settlers looking for someone to blame for environmental degradation (Mwangi & Ostrom, 2009). Thus, despite evidence pointing to European cereal monoculture as the source of soil degradation in the White Highlands (Anderson, 1984), Indigenous pastoral practices became the target of reformation efforts during a series of land commissions from the 1930s-50s (Mwangi & Ostrom, 2009).

The Carter Commission of 1932, the Dow Commission of 1952, and the 1954 Swynnerton Plan gradually cemented traditional Indigenous livestock management and land tenure as the root cause of environmental degradation (Mwangi & Ostrom, 2009). In response, the Colonial administration expanded policies of individualization, privatization, commercialization, and sedentarization as solutions to the ‘problems’ associated with traditional pastoral practices and land governance (Mwangi & Ostrom, 2009; Unks et al., 2019). To facilitate the enactment of these policies, grazing and settlement schemes were developed (Mwangi & Ostrom, 2009). These schemes proved incompatible with the ecological and social realities of life on the high savannas and ultimately intensified soil degradation and political unrest, largely at the expense of increasingly marginalized Indigenous communities (Mwangi & Ostrom, 2009).

While Kenyan Independence was achieved in 1963, the Land Adjudication Act of 1968 effectively ensured that the colonial era grazing and settlement schemes of the Swynnerton Plan were carried out. As Unks et al. (2019, p. 76) states:

> "The Land Adjudication Act of 1968, though post-independence, implemented this mandate [the Swynnerton Plan] (Grandin, 1991), and was backed by numerous international development agencies, and advocated for group ranches, or subdivisions within pastoralist reserves, intended to ultimately convert subsistence livestock husbandry to commercial beef production (Grandin, 1991). Subdivisions were intended to create formalized tenure and encourage investments to increase carrying capacity of the land, prevent degradation, reduce stocking rates, and to provide collateral for loans (Grandin, 1991; Mwangi, 2007), based upon the logic that individual land tenure would bring these changes (Hardin, 1968; Campbell, 1993). However, group ranches were frequently not delineated with respect to seasonal water and grazing access; the boundaries often crossed seasonal migration lines, resulting in decreased ability to access reserve grazing (Coldham, 1982; Halderman, 1972; Rutten, 1992) and reduced flexibility of socially coordinated responses at different scales" (Mwangi and Ostrom, 2009).

Thus, despite evidence as to the compatibility of traditional pastoral land management and environmental conservation goals (Niamir-Fuller et al., 2012), the formal end of Kenya's colonial era did nothing to subvert the reinforcement of European land tenure ideals and the rejection of traditional pastoral ethos.

At the same time that Colonial administrations were reshaping regional land tenure, they were also importing a set of European values for wildlife conservation and management. This began with the establishment of two "game reserves" at the turn of the twentieth century, one in north central Kenya and one in the south along the border with German East Africa (Matheka, 2005), although they were not meaningfully managed for conservation objectives when first established. While the relationships between Indigenous Africans, lands, and wildlife varied immensely across geographic, social, and ethnic lines during the pre colonial era (Galaty, 1982), early colonial wildlife management efforts, such as the game reserves, particularly affected pastoral groups. The two game reserves encompassed much of the same land established by Colonial administrators for use by pastoral Maasai and Samburu communities (Matheka, 2005). As a result of the increased concentration of wildlife and restricted mobility, these pastoralists were forced to deal with intensified grazing competition from wild herbivores, highly contagious wildlife diseases, and increased livestock depredation (Matheka, 2005).

Just as Indigenous Africans' interactions with wildlife varied across geographic and demographic lines, so too did those of Europeans. In the early days of Colonial occupation, white settlers largely engaged in the eradication of Kenyan wildlife in order to create and preserve commercial farms and ranches (Steinhart, 1989). At the same time, wealthy and powerful white globetrotters-- notably Theodore Roosevelt-- hunted big game across East Africa as 'sportsmen' or 'hunter-naturalists' (Steinhart, 1989). While these 'holiday hunters' may have posed less of a physical threat to Kenyan wildlife in the early colonial period than white settlers, as Steinhart (1989, pp. 253-254) points out:

> "They contributed to the ideological foundations of the hunting dilemma: their very eminence and wealth, their social standing and class backgrounds supported the belief that proper hunting was the sport of gentlemen who obeyed a civilized and humane set of rules of the game. These rules included the exclusive use of firearms and a disdain for the use of weapons and techniques which were considered 'unsporting.' Such a definition of proper hunting excluded Africans *ipso facto*."

This narrative building largely withstood the test of time and has proved most detrimental to Black Africans who became the face of wildlife poaching in the 1930s (Steinhart, 1989), an archetypal depiction which continues to be perpetuated to this day (Wall & McClanahan, 2015).

The categories of white settlers, native pastoralists, Black 'poachers', and elite sportsmen, among others, became significant identifiers in the early twentieth century. Intricately tied to the stories of these groups and that of Kenyan conservation and wildlife management as a whole was another emerging colonial identity: the 'gamekeeper' (Steinhart, 1989). Under the auspices of the Game Department, white gamekeepers became the "regulators" of hunting across Kenya (Steinhart, 1989). Since the presence of wildlife was largely considered to be a threat to white commercial agricultural interests and the settlement schemes for native groups, the early gamekeepers, often employing Black Africans in subordinate roles, primarily focused on revenue collection from hunting licenses and the extermination of wildlife pest species and particular problem animals (Steinhart, 1989). The actual preservation of wildlife remained a low priority for the Game Department until after World War II, even as notions of conservation, specifically soil conservation, rose in the early 1930's with the Carter Commission (Steinhart, 1989).

Out of the International Conference on the Preservation of Wildlife in 1933, a vision for protecting Kenya's wildlife through 'game sanctuaries' or 'national parks' emerged (Steinhart, 1989). This vision would be put on hold until the end of WWII, when the Royal National Parks of Kenya was developed, followed shortly thereafter by the creation of the first Protected Area (PA)- Nairobi National Park in 1946 (Steinhart, 1989). It was under the new system of protected areas that Kenyan wildlife began to be valued for its aesthetic appeal, sparking investments in commercial and international ecotourism (Steinhart, 1989; Cockerill & Hagerman, 2020). Leading up to Kenya's independence in 1963, this fortress conservation model for wildlife preservation was further enshrined through the creation of Protected Areas and a coordinated effort by the Game and Parks Department to combat poaching within park boundaries, especially for Africa's big five: leopards, elephants, lions, buffalo, and rhinoceros (Steinhart, 1994).

The fortress conservation model, unfounded narratives about Black Africans' antagonistic relationships to land and wildlife, and increasing international influence became part of the foundation underpinning Kenya's transition to a post-colonial state. The effects of colonial era land and wildlife policies shaped the post-colonial landscape for people and wildlife across Kenya, but perhaps nowhere was as uniquely affected as the Laikipia Plateau. It is there that traditional pastoral ranching was "perfected" by Maa speaking pastoral communities centuries before the colonization of Europeans (Sutton, 1993), there that Maasai were forcibly removed and killed to make space for white ranchers (Hughes, 2006), there that the second highest abundance of wildlife now exists in Kenya (Sundaresan & Riginos, 2010), and there that countless researchers try to figure out how to shape the conservation landscape so that both humans and wildlife can thrive together.

Post-Colonial Era

Attempts made during the Colonial era to formally separate land use types through settlement schemes, privatization, commercialization, and the establishment of national parks, have been reinforced, rejected, and reconceived since Kenya achieved its independence in 1963. Today, agriculture and tourism are the first and third largest sectors of the Kenyan economy, respectively (*Key Sectors*, n.d.). Letai (2011) evaluated the land use of Laikipia County and shows that land used specifically for farming and ranching activities make up at least 75% of the total land area and that all subdivisions surrounding Loisaba are explicitly used for livestock rearing, with the exception of two which are held by the government for military and livestock veterinary purposes. Though only 2% of lands in Laikipia County are formally designated for wildlife conservation (Sundaresan & Riginos, 2010), as Sundaresan & Riginos, (2010) and Letai (2011) affirm, wildlife conservation activities and commercial agriculture are geographically overlapping endeavors, with many private and group ranches also engaging in conservation enterprises across the county. This current land tenure structure has resulted both from a perpetuation of colonial legacies, and from a series of post-independence developments, including changes within the Kenyan state government, a transition to community-based conservation (CBC), and a new wave of international interests and resources, none of which can be understood as discrete issues.

The fortress conservation model for preserving wildlife has been expanded across Kenya through the establishment of sixty-five protected areas to date (*Overview*, 2021), the majority of which were gazetted during the 1960s-80s (Sindiga, 1995). In part, these protected areas represent the adherence to a belief that the centralization of wildlife conservation and land governance would yield the greatest benefits to environmental resources by facilitating the exclusion of people from those landscapes, often done through extreme militarization (Butt, 2016). In addition to protecting wildlife from the alleged perils of Indigenous land usage, these protected areas were intended to generate substantial tourism revenue for the state economy and indeed, by the late 1980's tourism was accounting for 12% of Kenya's GDP, surpassing the revenue produced from their primary agricultural exports (Akama, 2000).

Early post-colonial affinity towards a centralized wildlife conservation effort was codified in the 1977 Wildlife Conservation and Management Act (WCMA). The largest actions of the WCMA were a near-universal ban on the hunting and consumption of wildlife throughout the entire country, which was partially rescinded in 1992 but was reinstated in 2003 and is in effect today (Sundaresan & Riginos, 2010), the establishment of wildlife damage compensation concepts (Cockerill & Hagerman, 2020) and its merging of the Game Department and Kenya National Parks Trustees into the Wildlife Conservation and Management Department (WCMD). The WCMD was largely considered ineffective, however, and following international pressure for Kenyan political reformation in the 1980s, the Kenya Wildlife Service (KWS) succeeded the WCMD in 1989 (Cockerill & Hagerman, 2020).

Unlike its predecessor, the newly formed KWS was more willing to advance wildlife protection initiatives outside of formal Protected Areas and laid the foundation for practical community-based conservation efforts (Cockerill & Hagerman, 2020). Whether this was due to realizations that wildlife could not be adequately protected through the fortress conservation model (Kiringe & Okello, 2007; Western et al., 2009), or genuine concerns for the struggles of people displaced by and living near protected areas (Butt, 2011; Sindiga, 1995), the Kenyan government largely stopped creating formal Protected Areas in the 1990s (Sindiga, 1995). The fortress conservation model was succeeded by community conservation and development initiatives which decentralized conservation strategies and "while KWS remain[ed] the sole body with mandated custodianship over wildlife," international bodies such as the United States Agency for International Development (USAID), the World Bank, and countless NGOs became instrumental in the production and facilitation of this new conservation paradigm (Cockerill & Hagerman, 2020 p. 7). According to Cockerill and Hagerman (2020), "from 2004 to 2013 there was an 80% increase in the amount of land under conservation through non state conservation (Fig. 2). Most of this increase can be attributed to community conservation initiatives that account for 60.5% of all conservation areas by number in Kenya" (p. 7). In Laikipia County, a lack of formal state protected areas makes CBC initiatives the primary protectors of wildlife, with many private and group ranches taking on roles in wildlife conservation (Letai, 2011; Unks et al., 2019).

Integrated Conservation and Development Projects (ICDPs), the precursors to community-based conservation (CBC), "assume that human and nonhuman systems are interdependent and, therefore, that the challenges of conservation and development are inextricable" (Barrett & Arcese, 1995, p. 1073). State and non-state actors thus began treating them as such, with disputed benefit for wildlife and human communities (Barrett & Arcese, 1995). CBC eventually evolved out of ICDPs to better center communities within local conservation and development projects (Campbell & Vainio-Mattila, 2003). Conservancies have become the embodiment of the CBC idea in Laikipia, seeking to bridge the gap between human livelihoods and wildlife conservation through programs that allow local people to benefit from protecting environmental resources. Conservancies ideally aid communities through local infrastructure improvements, health care services, and support for primary education, among other things, while simultaneously providing undisturbed lands for wildlife to thrive (Muthiani et al., 2011). CBC is not without its flaws though. As scholars note, CBC often neglects to reconcile power inequities, allowing foreign actors to prioritize the conservation and development goals (Cockerill & Hagerman, 2020) and provide inadequate benefits to local communities from wildlife conservation activities (Campbell & Vainio-Mattila, 2003; Muthiani et al., 2011). The rise of conservancies during the post-colonial era has been complemented by other land tenure developments.

The colonial era policies and recommendations aimed towards the privatization of rangelands in Kenya-- which was supposed to solve the issue of degrading environmental conditions and transition subsistence pastoralists into a commercial ranching economy (Mwangi & Ostrom, 2009)-- were further perpetuated well after Kenya achieved independence. Similar to the use of Herskovits' 1926 Cattle Complex by colonial administrations to justify the rejection of traditional East African livestock and land management practices during the colonial era, the publication of Garrett Hardin's The Tragedy of the Commons in 1968, only 5 years after Kenyan independence, magnified the erosion of the common-pool resource model and self-governance of pastoral communities throughout the post-colonial era (Yurco, 2017). During this time, post-colonial rangeland land tenure has fluctuated greatly, transitioning between the grazing and settlement schemes of private individual ranches and community group ranches that were the output of agricultural commercialization goals (Mwangi & Ostrom, 2009).

The large-scale private ranches have largely stayed under the familial ownership of wealthy Kenyans and Kenyans of European descent since Kenya gained independence in 1963 (Letai, 2011), very much upholding the colonial era commercialization goals for livestock production. Following the collapse of the beef industry in the 1970's-80's however, these private ranch owners looked to diversify the use of their land and began incorporating conservation and tourism activities onto their vast properties (Pellis et al., 2018).

On the other hand, group ranches are land that is owned by a collection of people who customarily share land communally among themselves but which is governed by group representatives who decide how the land should be managed and used (Mwangi & Ostrom, 2009). The idea of group ranches gained traction from the 1965 Lawrence Report which:

> "recommended the establishment of group ranches, which were seen as an alternative way of realizing the same goals of accelerating pastoral development, but with the added advantage of safeguarding against alienation to non-Maasai. They were expected to provide tenure security, creating incentives for the Maasai to invest in range improvement and, ultimately, to reduce overaccumulation of livestock" (Mwangi & Ostrom, 2009, p. 208).

Group ranches comprise 7% of Laikipia's land areas (Pellis et al., 2018) and as of 2006, of the fifty-two group ranches created between 1968-1979 "thirty-two are subdivided, and fifteen are in progress, seven of which are disputed and under court injunction, five have not subdivided" (Mwangi & Ostrom, 2009, p. 209). Using a lens of institutional robustness and ecological resilience, Mwangi and Ostrom (2009) consider the division of group ranches to be a sign of their failure to provide stable and productive landscapes for pastoralists, which they say is largely due to their poorly 'nested' governance structures within the social and ecological context, though a return to individual ranches does not indicate the appropriateness of that land tenure model either.

In Laikipia, Kenya, group ranches and private ranches make up nearly 50% of the current land use and 40.3% of all land in Laikipia is owned by only 48 individuals (Letai, 2011). Those 48 private ranches are largely owned and operated by "wealthy foreigners and Kenyans of European descent who believe there is an intrinsic value to wildlife conservation" and who can withstand the lack of profit they make from livestock husbandry activities on their ranches (Sundaresan & Riginos, 2010, p. 19). This stands in stark contrast to group ranches which largely do not enjoy the same profitability from wildlife conservation efforts and which endure greater strains on environmental resources (Sundaresan & Riginos, 2010). However, previously illustrated, CBC initiatives have allowed group ranches to benefit from wildlife conservation activities by joining together to form regional conservancies or creating community wildlife sanctuaries in Laikipia (Mathiani et al., 2011; Sundaresan & Riginos, 2010). Kenyan land tenure and wildlife conservation have always been intricately related, but the rise of community-based conservation and investments in community conservancies have highlighted the interconnectedness of these issues. Of significant interest to Loisaba Conservancy (formerly Loisaba Ranch) and the surrounding community conservancies and group ranches are the presence of African leopards, one of the most prized tourist attractions and important ecosystem regulators.

African Leopards and the Laikipia Plateau

Leopard Biology and Ecology

The leopard, or *panthera pardus*, can be found throughout the continents of Asia and Africa, specifically in sub-Saharan Africa, northeast Africa, Central Asia, India, and China (NatGeo, 2020) (**Figure 1**). It is extant (resident) in over 60 countries worldwide (Stein, A.B. et al, 2020). The subject of this report, the African leopard, is one of nine leopard subspecies and is known as *panthera pardus pardus* (Stein, A.B. et al, 2020). All continental African leopards are attributable to the nominate form (Stein, A.B. et al, 2020).

The African leopard appearance can vary depending on location and habitat (SANBI, 2020). Leopard diet is strongly related to prey availability as well as the presence of competitors in the area. When given the choice, leopards prefer medium-sized ungulate prey (10-40kgs) (Stein, A.B., 2020). However, they will eat a large variety of animals as necessary, including small mammals, large ungulates, birds, reptiles, and even insects (Stein, A.B., 2020). Oftentimes, an individual leopard will become specialized on one specific type of prey, and eat only that, despite having other prey available. The chance of leopards eating larger animals increases when larger competitors are absent (Stein, A.B., 2020). However, it tends to remain low regardless, most likely due to the fact that leopards are solitary hunters and hunting a large animal alone carries inherent risk (SANBI, 2020). In some areas of its range, the diet of a leopard can consist almost entirely of domestic animals such as dogs, goats and cattle (Stein, A.B., 2020). However, when given the choice, leopards prefer wild prey to domestic livestock (Luri et al., 2020). They are stalking predators, meaning that they use the element of surprise to capture their prey before it can flee (Hayward, 2006). Leopards do not require a large amount of water to survive and are capable of going for periods of 10 days without drinking water (SANBI, 2020).

The home range and habitat of the African leopard are some of the most diverse of the world's large cats. Home range size is dependent on the availability of prey as well as habitat structure. The smallest recorded home ranges are in Asia with 8.8 km^2 for a female and 17.7 km^2 for a male, while the largest was found in the Central Kalahari with a mean of 2,182 km^2 (Stein, A.B., 2020). Leopards, like other large cats, will have well-defined home territories, marked by scent or announced with particular sounds (SANBI, 2020). Individual male’s ranges tend not to overlap but can include several female territories within them (SANBI, 2020). Leopards can occupy a huge variety of habitats, but are found in greatest numbers in riparian habitat, woodland, grassland savanna, and all forest types (SANBI, 2020). They can also be broadly found in montane habitats, coastal scrub, shrubland, semi-desert and desert (SANBI, 2020).

Leopards provide many benefits for their ecosystems and for human populations that they may share an area with. As apex predators, they maintain biodiversity by regulating trophic relationships and habitat structure (SANBI, 2020; Braczkowski et al., 2018). This regulation can in turn lead to indirect influences on flora, soil, and hydrological systems (O’Bryan et al., 2018). Studies have documented changes in carbon sequestration, biomass levels, productivity, and wildlife risk as a result of an apex predator’s absence from an ecosystem (O’Bryan et al., 2018). Leopards can also impact neighboring humans by reducing the spread of infectious diseases, decreasing crop damage, reducing harm from other species, and even increasing carbon sequestration (SANBI, 2020, O’Bryan et al., 2018).

The following examples highlight the important role leopards play within an ecosystem. Rabies caused by bites from stray dogs is a problem around the world, especially in areas with a high human population density. Several studies across Africa and Asia, including a 2018 study conducted in Mumbai India, found that leopards can improve public health by preying on stray dogs and thereby preventing deaths from rabies (Braczkowski et al., 2018). The study in Mumbai concluded that leopards consume almost 1,500 feral dogs per year, which prevents an estimated 90 human deaths (Braczkowski et al., 2018, O’Bryan et al., 2018). Leopards can positively influence humans via agriculture as well. A 2020 study in India found that, by regulating herbivore populations, leopards indirectly reduce damage done to crops (Puri et al., 2020). This is not insignificant, as crop damage by herbivores can lead to hundreds of dollars’ worth of economic loss per household annually (Puri et al., 2020). Overall, if managed correctly, leopards have the opportunity to provide a multitude of benefits to both human and non-human populations.

Unfortunately, leopards can also detrimentally affect humans. This is primarily due to predation, which is the focus of our research in this paper. Previous research has examined this as well. A 2017 study in a southern Kenyan group ranch observed predation by wildlife on livestock over the course of 18 months (Muriuki et al., 2017). Researchers found that leopards killed the most livestock after hyenas, killing 20.9% of total livestock lost to wildlife over the study period. They overwhelmingly killed shoats, likely due to their attractive size. Leopards were responsible for 12.4% of estimated economic losses in the area, totaling US$118,553.5 (Muriuki al., 2017). These losses are extremely detrimental to the communities that depend on this income for their livelihoods. There are also added, unquantified costs, such as stress or trauma, that can result from livestock depredation.

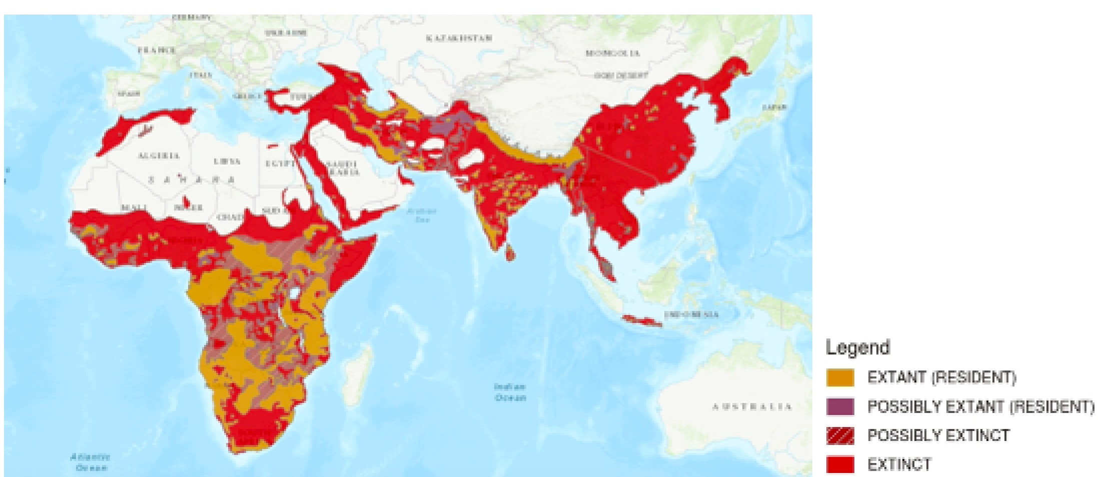


Figure 1. Distribution map of panthera pardus. Compiled by Peter Gerngross, 2019.

Laikipia Plateau Landscape and Ecology

The ecosystem of Laikipia County is defined by the upper Ewaso Ngiro river system, which has over 30 rivers that feed into the Ewaso Ngiro river and flow northwards (Musyima, 2016). The tributaries begin on the slopes of Mt. Kenya and the Aberdares range (MoALF, 2017). Settlements have largely been determined by the flow of these rivers, as they provide the predominant source of water for human usage (MoALF, 2017). The county is relatively high altitude, with a range of 1500-2611 m above sea level (M'mboroki et al., 2018). It is a plateau bordered by the Aberdares to the south, Mt. Kenya to the east, and the Great Rift Valley in the west (MoALF, 2017). The areas of highest altitude are the Marmanet, Mukogodo and Loldaiga forests.

Some areas of the county are forested, totaling 580 km^2 (M'mboroki, Wandiga & Oriaso, 2018). The forested areas are mostly in the wetter part of the river catchment, which is located in the northern part of the county and on the slopes of Mount Kenya. There are also wooded areas in the very western part of the county and in the Aberdare range to the south (MoALF, 2017; Musyima, 2016). The forests are a mix of naturally and artificially established. The rest of Laikipia, or about 85% of its surface area, is predominantly arid or semi-arid grasslands (Musyima, 2016). The area is strongly shaped by human activity. Agriculture exists at a small scale along rivers as well as in the south and west of Laikipia County, where precipitation measures higher than 600 mm (Musyima, 2016). On average, rainfall on the plateau is about 500 mm annually (MoALF, 2017), but range from 400 mm in the drier areas such as Mukogodo to over 900 mm in North Marmanet (MoALF, 2017). There are pronounced rainy and dry seasons. The short rains take place in October and November, while the dominant rainy reason occurs from March to May (MoALF, 2017). The temperature ranges between 16 and 26 degrees Celsius annually, with hotter mean temperatures in the low-lying northern areas and cooler ones near Mt. Kenya (MoALF, 2017).

Adverse weather events occur frequently as a result of the uneven spatial and temporal rainfall patterns. Droughts take place every 2-3 years, while floods occur more rarely (MoALF, 2017). Even droughts categorized as mild can wreak havoc on livestock numbers. Severe droughts such as the drought of 2000 resulted in the deaths of thousands of cattle, sheep and goats each, as well as a crop reduction of maize and beans by 84% and 72% respectively (MoALF, 2017). Droughts in Laikipia County directly and indirectly intensify desertification. Indirectly, droughts disrupt the farming livelihoods of Laikipia County's citizens, which leads to increases in alternative industries such as charcoal burning, illegal logging and sand harvesting, all of which are activities that cause desertification (MoALF, 2017). This further reduces the amount of available habitat for both leopards and livestock, which can lead to an increase in conflicts. Such problems are expected to increase in frequency with the onset of climate change (MoALF, 2017). Only two regions, the Mt. Kenya area and the Aberdare ranges, are spared from drought-related difficulties because they receive adequate rainfall year-round (MoALF, 2017). Other weather events, such as flash floods and heavy winds, are also a problem for Laikipia (MoALF, 2017).

As of 2018, livestock ranches occupied over 50% of the land (M'mboroki et al., 2018). Another 20% of land is arable, of which 80% is used for food crops (MoALF, 2017). Land use patterns in the non-forested areas of the county include mixed farming, pastoralism, ranching, agro-pastoral, and marginal mixed farming (M'mboroki et al., 2018). The type of land use in place in a particular area is almost exclusively determined by the climatic conditions and the ecological zones there (M'mboroki et al., 2018). Vegetation cover type can be used as an indicator of terrestrial environmental conditions (M'mboroki et al., 2018).

Contextualizing Our Project

This brings us to the Loisaba Conservancy/Community Trust, a place born out of the complex geographies of power described above, now nestled within a political and ecological landscape where they are called upon to uplift the livelihoods of their neighbors and to protect critically endangered native wildlife (*The Loisaba Wilderness*, n.d.). The Conservancy is a 65,000 acre wildlife conservancy located in the northern part of Laikipia County (Loisaba.com, 2021; **Figure 2**) though management is seeking to increase the size of the conservancy by an additional 40,000 acres (*About*, 2021). Pellis, Pas, and Duineveld (2018) note that "to overcome potentially dramatic outcomes for private ranchers and related conservation interests in Laikipia, many resources have been invested in securing land ownership across Laikipia in 2017, often under the umbrella of biodiversity conservation." Loisaba was purchased in the early 1970's by Count Ancilotto who ran it as a private ranch until the late 1990's. In 1997 an American investor and group of Kenyans leased the ranch and created the "Loisaba brand" (*The Loisaba Story*, 2021), with the help of Conservation Capital (*The Loisaba Wilderness*, n.d.). It was during this time that Loisaba transformed into the multi-use property it is today, operating as an intimate tourist destination, conservation and research center, and ranching business. The Nature Conservancy and other conservation organizations provided the operational and financial assistance that allowed Loisaba to undergo another structural change in 2014 when all ownership and management were transferred to the Loisaba Community Trust, a 501c(3) qualified Charitable Trust (*The Loisaba Story*, 2021) (*About*, 2021).

Now, Loisaba's mission is to "protect and enhance critical wildlife diversity, abundance and habitat in the Loisaba landscape while concurrently supporting sustainable livestock production and improving the lives of neighbouring communities. Both Tourism and Livestock bring revenue to the land, in an aim to being self-sustainable and offer over 300 jobs to local communities" (*Our Mission*, 2021). In fulfillment of this mission, Loisaba highlights several aspects of their ongoing work in the 2019 Loisaba Conservancy Impact Report, including outfitting Reticulated Giraffe and African Lions with GPS collars, funding salaries for local healthcare workers and providing mobile health clinics, providing livestock management and veterinary care services to local community cattle, removing invasive plant species, supporting the nearby community conservancies, and conducting both ecological and sociological programs related to the conservation of local leopard populations and protection of neighboring pastoral livelihoods (Loisaba Conservancy, 2019).

The Conservancy is a home and thoroughfare for hundreds of animal species. Over 260 bird species and 50 mammal species can be found in the area. It is a critical migration corridor for elephants, buffalo, the endangered Grevy's zebra, endangered reticulated giraffes and the greater kudu, a type of woodland antelope. Lions and cheetahs live in the area alongside the aforementioned leopards. Even the African wild dog, thought to be extinct in the region for years, has been sighted regularly in Loisaba's borders (Loisaba.com, 2021). They encourage tourism as a "self-sustainable" way of bringing revenue to the area. Loisaba offers activities such as game drives, walks, horse and camel riding, and "cultural visits" as low-impact ways to learn about the culture and ecosystem of the area.

Researchers from SDZWA's Community Engagement and Population Sustainability teams conduct the Leopard Conservation Program, known as Uhifadhi wa Chui with their partners at Loisaba Conservancy (Loisaba Conservancy, 2019). This interdisciplinary program seeks to "understand the mechanisms that drive leopard-livestock conflict and assess the efficacy of management decisions aimed at mitigating conflict" (*How We're Helping*, 2021, para. 2). Camera trapping leopards, citizen science and community reporting of leopard conflicts, boma monitoring of attacks on livestock, interviews with locals on their attitudes about leopards, and genetic testing of area leopards all function as elements helping to accomplish this goal (Loisaba Conservancy, 2019). These activities, while conducted through Loisaba Conservancy and on their property, are also conducted throughout the surrounding eighteen communities and their eleven associated community conservancies. In this way, the Uhifadhi wa Chui demonstrates the intricate relationships between local actors, land, wildlife, and livelihoods and the complex landscape into which our project team has arrived.

The work of leopard conservation done by SDZWA and our University of Michigan research team must be understood within the embedded contexts and geographies of Loisaba Conservancy and Laikipia County, Kenya. Leopard conflict and coexistence here are outcomes of unique socio-ecological circumstances and constantly interact with many other dimensions of the conservation and development landscape, and of the regional political ecology and economy. By acknowledging and understanding these critical points, we aim to provide recommendations for improving local human-leopard coexistence that are grounded in justice, efficacy, and sustainability.

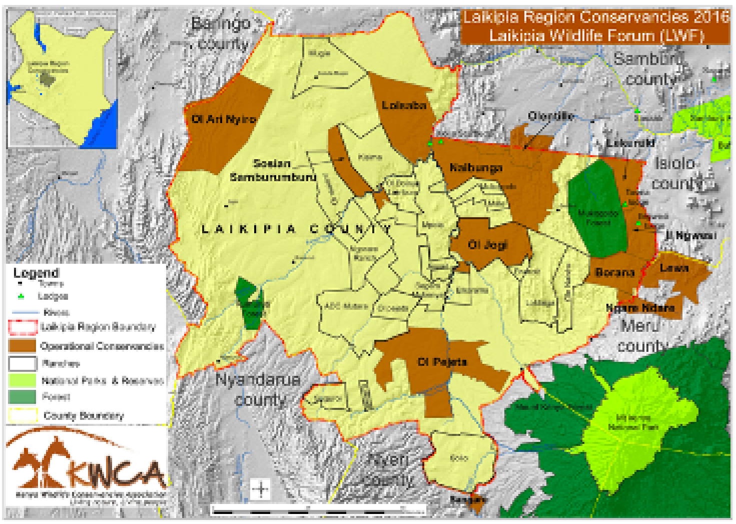


Figure 2. Laikipia Region Conservancies 2016. Laikipia Wildlife Forum, 2016.

Interpreting Human-Leopard Conflict Reports

Our partners at the SDZWA have provided us with livestock loss data. The data were obtained through self-reports by ranchers and pastoralists who have faced livestock depredation by leopards and other predators found in the study area. The survey includes variables ranging from demographic information to specifics of the attack such as when the attack occurred, the number of livestock deaths, and which predator was the cause of the attack. For this project, we isolated social and ecological variables important for assessing the risk of leopard attacks. We then created a subset of data containing only conflict reports associated with leopards as the project's goal is to reduce conflict with leopards while ensuring the conservation of leopards. Additionally, reports missing essential information were removed from our analyses. This resulted in a total of 400 conflict data points.

Methods

Social-Ecological Determinants of Livestock Depredation

Protective measures usage and husbandry practices

The data provided by San Diego Zoo global contained information on what types of protective measures were used by the ranchers and pastoralists to prevent predator attacks. There were eight different types of protective measures that were used which include: acacia bomas, metal bomas, wire fencing, livestock guards, fire, lights/torches, dogs, and other strategies that were not specified. We used this information to identify whether the number and combination of the protection method had an impact on the amount of damage done by leopard conflicts. When assessing the combinations of measures, we combined acacia and metal bomas into a single boma category and proceeded to do the same with fire, lights, and torches. This was done in order to reduce the noise of the data when conducting the analyses. This resulted in six categories (Boma, Wire fencing, Livestock guards, fire/light/torches, dog, and other). We did not use these combined variables when assessing how the number of measures used affected livestock depredation as there were less groups (n=8) and reduction of groups was not necessary.

To assess the damage that was caused due to the leopard attacks, we totaled the number of livestock injuries and kills for each specific report and also counted the number of specific livestock that were involved with each incident of conflict. A livestock is considered involved if they were directly impacted (harmed or killed) during the conflict. Though pastoralists often raise a variety of livestock, we only conducted analyses on the livestock types that were most affected which included cattle, goats, and sheep. We further combined the sheep and goats into one group (shoats) as they are often raised and ranched together.

We filtered the data so that the t information that was included in our analysis only included attacks that happened within a boma or enclosure. This ensures that the results accurately portray the effectiveness of measures as livestock are directly protected using those specific measures. We then categorized each data point based on the number of protective measures used and assigned each point with a numerical value between 0-8 depending on the number of measures associated with each conflict location. Groups of combined measures were differentiated using alphabetical labels in order to simplify analyses and legibility throughout this report.(i.e., if a conflict point had only a boma, fire, and dogs, the group number would be 145). As our data was non-normal, we used Kruskal-Wallis non-parametric tests to identify whether varying combinations and amount of measures were statistically related to the number of injured i) shoats, ii) cattle, iii) total livestock . If there was a significant relationship, we then conducted the Dunn's Multiple Comparison post-hoc test to further identify any statistical difference using a 95% confidence interval between each individual group for both the combinations and numbers of measures used. In addition to the Kruskal Wallis test, we conducted t-tests to assess if there were significance between conflict reports with or without the use of measures.

One major limitation that appeared in our dataset is the significantly different sample sizes that were creating biases in statistical analyses. In an attempt to reduce the biases, we decided to convert values based on per capita values. The per capita values were calculated by dividing the total livestock impacted of a conflict point with the total number of livestock affected in the entire group. This was a pseudo-method to attempt to add weighting and reduce the effects of unequal sample sizes. Analyses were conducted both using the per capita values and the total values of livestock affected.

Livestock Density and Poverty

Livestock density data was acquired from the World Resources Institute, collected by the Kenya Central Bureau of Statistics and International Livestock Research Institute. The data coverage includes density reports for cattle, sheep, goats, camels, and donkeys at a resolution of 5x5 km grid cells over rangelands between 1994-96. Larger herd sizes have been previously linked to increased risk for conflict (Manoa & Mwaura, 2016) and pastoralists historically maintained smaller herds over larger extents (Spear, 1993). A linear regression was conducted to examine whether livestock density influenced the number of attacks. Poverty index data was also acquired from the World Resources Institute and collected by the Kenya Central Bureau of Statistics. Poverty ratios from 1999 were aggregated according to the community conservancy boundaries provided by the Loisaba Conservancy. A linear regression was used to determine if the poverty ratio of a community influenced the number of leopard conflict incidents that community experienced. It is possible that more impoverished communities have less access and capacity to implement protective measures.

Environmental Determinants of Livestock Depredation

Rivers and Precipitation

We obtained river shapefiles in Kenya from ICPAC Geoportal (2017) to investigate whether being located closer to a river will impact the amount of damage that is received from leopard conflicts. Using ArcGIS Pro, we plotted our conflict locations on top of the river shapefile and used the NEAR tool to calculate the distance (in meters) each conflict location was from the closest river source. We then conducted linear regression analyses testing the following as dependent variables: the number of livestock killed, number of livestock injured, number of shoats involved in the conflict, and amount of cattle involved in the conflict. The distance from each point was used as the explanatory/predictor variable in these analyses and were binned at every 500 m. Local precipitation data was provided by the Loisaba Conservancy for each month throughout the collection of conflict reports. A linear regression was conducted to examine whether local precipitation levels influenced the number of attacks.

Land Cover

We included land cover type as a potential factor associated with conflict location and frequency by applying similar methodology to the river analysis as recent research has found associations between leopard higher habitat suitability and proximity to rivers as well as thicket or herbaceous land cover (Mann et al. 2020). Land cover data for Kenya was obtained from the Food and Agriculture Organization of the United Nations (FAO-UN) open access geospatial data portal, GeoNetwork. The dataset is a vector layer of polygons and is composed of land cover classification that was visually interpreted from LANDSAT TM satellite images in 1999 by the Africover project. Since the data were for the entire country of Kenya, the layer was clipped to the approximate boundary encompassing all the conflict incident locations using ArcGIS Pro. The land cover type was coded using the FAO's own Land Cover Classification System (LCCS) in great detail, so major land cover types were consolidated, and the dataset was reclassified to reflect seven land cover types: herbaceous, herbaceous with temporary floods, woody plants and trees, shrubs, natural lakes, riverbanks, and urban areas. Next, we performed a spatial join between the conflict data and land cover data to streamline them for the coming analyses.

We used RStudio statistical software version 1.3.1073 to quickly compute the distribution of conflict incidents and their respective land cover types to orient the data numerically. In ArcGIS, we converted the land cover polygon layer to lines representing the borders between different land cover types to begin testing for an association with "land cover (LC) transition boundaries", the lines where one land cover type becomes another. We used the "Generate Near Table" tool to create a csv file containing the distance between each conflict incident location and LC transition boundaries in kilometers. This table was joined with the conflict location data to form a consolidated CSV file that could be used for analyses in R. The column containing distances was split into deciles to form 10 bins from the minimum to maximum in 3 m intervals. To check for any important patterns in the data, a linear regression was done by plotting the conflict incident numbers with distance from LC transition boundaries. We ran a linear model to test for significance and obtain a R-squared value.

Interviews with Conservation Practitioners

We conducted qualitative interviews with conservation practitioners from Laikipia County. The objectives of this interview were to better understand: 1) the drivers of human-wildlife conflict at the community level and 2) the capacities of conservation organizations to respond to human-wildlife conflict. The interviews were semi-structured around a set of ten open-ended questions that were shared with the interviewee prior to and during the interview. The interviews were conducted and recorded via Zoom video conferencing. We defined conservation practitioners as individuals who are employed in a capacity where their primary job responsibilities revolve around the advancement of conservation goals and objectives. Participants were selected based on contacts made through San Diego Zoo Wildlife Alliance. Due to difficulty securing interviewees, we conducted only two interviews. However, the two interviews are integrated into our recommendations sections due to the respondents expert knowledge and in depth experience with the subject matter. We analyzed the interview responses for recurring themes and compared the responses to what our quantitative data and literature reviews were suggesting as far as human-wildlife conflict and coexistence themes, objectives, and strategies.

Table 1. Variables used in our analyses

	Variables	*Source*	*Importance of variable*
Socio-Ecological Variables			
	Number of Protective Measures used Combination of Protective Measures used	San Diego Zoo Wildlife Alliance Livestock Kills Report Survey	Investigating the types and number of protective measures that were used can provide us insight as to what number and types of protective measures are most effective at reducing and preventing damage from leopards
	Amount of Shoats and Cattle affected Total Livestock Kills and Injuries		The counts of livestock affected are needed as dependent variables for our analyses. They are important to assess the relationship of damages incurred during a leopard-livestock conflict and other socio-ecological and environmental variables
	Livestock Density	World Resources Institute	Exploring the geospatial occurrence of leopard attacks in relation to livestock density can help determine if corralling large herds increases risk of conflict.
	Poverty ratios	World Resources Institute	Identifying regions where local poverty overlaps with high frequency of leopard conflict can help determine where financial support for protective measures is most needed.

Environmental Variables

	Kenyan River Locations	IGAD Climate Prediction and Applications Centre (ICPAC) Geoportal (2017)	Investigating the relationship between livestock losses and distance to rivers can help identify areas that may be of high risk for leopard attacks. Past studies have found that oftentimes, livestock damages and attacks tend to be fewer towards river sources, however, others have also indicated that livestock attacks may also increase and are dependent on natural prey abundance.
	Kenya Land Cover Data	Food and Agriculture Organization of the United Nations (FAO-UN) open access geospatial data portal	Habitat suitability studies for leopards have found preferences for certain land cover types and environmental elements (Mann et al. 2020). Not much focus has been on transitions between land cover types and further connected to leopard and human conflicts.
	Local Precipitation Data	Loisaba Conservancy	Precipitation often is associated with seasonality. Past studies have found that during wet seasons or times of increased precipitation, livestock depredation may increase due to increased vegetation and higher dispersal and lack of accessibility of natural prey (Chaka et al. 2020, Kittle et al. 2016, Patterson et al., 2004).

Results

Descriptive Statistics

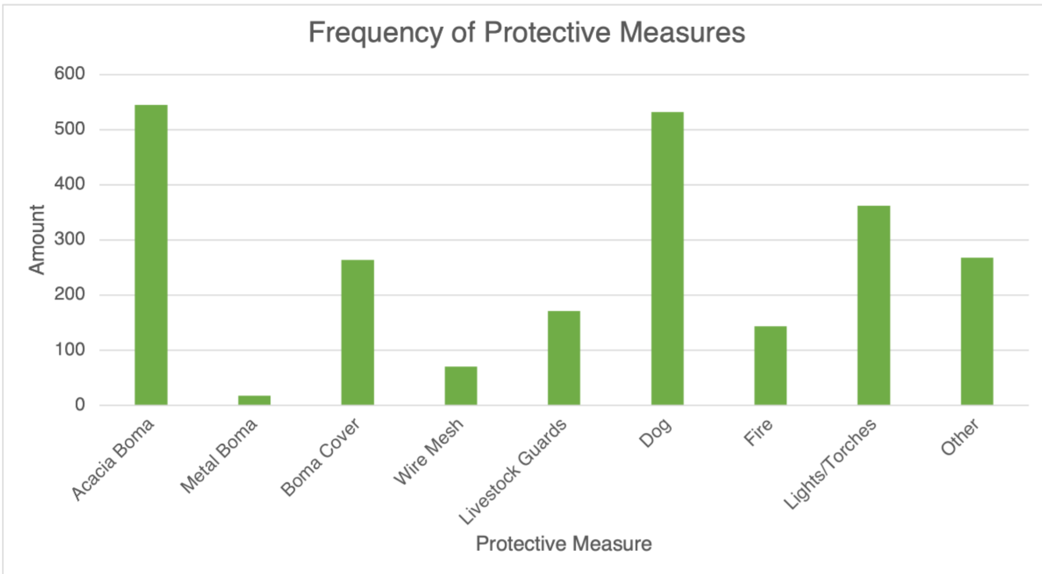


Figure 3. Frequency and type of protective measure use.

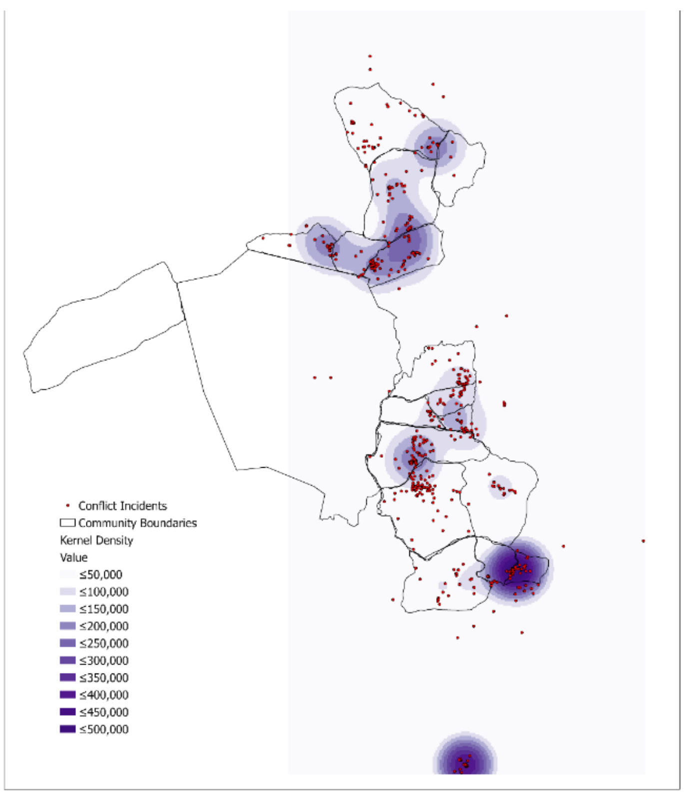


Figure 4. Kernel density map of conflict incidents (red) within community boundaries.

Protective Measures Usage and its Relationship to Livestock Damage

T-Tests

Our results found that having protective measures reduced the amount of shoats and cattle that were affected during a leopard attack. Having protective measures did not seem to affect the total number of livestock killed or injured (**Table 2**).

Table 2: T-test results

		Have Protective Measures (n = 90)	Does not have Protective Measures (n = 142)	t-calc	p-value
Number of Shoats Affected	***mean***	1.68	12.8	4.21	4.3e-05*
Number of Cattle Affected	***mean***	1.69	0.022	2.32	0.022*
Total livestock killed	***mean***	1.15	1.05	0.589	0.557
Total Livestock Injured	***mean***	0.396	0.239	1.42	0.157

***indicates significant values based on a 95% confidence interval.**

Kruskal Wallis Tests

Effectiveness of increasing measures to reduce incurred livestock damages

The Kruskal-Wallis test indicated that there was a significant difference in the number of shoats affected and the total amount of livestock injured between the different groups of total protective measure usage (**Table 3**). There was no statistical difference in the number of cattle affected and total livestock killed between these groups. Since significance was displayed for the number of shoats affected and total livestock injuries, we continued to run Dunn's post-hoc test to identify which groups were significantly different from each other. Dunn's post-hoc tests concluded that significance was only apparent between using 0 and 3), 2 and 3 and 3 and 7 protective measures (**Supp. Table 1**). While a significant difference in the number of livestock injured was observed between using 0 and 2, 0 and 5, 3 and 5, 4 and 5, 2 and 6, 5 and 6 different types of protective measures (**Supp. Table 6**).

When using the per capita values instead of the total amounts, the Kruskal Wallis test displayed a significant difference between the usage groups in the per capita values of shoats affected, livestock killed, and livestock injured (**Table 3**). Further analyses using Dunn's post-hoc test displayed that the differences in the per capita values of shoats affected were between groups using 0 protective measures and all other groups except 1 and 3, between groups using 3 protective measures and all other groups, and between groups 4 and 7 (**Supp. Table 2**). For the per capita values of total livestock deaths, the test displayed differences only between 0 and all other groups (**Supp. Table 4**). Finally, for the per capita values of livestock injured, the test identified differences between using 5 protective measures and all groups up to 6, between groups 2 and 3, 2 and 4, 2 and 5, and 2 and 7 (**Supp.Table 7**)

The inferences that can be made from these results are that i) in order to adequately reduce the amounts of shoats affected during a leopard attack, our analyses indicate that a minimum of at least 3 types of protective measures is needed, ii) the amount of cattle affected does not depend on the amount of protective measures that are present during time of attack iii) having at least 1 type of protective measure is sufficient to reduce livestock deaths and iv) using between 2 and 5 different types of protective measure may sufficiently reduce injuries to livestock.

Combination of different protective measure and its effects on livestock damage

When investigating the various existing combination groups of protective measures usage, there were significant differences found only for the total amount of livestock injured (**Table 3**). Running Dunn's post-hoc test indicated that the number of livestock injured were significantly different between several groups (**Supp. Table 8**). The most notable was that group D (group with all possible protective measures present) was statistically different to a many of the other combination groups.

When utilizing the per capita values, it was found that the combination groups were statistically different from each other in the per capita values of shoats affected, livestock killed, and livestock injured (**Table 3**). Investigating the intergroup using Dunn's test indicated differences for the per capita values of shoats affected were mainly between group A (having no protective measures) and all other combinations groups (**Supp. Table 3**). For the per capita value of livestock deaths, again, differences were primarily between group A (having not protective measures) and all other groups (**Supp. Table 5**). For the per capita value of livestock injured, differences were present between various groups without any identifiable pattern (**Supp. Table 9**).

What we can infer from these results is that i) there does not seem to be an apparent trend that indicates having a specific combination of protective measure affects livestock damages, ii) continual support having at least some combination of protective measure will ensure the reduction in livestock damages, and iii) there is slight evidence that having the maximum types of protective measures significantly reduces damages, particularly for livestock injuries.

Table 3. Kruskal-Wallis Test results

Variables		df	Chi-squared statistic	p-value
Number of shoats affected	*# of measures groups*	8	18.7	0.016*
	Combination groups	14	15.7	0.328
Number of cattle affected	*# of measures groups*	7	5.78	0.562
	Combination groups	15	10.48	0.789
Total livestock killed	*# of measures groups*	8	4.55	0.805
	Combination groups	18	14.8	0.676
Total livestock injured	*# of measures groups*	8	37.6	<0.00*
	Combination groups	18	27.6	0.004*
Per capita value of shoats affected	*# of measures groups*	8	71.3	<0.00*
	Combination groups	14	69.5	<0.00*
Per capita value of cattle affected	*# of measures groups*	7	5.57	0.591
	Combination groups	15	10.19	0.808
Per capita value of livestock killed	*# of measures groups*	8	191.84	<0.00*
	Combination groups	18	258.38	<0.00*
Per capita value of livestock injured	*# of measures groups*	8	32.7	<0.00*
	Combination groups	18	42.4	<0.00*

* indicates a significant p-value using a 95% confidence interval

Rivers and Precipitation

Our regression analyses using distance from rivers as a predictor displayed that the numbers of shoats and cattle affected increased as distance to a river decreased (**Figure 5A, 5B**). There was no significance in the total livestock killed and injured when compared with the distances from a river (**Figure 5C, 5D**) Our analysis also found no significance when the number of attacks was compared against either the number of rain days or amount of precipitation monthly. However, trends do seem to suggest a gentle increase in the number of attacks as precipitation measures increase (**Figure 6, 7**).

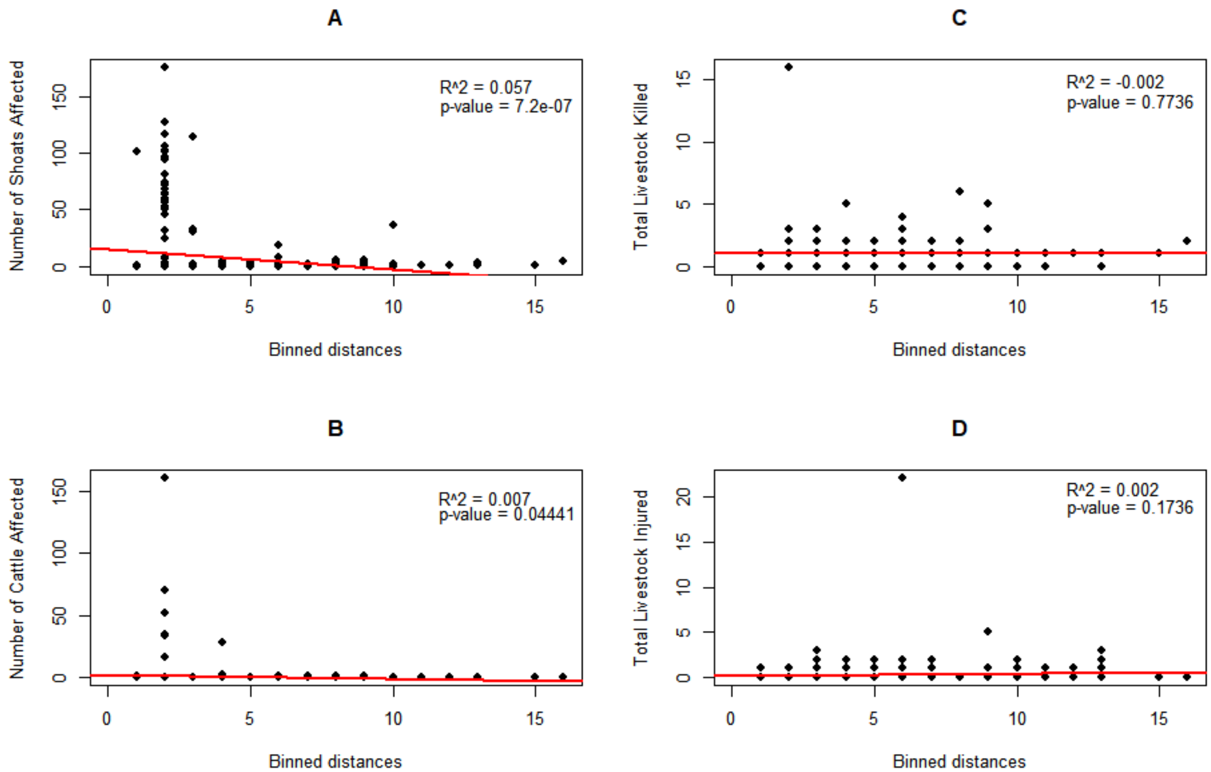


Figure 5. A: Number of Shoats affected vs binned distance (per 500m); B: Number of Cattle affected vs binned distance (per 500m); C: Total Livestock killed vs binned distance (per 500m); D: Total Livestock injured vs binned distance (per 500m)

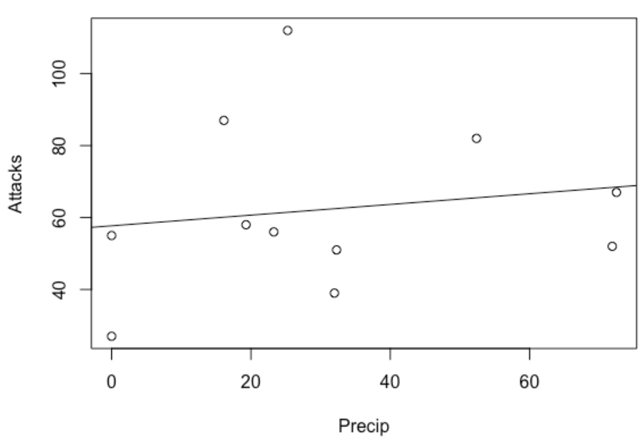
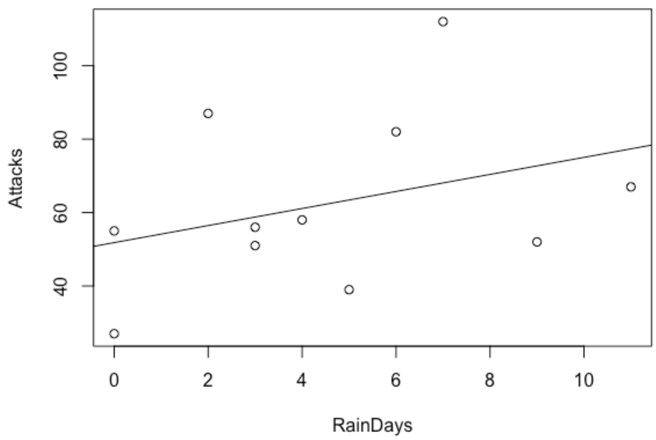


Figure 6. Monthly precipitation (mm) vs. monthly number of attacks



F**igure 7**. Monthly number of rain days vs. monthly number of attacks

Land Cover

In R, the summary of conflict incidents by land cover found that herbaceous land cover had the most conflict incidents at 259 out of 375 total conflict points, woody plants and trees had the second most at 88, shrubs had the least at 28. Note, there are actually 386 total conflict incidents involving leopards, but 375 is excluding those with incomplete information. After displaying the conflict incident locations as points on top of the land cover polygon data as a map, it was visually apparent that conflict locations may have an association with a specific land cover type and the polygon borders signifying a transition from one land cover type to another (**Figure 8**). Figure 8 also includes the boundaries and names of the relevant counties to show that not all the conflict incidents reported were located exactly in Laikipia county. The 'near table' deciles for distance in meters away from LC transition boundaries resulted in 11 breaks in the data to create 10 bins, each with a 3 meter range. The bar chart in **Figure 9** shows the distribution of the number of conflict incidents per interval of distance, represented by bins. The number above each bar represents the approximate proportion of the total number of conflicts falling in that particular bin, where the sum of all the values should equal 1. According to the bar chart, about 49.87% of the conflict incidents fall into the first bin (0-3 meters away from a land cover transitional zone), which is a surprisingly high proportion of conflicts. This was followed by about 31.47% of conflicts in the second bin (3-6 meters), again quite a large proportion, and the remaining conflict incidents were distributed relatively similarly across the rest of the bins in marginal amounts. The data plotted again as a line plot shows the same sharp drop pattern as the bar chart (**Figure 10**). As shown in **Table 4**, the resulting p-value from the linear model summary was less than 0.01 (marked by *** for the significance code), denoting a statistically significant relationship between the number of conflicts and distance away from LC transition boundaries. The R-squared value was 0.698, which means that there is a strong correlation within the context of ecological field data, which often includes natural error and variance.

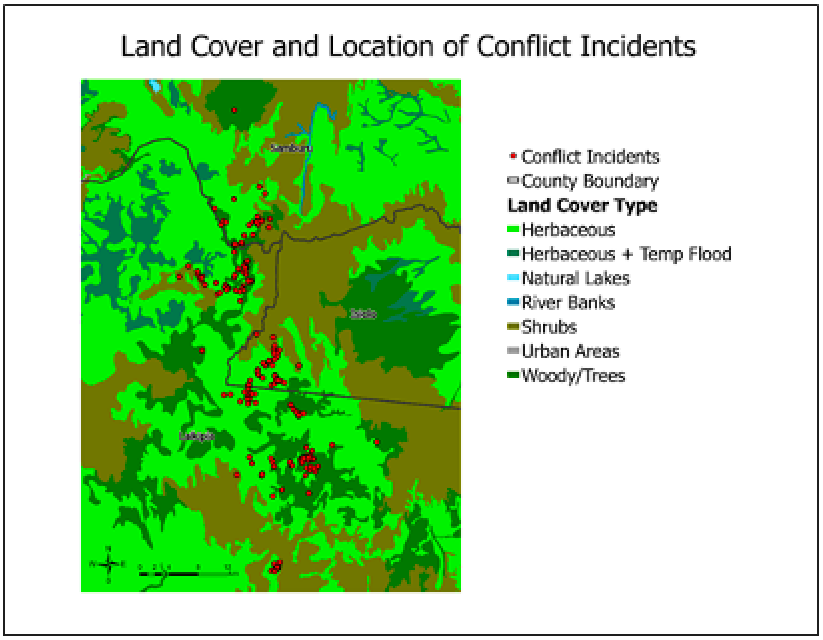


Figure 8. Reclassified land cover map with conflict incident locations overlayed.

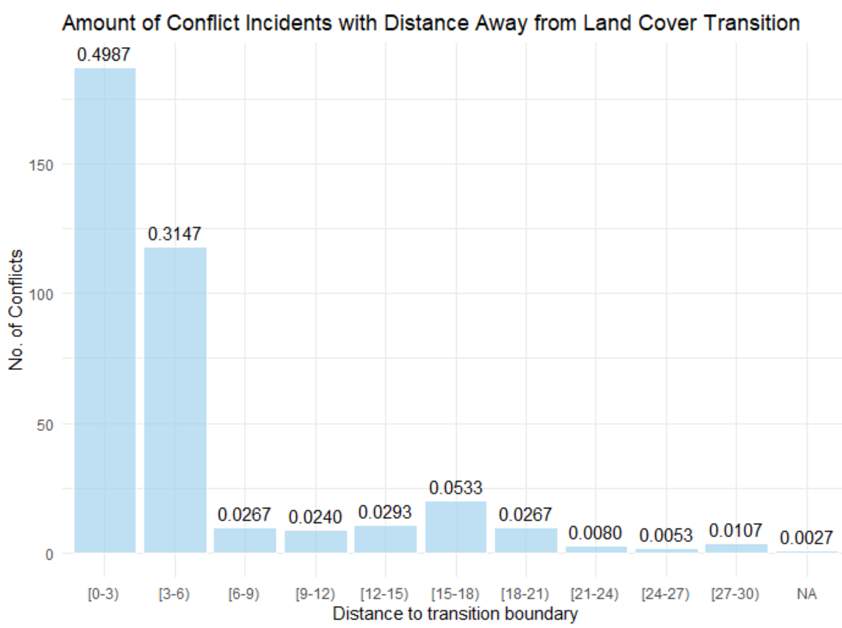


Figure 9. Bar plot of number of conflict incidents per bin, binned every 3 m.

Figure 10. Line plot of number of conflict incidents per bin (3m each), ten bins total.

	Dependent variable:
	bin
conflicts2	-1.680***
	(0.391)
Constant	9.736***
	(1.132)
Observations	10
R^2	0.698
Adjusted R^2	0.660
Residual Std. Error	1.765 (df = 8)
F Statistic	18.494*** (df = 1; 8)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 4. Summary of linear model where bin number is the independent variable and the number of conflicts is the dependent variable.

Livestock Density and Poverty

No statistical significance was found between either livestock density or community poverty ratios and conflict incident reports. However, geospatial analyses of the data sets may help to identify potential hotspots where groups of repeated conflict incidents intersect with high livestock density or greater levels of poverty (**Figures 11, 12**).

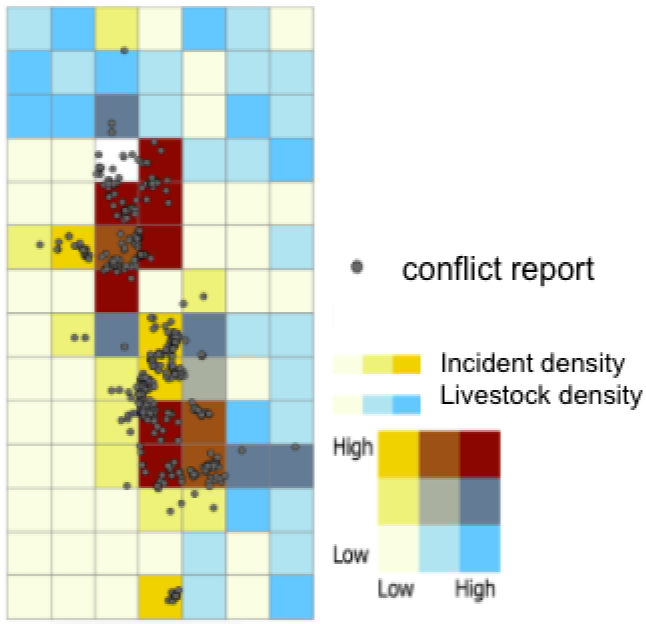


Figure 11. Combined livestock and conflict report densities within 5x5 km areas.

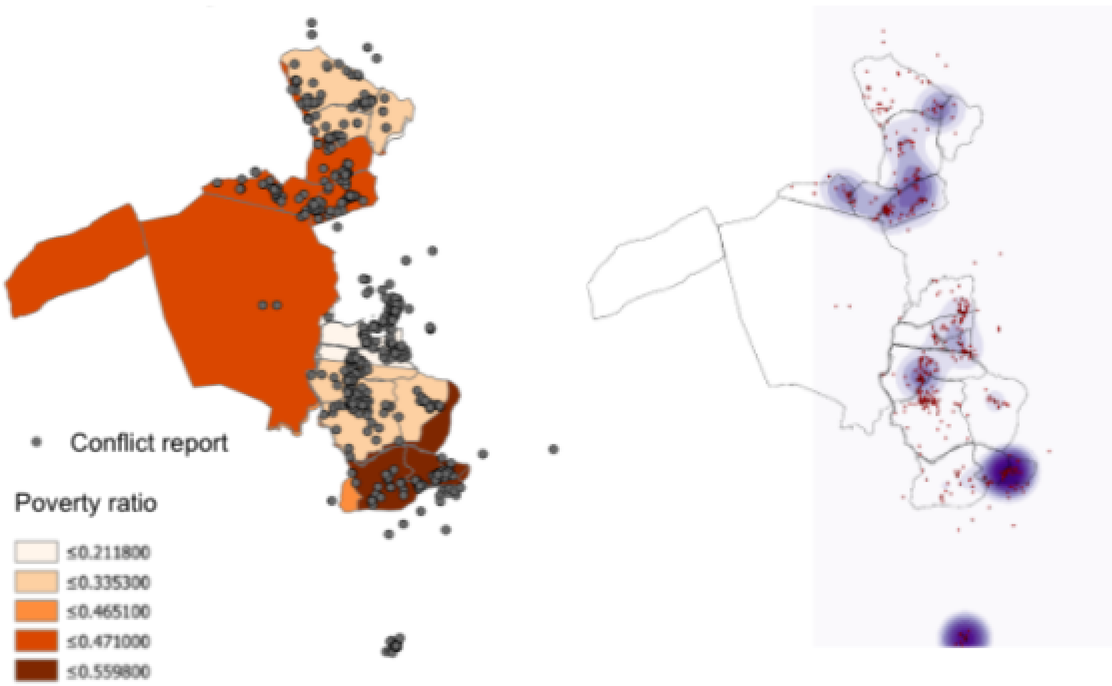


Figure 12. Poverty ratios for community conservancies (left) and conflict incident hotspots (right).

Interviews with Conservation Practitioners

Several broad themes were identified across interview responses. First, hyenas were consistently cited as the carnivore species of greatest threat to livestock and human-wildlife coexistence. Second, there was a consistent belief that improved bomas were the most effective way to improve human-carnivore relationships. Additionally, one respondent believed that predator proof bomas could truly eliminate predation taking place at the boma. Third, respondents indicated that they were unaware of local cultural connections to leopards as an animal species, signaling an absence of social or cultural motivations for protecting leopards. Fourth, the greatest logistical challenge to improving human-carnivore relationships is a lack of resources, such as funding for protective measures and other equipment, and conservation staff. Lastly, the respondents generally indicated that community awareness of the role of wildlife conservation and its benefits to local communities would also improve human-carnivore relationships. While qualitative data such as this can be extremely insightful, the small sample size and limited diversity of our respondents makes it challenging to draw conclusions that can be appropriately applied to the state of the human-leopard interactions in Laikipia County and Kenya more broadly.

Recommendations to San Diego Zoo Wildlife Alliance & Loisaba Conservancy

We offer the following recommendations with explanations to SDZWA and Loisaba Conservancy based on our geospatial and statistical analysis, interviews with conservation practitioners, and literature review.

I. Increasing Protective Measures Efficacy

A. Support boma operation and reinforcement

Our results support the idea that having at least some form of protective measure is necessary in order to effectively reduce the damage and number of individuals affected during a leopard-livestock conflict. For shoats, our results indicate that using three different types of protective measures may be the most optimal in reducing damages from leopard attacks. There is also some evidence that using between 3-5 protective measures may reduce livestock injuries. Any more does not seem to decrease damage and less may not be sufficient in reducing damage. Statistically, it does not seem that the number of protective measures affects the damage and number of affected individuals for attacks on cattle.

Though we saw several instances where a certain combination of existing measures were statistically different in the number of shoats affected, livestock killed, and livestock injured, we are unable to conclude which combination is best. There was no distinct or identifiable pattern of efficacy for differing groups of combined measures. We believe that the significant outcomes are a result of vastly different sample sizes between the groups, with some groups having extremely low sample sizes.

Though we were unable to identify the most ideal combination of measures, previous studies have suggested that a combination of an enclosure such as a boma, presence of a herder, and watch dogs are sufficient in reducing the livestock depredation by leopards while within the enclosure

(Ogada et al. 2003). This supports our findings that having at least some form of protective measures is optimal for reducing conflict. However, increasing the fortification of the boma and the number of herders and watch dogs may not lead to a decrease in livestock affected (Kolowski & Holekamp, 2006; Chaka et al., 2020). This supports our results that increasing the number of measures usage such as adding additional fencing may have minimal effect on reducing risk of leopard attacks.

Previous studies of other large cats have found contrary results, stating that fortified bomas were more effective at reducing livestock loss from lion depredation when compared to unfortified bomas. (Sutton et al., 2017; Lichtenfeld et al., 2014; Manoa & Mwaura, 2016). Nonetheless, it is evident that having at least a boma enclosure reduces livestock loss and damages. For our study area, many of those that were involved in a conflict already have a boma and/or watch dog. Though statistically it is unsupported in our analysis, having a boma and a watch dog may be the best combination to reduce livestock depredation based on previous studies investigating livestock loss by large predators. Additionally, geospatially identified hotspots of conflict and increased poverty indicate assistance from the SDZWA may be needed to alleviate the added economic burden of acquiring the necessary materials for boma construction to those that do not currently have one.

Interviewees strongly stated that reinforced bomas are the most effective way to improve human-leopard relationships. Interviewees suggested that by making the bomas “predator proof,” livestock losses at the boma site can be completely eliminated which will greatly reduce human conflict with predators- primarily hyenas which were cited as the most problematic predator. “Predator proof” bomas would also reduce leopard predation however, increasing human-leopard coexistence. By preventing predation, attitudes towards leopards and other predators are likely to improve.

B. Consider use of guard dogs

There have been many studies supporting the idea that guard dogs are effective at reducing livestock depredation (Andelt et al, 2000; Ogada et al., 2003) but others still caution the use of guard dogs as a panacea for livestock predation (van Niekerk, 2010). As with all protective measures, the efficacy of guard dogs in Laikipia County will be dependent on the social and ecological context.

In order to assess economic and social requirements for implementing a livestock guard dog program, we analyzed a well-established program from Namibia: The Cheetah Conservation Fund’s Livestock Guarding Dog Program (*Livestock Guarding Dog Program*, n.d.). Some of the lessons learned from this program and supported by other research (Khorozyan & Waltert, 2019; van Niekerk, 2010) are that:

- Livestock guarding dog programs require intensive long-term investment on behalf of both the administrating body and recipient of the dog.
- The livestock species to be guarded by the dogs would be shoats and smaller livestock
- Further studies into the herd size that can be protected by guard dogs needs to be conducted

For the context of livestock depredation in Laikipia, guard dogs do offer one specific advantage. Specifically trained guard dogs can be mobile with the livestock, protecting them both at the boma and while out grazing. This makes the use of guard dogs worth considering as roughly half of the attacks we analyzed took place outside the boma where there are far fewer protective measures in place.

One of our interviewees believes that guard dogs are an ineffective tool for reducing livestock depredation because dogs tend to seek shelter when it is raining, leaving livestock vulnerable to predators. This commentary provides support to calls for a greater diversity of protective measures and further research into the efficacy of protective measures across spatial and temporal scales.

C. Consider use of noise and light emitting devices

One interviewee stated that noise and light emitting devices were some of the most effective livestock predation mitigation tools that can be installed at the boma sites. The interviewee considered noise and light emitting devices to be so effective because of their ability to operate in inclement weather, compared to guard dogs. The interviewees discussed the need for additional resources, specifically financing which would be used to develop and expand access to noise and light emitting devices at boma sites.

The interviewees concerns for adequate resources to protect bomas from predators are especially relevant when considering the expansion of noise and light emitting devices as a strategy for reducing livestock depredation. We did not have information on the costs of the particular noise and light emitting devices used by SDZWA and Loisaba Conservancy so we do not attempt to calculate the relative costs of making noise and light emitting devices a widely distributed and used strategy for livestock protection. However, some general financial considerations for the implementation of noise and light emitting devices are: upfront costs, installation costs, maintenance costs, infrastructure needs, device longevity, and the costs related to public education and management of these devices as a strategy for protection livestock.

Habituation is also a serious challenge to the long-term efficacy of noise and light emitting devices. As van Niekerk (2010) states, noise and light emitting deterrents should be "used intermittently at times when the risk of predation is at its highest" (pp. 24-25). This is because predators show fast habituation to the consistent use of noise and light emitting devices (Khorozyan & Waltert, 2019). However, it is possible that the noise and light emitting devices will remain an effective strategy for reducing livestock depredation even if predators become habituated to the sounds and lights if other strategies for reducing depredation are simultaneously pursued. Further site-specific research into the long term efficacy of noise and light emitting devices is needed in addition to research into what combinations of protection measures provide the most long-term efficacy.

D. Focus on protecting shoats

It is evident from our findings that shoats were affected more frequently than were cattle. This pattern was observed also in previous studies conducted by Kabir et al. (2014). They investigated livestock depredation by leopards in Pakistan and found that small-bodied livestock such as goats and sheep were more heavily preyed on than large-bodied livestock such as cattle. As mentioned in our ecology section, Muriuki et al. (2017) found similar results with livestock depredation in southern Kenya, where leopards preyed on shoats far more than cattle or donkeys.

Leopards have a preference for prey that is between 20-25 kgs (Karanth and Sunquist, 1995; Hayward, 2006). Cattle weigh an average of about 800 kgs whereas the weight of an average goat or sheep is between 20-100 kgs. Small-bodied prey are easier to catch and succumb easily to wounds allowing predators to expend less energy while hunting prey (Manoa & Mwaura, 2016). Shoats fall directly within the range of the preferred prey weight for leopards and could explain why we saw a significant decrease in affected shoats when using some sort of protective measure. As the preferred prey, leopards may more frequently target shoats over cattle, leading to a disparity in the number of individuals affected in each livestock group. The high frequency of attacks on shoats may be impactful enough such that protective measures are necessary in order to reduce these attacks whereas there may not have been enough attacks and damage to cattle for the need of measures.

E. Focus on protecting larger herds

The disparity could result from the difference in herd sizes between shoats and cattle. A larger herd size may indicate higher risk for conflict. This is supported by the study conducted by Manoa & Mwaura (2016) where they discovered a positive correlation with Hyena attacks and the numbers of individual livestock in a boma. Several reasons could account for more attacks on larger herd sizes. Having a larger herd sizes often imply greater dispersal over a larger extent, therefore creating more opportunities for leopards to attack as some areas may be left unattended or are too large to appropriately defend (Mijiddorj et al. 2018). Having larger herd sizes may also lead to larger clustering of individuals, allowing for leopards to easily capture prey without exerting too much energy chasing individuals down. Our geospatial analysis of livestock density in relation to leopard attacks may help identify areas where decreased clustering is needed; however, more recent livestock density data is needed.

Efforts should be focused on protecting the shoat population by first creating and implementing mitigation strategies for those who do not have any currently in place. In addition, finding methods to ensure that larger herd sizes are effectively protected is necessary. Whether this be in the form of dividing up herds into separate bomas or through other means, it is clear larger herds need more protection than smaller ones. This may imply that more protection is needed for shoats as they often reside in larger herds. However, protection for cattle should not be neglected. If shoats become less accessible for leopards, preferences may change and cattle depredation may increase.

F. Focus on protecting livestock closer to rivers

Our analyses found that leopards attacked enclosed shoats and cattle more frequently closer to a river source. There was no other evidence that suggests moving closer to rivers leads to higher instances of livestock deaths and injuries. Similar results were found by Beattie et al. (2020), where they investigated livestock depredation by lions in Tanzania and discovered that livestock risk was higher closer to water sources year-round. Most large predatory cats, such as lions and leopards, have preferential home ranges along rivers and water sources (Lehmann et al., 2008; Simcharoen et al., 2008). This may explain why livestock depredation seems to occur more frequently near rivers and water sources. As hunting closer to their home ranges is less costly than travelling and scouring for prey elsewhere. Additionally, the potential positive correlation between depredation and precipitation may be due to increased vegetation cover in times of greater rainfall, making it easier for leopards to stealthily and successfully attack.

However, other studies have contrary findings concluding that conflicts with livestock decrease closer to rivers and water sources (Chaka et al., 2020). Natural prey is often more abundant near water sources, especially during dry seasons (de Boer et al. 2010, Kittle et al. 2016). The abundance of natural prey could reduce the need for Leopards to rely on livestock and reduce the risk of livestock depredation. It has been found that large carnivores will attack livestock once natural prey is inaccessible and occurs more commonly away from river sources or during wet seasons where prey abundance is more evenly distributed throughout the landscape (Chaka et al. 2020, Kittle et al. 2016, Patterson et al., 2004). As natural prey abundances decrease, predators begin to rely more on livestock for food.

Though we did not find evidence in our analyses to support this conclusion, it is possible that natural prey distribution in our study does not follow typical patterns or are relatively low throughout the study area. This would explain why there was an increase in shoats and cattle affected as we moved closer to river sources and potentially with increased precipitation. Future studies may investigate whether natural prey availability may be influencing livestock attacks.

G. Focus on protecting livestock near land cover transition zones

Areas where the land cover type is changing from one to another, like herbaceous to woody for example, may be associated with high occurrence of conflict incidents between leopards and livestock, and therefore leopards and humans. Leopards may have a preference for these transitional zones of mixed land cover type with possible relation to the abundance and type of available prey. Therefore, if a livestock enclosure is in close proximity to a mixed vegetation or transitioning land cover area, it may prove beneficial to consult our recommendations about the number and types of protective measures. It is important to note that there are limitations to our data analyses and their subsequent statistical significance due to the absence of data for the use of certain protective measures without resulting conflict in the form of livestock depredation to serve as a control in our statistical analyses. In addition, due to the variance in sample size and report completeness (within the conflict data), as well as relatively old data sources for land cover, we are careful to push forward strong recommendations for conflict mitigation and remain cautious in language.

II. Advocating for Long-Term Reform

A. Advocate for statewide reformations of wildlife policy

Despite local, state, and international efforts to preserve the diverse and dense wildlife of Kenya’s various ecosystems, wildlife numbers in Kenya have been on the decline over the past 50 years (Norton-Griffiths, 2000; Ogutu et al., 2016). While there are many factors driving wildlife population declines, state-level policies that do not allow local communities to shape their interactions with wildlife, while also not providing adequate benefits from protecting wildlife, play a significant role (Norton-Griffiths, 2000; Ogutu et al., 2016; Western & Waithaka, 2005). The relative absence of the KWS in Laikipia County due the areas’ lack of PAs, has likely saved pastoral communities from the devastations PAs have caused pastoralists elsewhere in Kenya (Butt, 2011). However, this has also meant that state wildlife tourism revenue has eluded Laikipia County and adjacent rangelands (Ogutu et al., 2016); though ultimately the region is still forced to conform to state-level wildlife policies.

In order to foster greater human-wildlife coexistence in Laikipia County, wildlife management should therefore be devolved to the community level. As made evident by our research, the circumstances of human-wildlife conflict and coexistence in Laikipia County, and even more precisely, that of human-wildlife conflict and coexistence in the communities surrounding Loisaba Conservancy, are extremely unique. Therefore, human-wildlife interactions here should not be blanketed by state-level policies that effectively determine how wildlife is managed. Some state-level policies are useful but greater discretion needs to be afforded to local communities to decide how to best utilize and conserve their local wildlife. This will ultimately lead to less human-wildlife conflict, greater wildlife tolerance, and the creation of more sustainable and cohabitable landscapes.

Broadly speaking, international organizations and NGOs have considerable power to shape the human-wildlife landscape of Kenya (Cockerill & Hagerman, 2020) With this in mind, we recommend that SDZWA advocate for state-level changes in Kenya's wildlife policy. As previously illustrated, state wildlife policies are not providing adequate support to local communities and indeed hamper the ability of local communities to respond to conflicts with wildlife in either socially or ecologically sustainable ways. Any advocacy work done by SDZWA should be tailored to the interests of the communities surrounding Loisaba Conservancy and should increase their autonomy to interact with wildlife as they see fit. It should be noted that facilitating greater local autonomy in wildlife management is inseparable from facilitating greater local autonomy in rangeland management and pastoral governance.

B. Increase capacity for pastoral mobility

Pastoralism is considered one of the most sustainable livelihood strategies for semi-arid landscapes (Butt, 2010) and these landscapes can benefit from "policies that build on and facilitate the traditional pastoral strategies rather than constrain them" (Ellis, 1999, p. 450). This indicates that regional leopard populations would benefit from the empowerment of traditional pastoralism. Traditional pastoralists managed the rangelands in a manner that was sustainable and thus provided the opportunity for wildlife, such as leopards to thrive peacefully alongside humans.

While our interviewees and literature suggests that there are numerous benefits to a more sedentary lifestyle (e.g. education, health care, water access) mobile livestock management once provided beneficial ecosystem services and greater productivity to livestock and wildlife (Lankester & Davis, 2016). Mobility of livestock should therefore be balanced against the benefits of more sedentary lifestyles. Sedentarism and mobility should become topics for open discussion between Loisaba Conservancy and the local communities so that strategies can be developed for striking an appropriate balance between the two lifestyle systems.

In support of pastoralists who wish to engage in a more mobile lifestyle, SDZWA and Loisaba Conservancy should take the following actions:

- Identify physical boundaries that are inhibiting pastoral mobility (e.g. fences, rivers, infrastructure)
- Identify social and institutional boundaries that are inhibiting pastoral mobility (e.g. laws that criminalize pastoral presence on particular lands; colonial era settlement schemes that divide communities)
- Identify social factors that are inhibiting pastoral mobility (e.g. pressure on pastoralists to live within a certain distance from infrastructure or other social goods, pressures to engage in multiple economic sectors)
- Coordinate with pastoralists to overcome various barriers that limit the flexibility and adaptability of traditional pastoral lifestyles

Again, by allowing for greater pastoral mobility, the rangelands of Laikipia may become more sustainably managed and thus support more prosperous habitats for African leopards.

C. Advocate for reformed land governance structures

In order to facilitate the sustainable use of Laikipia's rangelands and thus conserve the habitats of vulnerable species like the African leopard, proper land governance structures must be in place. As was discussed in the historical geography sections of this paper, land governance in Kenya is still defined by colonial era policies and institutions. Traditional land governance systems have been eroded and poorly situated within broader colonial systems. For example, Mwangi and Ostrom (2009) discuss the ongoing subdivision of Kenyan group ranches as a sign of the inadequacy of the colonial Group Ranch scheme. This failure is attributable to both insufficient ecological design and a lack of power divested to the committees who oversaw the operation and priorities of the group ranches (Mwangi & Ostrom, 2009).

SDZWA and Loisaba Conservancy's role here is complicated and will require significant long-term investment. Initially, further assessment of the land tenure and governance structures of the area surrounding Loisaba Conservancy need to be mapped, taking into account the varying levels of governance, from community to state, and even international influences on state land management. Secondly, SDZWA and Loisaba Conservancy should discuss the governance roles, challenges, and needs of individual community members as well as local governance organizations. At this point, there should be opportunities to use the power of SDZWA and Loisaba Conservancy to advocate for changes to local and state governance structures on behalf of the communities surrounding Loisaba Conservancy.

What this advocacy work will possibly entail is urging greater autonomy for group ranch committees, including less pressure to meet state mandated livestock control requirements, as well as pushing for greater state investments into group ranch lands.

D. Facilitate the elevation of traditional ecological knowledge

> "Why would research entities set aside mega budgets to teach the pastoralist about human–wildlife conflict? A pastoralist who has long roamed drylands with his livestock grazing alongside elephants and lions, and whose major life transition ceremonies, celebrations, songs, riddles, proverbs, sayings, poetry and jokes fundamentally feature wildlife. What makes these trainings in 'imparting knowledge' superior to the 'indigenous knowledge' already in the custody of the Borana or the Turkana or the Rendile?" (Mercy, 2020, p. 1).

Mercy (2020) brings up a particular insightful point here. However, it may be the case that traditional ecological knowledge is declining with the shifting political economy as traditional pastoralists are transitioning into a more diversified ranching economy (Yurco, 2017). As traditional pastoralists transition away from the practices that make their form of pastoralism traditional, there is likely a loss of pastoral knowledge systems, including issues of land management and human-wildlife conflict.

Reviving this knowledge without appropriating it can play an essential role in community empowerment and wildlife conservation. In order to do this, physical space and time should be created for discussions of elder community members' ecological knowledge, how the ecological landscapes have changed, and what generational gaps exist in local ecological knowledge.

E. Facilitate the actionability of traditional ecological knowledge

Making space for traditional ecological knowledge to be used by local communities is essential. This will move the revived traditional ecological knowledge out of a rhetorical space and into a physical space. In support of calls for revived pastoral knowledge and practice, Ogada et al. (2003) have shown that traditional livestock husbandry practices are very effective at reducing livestock depredation and thus human-carnivore conflict. SDZWA and Loisaba Conservancy can assist in creating the space for this knowledge system to be enacted. By learning from Indigenous pastoralists about conflict hotspots, conflict avoidance strategies, and traditional ways of dealing with problematic wildlife, SDZWA and Loisaba Conservancy can realize and then advocate for and enact the institutional, structural, physical, and rhetorical changes needed to allow pastoralists to engage in traditional livestock management practices and wildlife coexistence strategies.

F. Engage in public outreach campaigns that discuss the relative threats to community livestock

The threats to livestock in Laikipia County and across Kenya are numerous (Kiringe & Okello, 2007). Particular threats to livestock pose the possibility of killing greater numbers of livestock than others however (Frank et al., 2005). At the same time, particular threats may garner more attention and take greater priority than threats that appear to do greater damage to livestock populations.

As our interviewees stated, hyenas are the greatest threat to local livestock. These statements were corroborated by conflict incident reports from SDZWA data. This would appear to indicate that local communities have more conflictual relationships with hyenas than leopards. However, leopard retaliatory killings for livestock depredation is still of major concern, more so than that of hyenas. The apparent paradox here and the differences in how particular predator species are being valued is of consequence. Rationales behind various species valuation and subsequent conservation programs need to be openly discussed with local communities for transparency and building rapport and credibility. Ideally also allowing local communities to decide what species they want to prioritize for conservation.

Another great threat to livestock is disease. In fact, diseases are a more serious threat to livestock than predators in Kenya (Frank, L. G., Woodroffe, R. O. S. I. E., & Ogada, M. O., 2005). As Lankester and Davis (2016) point out, "a 23-year study estimated that disease caused twice the losses incurred by predation from carnivores (28), and recent work in Laikipia County (Kenya) puts the figure even higher" (p. 474). SDZWA should discuss this information with local herders to frame the threat of leopards predating livestock as relatively low compared to the threats posed to livestock by disease. A public outreach campaign with this goal should reduce the inclination to engage in the retaliatory killing of leopards due to livestock depredation. At the same time, substantial additional resources should be put into eradicating livestock disease in the area so that herders are more able to withstand the occasional predation of livestock.

Discussions with community members on relative threats to livestock should be conversation based, rather than lecture based in keeping with the premise of recommendation part II, subpart D. SDZWA and Loisaba Conservancy's role here should be to organize and facilitate discussions between various actor groups so that they can exchange information from their knowledge systems.

III. Future studies

A. Conduct research and expand interviews into further understanding historical human-wildlife interactions and the cultural significance of wildlife in the region.

While we only conducted two interviews, both interviewees stated that they were unaware of any social or cultural connection to leopards. Our hypothesis that there would be socio-cultural connections to the leopard as an animal species may have been rooted in a misguided assumption or overestimation that most Indigenous communities did at one point in their history place socio-cultural significance in particular animal species. However, as Kideghesho (2009) states, there are well documented historical instances of various East African ethnic groups placing socio-cultural significance in particular wild animal species and formulating accompanying rules and norms regarding interactions with those species.

We believe that research that elucidates the historical cultural significance of particular species like the leopard, as well as the historical cultural significance of particular human-wildlife interactions, could reveal yet another strategy for protecting vulnerable and endangered animal populations. Historically speaking, "African cultural practices are generally built into ways of conserving and protecting natural resources against overexploitation through the use of taboos and totemic affiliation with localities and wild flora and fauna species" (Kideghesho, 2009, p. 87). As such, researching the socio-cultural connections to animals and places may reveal lost cultural significance that could be valuable for improving beliefs about, attitudes towards, and interactions with particular species-- adding another tool for improving human-leopard coexistence. Researching the regional history of cultural connections to leopards should be done in a way that supports part D & E of part II described above.

B. Conduct research that collects richer socioeconomic data including poverty and herd sizes

Detailed information on individual household herd sizes as well as household income would begin to address inequities across communities and between individuals. Larger herd sizes have been previously linked to increased risk for conflict (Manoa & Mwaura, 2016) and livestock depredation by leopards can result in significant economic losses (Muriuki et al., 2017). Updated socioeconomic data on an individual and community scale would guide efforts towards aiding regions and individuals most affected by livestock losses. For example, households with lower incomes could receive additional financial support to replace losses or for implementing protective measures. Additionally, individuals and communities at the intersection of increased ecological and socioeconomic risks for leopard-livestock conflict can be prioritized for new conflict mitigation strategies.

C. Conduct future studies that collect richer ecological data on things like wild prey densities and higher resolution precipitation/seasonal data

Natural prey densities may play an important role in influencing leopard-livestock conflicts. As mentioned earlier in our report, leopards will target natural prey first before livestock or other food sources (Chaka et al. 2020, Kittle et al. 2016, Patterson et al., 2004). If natural prey densities are high and can satiate the leopard, there could be a reduction in livestock conflicts. This project did not investigate natural prey abundances, but we suspect that natural prey densities may be low throughout our study area and is influencing leopards to resort to livestock as the primary food source. We highly recommend future studies to investigate and conduct a prey inventory to identify the effects and relationship with human-livestock conflicts.

Weak trends in increased precipitation linked with increased leopard-livestock conflict indicate that levels of precipitation may be a statistically significant variable if higher resolution precipitation data is collected and analyzed. Previous studies have found that livestock depredation can increase in wet seasons as well as other times of increased precipitation. This was due to the resulting increase in vegetation and higher dispersal and lack of accessibility of natural prey (Chaka et al. 2020, Kittle et al. 2016, Patterson et al., 2004). Our study area has pronounced wet and dry seasons, which makes it an opportune area to research this trend further.

D. Standardize collection of leopard conflict data from pastoralists on a non-self reporting basis

As the data was composed of voluntary reports, there could also be non-response biases that could affect the accuracy of our results. It is possible that human-leopard conflict occurred more frequently but was not reported. In addition, the data set provided was entirely composed of conflict reports, which inherently excludes any information on the measures used by those who do not experience leopard attacks. Having this information would have benefited our analyses as we can more easily pinpoint what combination or number of protective measures best protected livestock from leopard attacks. Future studies should collect information from both those that had conflict and those that did not have conflict with leopards.

Avoiding a Crisis Narrative

> "This article is not arguing that environmental degradation isn't occurring in Laikipia, but rather there is evidence to suggest that the narrative of environmental degradation is being used to legitimize the exclusion of certain groups from accessing resources. This is similar to the argument that institutions and development experts use crisis narratives to make themselves 'stakeholders', and involve themselves in the management and decision making of resources which they don't own (Roe, 1995)" (Bond, 2014).

Given the colonial history of land dispossession and environmental degradation in the region, steps must be taken to dissect the power imbalance between local communities and outside interest groups. San Diego Zoo Wildlife Alliance and the Loisaba Conservancy have the unique opportunity to reimagine their relationship with local pastoralist communities and challenge unjust land tenure practices. Framing local engagement efforts around a "human-leopard conflict" crisis narrative obscures the legacies of colonialism that catalyzed this conflict. A more holistic approach to restoring human relationships with the land is called for, including a broader assessment of threats to sustainable livelihoods (**Figure 13**), a bottom up approach to reclaiming lands and historical rangeland mobility, and financial support and advocacy for grass roots environmental justice movements driving changes to local and national policies.

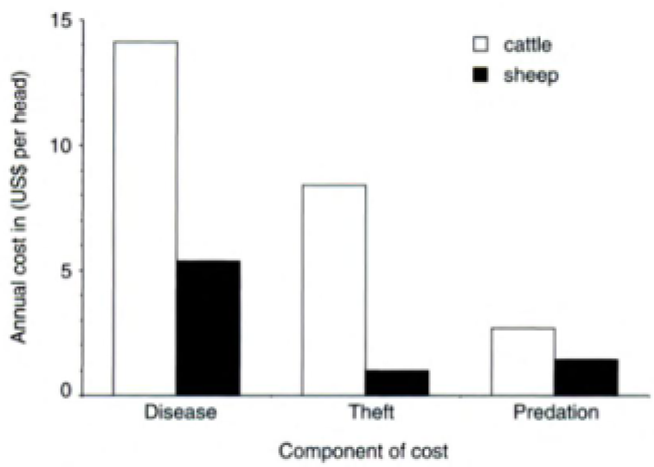


Figure 13. Frank, L. G., Woodroffe, R. O. S. I. E., & Ogada, M. O. (2005). People and predators in Laikipia district, Kenya. *CONSERVATION BIOLOGY SERIES-CAMBRIDGE-*, *9*, 286. Relative costs of livestock depredation on commercial ranches.

Conclusion

Human and natural landscapes are two inextricable parts of one system. Humans have always shaped and been shaped by the natural world. However, changes to the dynamics between the built and natural world have increased and intensified human-wildlife conflicts. In order to ensure the integrity of the socio-natural system, we must realize that coexistence with wildlife is key. This means utilizing and implementing conflict reduction methods that ensure the integrity of both parts of this complex system.

The current practices and norms created through historical events have made it considerably difficult to promote coexistence with wildlife. The artifacts of colonialism continue to demonize, victimize, and disenfranchise Indigenous communities. It is often the case that those who are currently facing the most serious damages from human-wildlife conflict are also those who have been historically marginalized, but many conservation practices continue to benefit those other than these Indigenous communities. Understanding the history of conservation and colonialism is important for developing strategies that do not (un)intentionally continue to ostracize Indigenous communities and which ensure Indigineous communities are provided the means to preserve their livelihoods and the abilities to shape conservation practices and policies.

In this report we have analyzed contemporary data concerning human-leopard conflict surrounding Loisaba Conservancy and contextualized these conflicts within the historical geography of Kenya's rangelands. This interdisciplinary approach has complicated our production of recommendations for how the San Diego Zoo Wildlife Alliance and Loisaba Conservancy can improve regional human-leopard coexistence. Ultimately, we recommend taking a multi-pronged approach that expands the efficacy of livestock protection measures in the short-term, while also addressing the legacies of colonialism through long-term advocacy work that restores the rights and powers of Indigenous communities. We believe this strategy will reduce the acuteness with which human-leopard conflict affects local pastoralists and that it will restore the abilities of these communities to respond to human-wildlife conflicts in a just and sustainable way.

While we acknowledge the limitations and shortcomings of our research, we hope this report is a step towards promoting human-wildlife coexistence through a decolonial lens. And we hope that the recommendations we provide will help conserve regional leopard populations while simultaneously benefitting and empowering the Indigenous pastoral communities surrounding Loisaba Conservancy.

StoryMap: Human-Leopard Conflict and Coexistence in Northern Kenya

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Appendix

This interview is part of a Master's Project with the University of Michigan, School for Environment and Sustainability under the directive of the Uhifadhi Wa Chui Leopard Conservation Team with Loisaba Conservancy and San Diego Zoo Global.

The objectives of this survey are to better understand: 1) the drivers of human-wildlife conflict at the community level and 2) the capacities of conservation organizations to respond to human-wildlife conflict.

We invite you to participate in this research as it relates to your views of human-wildlife conflict and coexistence in your geographical work area. Your expertise will provide crucial on-the-ground insights into the challenges and opportunities associated with creating and sustaining human-wildlife coexistence.

Participation in this research is voluntary, and anything you say might be used for this research, but your answers will be anonymous and confidential. There will not be any direct benefit through participation in this research. If you have any questions or concerns about this work, please contact Kirstie Ruppert at kruppert@sandiegozoo.org or Miami University Research Ethics and Integrity at sullivnh@miamioh.edu.

Do you agree to proceed?

Human-Leopard Conflict and Coexistence Interview Template

Please rely upon your own area of expertise to answer these questions.

1. In what geographic region do you primarily work?

2. How would you describe your role in conservation?

3. What does conflict between humans and large carnivores look like?
    a. What is the greatest source of conflict between humans and large carnivores?
        i. Are there additional impacts associated with that conflict?
        ii. Which particular species are most associated with conflict?

4. What does coexistence between humans and large carnivores look like?
    a. What are the greatest benefits of human-carnivore coexistence?

5. What strategies for reducing human-carnivore conflict are most effective?
    a. What factors make those strategies most effective?

6. What strategies for reducing human-carnivore conflict are least effective?
    a. What factors make those strategies least effective?

7. Do individuals and communities have strong cultural connections to leopards in the region? If so, please describe.

8. What are the logistical challenges you face in managing human-wildlife interactions?
    a. What resources would be most helpful to you to overcome these logistical challenges?

9. Which tangible and intangible benefits are associated with the current carnivore conservation programs?
    a. How can these programs be improved to maximize benefits?

10. Please provide any remaining thoughts you have on how human-leopard coexistence can be improved.

If you have any questions or concerns about this research, please contact the Institutional Review Board of Miami University at sullivnh@miamioh.edu

Supplementary Tables

Table 1. Dunn's test results for the number shoats affected between # of PM used

	0	1	2	3	4	5	6	7	8
0		1.24 0.21	0.08 0.94	3.72 0.00*	1.31 0.19	1.16 0.24	0.36 0.72	-0.36 0.72	-1.18 0.24
1			-1.17 0.24	-0.11 0.92	-0.68 0.49	-0.72 0.47	-0.97 0.33	-1.26 0.21	-1.69 0.09
2				2.62 0.01*	1.00 0.32	0.89 0.37	0.26 0.79	-0.36 0.72	-1.17 0.24
3					-1.31 0.19	-1.37 0.17	-1.76 0.08	-2.10 0.04*	-1.95 0.05
4						-0.08 0.94	-0.57 0.57	-1.06 0.29	-1.50 0.13
5							-0.49 0.62	-0.98 0.33	-1.46 0.14
6								-0.52 0.61	-1.24 0.22
7									-0.96 0.34
8									

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results

Table 2. Dunn's test results for per capita values of shoats affected between # of PM used

	0	1	2	3	4	5	6	7	8
0		-0.66 0.51	-5.18 0.00*	1.02 0.31	-2.36 0.02*	-3.59 0.00*	-3.38 0.00*	-4.56 0.00*	-2.05 0.04*
1			-1.03 0.30	0.94 0.35	-0.26 0.80	-0.75 0.45	-0.89 0.37	-1.75 0.08	-1.30 0.19
2				4.85 0.00*	1.65 0.10	0.55 0.58	0.18 0.86	-1.43 0.15	-0.81 0.42
3					-2.64 0.01*	-3.69 0.00*	-3.56 0.00*	-4.67 0.00*	-2.24 0.03*
4						-0.98 0.33	-1.17 0.24	-2.54 0.01*	-1.35 0.18
5							-0.28 0.78	-1.74 0.08	-0.98 0.33
6								-1.40 0.16	-0.85 0.39
7									-0.15 0.88
8									

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results

Table 3. Dunn's test result for per capita values of shoats affected between different PM combination groups.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

A	-0.71	-2.07	-1.62	-2.71	-3.55	-1.67	-0.88	-3.20	-1.63	-2.07	-2.07	-2.18	-5.30	-0.67	-2.07
	0.48	0.04*	0.11	0.01*	0.00*	0.10	0.38	0.00*	0.10	0.04*	0.04*	0.03*	0.00*	0.50	0.04*
B		-1.28	-0.48	-0.87	-1.50	-0.02	0.07	-0.65	-0.49	-1.28	-1.28	-1.04	-1.06	0.48	-1.28
		0.20	063	0.38	0.13	0.98	0.95	0.52	0.62	0.20	0.20	0.30	0.29	0.63	0.20
C			0.98	0.77	0.25	1.49	1.46	1.03	0.97	0.00	0.00	0.43	0.76	1.89	0.00
			0.33	0.44	0.80	0.14	0.14	0.30	0.33	1.00	1.00	0.67	0.45	0.06	1.00
D				-0.40	-1.13	0.65	0.65	-0.09	-0.01	-0.98	-0.98	-0.66	-0.57	1.29	-0.98
				0.69	0.26	0.52	0.52	0.93	0.99	0.33	0.33	0.51	0.57	0.20	0.33
E					-0.85	1.32	1.17	0.43	0.39	-0.77	-0.77	-0.38	-0.12	2.20	-0.77
					0.40	0.19	0.24	0.67	0.70	0.44	0.44	0.71	0.90	0.03	0.44
F						2.19	1.92	1.37	1.11	-0.25	-0.25	0.29	0.92	3.05	-0.25
						0.03*	0.06	0.17	0.27	0.80	0.80	0.77	0.36	0.00*	0.80
G							0.13	-1.13	-0.66	-1.49	-1.49	-1.34	-2.04	1.01	-1.49
							0.90	0.26	0.51	0.14	0.14	0.18	0.04*	0.31	0.14
H								-0.95	-0.66	-1.46	-1.46	-1.27	-1.54	0.55	-1.46
								0.34	0.51	0.14	0.14	0.20	0.12	0.58	0.14
I									0.08	-1.03	-1.03	-0.71	-0.77	2.33	-1.03
									0.94	0.30	0.30	0.48	0.44	0.02*	0.30
J										-0.97	-0.97	-0.65	-0.55	1.31	-0.97
										0.33	0.33	0.51	0.58	0.19	0.33
K											0.00	0.43	0.76	1.89	0.00
											1.00	0.67	0.45	0.06	1.00
L												0.43	0.76	1.89	0.00
												0.67	0.45	0.06	1.00
M													0.34	1.90	-0.43
													0.73	0.06	0.67

N	3.69 0.00*	-0.76 0.45
O		-1.89 0.06
P		

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results. A = 0, B = 1, C = 12, D = 123456, E = 12356, F = 1245, G = 12456, H = 125, I = 1256, J = 13456, K = 1356, L = 145, M = 1456, N = 15, O = 156, P = 4; Boma = 1, Wire fencing = 2, Livestock guards = 3, fire/light/torches = 4, dog =5, and other = 6.

Table 4. Dunn's test results for per capita values of livestock killed between # of PM used

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
0		-3.30 0.00*	-5.92 0.00*	-6.90 0.00*	-7.02 0.00*	-5.26 0.00*	0.70 0.49	-5.54 0.00*	-2.35 0.02*
1			1.31 0.19	1.23 0.22	0.64 0.52	1.12 0.26	-1.06 0.29	0.07 0.95	-0.02 0.99
2				-0.23 0.82	-1.43 0.15	-0.34 0.73	-0.93 0.35	-1.97 0.05	-0.97 0.33
3					-1.29 0.20	-0.16 0.87	0.15 0.88	-1.87 0.06	-0.97 0.36
4						0.97 0.33	-0.70 0.48	-0.89 0.38	-0.49 0.63
5							-5.54 0.00	-1.61 0.11	-0.84 0.40
6								-0.93 0.35	-0.54 0.59

7	-0.07 0.94
8	

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results

Table 5. Dunn’s test result for per capita values of livestock killed between different PM combination groups.

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**
A		-4.14	1.10	-3.08	-6.20	-5.19	-6.67	-3.45	-6.17	-5.41	-2.49	-5.50	-4.06	-3.45	-6.65	-7.60	-5.43	-2.49	-2.49
		0.00*	0.27	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.01*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.01*	0.01*
B			1.78	1.60	0.60	0.08	1.82	-0.05	0.27	2.42	-0.08	0.80	1.03	-0.05	0.53	1.44	2.22	-0.08	-0.08
			0.08	0.11	0.55	0.94	0.07	0.96	0.79	0.02*	0.94	0.43	0.30	0.96	0.59	0.15	0.03*	0.94	0.94
C				-0.61	-1.58	-1.87	-0.71	-1.67	-1.82	-0.24	-1.40	-1.40	-1.10	-1.67	-1.66	-1.02	-0.38	-1.40	-1.40
				0.54	0.11	0.06	0.48	0.10	0.07	0.81	0.16	0.16	0.27	0.10	0.10	0.31	0.70	0.16	0.16
D					-1.42	-1.77	-0.06	-1.44	-1.76	0.73	-1.13	-1.13	-0.70	-1.44	-1.54	-0.56	0.48	-1.13	-1.13
					0.16	0.08	0.95	0.15	0.08	0.46	0.26	0.26	0.48	0.15	0.12	0.57	0.63	0.26	0.26
E						-0.62	1.93	-.0.57	-0.46	2.97	-0.46	0.29	0.64	-0.57	-0.11	1.30	2.60	-0.46	-0.46
						0.54	0.05*	0.57	0.65	0.00*	0.64	0.77	0.52	0.57	0.91	0.19	0.01*	0.64	0.64
F							2.16	-0.12	0.22	2.93	-0.14	0.85	1.10	-0.12	0.54	1.68	2.66	-0.14	-0.14
							0.03*	0.90	0.83	0.00*	0.89	0.40	0.27	0.90	0.59	0.09	0.01*	0.89	0.89
G								-1.57	-2.32	1.43	-1.17	-1.50	-0.84	-1.57	-2.14	-0.86	0.94	-1.17	-1.17
								0.12	0.02*	0.15	0.24	0.13	0.40	0.12	0.03	0.39	0.35	0.24	0.24
H									0.29	2.06	-0.04	0.74	0.94	0.00	0.51	1.26	1.90	-0.04	-0.04
									0.78	0.04*	0.97	0.46	0.35	1.00	0.61	0.21	0.06	0.97	0.97

I	3.27	-0.26	0.72	1.01	-0.29	0.36	1.73	2.93	-0.26	-0.26
	0.00*	0.80	0.47	0.31	0.78	0.72	0.08	0.00*	0.80	0.80
J		-1.52	-2.48	-1.65	-2.06	-3.22	-2.31	-0.43	-1.52	-1.52
		0.13	0.01*	0.10	0.04*	0.00*	0.02*	0.66	0.13	0.13
K			0.59	0.76	0.04	0.42	0.95	1.41	0.00	0.00
			0.56	0.45	0.97	0.67	0.34	0.16	1.00	1.00
L				0.37	-0.74	-0.41	0.90	2.14	-0.59	-0.59
				0.71	0.46	0.68	0.37	0.03*	0.56	0.56
M					-0.94	-0.74	0.33	1.39	-0.76	-0.76
					0.35	0.46	0.74	0.17	0.45	0.45
N						0.51	1.26	1.90	-0.04	-0.04
						0.61	0.21	0.06	0.97	0.97
O							1.48	2.83	-0.42	-0.42
							0.14	0.00*	0.67	0.67
P								1.79	-0.95	-0.95
								0.07	0.34	0.34
Q									-1.41	-1.41
									0.16	0.16
R										0.00
										1.00
S										

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results. A = 0, B = 1, C = 12, D = 123456, E = 12356, F = 1245, G = 12356, H = 12456, I = 1246, J = 125, K = 1256, L = 1345, M = 13456, N = 1356, O = 145, P = 1456, Q = 15, R = 156, S = 4; Boma = 1, Wire fencing = 2, Livestock guards = 3, fire/light/torches = 4, dog =5, and other = 6.

Table 6. Dunn's test results for the number of livestock injured between # of PM used

	0	1	2	3	4	5	6	7	8
0		0.48 0.63	-3.22 0.00*	-0.82 0.41	-1.39 0.16	-3.92 0.00*	0.17 0.87	-1.24 0.22	0.34 0.73
1			-1.46 0.14	-0.70 0.49	-0.94 0.35	-1.91 0.06	-0.36 0.72	-1.04 0.30	0.00 1.00
2				1.91 0.06	1.10 0.27	-1.03 0.30	1.99 0.05*	0.50 0.62	1.06 0.29
3					-0.61 0.54	-2.75 0.01*	0.58 0.56	-0.75 0.45	0.50 0.62
4						-1.95 0.05*	1.01 0.31	-0.30 0.77	0.69 0.49
5							2.69 0.01*	1.21 0.23	1.40 0.16
6								-1.08 0.28	0.27 0.79
7									0.79 0.43
8									

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results

Table 7. Dunn's test results for per capita values of livestock injured between # of PM used

	0	1	2	3	4	5	6	7	8
0		0.48 0.63	1.48 0.14	-1.25 0.21	-1.86 0.06	-4.74 0.00*	0.03 0.97	-1.77 0.08	0.34 0.73
1			0.00 1.00	-0.82 0.41	-1.10 0.27	-2.21 0.03*	-0.42 0.67	-1.31 0.19	0.00 1.00
2				-2.00 0.05*	-2.43 0.01*	-4.72 0.00*	-0.82 0.41	-2.30 0.02*	0.00 1.00
3					-0.71 0.48	-3.16 0.00*	0.70 0.48	-1.04 0.30	0.59 0.56
4						-2.25 0.02*	1.19 0.23	-0.50 0.62	0.80 0.42
5							3.12 0.00*	1.24 0.22	1.62 0.10
6								-1.41 0.16	0.31 0.76
7									0.99 0.32
8									

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results

Table 8. Dunn's test result for the number of livestock injured between different PM combination groups.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
A		-2.30	0.51	-3.78	0.33	-1.46	-3.15	-1.29	0.12	0.03	0.36	0.23	-1.40	0.51	0.42	-0.61	0.99	0.36	0.36
		0.02*	0.61	0.00*	0.74	0.15	0.00*	0.20	0..90	0.98	0.72	0.82	0.16	0.61	0.67	0.54	0.32	0.72	0.72
B			1.87	-0.32	2.20	0.93	1.20	0.47	2.04	2.24	1.47	2.13	1.07	1.87	2.26	2.00	2.53	1.47	1.47
			0.06	0.75	0.03*	0.35	0.23	0.64	0.04*	0.02	0.14	0.03*	0.28	0.06	0.02*	0.05*	0.01*	0.14	0.14
C				-2.36	-0.33	-1.22	-1.34	-1.28	-0.40	-0.49	0.00	-0.36	-1.15	0.00	-0.30	-0.66	-0.23	0.00	0.00
				0.02*	0.74	0.22	0.18	0.20	0.69	0.62	1.00	0.72	0.25	1.00	0.76	0.51	0.82	1.00	1.00
D					3.24	1.50	2.13	0.80	2.98	3.58	1.79	3.12	1.71	2.36	3.34	3.21	3.93	1.79	1.79
					0.00*	0.13	0.03*	0.42	0.00*	0.00*	0.07	0.00*	0.09	0.02*	0.00*	0.00*	0.00*	0.07	0.07
E						1.40	-1.98	-1.32	-0.13	-0.29	0.24	-0.06	-1.33	0.33	0.05	-0.63	0.23	0.24	0.24
						0.16	0.05*	0.19	0.89	0.77	0.81	0.95	0.18	0.74	0.96	0.53	0.82	0.81	0.81
F							0.09	-0.31	1.23	1.40	0.93	1.32	0.13	1.22	1.46	1.10	1.76	0.93	0.93
							0.93	0.76	0.22	0.16	0.35	0.19	0.90	0.22	0.14	0.27	0.08	0.35	0.35
G								-0.41	1.66	2.54	0.96	1.83	0.08	1.34	2.12	1.87	3.13	0.96	0.96
								0.68	0.10	0.01*	0.34	0.07	0.94	0.18	0.03*	0.06	0.00*	0.34	0.34
H									1.21	1.27	1.04	1.27	0.41	1.28	1.36	1.08	1.52	1.04	1.04
									0.23	0.21	0.30	0.20	0.68	0.20	0.17	0.28	0.13	0.30	0.30
I										-0.10	0.30	0.07	-1.15	0.40	0.19	-0.42	0.37	0.30	0.30
										0.92	0.76	0.94	0.25	0.69	0.85	0.68	0.71	0.76	0.76
J											0.35	0.20	-1.33	0.49	0.37	-0.51	0.77	0.35	0.35
											0.72	0.84	0.18	0.62	0.71	0.61	0.44	0.72	0.72
K												-0.27	-0.87	0.00	-0.22	-0.48	-0.17	0.00	0.00
												0.79	0.38	1.00	0.82	0.63	0.87	1.00	1.00
L													-1.25	0.36	0.11	-0.53	0.30	0.27	0.27
													0.21	0.72	0.91	0.60	0.77	0.79	0.79

M	1.12	1.10	1.02	1.73	0.87	0.87
	0.25	0.16	0.31	0.08	0.38	0.38
N		-0.30	-0.660.5	-0.23	0.00	0.00
		0.76	1	0.82	1.00	1.00
O			-0.71	0.18	0.22	0.22
			0.48	0.86	0.82	0.82
P				1.20	0.48	0.48
				0.23	0.63	0.63
Q					0.17	0.17
					0.87	0.87
R						0.00
						1.00
S						

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results. A = 0, B = 1, C = 12, D = 123456, E = 12356, F = 1245, G = 12356, H = 12456, I = 1246, J = 125, K = 1256, L = 1345, M = 13456, N = 1356, O = 145, P = 1456, Q = 15, R = 156, S = 4; Boma = 1, Wire fencing = 2, Livestock guards = 3, fire/light/torches = 4, dog =5, and other = 6.

Table 9. Dunn's test result for per capita values of livestock injured between different PM combination groups.

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**	**S**
A		-2.87	0.46	-3.78	0.06	-1.92	-3.35	-1.71	-0.16	-0.24	0.33	-0.04	-1.57	0.46	0.16	-0.87	0.66	0.33	0.33
		0.00*	0.64	0.00*	0.95	0.05*	0.00*	0.09	0.88	0.81	0.74	0.97	0.12	0.64	0.87	0.38	0.51	0.74	0.74
B			2.19	0.15	2.57	1.09	1.67	0.50	2.38	2.71	1.73	2.48	1.44	2.19	2.64	2.46	2.97	1.73	1.73
			0.03*	0.88	0.01*	0.27	0.09	0.63	0.02*	0.01*	0.08	0.01*	0.15	0.03*	0.01*	0.01*	0.00*	0.08	0.08
C				-2.32	-0.40	-1.43	-1.35	-1.54	-0.49	-0.51	0.00	-0.44	-1.20	0.00	-0.36	-0.69	-0.27	0.00	0.00

	0.02*	0.69	0.15	0.18	0.12	0.63	0.62	1.00	0.66	0.23	1.00	0.72	0.49	0.78	1.00	1.00
D		3.07	1.15	2.04	0.43	2.80	3.47	1.76	2.95	1.58	2.32	3.18	3.09	3.79	1.76	1.76
		0.00*	0.25	0.04*	0.67	0.01	0.00*	0.08	0.00*	0.11	0.02	0.00*	0.00*	0.00*	0.08	0.08
E			-1.63	-1.85	-1.59	-0.16	1.74	0.29	-0.07	-1.30	0.40	0.06	-0.53	0.30	0.29	0.29
			0.10	0.06	0.11	0.87	0.08	0.77	0.94	0.19	0.69	0.95	0.59	0.77	0.77	0.77
F				0.44	-0.41	1.43	-0.18	1.09	1.54	0.36	1.43	1.70	1.43	2.07	1.09	1.09
				0.66	0.68	0.15	0.86	0.27	0.12	0.72	0.15	0.09	0.15	0.04*	0.27	0.27
G					-0.76	1.50	2.51	0.97	1.69	0.01	1.35	2.00	1.82	3.04	0.97	0.97
					0.44	0.13	0.01*	0.33	0.09	0.99	0.18	0.05*	0.07	0.00*	0.33	0.33
H						1.46	1.61	1.26	1.53	0.69	1.54	1.64	1.42	1.84	1.26	1.26
						0.14	0.11	0.21	0.12	0.49	0.12	0.10	0.16	0.07	0.21	0.21
I							0.03	0.36	0.09	-1.10	0.19	0.23	-0.30	0.47	0.36	0.36
							0.97	0.72	0.93	0.27	0.63	0.82	0.77	0.64	0.72	0.72
J								0.37	0.08	-1.39	0.51	0.27	-0.53	0.71	0.37	0.37
								0.71	0.94	0.17	0.61	0.79	0.59	0.48	0.71	0.71
K									-0.33	-0.91	0.00	-0.27	-0.50	-0.20	0.00	0.00
									0.75	0.36	1.00	0.79	0.62	0.84	1.00	1.00
L										-1.21	0.44	0.14	-0.42	0.38	0.33	0.33
										0.23	0.66	0.89	0.67	0.71	0.75	0.75
M											1.20	1.38	1.06	1.75	0.91	0.91
											0.20	0.17	0.29	0.08	0.36	0.36
N												-0.36	-0.69	-0.27	0.00	0.00
												0.72	0.49	0.78	1.00	1.00
O													-0.63	0.23	0.27	0.27
													0.53	0.82	0.79	0.79
P														1.16	0.50	0.50

	0.25	0.62	0.62
Q		0.20	0.20
		0.84	0.84
R			0.00
			1.00
S			

Note: Values represented on top are Z-values, bottom are p-values. Values with * indicate significant results. A = 0, B = 1, C = 12, D = 123456, E = 12356, F = 1245, G = 12356, H = 12456, I = 1246, J = 125, K = 1256, L = 1345, M = 13456, N = 1356, O = 145, P = 1456, Q = 15, R = 156, S = 4; Boma = 1, Wire fencing = 2, Livestock guards = 3, fire/light/torches = 4, dog =5, and other = 6.