Informing large carnivore conservation through research into ecology and conflict in two key landscapes in southern Tanzania

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I. SUMMARY

Southern Tanzania is home to some of Africa's most important large carnivore strongholds. However, they are also some of the continent's least known in terms of both status and threats, which may hinder their long term conservation. This project aims to address this knowledge gap by conducting research into large carnivore ecology and conflict within Selous-Nyerere and Ruaha-Rungwa, two key conservation landscapes in southern Tanzania. In doing so, we hope to continue building scientific understanding of Tanzania's globally-important large carnivore populations and providing insights that can be used to inform conservation and management plans. At the same time, the research activities will continue to be used as a platform to help build long-term research and conservation capacity in Tanzania, by collaborating with students & academics, government researchers, and protected area (PA) management authorities.

II. INTRODUCTION

Over the last century, African large carnivores have undergone marked continent-wide range contractions, with losses estimated at 94% for lion (*Panthera leo*), 93% for African wild dog (*Lycaon pictus*), 92% for cheetah (*Acinonyx jubatus*), 48-67% for leopard (in Africa; *Panthera pardus*; Jacobson et al., 2016), 24% for spotted hyaena (*Crocuta crocuta*), and 15% for striped hyaena (across its global range; *Hyaena hyaena*; Wolf & Ripple, 2017). All of these species are also facing declining population trends (AbiSaid & Dloniak, 2015; Bauer et al., 2016; Bohm & Höner, 2015; Durant et al., 2015; Stein et al., 2020; Woodroffe & Sillero-Zubiri, 2020). As a result, four of the six large carnivore species found in Tanzania are classified as Threatened by the IUCN (Endangered: African wild dog; Vulnerable: lion, leopard, cheetah), while striped hyaena is classified as Near Threatened and spotted hyaena as Least Concern.

These declines are primarily a result of ongoing habitat loss and degradation (Craigie et al., 2010; Newmark, 2008; Ogutu et al., 2016), declining prey numbers (Winterbach et al., 2013; Wolf & Ripple, 2016), and direct persecution by humans in retaliation for livestock predation (Dickman et al., 2014; Ogada et al., 2003; Woodroffe & Frank, 2005). Research into the status and ecology of large carnivore populations is essential to ensure their long-term conservation in the face of these threats (Boitani & Powell, 2012). Alongside this, efforts should be made to understand how different threats are impacting carnivore populations, and how these vary across different contexts. Having access to robust, site-specific scientific information of this kind enables decision-makers to evaluate the impact of different land uses and management strategies on the health of carnivore populations, and develop evidence-based policy and management plans.

III. PROBLEM STATEMENT

This project encompasses large carnivore research, monitoring, and training programmes in Selous-Nyerere and Ruaha-Rungwa, targeting lion, leopard, cheetah, African wild dog, spotted hyaena, and striped hyaena. The proposed sites were targeted for this research because (1) they are lion strongholds, and host important populations of other large carnivores including the endangered African wild dog; (2) they are part of some of Tanzania's most important wildlife corridors; (3) they have historically lacked research attention; (4) they experience human-carnivore conflict; and (5) they contain PAs where research findings can be used to help improve conservation and management of large carnivore populations.

Selous-Nyerere

The Selous-Nyerere ecosystem is believed to be home to some of Africa's most important remaining populations of lion and African wild dog, as well as globally important populations of leopard and spotted hyaena (Bauer et al., 2016; Woodroffe & Sillero-Zubiri, 2020; TAWIRI, 2009a). Until recently, there was a paucity of information on the larger-scale spatial dynamics governing large carnivore distribution, habitat-use, and movement in the landscape. This hindered the development of larger-scale conservation strategies, and limited our understanding of factors driving large carnivores to utilise areas where the likelihood of conflict is greatest.

From 2020 to 2022, we carried out spoor and camera trap surveys across Selous GR and Nyerere NP; in 2023 and 2024, we conducted repeat camera trap surveys and deployed GPS collars on lions and wild dogs in areas where we believe them to be most at risk of human impacts. Findings from this research suggest that there are anthropogenic impacts that are likely to impact large carnivore status (e.g. snaring) in areas close to PA boundaries. Continued monitoring of population trends for all large carnivores and in-depth research on demographics and movement of lions and wild dogs - two key species for conservation-related revenue generation - is required to investigate the status of these species in the landscape, to help effectively identify threats and develop appropriate conservation and conflict-mitigation interventions.

Ruaha-Rungwa

Also located in southern Tanzania, the Ruaha-Rungwa ecosystem is recognised by the EU as a Key Landscape for Conservation due to its internationally important wildlife populations, attributed to its unique positioning at the transition zone between Eastern and Southern African ecoregions (European Commission, 2016). Ruaha-Rungwa is believed to harbour globally important populations of lion (Bauer et al., 2016), cheetah (Durant et al., 2017), and African wild dog (Woodroffe & Sillero-Zubiri, 2020), as well as regionally important populations of leopard, spotted hyaena, and striped hyaena (TAWIRI, 2009a). Nevertheless, until recently no empirical estimates of population abundance or density existed for these populations, with the only available estimates being based on expert opinion or extrapolations from known densities elsewhere (e.g. Mesochina et al., 2010; Riggio et al., 2013).

Research by members of this project between 2017 and 2019 resulted in some of the first studies of large carnivore population status and ecology for the landscape (Searle et al., 2021a, 2021b; Strampelli et al., 2021; Strampelli et al., 2022a, 2022b, 2022c), providing valuable baseline information for future

research, and a repeat camera trap survey in MBOMIPA WMA in 2022 suggested that the area's lion population may be declining. Additional follow-up research is therefore required to continue investigating carnivore population trends, and equip PA management authorities in the landscape with up-to-date information that can inform effective conservation actions.

IV. REASON FOR EXTENSION

This proposal is a continuation and extension of research carried out by the applicants in 2020 (under research permits 2020-159-NA-1997-20 & 2020-160-NA-1997-20), 2021 (under research permits 2021-173-NA-2021-42 & 2021-174-NA-2021-42), 2022 (under research permits 2022-526-NA-2021-042, 2022-527-NA-2021-042 & 2022-528-NA-2021-042), 2023 (under research permits 2023-665-ER-2021-287 & 2023-666-ER-2021-287), and 2024 (under research permits CST00000522-2024-2024-00420 & CST00000522-2024-2024-00422).

From 2020 to 2022, we carried out a large carnivore assessment in Selous-Nyerere as part of a collaboration between the University of Oxford's Wildlife Conservation Research Unit (WildCRU), Lion Landscapes, Frankfurt Zoological Society, Tanzania Wildlife Research Institute (TAWIRI), Tanzania Wildlife Management Authority (TAWA), and Tanzania National Parks (TANAPA). The goal of this effort was to assess the status and ecology of large carnivores across the landscape, while building capacity in large carnivore assessment and monitoring among our Tanzanian collaborators, and assisting them to develop long term monitoring plans for the study populations. Data collection has been completed for this assessment, and we are currently in the process of analysing the data.

In 2023 and 2024, we carried out a number of follow-up research activities that we identified as being of high priority based on the insights from the landscape-wide assessment. These included repeat camera trap surveys in the Matambwe sector of Nyerere NP (2023) and eastern Selous GR (2024) to study trends in population density and distribution since the 2020-2022 surveys, and GPS collaring of lions and wild dogs in Nyerere NP and Selous GR to understand movement patterns in areas close to protected area boundaries.

This proposal for renewal encompasses a continuation of these activities. We are planning to conduct at least one repeat camera trap survey in Selous-Nyerere to study trends in large carnivore population density and distribution, and continue efforts to deploy collars on lions and wild dogs in Selous GR and Nyerere NP.

In parallel to follow-up activities in Selous-Nyerere, this permit extension also encompasses activities in the Ruaha-Rungwa landscape, building upon work carried out from 2017 to 2019 (under research permits 2017-210-NA-2017-107, 2018-367-NA-2017-107, 2018-368- NA-2018-107, 2019-96-ER-97-20 & 2019-424-NA-2018-184) and in 2022 (under research permits 2022-527-NA-2021-042 & 2022-528-NA-2021-042), 2023 (under research permits 2023-665-ER-2021-287 & 2023-666-ER-2021-287), and 2024 (under research permits CST00000522-2024-2024-00420 & CST00000522-2024-2024-00422). Data on wildlife presence in village lands will be collected via camera trapping and walked spoor transects by Lion Defenders, to investigate wildlife distributions and habitat use outside PAs. We will

also conduct a camera trap survey in Ruaha NP and/or MBOMIPA WMA, to assess large carnivore population density trends.

Alongside the ecological research activities, we plan to continue previous research conducted into human-carnivore conflict within both landscapes, using data collected by Conflict Officers, to provide a more in-depth understanding of the threats facing these globally-important large carnivore populations.

We will also continue our efforts to assess wildlife corridors linking key landscapes in southern Tanzania. In 2023 and 2024, we deployed camera traps in the Kilombero Elephant Corridor (Selous-Nyerere – Udzungwa corridor), to monitor its use by large carnivores and other mammals. In 2024, we are also planning to assess functional connectivity in the Ruaha-Rungwa – Udzungwa corridor. In 2025, we will prepare reports on these assessments, continue camera trap-based monitoring in the Nyerere-Udzungwa corridor (Kilombero Elephant Corridor), and potentially carry out additional data collection on the Ruaha-Udzungwa corridor, depending on the funding and resources available. All corridor-related work will continue to be carried out in collaboration with Dr Josephine Smit, a researcher affiliated with the Southern Tanzania Elephant Program (STEP).

The findings of all the planned research activities will continue to be used to help local stakeholders, including by providing much-needed data for TAWA and TANAPA to develop evidence-based monitoring plans. In doing so, this project will support Tanzanian wildlife research and management authorities in their efforts to conserve the country's natural assets in these key ecosystems.

The research project will also continue to be used as a platform to build in-country capacity in wildlife research and conservation. We will continue to support Tanzanian students, including at least four Master's and one PhD student with whom we have already established supervisory relationships (Ms Janeth Mngulwi, Mr Singira Parsais, Ms Hyasinta Tarimo, Ms Jamila Yassin, and Mr Leonard Haule). Training in theory, field methods and analytical techniques will continue to be provided to participants in the Selous-Nyerere research activities from TAWIRI, TAWA and TANAPA through collaborative data collection and workshops.

Lion Landscapes will be an operational partner for all field activities, and Frankfurt Zoological Society will be an operational partner for ecological activities in Selous-Nyerere. This year we are also incorporating a Lion Landscapes staff member (Joseph Francis) as a co-researcher as he is taking more responsibility in running the camera trap surveys and other activities.

V. PROGRESS TO DATE

The proposed work in Selous-Nyerere follows on from research carried out by the applicants from 2020-2024. The progress made in this research is outlined below; reports providing detailed updates on the research activities and preliminary outputs have been shared with COSTECH and TAWIRI.

2020: Data collection & training in Matambwe sector, Nyerere NP

- 238 km of spoor transects completed across central & eastern Matambwe
- 1 camera trap survey carried out in the central area of Matambwe (total of 106 cameras)

- Direct sightings data collected for lion in central Matambwe via search encounter & call-ins
- Training in field methods & theory provided to 14 participants

2021: Data collection & training in Selous GR

- 1,558 km of spoor transects completed across Selous GR
- 4 camera trap surveys carried out across Selous GR (total of 366 cameras)
- 74 call-ins carried out in Kingupira and Miguruwe
- Direct sightings data collected for lion and wild dog
- Training in field methods & theory provided to 8 Tanzanian TAWIRI, TAWA, TANAPA, and Lion Landscapes participants
- Data analysis workshop provided to 6 Tanzanian TAWIRI, TAWA, and TANAPA participants
- Supervision provided to 2 Tanzanian Master's students

2022: Data collection & training in Nyerere NP, Ruaha NP, MBOMIPA WMA, and village lands

- 990 km of spoor transects completed remaining sectors of Nyerere NP (Msolwa, Ilonga, Likuyu-Seka, Kalulu, Liwale)
- 2 camera trap surveys carried out across Nyerere NP (total of 166 cameras)
- 1 camera trap survey carried out in MBOMIPA WMA (80 cameras)
- Training in field methods & theory provided to 24 participants in Nyerere NP (1 TAWIRI, 22 TANAPA, 1 Lion Landscapes) and 16 participants in MBOMIPA WMA (6 Lion Landscapes staff and interns, 10 MBOMIPA Village Game Scouts)
- Supervision provided to 2 Tanzanian Master's students and 1 Tanzanian PhD student
- Hosted 4 UDSM students during field practicum
- Responded to and documented 269 livestock depredation events in the Ruaha-Rungwa landscape and 60 in the Selous-Nyerere landscape
- Documented 8 large carnivore mortalities in Ruaha-Rungwa and 6 in Selous-Nyerere
- Collected over 2,000 carnivore sightings in Ruaha NP through the guide sightings programme
- Deployed 3 camera traps per village in 13 villages around Ruaha NP and 1 village around Nyerere NP

2023: Data collection & training in Nyerere NP, Ruaha NP, the Kilombero Elephant Corridor, and village lands

- Carried out 1 camera trap survey in Nyerere NP (total of 128 cameras)
- Collaborated with a British PhD student to carry out 1 acoustic survey in Nyerere NP (total of 50 autonomous recording units)
- Deployed GPS collars on 4 lions in Nyerere NP
- Collaborated with other research projects to deploy 30 camera traps for mammal monitoring in the Kilombero Elephant Corridor (Nyerere-Udzungwa)
- Hosted a lion density analysis workshop for 8 Tanzanian TAWIRI, TAWA, TANAPA, and Lion Landscapes participants
- Provided supervision to 2 Tanzanian Master's students and 1 Tanzanian PhD student

- Sponsored 1 Tanzanian Master's student, 1 Tanzanian PhD student, and 1 Tanzanian Research Assistant to complete a training visit to Zambia
- Sponsored 1 Tanzanian Master's student, 2 TAWA ecologists, and 1 Tanzanian Research Assistant to attend the TAWIRI Scientific Conference
- Set up a guide sightings programme with 15 participating guides in Nyerere NP
- Responded to and documented 249 livestock depredation events in the Ruaha-Rungwa landscape and 84 in the Selous-Nyerere landscape
- Documented 11 large carnivore mortalities in Ruaha-Rungwa and 19 in Selous-Nyerere
- Collected over 535 carnivore sightings in Ruaha NP and 287 in Selous-Nyerere through the guide sightings programme
- Deployed 3 camera traps per village in 13 villages around Ruaha NP and 3 villages around Nyerere NP

2024: Data collection & training in Nyerere NP, Selous GR, Ruaha NP, the Nyerere-Udzungwa corridor, the Ruaha-Udzungwa corridor, and village lands, plus additional training

- Carried out 1 camera trap survey in eastern Selous GR (total of 232 cameras)
- Deployed GPS collars on 7 lions and 7 wild dogs in Selous-Nyerere and 7 lions in MBOMIPA WMA and neighbouring village lands
- Collaborated with other research projects to deploy 30 camera traps for mammal monitoring in the Nyerere-Udzungwa corridor (Kilombero Elephant Corridor)
- Collaborated with other research projects to carry out an assessment of connectivity in the Ruaha-Udzungwa corridor
- Provided supervision to 4 Tanzanian Master's students and 1 Tanzanian PhD student
- Hosted a workshop on how to carry out camera trap surveys to estimate large carnivore population density for 18 TAWIRI researchers and field assistants
- Organised a training for 24 wildlife veterinarians and veterinary assistants from TAWIRI, TANAPA, TAWA, and NCAA
- Organised training for UDSM students and faculty on large carnivore monitoring using camera traps
- Responded to and documented 221 livestock depredation events in the Ruaha-Rungwa landscape and 53 in the Selous-Nyerere landscape
- Documented 2 large carnivore mortalities in Ruaha-Rungwa and 5 in Selous-Nyerere
- Deployed 3 camera traps per village in 13 villages around Ruaha NP and 3 villages around Nyerere NP

VI. OBJECTIVES

This project has five overarching objectives: (1) to assess and monitor the status and ecology of large carnivores and their prey in two key landscapes in southern Tanzania; (2) to investigate the extent of human-carnivore conflict in these landscapes; (3) to assess wildlife corridors linking these landscapes;

(4) to build carnivore research and monitoring capacity in Tanzania; and (5) to disseminate the findings of this research to stakeholders within and beyond Tanzania.

The specific activities we plan to carry out in pursuit of these objectives are detailed below.

1. To assess and monitor the status and ecology of large carnivores and their prey in key landscapes in southern Tanzania

    1.1 Assess landscape-scale distribution and habitat use of large carnivores and their prey across Selous-Nyerere (Methodology: spoor surveys, occupancy modelling)

    1.2 Explicitly estimate population density of large carnivores at targeted sites within Selous-Nyerere and Ruaha-Rungwa, and investigate how this varies across habitats and land management types (camera trap surveys, SECR modelling)

    1.3 Investigate fine-scale movement, population density, survival and demographic structure of lion and wild dog in areas of Selous-Nyerere and Ruaha-Rungwa identified as a priority for further research after baseline assessments (GPS collaring, focal monitoring)

    1.4 Monitor distributions and habitat use of wider wildlife communities outside PAs in Selous-Nyerere and Ruaha-Rungwa (non-systematic camera trapping, walked spoor transects)

2. To investigate the extent of human-carnivore conflict in key landscapes in southern Tanzania

    2.1 Investigate levels and patterns of human-carnivore conflict in Selous-Nyerere and Ruaha-Rungwa (collection of data on depredation events and carnivore mortality)

    2.3 Investigate vulture and lion feeding clusters using information from tagged animals to monitor possible illegal activities (poaching) and prevent possible poisoning incidents

    2.4 Assess the effectiveness of performance payments (CCT+) on willingness to coexist with wildlife and guide the future design of the mechanism

3. To assess wildlife corridors linking key landscapes in southern Tanzania

    3.1 Monitor large carnivores' and other species' use of the corridor linking Nyerere NP and Udzungwa Mountains NP (camera traps)

    3.2 Assess large carnivores' and other species' use of the corridor linking Ruaha NP and Udzungwa Mountains NP (spoor surveys, questionnaires)

4. To improve carnivore research and monitoring capacity in Tanzania

    4.1 Support Tanzanian students to conduct research on large carnivore ecology and conflict, both by using existing data and collecting their own data

4.2 Deliver training in large carnivore research and monitoring to Tanzanian researchers and conservationists (fieldwork training integrated into Selous-Nyerere surveys, analytical training workshop to be held after completion of surveys in Nyerere NP)

4.3 Provide internships for recent wildlife graduates and youth from local communities, and continue working with UDSM to host students during their field practicum to give them hands-on experience on human-wildlife conflict

5. To disseminate information on southern Tanzania's large carnivore populations, both within and beyond Tanzania

5.1 Publish scientific papers

5.2 Present at TAWIRI scientific conference (in 2025) and international conferences

5.3 Share research findings with TAWIRI and relevant PA management authorities to inform evidence-based monitoring programmes

VII. SIGNIFICANCE OF THE RESEARCH

Overall, this project is closely aligned with national conservation and research priorities for Tanzania.

TAWIRI Priority Areas for Research (2012)

The work will make an important contribution to a number of TAWIRI's current research priorities for NPs highlighted in the Tanzania Wildlife Research Agenda (TAWIRI, 2012). These include: monitoring of animal population-ecology including rare, endemic and keystone species of different taxa as indicators of ecosystem health (1); baseline terrestrial and aquatic biodiversity inventories as benchmarks for informed long-term ecosystem monitoring (4); monitoring of wildlife corridors and dispersal areas including addressing their conservation threats given the increasing isolation of protected areas (5); human-wildlife conflicts and mitigation options to address the increasing public outcry of destructive wildlife species (8); and climate change and its impact on ecosystem dynamics and human livelihoods and mitigation options to address the current global and local shifts in climatic profiles (9; through range mapping of species and the resulting potential for predictive modelling).

Tanzania Conservation Action Plans for wild dog (2009b), cheetah (2009c), lion & leopard (2009d), and hyaena (2009e)

For cheetah and wild dog, this project will address the information priorities identified by TAWIRI relating to their distribution and density (high priority), and will shed light on the threats facing the species, including persecution and interspecific competition (TAWIRI, 2009b; TAWIRI, 2009c). The project will also provide information on wild dog demography in both landscapes (low priority for Selous-Nyerere; high priority for Ruaha-Rungwa) and ranging patterns in Selous-Nyerere (medium priority). For lion and leopard, this project will address the information needs surrounding anthropogenic threats, status in representative areas, distribution, and movements in areas with human-lion conflict (TAWIRI, 2009d).

For hyaena, the project will help establish the national distribution of aardwolf and striped hyaena (TAWIRI, 2009e).

Tanzania Carnivore Conservation Action Plan (TAWIRI, 2009a)

In addition, the proposed research addresses multiple research priorities identified in the Tanzania Carnivore Conservation Action Plan (TAWIRI, 2009a). Specifically, the research will contribute to efforts to: obtain information on distributions of carnivore species (1.1); survey prey availability outside PAs for spotted hyaena (1.4); establish the status of the miombo genet and Meller's mongoose (through camera trapping; 1.8); contribute to a monitoring programme for lions in Selous-Nyerere (1.25); train personnel in data capture, management and analysis for lion and leopard (1.31); improve systems for carrying out surveys in Selous-Niassa (1.31); collect information on trends for cheetah, wild dog and caracal in Selous-Nyerere (2.2); carry out research into lion and leopard in priority areas (2.29); develop field based training programmes for lion and leopard research (3.10); establish levels of conflict between hyaena and humans (5.5); and contribute to lion and leopard management planning for MBOMIPA WMA (6.11). The research carried out will also make a significant contribution to future national carnivore management planning.

COSTECH Research Priorities for Tanzania 2021/22-2025/26 (2021)

The project objectives also align with COSTECH's National Research Priorities for Tanzania 2021/22-2025/26 (COSTECH, 2021). This report highlights the issue that, despite the abundance of wildlife resources in Tanzania and their contribution to the country's economy, there is a limited understanding of the potential of wildlife biodiversity and how best to conserve them. As a consequence, the body emphasises that research to provide baseline data and information on wildlife biodiversity – as per the core objective of the proposed research (Obj. 1) – is essential to enhance wildlife protection, utilisation, management and development in PAs, and increase the contribution of the wildlife subsector to the country's GDP. This latter point is particularly relevant to lion and leopard, as the species are a key generator of revenue through both photographic and hunting tourism. The priorities also specifically highlight that research must be carried out on wildlife inventory and population dynamics, protection of wildlife corridors and dispersal areas, and human-wildlife interactions, which are directly addressed by Obj. 1, Obj. 3, and Obj. 2 of this research project, respectively.

Division of Environment National Biodiversity Strategy and Action Plan 2015-2020 (2015)

The project objectives align closely with the Division of Environment's National Biodiversity Strategy and Action Plan (NBSAP) 2015-2020 (Division of Environment, 2015). Most notably, the work will contribute significantly to Target 12, that species requiring special attention should be identified and managed for long-term sustainability in biodiversity assessment. The NBSAP highlights the lack of consistent data on different components of biodiversity, such as population assessments for key species (as per Obj, 1.1, 1.2, & 1.3), as one of the major hurdles preventing effective biodiversity conservation in Tanzania. The document also emphasises the importance of developing and implementing monitoring programs for threatened species, which is one of the key objectives of the proposed project (Obj. 4.3). As such, the proposed work's effort to assess population status for

carnivore and prey species in two areas of globally important biodiversity (Obj. 1) will make a significant contribution to Strategic Goal C of the NBSAP; to improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity. Additionally, the research activities in MBOMIPA WMA (Obj. 1.5) will contribute to Strategic Goal D of the NBSAP; to enhance the benefits to all from biodiversity and ecosystem services. Finally, the project will contribute towards Strategic Goal E, to enhance implementation of scientific knowledge, by improving capacity among local researchers and PA management authorities to record and disseminate scientific information relating to wildlife (Obj. 3).

Tanzania Wildlife Corridor Assessment, Prioritization, and Action Plan (2021)

Finally, the project objectives relating to functional connectivity assessments of key wildlife corridors in southern Tanzania will make an important contribution to research priorities identified in the Tanzania Wildlife Corridor Assessment, Prioritization, and Action Plan (TAWIRI, 2021). Out of 61 wildlife corridors considered in the assessment, the Ruaha-Rungwa – Udzungwa corridor was identified as having the highest conservation value (conservation value score = 90) and therefore being the highest priority corridor in Tanzania, while the Nyerere-Selous – Udzungwa corridor was identified as being the second most vulnerable (vulnerability score = 77). This project will provide valuable information on functional connectivity within both of these corridors.

VIII. RESEARCH QUESTIONS

The project will address a number of different research questions:

Selous-Nyerere

1. What is the distribution of wild dog, lion, leopard and spotted hyaena across the Selous-Nyerere landscape?
2. Can the distribution of wild dog, lion, leopard and spotted hyaena across the landscape be explained by environmental, anthropogenic, and con-specific resources and pressures?
3. How do population densities of lion, leopard and spotted hyaena vary between different sites within the landscape?
4. How does mammal species diversity vary between different sites within the landscape?
5. What is the demographic structure of lions and wild dogs in northern Nyerere NP and eastern Selous GR?
6. What are the movement patterns of lions and wild dogs in northern Nyerere NP and eastern Selous GR?
7. What are the levels and patterns of conflict in the village lands to the east of Nyerere NP?
8. Are large carnivores and other species using the Nyerere-Udzungwa corridor?
9. Are the performance incentive programmes having an impact on the willingness to coexist with large carnivores? What aspects of the scheme are most impactful?

Ruaha-Rungwa

1. How does the population density of lions in the core tourist area of Ruaha NP compare to estimates obtained using similar methods in 2018 (Strampelli & Searle et al., 2022)?

2. How do the population densities of lion, leopard, spotted hyaena, striped hyaena, aardwolf and serval in MBOMIPA WMA compare to estimates obtained using similar methods in 2018 (Strampelli & Searle et al., 2022; Searle et al., 2021a; Hardouin et al., 2021)?
3. What are the movement patterns of lions in the WMAs and village lands bordering Ruaha NP to the east?
4. What is the status of wider wildlife communities in the WMAs and village lands bordering Ruaha NP to the east?
5. What are the levels and patterns of conflict in the village lands to the east of Ruaha NP? Are the patterns changing over time? Can conflict management recommendations be derived from the data?
6. Can tagged lions and vultures be used as sentinels for conflict events? How much overlap is there in detection capacity between both species?
7. Are large carnivores and other species using the Ruaha-Udzungwa corridor?
8. Are the performance incentive programmes having an impact on the willingness to coexist with large carnivores? What aspects of the scheme are most impactful?

IX. METHODOLOGIES

Data collection in Selous-Nyerere will encompass:

- Camera trap surveys – at least 1 grid in Nyerere NP and/or Selous GR
- GPS collaring – up to 8 lions and 12 wild dogs in eastern Nyerere NP and Selous GR
- Walked spoor transects – by Lion Extension Officers in village lands to the east of Nyerere NP
- Collection of conflict data – by Lion Extension Offiers and Conflict Officers in at least 6 villages around Nyerere NP
- Corridor assessment – camera traps in Nyerere-Udzungwa corridor
- Investigation of low-movement clusters of tagged vultures and lions in the community land surrounding the protected areas

Data collection in Ruaha-Rungwa will encompass:

- Camera trap survey – at least 1 grid in Ruaha NP and/or MBOMIPA WMA
- GPS collaring – up to 7 lions in WMAs and village lands to the east of Ruaha NP
- Non-systematic camera trapping – in village lands to the east of Ruaha NP
- Walked spoor transects – by Lion Defenders in village lands to the east of Ruaha NP
- Collection of conflict data – by Conflict Officers in at least 13 villages around Ruaha NP
- Investigation of low-movement clusters of tagged vultures and lions in the community land surrounding the protected areas

Further detail on the methods employed is provided below.

Spoor surveys

Spoor surveys in Selous-Nyerere took place from 2020 to 2022 in the form of vehicle based, large-scale carnivore spoor surveys, altered to obtain spatially replicated samples required for occupancy modelling

(Hines et al., 2010; Henschel et al., 2020). The total survey area was divided into a regular grid of 15 x 15 km^2 cells, and a representative subset of cells (randomly selected across several predefined strata) were surveyed at an intensity of 20 km of vehicle transects per cell. During surveying, a vehicle was driven along roads with appropriate substrate at a speed of approximately 10 km/h. Spoor of any large carnivore was recorded, as well as data on prey species and direct anthropogenic impacts (i.e. human/livestock signs), to allow for the modelling of prey/human distribution and site-use in an occupancy framework. In 2023, additional spoor surveys may be carried out in the WMAs and OAs adjoining Nyerere NP and Selous GR to the east, to provide additional data to complement data collected in 2020-2022. Spoor data relating to elephants will be shared with Dr Josephine Smit, a researcher affiliated with STEP.

Vehicle-based spoor surveys were selected as the preferred data-collection methodology for distribution and habitat use modelling because the technique has already been successfully employed to assess the distribution and habitat use of all the target species, and because a camera trap survey aimed at assessing distribution and habitat use over the whole study area would have been prohibitive in terms of both time and cost.

Single-season occupancy models will be developed to estimate distribution, occupancy, and the relative impacts of individual environmental, anthropogenic and con-specific pressures on these parameters for each species (Strampelli et al. 2022b). Habitat covariates will be obtained through existing GIS layers and remote sensing, while novel prey and human occupancy models will be developed to include as covariates in the large carnivore models. Co-occurrence occupancy interactions will be modelled to provide insights into competition among different carnivore species. Occupancy modelling was selected over presence-only habitat-suitability modelling tools due to the technique's ability to explicitly account for imperfect detection in the modelling (Mackenzie, 2006; Hines et al., 2010). Furthermore, occupancy analyses also provide estimates of the proportion of area occupied by a species. This is increasingly being employed as a status indicator for carnivore populations, and will provide management authorities with a further status parameter, in addition to population abundances and density estimates, that can be monitored over time. Finally, the spoor data collected will also be employed to obtain index-based population density estimates (Funston et al., 2010; Winterbach et al., 2016). This will allow comparisons with similar surveys carried out in the landscape in 2014 (Crosmary et al., 2018), thus providing an opportunity to determine trends in the landscape.

Spoor data will also be collected in both Ruaha-Rungwa and Selous-Nyerere via walked spoor transects conducted by Lion Defenders in village lands neighbouring Ruaha NP and Nyerere NP. This information will be used in combination with data from non-systematic camera traps to obtain insights into wider wildlife communities in the area.

Camera trapping

Lion, leopard and spotted hyaena density will be estimated at camera trap survey sites within Selous-Nyerere and Ruaha-Rungwa, to monitor population trends since previous surveys in the same sites. Data will be gathered using grids of 40-120 paired camera stations set 3-5 km apart, each covering an

area of 200-1,000+ km^2. Cameras will be mounted on trees 40 cm from the ground, with precise locations selected to maximise the likelihood of photographing large carnivores, prioritising placement along roads and, where roads are not available, major game trails.

Density of lion, leopard and spotted hyaena (defined as individuals per 100 km^2) will be estimated via spatially-explicit capture-recapture (SECR) analysis, a technique that allows population densities to be estimated for individually identifiable species (Karanth & Nichols, 1998; Efford et al., 2004; Borchers & Efford, 2008). Camera trap data relating to elephants will be shared with Dr Josephine Smit, a researcher affiliated with STEP.

Non-systematic camera trapping will also be conducted in the WMAs and village lands to the east of Ruaha NP and in the village lands to the east of Nyerere NP. Alongside data from the systematic camera trap grids, the data collected will be used to produce species inventories, and investigate research questions relating to wildlife diversity, distributions, habitat use, and behaviour.

GPS collaring

Data on movement of large carnivores in and near human-impacted areas in both landscapes will be collected via GPS satellite collars. In Ruaha-Rungwa, we will deploy collars on up to 7 lions in the WMAs and village lands neighbouring Ruaha NP, in order to investigate how lion movement varies across anthropogenic gradients. In Selous-Nyerere, we will deploy collars on up to 8 lions and up to 12 wild dogs in the Matambwe sector of Nyerere NP and the Kingupira & Miguruwe sectors of Selous GR, to shed light on the movement patterns of these key carnivore species in the area. This work will be carried out in collaboration with TAWIRI researcher & PhD student Mr Leonard Haule and TAWA ecologist & MSc student Mr Singira Parsais.

The collars will also be used by collaborating students Mr Leonard Haule and Mr Singira Parsais to direct focal monitoring follow-ups, which will be used to collect information on the demographic structure of lion prides and wild dog packs. This represents the most efficient method to collect such data in an area where photographic tourism does not take place and animals are less habituated.

Conflict data

Data on human-carnivore conflict will be collected in both landscapes by Conflict Officers, who will map household locations, monitor depredation events and livestock losses, and collect information on carnivore mortality events. These data will be used to investigate levels of conflict, identify patterns and hotspots, and assess how the intensity and drivers of conflict compare between the two landscapes. The data will also be used to devise strategies for conflict mitigation that are appropriate for the local conditions.

Data will also be collected on vulture clusters signalling low movement in tagged vultures outside protected areas. This is part of a collaboration with the Eye in the Sky project led by vulture researchers Dr Claire Bracebridge and Dr Corinne Kendall, which aims to use vultures as sentinels for poisoning and other activities that threaten the conservation of wildlife. This will be done In collaboration with the.

Vulture clusters are flagged automatically by Movebank; when those clusters are identified outside protected areas, the point will be visited and data will be collected on what is found in the area.

Finally, surveys will be conducted to evaluate the effectiveness of performance payments on the willingness to coexist with large carnivores and other wildlife. Furthermore, the surveys will focus on what aspects of the mechanism could be changed in order to increase their impact. We will survey what is deemed to be a representative sample of households in villages that experience Community Camera Trapping. We will conduct semi-structured interviews.

Corridor assessments

We will use multiple methods to assess the functional connectivity of two key wildlife corridors in southern Tanzania. This work will be carried out in collaboration with Dr Josephine Smit, a researcher affiliated with STEP. We will deploy approximately 50 camera traps across the newly gazetted Nyerere-Udzungwa corridor, and will use the data collected to assess whether the corridor is being used by large carnivores and other mammal species. In 2024 we conducted a survey of the Ruaha-Udzungwa corridor (TAWIRI, 2021) in collaboration with Dr Josephine Smit and STEP, following the methodology of Epps et al. (2011) and Nahonyo (2009), in order to gain an up-to-date understanding of the status and wildlife presence in this corridor. In 2025, we may carry out additional data collection as part of this assessment. If completed, this will include foot transects, key informant interviews with village leaders and elders, and opportunistic deployment of camera traps to collect data on use of the corridor by elephants and other wildlife. On transects, we will record wildlife signs, habitat type, and any signs of human disturbance encountered. For both corridor assessments, data will be shared with Dr Josephine Smit. Survey results will be shared with all relevant government stakeholders through a technical report.

Capacity building

This project aims to build capacity of a number of local partners in large carnivore research and monitoring techniques. Through the work Selous-Nyerere, theoretical training will be provided in the techniques employed to TAWIRI researchers, Nyerere NP ecologists (TANAPA), and Selous GR ecologists (TAWA). In addition, TAWIRI, TANAPA, and TAWA will continue to participate in data collection for research activities that build upon the 2020-2022 surveys. This will ensure that practical training in the monitoring techniques employed will be provided to a number of relevant management staff, and that long-term ecological monitoring capacity continues to be built in the landscape.

The project will also be used to build capacity among Tanzanian students and researchers. Data from all the above activities will be made available to Tanzanian Master's and PhD students for their research projects, and advisory support will be provided to maximise the success of their research. We will provide supervision to and share data with TAWIRI researcher Mr Leonard Haule for his PhD research and TAWA ecologist Mr Singira Parsais for his MSc research. Both Mr Haule and Mr Parsais will collaborate on the planned camera trapping, spoor surveys, wildlife collaring, and focal monitoring, and we will share data with them for their thesis research. Mr Haule will share genetic and collar data with us.

Data analysis and publication of research will be carried out in collaboration with TAWIRI, TAWA and TANAPA staff, as well as other collaborators as appropriate.

Dissemination of outputs

All outputs will be made accessible to wildlife managers (at a local, regional, and national scale), NGOs working in the conservation and wildlife sector, and the wider scientific community, through a variety of means appropriate to the different audiences. The major outputs from this project, and the main way its results will be disseminated, will be scientific publications co-authored by the co-investigators and TAWIRI, TAWA and TANAPA staff, as well as other collaborators as appropriate. Wherever possible, these will be made public through an open access publication process, and thus will be freely available to scientists, conservationists, and wildlife managers across Tanzania and beyond.

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