Conservation and management of lions in Kenya: an assessment of factors influencing Panthera leo melanochaita (Hamilton Smith, 1842) population dynamics

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Synthesis and General discussion

6.1 Background

Lions (*Panthera leo*) form a vital component of natural ecosystems in Africa and Asia, where they contribute to maintaining ecosystem structure and function through trophic interactions with prey species (Ripple et al., 2014). They are also valuable indicators of ecosystem health because they rely on intact habitats, an adequate prey base, and shelter from anthropogenic threats (Lindsey et al., 2017). However, several protected areas (PAs) established for the conservation of lions and other wildlife are struggling to adequately conserve them due to increasing anthropogenic pressures, inadequate funding, inefficient management, insufficient size or extreme isolation (Barnes et al., 2016; Craigie et al., 2010; Lindsey et al., 2018; Ottichilo et al., 2001; Robson et al., 2022). Further, since protected areas are designed to focus on the protection of wildlife, conflict with humans often fosters negative attitudes among communities, which hinder conservation efforts beyond PAs (Western et al., 2009). In Kenya, wildlife is legally protected across a network of state-run national parks and reserves, community-owned conservancies, group ranches and private ranches/conservancies (Kenya Wildlife Service, 2018). In spite of this legal protection, Kenya has experienced a marked decline in its wildlife populations over the past decades (Ogutu et al., 2016). However, in conservancies where the communities directly benefit from wildlife conservation through tourism or where they have access to resources, wildlife populations are reported to have increased (Blackburn et al., 2016; Ogutu et al., 2017; Western et al., 2009).

The marked increase in the human population and subsequent development activities in Kenya have further challenged conservation efforts through land use change and habitat fragmentation and have substantially reduced connectivity between lion populations (Kenya Wildlife Service, 2020; Lesilau et al., 2021). Additionally, the country is experiencing an increasing frequency and intensity of extreme weather events such as droughts, which have resulted in regular livestock incursions into national parks (Butt, 2014; Huqa, 2015; Waweru et al., 2021). These incursions lead to competition between livestock and wildlife for critical water and forage resources (Ngugi & Conant, 2008). This has in-turn increased conflict incidences and subsequent retaliatory killings of lions both inside and outside PAs (Bhalla, 2017; Woodroffe & Ginsberg, 1998). Lions have also been known to leave the confines of parks/wildlife areas in pursuit of migratory prey, thus coming into contact with people and their livestock leading to conflict incidences (Huqa, 2015; Lesilau et al., 2018, 2021).

To address these threats, Kenya has developed a number of policies and strategies (e.g., fencing PAs and translocation of 'problem' lions) to guide the management and conservation of lions (Kenya Wildlife Service, 2019, 2020; Ministry of Tourism and Wildlife, 2018). Therefore, in line with these documents, this research aimed to enhance the knowledge of the threats faced by lion populations in Kenya and to inform conservation strategies and policies.

This research covers a multifaceted examination of the impacts of management on lion genetic diversity, the effects of ecological and anthropogenic factors on lion grouping patterns, and the effects of rainfall on lion home range and movement. This research also intends to contribute to a robust and cost-effective option for establishing long-term conservation and monitoring programs of lions in Kenya through the use of Spatially Explicit Capture-Recapture (SECR) methods. The findings of this research highlight the need for prioritisation of conservation efforts through the implementation of a site-specific, tailored approach to lion populations. This may include conservation actions focused on the maintenance of suitable habitats to facilitate population connectivity, genetic restoration efforts of local lion populations, adaptive management and conservation actions that account for the unique evolutionary histories of lion populations and seasonal shifts in lion movement and home range. Finally, the results of this research demonstrate how different data collection strategies can be employed within a robust monitoring framework to derive comparable estimates that can be integrated directly into management interventions and strategies.

6.2 Significance of the study for the management of the Kenyan lion population

The outcomes of this study are categorised into three broad areas: 1.) the impact of management practices on lion populations in Kenya; 2.) the impact of ecological factors on lion populations in Kenya and 3.) the impact of anthropogenic factors on lion populations in Kenya. The outcomes of this research have been synthesised to guide informed and adaptive conservation and management strategies and are applicable at a national scale because this research covered multiple sites across Kenya.

6.2.1 Impact of management practices

The Convention on Biological Diversity (2022) emphasizes that management of wildlife should integrate genetic, ecological and demographic considerations. This is recommended, because long- term conservation relies on understanding the processes that allow demographic and genetic connections between small and increasingly isolated populations (Björklund, 2003; Creel et al., 2019). Also, it is important to acknowledge both historical events and past management interventions that may influence contemporary patterns of lion genetic diversity. In this context, the second chapter of this PhD thesis provides the first comprehensive scientific analysis of the genetic composition of Kenya's lion population and assesses the impact of management interventions, such as fencing of protected areas and the translocation of 'problem' lions.

The impact of fencing on genetic diversity was evident for the small and fenced lion populations in Lake Nakuru NP (LNP) and Solio ranch, which showed indications of genetic erosion (Chege et al., 2024). These two populations had lower genetic diversity scores, a high percentage of monomorphic loci, and formed distinct genetic clusters in the PCA and DAPC analysis plots, as well as in the sNMF and the structure bar plots at K = 2 and K = 4. Situated close to densely populated human settlements, the two lion populations have been completely fenced for several decades, without genetic supplementation from other lion populations through introduction of unrelated individuals. This finding provides clear evidence of the potential impacts of long-term isolation of lion populations and reveal the need for adaptive management for small and enclosed populations, as is typically done in South Africa (Miller et al., 2015). Previous research on the long-term isolation of lion populations has shown that prolonged genetic isolation can reduce fertility, increase sperm abnormalities and susceptibility to disease (Packer et al., 1991; Trinkel et al., 2010; Wildt et al., 1987). Nevertheless, genetic rescue efforts through human-mediated translocations in areas such as LNP and Solio ranch, where dispersal is not possible, may be beneficial (Bertola et al., 2022; IUCN/SSC, 2013). For example, lions in Hluhluwe-iMfolozi park, a small, enclosed reserve in South Africa, showed indications of inbreeding due to long term isolation, the population recovered after genetic rescue efforts through the introduction of new individuals into the park (Miller et al., 2020; Trinkel et al., 2008). Therefore, it is recommended that LNP and Solio ranch populations be supplemented by the translocation of lions from other populations following the guidelines listed by Bertola et al. (2022) and Miller et al. (2013), while ensuring evolutionary lineages are maintained.

On the other hand, the Nairobi NP (NNP) lion population inhabits a partially fenced habitat, with sections that border Nairobi city being fenced, while the southern section that borders Athi-Kapiti plains, an area of 2,456 km^2 pastoralist rangeland, is unfenced (Reid et al., 2008). The Athi Kapiti plains are vital for lions as demonstrated in chapter 5 of this study, which used SECR in three different field survey techniques to infer spatiotemporal variation of lion density and space use in NNP across the years 2018, 2021 and 2022. Results indicated that the mean lion density (lions/100 km^2) in the park was higher during the dry season (2021 and 2022) compared to the wet season (2018), when prey species are dispersed outside the park. The distance moved by all lions, which was inferred by the sex ratio-weighted spatial scale parameter (σ_w) in km, was largest during the wet season and lion activity centres were more clustered near the southern boundary of the park during the wet season compared to during dry seasons (Chege et al., *in press*). Similar results were observed using collar data in chapter 4, where lions increased the distance moved with increase in rainfall (Chege et al., 2025). Also Lesilau et al. (2021) had similar findings in his research in NNP. However, these movements have been associated with increased conflicts during the wet season as a result of livestock depredation, when lions venture out of NNP through the unfenced section in pursuit of wild prey (Lesilau et al., 2018, 2021). Thus this population has a history of severe persecution, where several individuals have been killed in retaliatory attacks (Lesilau, 2019; Whitman et al., 2007). In addition, some 'problem' lions have been translocated out of the park to Tsavo NP and Meru NP to reduce conflicts. Remarkably, despite the frequent retaliatory killings, the NNP population has remained stable over the past six decades oscillating between an estimated number of 25 and 35 individuals (Chege et al., *in press*; Lesilau, 2019; Rudnai, 1973). This phenomenon may be attributed to the estimated high female-to-male ratio (see chapter 5), which, may contribute to a stable reproduction rate that compensates for the high mortality. This tendency towards a higher number of females is characteristic for lions occupying open or partially enclosed habitats that are close to human settlements, because males are more prone to dispersal related mortality as a result of conflict (Funston, 2011). However, the frequent conflicts in addition to the increasing human and infrastructural developments on the Athi-Kapiti plains and inside the park, pose significant threats to the population (Lesilau et al., 2021; Mwangi et al., 2022). These developments are increasingly limiting lion movement and dispersal, as evidenced in the PCA analysis in chapter 2, where the population formed a diffuse cluster on axes 1 and 2 and with sNMF, the population was grouped together with the LNP population suggesting ongoing genetic drift (Chege et al., 2024). These results highlight the need for enhancing community tolerance so as to safeguard corridors that allow movement and dispersal of lions. In order to build tolerance, communities can be supported to establish community conservancies, where they can derive benefits. Additionally, a well-equipped and strategically placed conflict response unit during the wet season can be established. To prevent further genetic degradation, managers should consider human- mediated dispersal through translocation, by introducing individuals with similar evolutionary lineage. However, the translocation of 'problem' lions is compounded by several challenges due to their complex behavioural ecology (i.e., territoriality, sociality etc.), monitoring difficulties, inadequate funding, quality of release habitat, lack of baseline knowledge and public support (Berger-Tal et al., 2020). Therefore, implementation of a robust lion monitoring program, for example one that incorporates the SECR framework described in chapter 5 of this thesis, will be crucial for guiding, tracking and ensuring the success of management interventions.

The impact of fencing was also evident when assessing the influence of rainfall on lion home range and movement in chapter 4. For the completely fenced LNP, female lion home ranges spanned the entire park unlike the patterns observed in NNP and Meru NP (MNP), where the lion home ranges were restricted to sections of the park. Similar observations have been made in other small and enclosed parks in South Africa i.e., Turner et al., (2022). In such parks, repeated interactions, due to limited space, may foster social tolerance and reduce territoriality, provided the prey base is sufficient (McEvoy et al., 2022; Spong, 2002), This may lead to home ranges that cover (almost) the entire park. Also lions from LNP and NNP had smaller home ranges compared to lions in MNP, which can be attributed to higher prey densities and the presence of fences that limit the space for lions. In MNP, the density of prey populations is lower compared to LNP and NNP, and lions have more space to move in search of prey, which may explain their larger home ranges (Chege et al., 2025). Additionally, the lower availability of water in MNP compared to LNP and NNP may also contribute to the larger home ranges observed in MNP, since this park has a more variable rainfall pattern.

Livestock depredation often results in retaliatory killing of lions and this represents one of the most serious threats facing lions in Africa (Woodroffe & Frank, 2005). Translocation of ‘problem’ lions as a conflict mitigation strategy has been employed for several decades due to the threatened status of lions in Kenya since lethal control is not preferred (Kenya Wildlife Service, 2018). The main recipient sites for the translocation of ‘problem’ lions in the past decades have been MNP and Tsavo NP, as these two parks are quite large and it has been presumed they have a large prey base and that the translocated individuals would survive (Jenkins, 1996). However, post-translocation monitoring has rarely been conducted over extended periods in Kenya, with the exception of a study in MNP (Goeminne, 2019). This study, gives an account of a translocated, satellite-collared male lion, which successfully integrated into a pride and was able to breed, while two other translocated, satellite-collared individuals were soon afterwards killed by livestock owners due to livestock depredation outside the park (Goeminne, 2019). In most cases translocation of lions, especially ‘problem’ individuals, have low success rates due to significant mortality rates either during capture and transport (due to capture-related stress, injuries) or after release (due to extensive post release movements as well as being killed by territorial conspecifics) (as reviewed by Bilby, 2024; Linnell et al., 1997; Miller et al., 1999; Morapedi et al., 2021). In chapter 2 of this study, the results provide possible evidence of the impact of translocation of ‘problem’ lions on the genetics of the lion population in Tsavo NP. The genetic results revealed an admixture of different haplotypes with signatures from lion populations both from the north and from the south. Theoretically the observed admixture could also have been as a result of Tsavo NP being a natural suture zone due to its geographic location, where species of different genetic lineages meet and co-occur (Garcia-Erill et al., 2022; Lorenzen et al., 2008). However, the low F_{ST} values between the Tsavo lion population and all the other lion populations, further corroborate that some of the translocated individuals may have managed to breed and contributed to the admixture. Unfortunately, this could not be properly assessed for the Meru NP population, due to data quality problems (i.e., a larger amount of missing data in the genotypes). It is recommend to consider a follow-up study into possible genetic signatures of translocations in Meru NP.

Lion social dynamics are influenced by the availability, density and distribution of resources, with larger group sizes typically being formed in areas with abundant and high quality resources (Macdonald & Johnson, 2015). Larger groups are better able to defend high quality habitats against rival prides (Packer & Ruttan, 1988). Therefore, chapter 3 of this thesis, assessed the variation in lion group size across different land management types (i.e., national parks, group ranches, community and private conservancies) and across different sites irrespective of management. Additionally, the effect of ecological and anthropogenic factors on lion sub-group size within the different study sites was assessed. Since national parks and reserves are designed to focus solely on the protection of wildlife, larger lion group sizes were expected to occur here. However, results of this research indicated that community conservancies (CC) had significantly larger lion group sizes compared to national parks and reserves, private conservancies and group ranches. A similar pattern was also observed in the Maasai Mara, where the CC had significantly larger lion group sizes compared to the national reserve. Larger lion group sizes in CC were attributed to: (1) the period within which data were collected, as this may have coincided with a time when lions were driven to form large groups either due to the presence of cubs or by the seasonal distribution of resources or (2) larger lion groups could be related to the presence of a larger lion population (Elliot & Gopalaswamy, 2017). These results corroborate the importance of community conservancies in the conservation of lions, particularly because several national parks and reserves are too small to encompass wide-ranging carnivores such as lions. In terms of management, it is important that monitoring programs track the dynamics of size and structure of the lion population as an indicator of ecosystem health. Lion group size can be one of the indicators for this. A decline in the mean lion group size (through smaller groups or even more single lions) may be an indication of deteriorating ecosystem health and declining resource availability. Overall smaller lion group sizes can have an impact on the general lion population in an area, since solitary females have very low reproductive success (Pusey & Packer, 1987). In fenced reserves, solitary lions can disrupt predator – prey dynamics (Ferreira & Hofmeyr, 2014).

6.2.2 The impact of ecological factors and relevance for management

This study corroborated that there are two major mitochondrial haplotypes in Kenya i.e., one from the south and the other from the north, likely resulting from historical environmental changes driven by climatic fluctuations (Bertola et al., 2016). Since these two haplotypes point to different genetic lineages, and different evolutionary histories, it is recommended that the management and conservation of the Kenyan lion population focus on managing these populations separately (chapter 2 of this thesis; Bertola et al., 2022). This is a relevant consideration for future translocation decisions as Bellis et al. (2020) and the IUCN/SSC (2013) underscore the importance of taking into account the genetic composition and climatic suitability for species when selecting release sites for translocation. This approach enhances the likelihood of translocation success by ensuring individuals are introduced to environments where they are well-adapted in terms of genetic constitution relative to the local climate and the presence of pathogens. Failure to consider these factors may result in increased mortality of the introduced individuals due to poor adaptation to the local circumstances, possible susceptibility to disease, and the disruption of existing patterns of genetic and ecological variation.

This study established that local conditions across different study sites determine how lions respond to varying environmental conditions and therefore advocates for prioritisation and implementation of site specific management strategies. For example, in chapter 3, out of the eight studied sites covered by this research, availability of water was an important parameter for lion populations in five sites i.e., Laikipia, Maasai Mara, MNP, LNP and Samburu where larger subgroups were found closer to rivers. This finding was in line with expectations, because riverine habitats represent good-quality habitats that contain sufficient resources such as prey, cover for hunting and protection of cubs. This has also been confirmed in other research (Hopcraft et al., 2005; Mosser et al., 2015). While, vegetation cover was an important parameter for the lion populations in Tsavo and Amboseli, where larger lion subgroups were mostly associated with intermediate proportions of non-tree vegetation. In Samburu, lion subgroup size increased with increased non-tree vegetation cover. Vegetation cover provides important ambush opportunities and may also serve as a refuge from potential encounters with people and livestock (Mosser & Packer, 2009; Oriol- Cotterill et al., 2015). This may be particularly important in the Amboseli and Samburu study sites due to the presence of human settlements and livestock within these areas (Bhalla, 2017; Dolrenry, 2013), and the frequent illegal livestock incursions into Tsavo (Waweru et al., 2021). Therefore, in order to protect and restore lion populations, managers need to ensure that habitats always have sufficient vegetation cover and they should implement measures to prevent habitat degradation.

Proactive management of lion populations is vital because the variation in climatic conditions can have an impact on the distribution and abundance of herbivore species, which may in turn influence the ranging behaviour of lions. Therefore, in chapter 4, using satellite and GPS-GSM collar data from three different national parks in Kenya -- Meru National Park (MNP) with limited fencing, Nairobi National Park (NNP) –partial fencing and the fully fenced Lake Nakuru National Park (LNP) -- this study analysed the average monthly home ranges and distance moved by lions in relation to monthly rainfall. It was expected that in MNP lions would have larger home ranges and more extensive movements since the park has limited fencing, a lower herbivore biomass density, and an irregular rainfall pattern. It was also expected that in NNP rainfall would have no significant effect on lion home range size but would be significantly correlated with movement. In LNP, it was expected that there would be no significant correlation between rainfall, home range size, and distance moved, since the park is fully fenced and has a substantial prey base. Contrary to expectations, the results revealed that across the three parks, lions increased their distance moved with an increase in rainfall. Model comparisons revealed that lions in LNP significantly expanded their home ranges with higher monthly rainfall, compared to those in NNP. However, lions in NNP covered significantly larger distances than those in LNP. The results from LNP were unexpected as the park is completely fenced meaning that the lions have limited space for movement. It is suggested that the observed changes in lion home range size in LNP could be in response to fluctuations in lake levels, among other factors, which in turn influence the availability of the land which influences the area used by lions. Similar patterns were found by Kotze et al., (2018), who found that the availability of dry land is an important resource for lions in the Okavango Delta in Botswana, with changes in its availability impacting lion social organisation and reproductive rates. For MNP, interestingly, the effect of rainfall on lion home range size and movement was not significantly different from the other two parks, which may be attributed to the lions having their home ranges on the northern section of the park which receives more rainfall and has a higher concentration of wild prey (Kennedy, 2019; Chege et al, 2024).

In both chapter 4 and 5 male lions covered significantly larger distances than females. This is not surprising as male lion movements are influenced by both food resources and the need to defend their territory and access female prides, while female movements are influenced by access to resources (Schaller, 1972).

6.2.3 The impact of anthropogenic factors and relevance for management

The impact of anthropogenic activities on lion genetic diversity was observed in the Amboseli and Shompole lion populations, which had significant proportions of monomorphic loci and distinct clustering in the PCA and DAPC plots. For the Amboseli population, this is attributable to a historical population decline in 1990 as a result of human-lion conflicts (Chardonnet, 2002). For the Shompole lion population, increased land subdivision for farming could be impacting the connectivity of natural habitats, thus limiting lion movement (Schuette et al., 2013). Further research is however recommended for the Shompole lion population as the sample size in this study was quite small.

It should be noted that lions in Mararal and part of Isiolo inhabit ecosystems that are interspersed with human settlements and in some areas there is no active conservation and management (Chege et al., 2024). These two lion populations had genetic diversity scores that were similar to the protected areas of Tsavo NP and Maasai Mara national reserve. This confirms the significance of genetic exchange among lion populations in unprotected areas and their potential contribution to the larger gene pool. Although, the nine private alleles observed in the

Isiolo lion population are indicative of a low gene flow and the F_{IS} values point to a small population size, which may both result from increasing human development activities and conflict incidences. Such populations outside of PAs can augment the recovery of other lion populations as is likely what happened for Laikipia, since its lion population had been extirpated in the 1960s and recovered in subsequent years through immigration of lions from outside the area (Denney, 1972). This finding suggests that unprotected areas are important for lion conservation as they provide corridors for movement. In general, lions will avoid humans as was described in chapter 3 of this thesis where larger lion subgroups were observed further away from human settlements, likely to avoid persecution. They have also shown the capacity to travel large distances even across high human density areas through the spatial and temporal avoidance of people (Oriol-Cotterill et al., 2015). They do this by partitioning their activities spatio-temporally with those of humans thus minimising the risk of persecution and in turn maximising their use of human-dominated landscapes (Dolrenry et al., 2020; Oriol-Cotterill et al., 2015). Thus, as climate variability results in an increase in the frequency of extreme weather events, livestock incursions into protected areas are bound to have an increasingly negative impact on lion populations inside PAs. Therefore, in order to ensure connectivity between ecosystems, it is imperative that suitable habitats with sufficient vegetation cover are maintained both inside and outside protected areas. For this to succeed, communities must derive benefits from wildlife conservation efforts, to foster tolerance and coexistence in turn allowing lions to adapt to living in human- and livestock-dominated landscapes (Blackburn et al., 2016; Dolrenry et al., 2014; Schuette et al., 2013). Key to the conservation of lions will also be the establishment of buffer zones – areas adjacent to core PAs with regulated human activities that help mitigate conflicts while providing livestock grazing grounds during periods of scarcity (Schooler et al., 2022; Schuette et al., 2013). Oriol-Cotterill et al., (2015) further recommend zonation -- to cluster human dwellings and night-time livestock enclosures to prevent conflict and allow lions space to utilise areas while avoiding both people and livestock.

6.3 Study limitations and related future research recommendations

1. One of the limitations of this study, identified in chapter 2, was the lack of good quality genetic samples for Meru National Park. Therefore, future studies should aim to collect good quality samples along with comprehensive metadata. The ideal would be for the veterinary doctors to collect samples opportunistically during routine activities and those samples could be preserved in a bio bank within the genetics- and forensics lab at the Kenya Wildlife Service.

2. Future studies should try to assess the Meru national park population for possible genetic signatures of historical translocations. The study should also possibly include establishing long- term monitoring programs for lion population dynamics, including social structure and genetic analyses for admixture assessment. Such a study should also be considered for the admixed Tsavo NP population.

3. The Shompole lion population had a rather high percentage (38%) of monomorphic loci and a distinct clustering in the PCA and DAPC likely attributable to dispersal limitations. It is recommended to implement a follow-up study with a larger sample size in order to substantiate the findings in chapter 2 of this study.

4. A landscape genetics study is recommended to evaluate the impact of anthropogenic barriers on gene flow for the Isiolo population in order to determine its effective population size.

5. When assessing the effect of ecological and anthropogenic factors on lion grouping patterns across Kenya in chapter 3, one of the limitations of this study is that it was conducted over a relatively short period of time and in-depth knowledge of the social groups was not acquired. Four of the study sites in this research i.e.,

MNP, Samburu, NNP and LNP had relatively small lion populations with fewer groups and exhibited notably low marginal and conditional R^2 measures. Therefore, it is recommended to implement a similar multi-site study or on specific sites for longer time periods. A follow-up study should consider inclusion of additional predictor variables, such as prey abundance and / or distribution.

6. A limitation in chapter 4 of this study i.e., the influence of rainfall on lion home range and movements was the small sample size i.e., a total number of 10 collared individuals. It is recommended for future studies to acquire larger sample sizes over a longer time-period to gain a more comprehensive understanding of lions' response to environmental factors.
7. Given that rainfall had an influence on lion home range and movement in LNP, being an enclosed system, it is recommended to implement follow-up studies on lion- prey dynamics including the impact of lake-level fluctuations on the lion population. It is also recommended to implement a longer-term study on the influence of rainfall and prey distribution on lion home range and movements in relation to conflicts in MNP. The study should not only cover seasonal variations but also inter-annual variability since the park has an erratic rainfall pattern.
8. In chapter 5, variations in the estimates of global abundance were observed when looking at lion density estimates across the three surveys carried out in NNP. The variations were likely a result of the study being restricted to within the park boundary. Therefore, to ensure stability in the global abundance (Nsuper), a future study should also sample outside the park and include spatial covariates in the SECR models.

6.4 Conclusions

1. Overall, this study confirmed the presence of two diverged groups in Kenya, distributed in the northern and southern part of the country respectively (chapter 2). It revealed that none of the tested lion populations were significantly inbred and that a predominant portion of genetic variation was within individual populations rather than between populations, indicating substantial genetic diversity within each distinct population. However, the impacts of past management interventions and isolation were observed in the genetic make-up of the Kenyan lion population. Therefore, to avoid negative impacts in the future, genetics should be integrated into policy and management of the lion population in the country, especially in genetic restoration efforts and translocation programs.

2. This study showed that anthropogenic impacts were evident in the genetic signatures of the NNP, Amboseli NP, Isiolo and Shompole populations (chapter 2). In addition, this study also showed that edge effects had an impact on lions, as larger groups were further away from human settlements (chapter 3). Therefore, the long-term viability of lion populations (and other wildlife) in Kenya is pegged on the country's ability to balance between rapid infrastructural developments, impacts of climate change and conservation of biodiversity. Indeed Kenya's conservation agenda recognises this, and is guided by a commitment to protect biodiversity by addressing challenges of human-wildlife conflict, biodiversity loss through advocacy for establishment of additional community conservancies, climate change resilience programs and strengthening of legislative and policy frameworks. Further, the national strategy for the conservation of lions 2020 – 2030, the Wildlife Conservation and Management ACT, 2013 and National Wildlife Strategy 2030 all recognise the need for community partnership in conservation. This is because government run PAs cannot solely conserve wildlife, and there is need for a comprehensive policy that aims to protect habitats beyond state-managed Pas, including historical ranges that may still be intact (Tyrrell et al., 2020). As demonstrated in this study, private, community conservancies and group ranches had group sizes and genetic diversity scores comparable to PAs (chapter 3 and 2). Further, seasonal movements and changes of lion densities inside NNP highlight the importance of community areas (chapter 5). Indicating that these areas are vital when setting up of lion conservation units to ensure connectivity between habitat patches.

3. Intact habitats are vital for the long-term survival of lions since larger lion sub-groups were associated with a higher non-tree cover and a proximity to rivers (chapter 3). Availability of prey is also paramount to the existence of lions, as lions increased the distance moved and home range during periods of higher rainfall or shifted their activity centres in response to prey migrations (chapter 4 and 5). Thus ensuring connectivity between wildlife areas or land management types in tandem with building community tolerance should be the focus of management strategies. Further, Schooler et al. (2022) advocate for the establishment of buffer zones around PAs, and Blackburn et al. (2016) emphasise that in areas where community conservancies serve as buffer zones for PAs, there is a layered need for protection -- where such conservancies also require buffer zones of their own to reduce edge effects and maintain ecological integrity.

4. To achieve the above, the country will require systematic and evidence based research and monitoring programs that use frameworks such as SECR which provide robust and comparable estimates and can accommodate various field monitoring methods (chapter 5). In addition, this framework can be employed either independently for monitoring single species (Elliot et al., 2020) or as part of simultaneous monitoring efforts for multiple species (Braczkowski et al., 2024).

5. As well, the results of this study showed that lion genetic diversity is influenced by local environmental conditions and management strategies (chapter 2). While lion grouping patterns are shaped by site-specific ecological and anthropogenic factors (chapter 3), rainfall had variable influence on lion home range and movement (chapter 4). Thus, while the recommendations are broadly applicable across all the sites, their implementation should be prioritised based on site-specific needs, ecological conditions and conservation urgency.

6.5 Recommendations for Management

1. To maintain the genetic integrity of lion populations in the country, it is important that populations have connectivity to ensure gene flow. Therefore, management strategies should prioritise the establishment and protection of wildlife corridors, linking habitats that have sufficient vegetation, prey and minimal conflicts. In areas where the habitat is degraded, targeted rehabilitation programs should be implemented to restore and support long-term population viability. The involvement of communities through consultation and participation in decision making will be crucial for success.

2. Genetic restoration efforts are required for populations in LNP, Shompole and NNP. Thus if this recommendation is adopted, managers should follow the guidelines of Becker et al. (2022), Bertola et al. (2022) and IUCN/SSC (2013). Further, because translocation of 'problem' lions has several challenges stemming from conflicts with humans and resident lion populations, adaptive management and long-term monitoring is recommended.

3. Chapter 2 of this study provides baseline data required for integrating genetics into the management of lions. Therefore, the national translocation protocol should take into account the genetic characteristics of both translocated and recipient lion populations, including factors such as densities and sex ratios of conspecifics at recipient sites, target individuals and wild prey. Integration of genetics into a translocation policy should also consider evolutionary histories and distinguish between translocation for population restoration, for management of 'problem' individuals and possibly translocation of 'problem' individuals with an aim to restore genetic diversity.

4. The SECR framework provides an adaptable and flexible research and monitoring option for adoption especially because most monitoring programs in Kenya are hampered by limited funding. The recommendation is to conduct in other sites a study similar to that carried out in NNP (chapter 5), particularly where funding or systematic monitoring may be limited or absent. This can be achieved through a citizen science approach or other approaches that facilitate the application of SECR.

5. Since unprotected areas are key to the conservation of lions, monitoring programs should extend to these areas in Kenya and where habitats cross international boundaries, cross-border collaboration will be key.

6. Overall the anthropogenic activities had an impact on the lion populations, thus measures to minimise these impacts especially in wildlife areas should be prioritised. This study also found that periods of high rainfall/ wet season were associated with conflicts. It is therefore recommended to consider the strategic placement of well-equipped conflict response units. Use of satellite technology as early warning systems i.e., collars to track individuals that may cause conflict is highly recommended.

7. In line with the results from this thesis and the national recovery and management plan for lions in Kenya 2020–2030, a site-specific approach to lion conservation is recommended. This should involve the establishment of collaborative landscape-level lion conservation units, encompassing government-protected areas, community conservancies, private conservation areas, and group ranches.

8. In a bid to enhance wildlife conservation and promote community involvement, the Wildlife Conservation and Management ACT, 2013 has provisions for grazing and watering of livestock in national parks in times of drought and other natural disasters; this further elevates the need for well-designed monitoring programs that will monitor the impact of such activities on lions and other wildlife.

9. Although this study focussed on the African lion, similar methodologies and approaches, as discussed in this thesis, can be adapted for other species and other sites in Kenya and beyond.

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