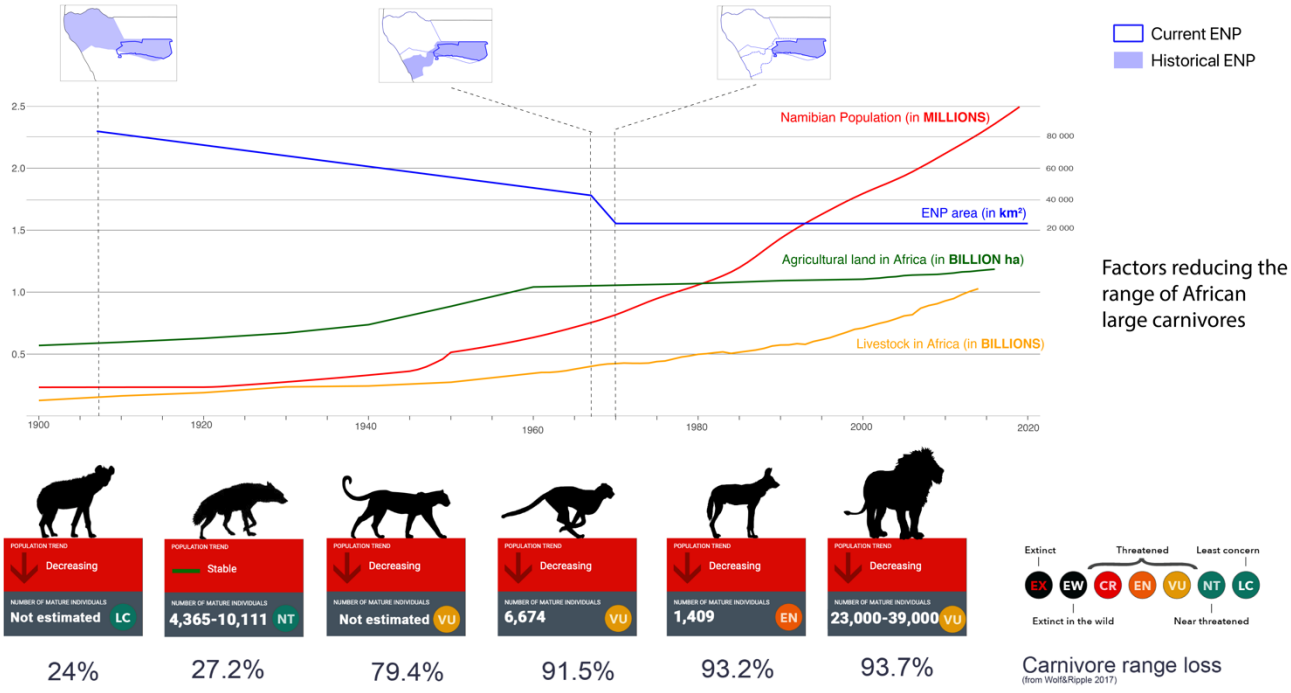
Carnivores in a changing world:

Determinants of Carnivores Fitness & Distribution in the Greater Etosha Landscape

Statement of research issue/problem/question

Large carnivores are one of the most studied animal taxa. There is evidence from around the globe that apex predators influence ecosystem functioning at many levels, affecting prey populations, and thus vegetation and landscape structure. Due to the expansion of anthropogenic activities, they are increasingly dependent on protected areas for their persistence (Fig. 1). This has several consequences. For instance, in protected areas, intra- and inter-specific interactions are likely to intensify with implications for resources competition and disease transmission. Conversely, as carnivores move beyond protected area boundaries, they often interfere with human interests, frequently resulting in conflict and persecution. Hence, the drivers of large carnivores' fitness and distribution vary throughout the landscape.

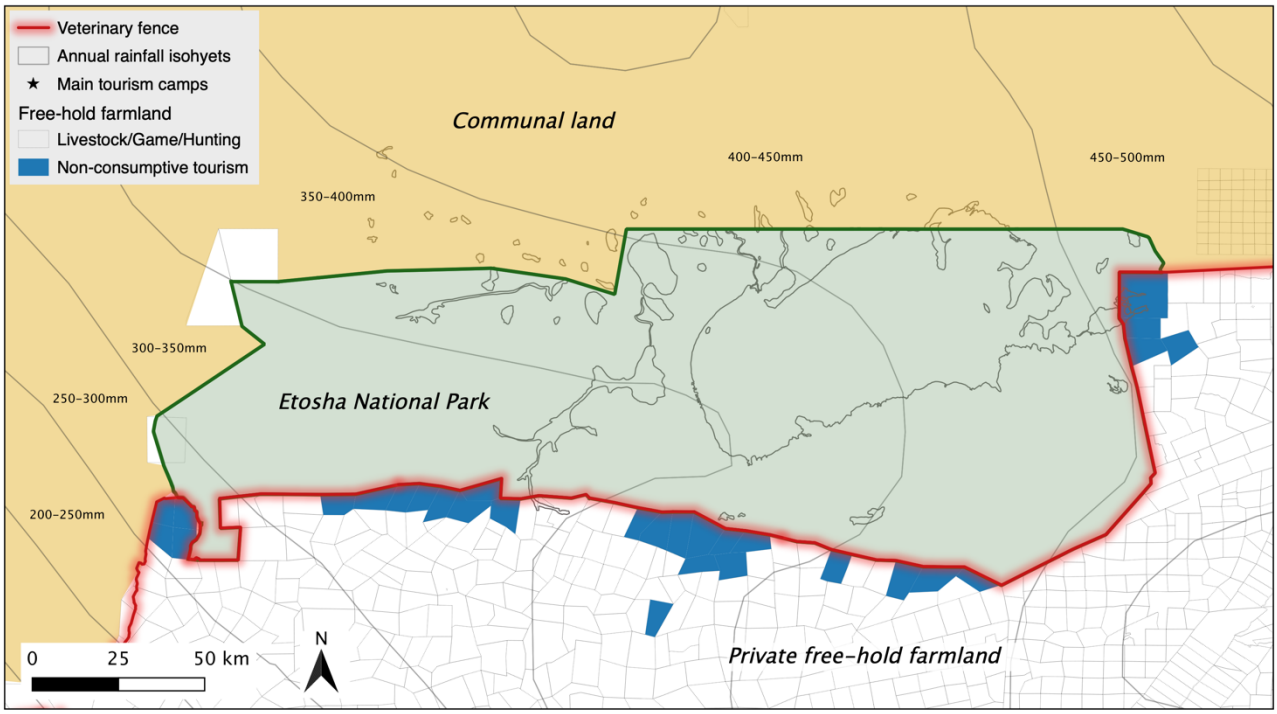
Fig. 1: African large carnivores in a changing world



The Greater Etosha Landscape (GEL, Fig. 2) in northern-central Namibia exemplifies global conservation challenges. The GEL comprises one of the world's most renowned protected areas, the Etosha National Park (ENP), that is surrounded by a diverse matrix of land tenures and land uses, which translate into different management approaches. This complex matrix is one of the key

representative conservation landscapes, alongside with for example South Africa's Greater Kruger NP or Serengeti NP in Tanzania, and outside Africa for instance the Greater Yellowstone Ecosystem in the USA or Ranthambhore NP in India.

Fig. 2: The Greater Etosha Landscape

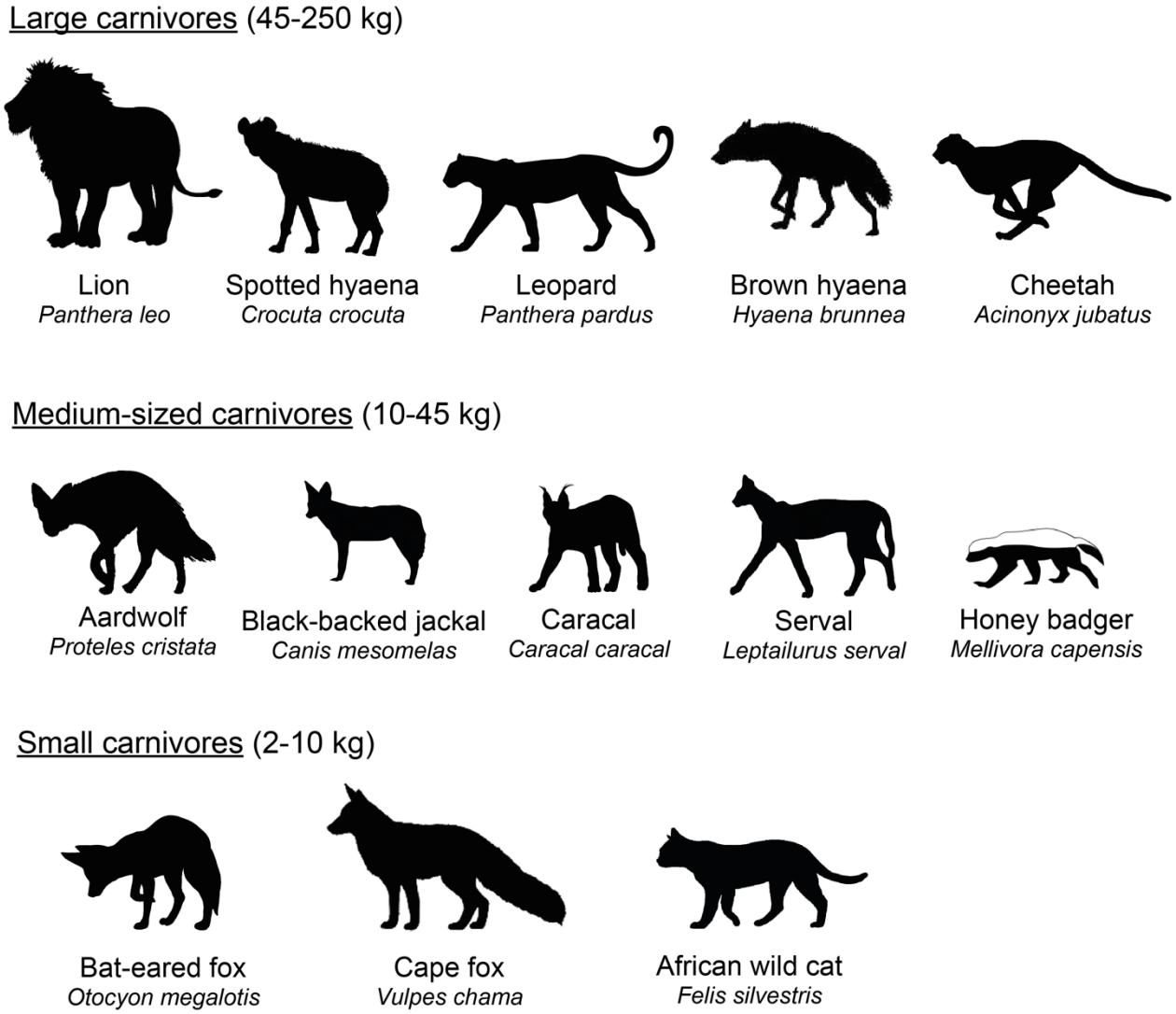


While large carnivore research has a long history in the Etosha landscape, changing land use and climatic conditions require a new detailed understanding of the drivers of carnivore fitness and persistence. The paucity of current information includes simple natural history, complex intra-guild interactions, ecological responses to human and environmental stressors, and the challenges surrounding human-carnivore coexistence. How these individual factors intertangle and mediate each other has received very little attention and remains poorly understood. Considering increasing human land conversion and the accelerating impacts of a changing climate, we can expect these factors and their interactions to become more important and complex. Throughout the GEL, five species of large carnivores occur, along with four meso-carnivores (Fig. 3). They occur across a variety of environmental gradients and are exposed to different human interests along the park's boundaries that often result in direct conflict and persecution.

Research objectives

Large carnivore abundance, distribution and persistence are determined by individual fitness, the ability to survive and successfully reproduce in a given environment. Survival and recruitment, in turn, are influenced by numerous factors including food availability, habitat quality, disease, genetics, intra- and inter-specific interactions and anthropogenic factors. The goal of this collaborative programme will be to **identify, understand and quantify the drivers of large carnivore fitness, and thus distribution and abundance.**

Fig. 3: Carnivore diversity in the Greater Etosha Landscape



We will determine the macro- and micro-drivers of carnivore fitness, and examine how they vary across different land tenures and management systems, considering the effects of interactions between the environment, prey, large carnivores, and humans. Investigations will be made into natural history, ecological responses to human and environmental stressors, and the challenges surrounding human-carnivore coexistence. The focal species comprise the large carnivore guild, with lion (*Panthera leo*), leopard (*Panthera pardus*), cheetah (*Acinonyx jubatus*), spotted hyaena (*Crocuta crocuta*), and brown hyaena (*Parahyaena brunnea*) as well as the meso-predator guild including honey badger (*Melllivora capensis*), serval (*Leptailurus serval*), black-backed jackal (*Canis mesomelas*), aardwolf (Proteles cristata) and caracal (*Caracal caracal*). African wild dogs (*Lycaon pictus*) were historically present in the ecosystem but are currently absent. They may be included as a focal species in the future, if reintroduction or natural recolonisation occur. Smaller carnivores, including bat-eared fox (*Otocyon megalotis*), Cape fox (*Vulpes chama*), African wild cat (*Felis silvestris*) and the Mustelids will mainly be considered as part of disease network studies.

Research work will entail minimally invasive and non-invasive methods, including the immobilisation of animals and collection of samples. This programme is planned as a long-term collaboration between the Etosha Ecological Institute (EEI), as part of the Ministry of Environment, Forestry and Tourism (MEFT), Ongava Research Centre (ORC) and a range of accomplished national and international collaborators.

Within the larger research framework of this study (see below for the full scope of research), selected examples of particular research novelty and interest are:

1. *How important is disease for population persistence?*

Diseases play an important role in controlling animal populations. They directly affect an individual's health, in terms of body condition and reproductive ability, in severe cases causing mortality. For instance, in the GEL, anthrax is known to impact carnivore populations and their prey to varying degrees.

While some diseases have already been studied intensively in the GEL, the presence, incidence, effects, prevalence, severity and transmission of many others are not well understood. Which carnivores, including large and medium-sized species, act as reservoirs and/or vectors warrants more detailed investigation. As carnivores are increasingly restricted to protected areas, understanding the role of their interactions, contact rates, modes of pathogen contraction and routes of disease transmission is important. Important corollary questions are: how susceptible are carnivores to specific diseases and what are their immune responses? Answering these, also taking into account the impact of physical boundaries as potential disease barriers and the influence of changing climatic conditions on disease emergence and prevalence, will help us determine the effect of diseases on overall carnivore fitness and persistence.

2. *Can humans coexist with dangerous wildlife?*

Human activities shape landscapes and resource availability by modifying animal and plant communities, thus influencing landscape suitability for wildlife. Human-wildlife coexistence is mainly driven by human choices, which are often influenced by perceptions of benefit and loss, as well as danger.

Carnivores have traditionally been viewed either as assets (tourism value) or as a source of conflict (livestock and game production and danger to humans), determining where they are tolerated or persecuted. Etosha National Park harbours significant carnivore source populations that overspill into human landscapes surrounding the park where attitudes towards them differ. Tolerance is critical for effective carnivore dispersal that provides connectivity with other populations. For example, the GEL has been identified as one of Africa's key landscapes for the long-term survival of free-ranging lions. Finding ways to improve human-carnivore coexistence is therefore important to ensure carnivore persistence in human dominated landscapes and population connectivity, thus also maintaining gene flow. This requires a detailed understanding of human-carnivore interactions across different land uses, for example through conflict and carnivore persecution risk mapping. Local interactions between people and predators may be mediated by both carnivore ecology (species, age, etc) and human factors (fences, livestock farming, tolerance, etc), and risk management needs to progress from a traditional focus on reactive carnivore control to proactive conflict mitigation and prevention.

3. *How do species with similar ecological niches coexist with each other?*

Sympatric species affect each other in many ways, either directly or indirectly. Coexistence within the same ecological niche requires a balance between positive and negative interactions. Thus, there is a need to expand from a single species study approach to a more holistic view of ecosystem and guild functioning.

The GEL is one of the last African landscapes with a complex guild of large and medium-sized carnivores that continually interact with each other in an increasingly restricted system. Yet, the consequences and mechanisms of these interactions are not well understood. While carnivores directly compete for prey (exploitative competition), they also indirectly influence each other by competing for the use of the same food patches (interference competition). Furthermore, they detrimentally affect each other through predation, kleptoparasitism and disease transmission. Positive interactions can also be either direct (e.g. scavenging opportunities) or indirect (e.g. prey behavioural adjustments). While some factors are known to influence interactions (e.g. body size, group size), the relative importance of other variables such as prey diversity, anthropogenic disturbances and habitat structure are far less understood, especially within complex guilds.

4. *How do animals living at low density communicate over long distance?*

Many terrestrial mammals naturally occur at low densities, requiring effective communication over long distances and long time periods. Different degrees of sociality imply the use of different communication strategies. Communication is essential for mating, territoriality, social relationships and indeed many other purposes. In mammals, communication often takes the form of auditory, visible and biochemical cues, and different species may employ variable combinations of these cues to communicate effectively. While some of these cues are short-lived, others persist longer in the landscape.

In complex carnivore guilds, communication occurs intra- and inter-specifically, facilitating effective social relationships and niche partitioning. How exactly carnivores communicate amongst each other in time and space has received very little attention though. Some species are highly vocal (e.g. lions and spotted hyaenas), whereas others appear to rely more on chemical communication (e.g. brown hyaenas and cheetahs). Communication also strongly influences carnivore movements, for instance males following females in oestrus or predators perceiving the presence of vulnerable prey on farms bordering Etosha National Park. Carnivore research often does not take into account the role of different auditory and olfactory cues in shaping specific behaviours. One goal of this study is to identify mechanisms of communication and their specific purposes and functioning in a multi-predator system.

5. *How do waterholes shape animal ecology in a semi-arid environment?*

In semi-arid environments, water is a critical resource determining wildlife distribution, abundance and, ultimately, persistence. Artificial provision of water throughout the year intensifies animal interactions and activity around waterholes, with significant implications for predation risk, feeding ecology, reproduction, pathogen accumulation and disease transmission, for instance. Hence, we can expect waterholes to be an important driver of different ecological processes. Therefore, understanding the role of waterhole characteristics and distribution in shaping animal behaviour and activity will be a core topic of investigation in this study.

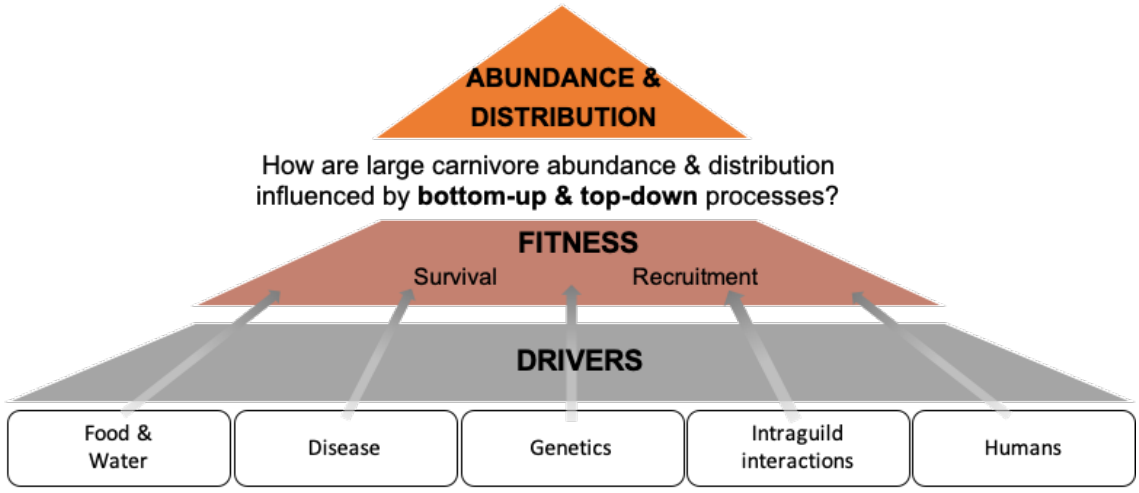
Scope of research

The GEL provides an ideal study environment of global relevance. Unresolved conservation issues and knowledge uncertainties are very similar elsewhere. In close partnership with the EEI, the ORC seeks to develop a professional long-term research and conservation project that will involve some of the world's leading carnivore ecologists as well as conservation management experts. Together, we will investigate macro- and micro-drivers of carnivore biology under changing conditions and circumstances, considering the effects of trophic interactions between the environment, prey and large carnivores. This programme seeks to answer important questions about carnivore ecology and persistence. It will expand on carnivore surveys carried out by the EEI and carnivore work undertaken across the larger ecosystem by other stakeholders such as ORC, UNAM veterinary school and the Leibniz Institute for Zoo and Wildlife Research (IZW).

We expect that this collaboration will yield a detailed understanding of the many different, but connected, parts that form the Greater Etosha Landscape. Core elements of investigation will include carnivore natural history, prey guild composition, and environmental variables under different human management regimes. Through a series of national and international studies, we aim to disentangle how these variables interact and influence carnivore distribution and abundance as well as human-carnivore coexistence. A multi-disciplinary team of accomplished researchers will design and pursue fine-scale investigations, covering a range of ecological disciplines and concepts. **In short, we aim to establish a leading ecology collaboration that takes a holistic study view on carnivore conservation over an extended period of time and at landscape scale.**

Research interests include, but are not limited to, those listed below (Fig. 4) – many topics are also intrinsically interlinked, or build on each other, and will therefore require carefully aligned methods. Topics may also be species- or area-specific. As this programme grows from specific investigations into a more holistic assessment, it will require increasing levels of funding, coordination and management.

Fig. 4: Research Framework



Factors to be measured	Abundance, diversity, distribution & availability of resources	Diversity, prevalence, transmission & effects of diseases and parasites	Genetic diversity, population structure & relatedness	Intra- & interspecific interactions Extent of negative & positive interactions	Anthropogenic effects via conflict, fencing & conservation
Direct effects	- Provision of primary physiological requirements - Diet composition & prey preference	- Mortality rate - Behavioural changes	- Individual relatedness within & between social groups - Inbreeding - Contribution to recruitment (super-moms)	- Mortality - Competition for space & mate - Scavenging opportunities - Communication	- Mortality/protection - Fencing & movement barriers
Other factors	- Habitat type & quality affecting hunting success & prey distribution - Intraguild interactions - Anthropogenic effect (waterhole distribution)	- Intraguild interactions & transmission - Role of prey & waterhole distribution	- Fencing & barriers to movement & gene flow - Conflict related mortality	- Attitude toward large carnivores - Habitat refuges - Prey distribution& preferences	- Modifications of intraguild interactions - Changes in food diversity & waterholes distribution

1. *Food availability & habitat components*

- Carnivore diet composition and preferences in relation to prey abundance & diversity;
- Wild prey availability and intensity of human-carnivore conflicts involving domestic prey;
- Diet overlap between carnivore species;
- Influence of water (artificial or natural) distribution and quality;
- Distribution and abundance of carnivores as influenced by food availability, topography and vegetation structure (including composition), fencing and overall habitat quality.

2. *Disease*

- Pathogen diversity, their incidence and prevalence;
- Disease network between carnivores and possible transmission routes;
- Importance of disease in affecting individual fitness and as a cause of mortality across the landscape;
- Potential of the immune system of carnivores to react with an adequate immune response when challenged with a pathogen
- Role of meso-carnivores as disease hosts and vectors;

- Disease/pathogen emergence, re-emergence and zoonotic potential.

3. *Genetics*

- Species-specific variance and structure across the landscape;
- Degree of relatedness as a predictor of fitness (survival and reproduction);
- Role of fencing in genetic isolation (degree of landscape genetic connectivity);
- Importance of GEL populations towards global populations.

4. *Intraguild interactions*

- Investigating the balance between competition and facilitation that allows for coexistence, ranging from diet and prey preference topics to spatio-temporal overlap and avoidance;
- Interactions through prey anti-predatory behaviour;
- Inter- and intra-specific communication;
- Large carnivore influence on meso-predators.

5. *Human activities*

- Variance in land tenure, land uses, income strategies and fencing around ENP;
- Attitudes towards carnivores and levels of conflict and persecution;
- Conflict risk and persecution probability modelling, including domestic and wild prey, land use and predator information;
- Empirical testing of conflict mitigation measures;
- Economic benefits and losses of living with large carnivores;
- Determine predator-livestock interactions through simultaneous GPS tagging, incl. predation risk modelling;
- Effectiveness of ENP's boundary and the influence of different fencing types on landscape permeability, thus also guild composition outside ENP with associated implications of disease transmission, conflict etc.

Methodology

1. *Carnivore immobilisation, sampling & tagging*

    a. *Immobilisation*

Carnivore immobilisations will be conducted by a professional wildlife veterinarian or a para-veterinarian registered with the Veterinary Council of Namibia. The primary reason for immobilisation is the tagging of carnivores with suitable tracking devices and sample collection. Methods and drugs used will vary between species and locations. We will use a range of techniques including baiting, call-ups, free darting and cage traps to capture carnivores for immobilisation. During immobilisation, body measurements and samples (see below) will be taken.

b. Sample collection

The following samples will be collected non-invasively or minimally invasively for genetic analyses, disease screening, diet and communication investigations:

- Non-invasive collection from the environment:
  - faeces (scat),
  - scent marks (e.g. brown hyaena paste marks),
  - hair;
- Minimally invasive collection from free-ranging specimens:
  - tissue biopsy from free darting;
- Minimally invasive collection from immobilised specimens:
  - Ectoparasites and endoparasites for presence, diversity and load,
  - Faeces and hair,
  - Saliva, conjunctival and nasal smear,
  - Blood;

During immobilisation, sample collection will be conducted by certified personnel.

- *Ad hoc* non-invasive collection from mortalities:
  - Tissue samples and body fluids relevant to disease screening, incl. brain tissue for e.g. rabies screening;
  - Faecal matter.
- *Ad hoc* non-invasive sample collection from the environment:
  - Faecal matter;
  - Carnivore scent markings from latrines, trees, roadsides etc.

Samples from mortalities will be used for genetic purposes and disease screening (potentially identifying the cause of death). Carnivore faeces will mainly be used for diet analysis, although DNA extraction might be possible from fresh samples. Carnivore markings will be collected at known marking sites, such as latrines, trees, roadsides etc. to investigate carnivore communication and obtain additional genetic samples.

c. Tagging

Large and medium-sized carnivores will be equipped with commercially available tracking devices including radio telemetry and GPS capabilities. The type of devices and their settings (e.g. GPS position acquisition rate) will depend on the study species (body weight, age, sex, etc.), specific research questions and equipment manufacturer. We plan to attach audio-loggers to some transponders to study intra- and inter-specific communication. Movement data recorded with tracking devices will be used to study a range of questions including habitat selection, movement metrics, barrier effects, diet, hunting behaviour and interactions. For instance, GPS location clustering will be used to identify feeding sites and locate marking and denning sites.

2. Direct observations

Carnivores will be observed directly in the study area to gather data on their fine-scale behaviour and inter- and intra-specific interactions as well as prey choice. Direct observations will also be

necessary to record demographic information including group size and composition, mating, litter size and behavioural data such as social interactions and outcome of agonistics encounters.

3. Call-up & bait stations

We will use a combination of audio call-ups and baiting to collect data on population size, group composition, survival and reproduction. Call-ups will use different sounds attractive to predators (e.g. prey distress calls, spotted hyaena whooping, lion roars etc.) to lure them to the call-up stations. Depending on the purpose, these call-ups can be tailored to target specific species and be used to conduct behavioural experiments.

4. Herbivore census

Transect-based counts will be used to determine the distribution and abundance of herbivore species across core study areas. Depending on the specific research focus, we will use an array of methods to census herbivores, ranging from road-based vehicle counts and aerial transect surveys to waterhole counts and capture-recapture via camera trapping.

5. Camera trapping

Camera trapping will be employed to provide additional information on carnivore distribution (presence/absence/occupancy), abundance (capture-recapture) and their behaviour. Camera traps will be deployed at specific points of interest such as bait stations, carcasses, communication and marking sites, den sites, permanent water sources, fence holes etc.

6. Remote sensing techniques

We will use remote sensing techniques to collate information on environmental variables (e.g. rainfall, NDVI) at both large and fine spatio-temporal scales. Remoting sensing data will require ground truthing to produce accurate feature/habitat maps in the core study areas.

7. Water samples

Water samples (2 x 50 ml) will be collected from both artificial and natural water sources (permanent and seasonal waterholes) through the landscape. These will be used to assess water quality in terms of chemical composition and disease transmission/infection risk. Sampling of artificial waterholes will be carried out twice annually, once at the end of the wet season (April-May) and once at the end of the dry season (September-October). Natural waterholes will mainly be sampled during the wet season.

Conceptual definitions

n/a

Monitoring methods

As outlined in the methodology above.

Indirect carnivore monitoring methods include remote GPS tracking via tracking devices and camera traps. Direct ground or aerial follow-up of carnivores will be necessary when carnivore body size prevents the use of GPS satellite tracking technology and carnivores will be fitted with radio telemetry gear, or GPS data loggers. In addition, direct, focal sampling will be undertaken from vehicles and aircrafts, including behavioural and demographic observations. Direct investigations of prey remains, mortalities, marking locations, den sites etc. and the deployment of research gear (mainly capture cages and camera traps) will occasionally require work on foot. As much as is feasible, research will be conducted non-invasively.

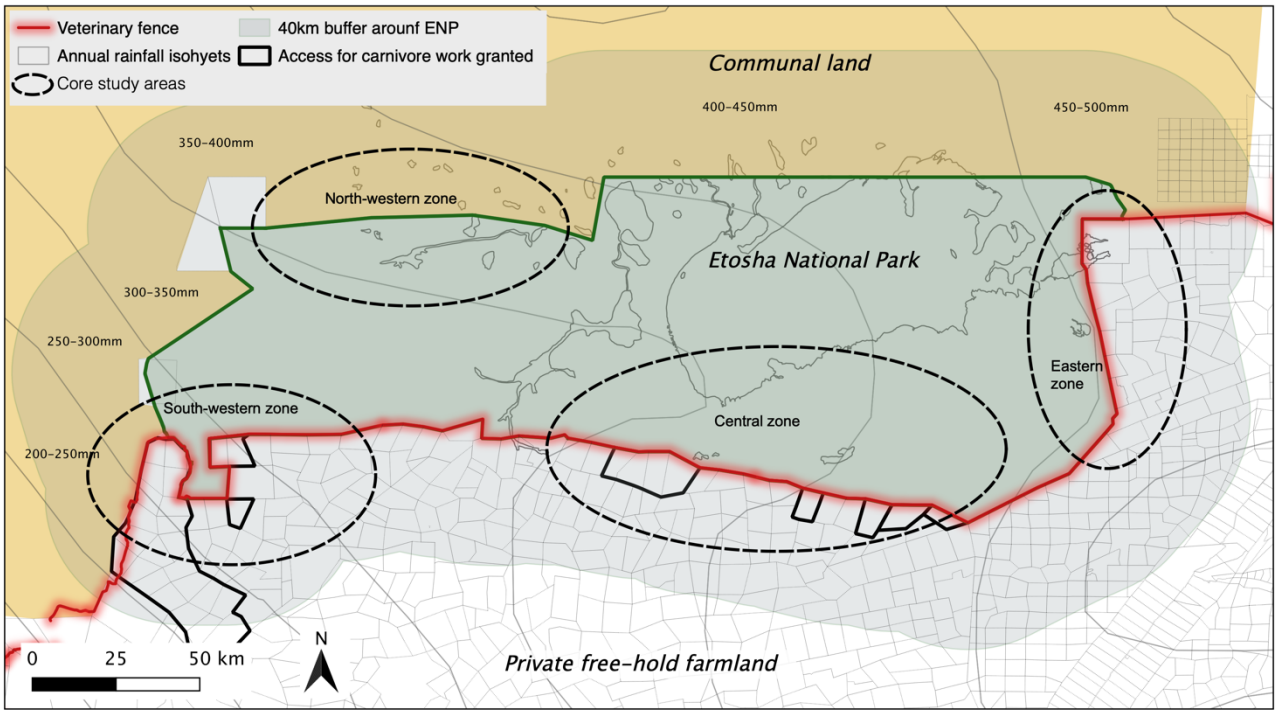
Carnivore prey will be monitored directly during aerial transect surveys, at waterholes and along road-transect vehicle surveys (e.g. distance sampling). Additional indirect monitoring will include camera trapping at waterholes.

Environmental conditions will be monitored through samples (e.g. water), plot sampling (e.g. fine-scale vegetation composition and nutrient composition) and via remote sensing techniques. In addition, interviews and direct investigations throughout the four core study zones (see Fig 5.) will be required to record and map details on land tenure, land use, fencing structure, domestic and wild carnivore prey guild composition, conflict with carnivores, and other variables. Much of the monitoring work will be carried out by graduate and post-graduate students.

Geographical location where research will be conducted

This research project will be conducted within the Etosha National Park (ENP) and in select areas within a 40 km buffer radius around ENP boundaries. The buffer zone will include free-hold farms with a variety of human activities as well as communal land. The geographic expanse of this landscape prevents intensive surveys over its entire area. We therefore propose to carry out intensive work in four core study zones as representative samples of the larger landscape (see Fig. 5). These zones span different environmental gradients as well as different land uses and management systems. The distribution of intensive core study areas will take into account carnivore research already underway by the EEI as well as independent researchers.

Fig. 5: Overview of the proposed core study areas in the Greater Etosha Landscape



Detailed list of all scientific equipment and instruments to be used

- Combined GPS/VHF tracking transponders by various manufacturers (specific detail dependent on carnivore species, body size and research question) – VHF frequency band: 148.000 – 151.999 Mhz – transponders will contain UHF proximity sensors;
- 50-60g audio-logger (supplemental external collar attachment);
- VHF telemetry tracking gear, including receivers and directional antennae;
- Standard carnivore trap cages with approximate dimensions: L:2.6m, W:0.85m, H:0.95m;
- Approx. 70 remotely triggered camera traps of different brands (mainly Reconyx and Bushnell);
- Sample preservation containers of various sizes;
- Portable audio system for call-up surveys;
- Laser range finder;
- Binoculars and cameras;
- Research vehicles; aircraft opportunistically for game census and collar data download purposes;
- Immobilisation: Immobilisation and sample collection utensils (veterinarian), weigh scale, calipers, measuring tapes, sample containers, holding box for safe recovery.

Details of all vessels, vehicles, aircraft and the likely to be used

ORC vehicles: CEO14824 / N1685OJ / N3221OJ / N339OJ
Other vehicles will include EEI, IZW, UNAM, Namibian Lion Trust fleets.

Schedule of research

COVID restrictions and funding permitting, field work is expected to start in 2021.
During the first 12-18 months of this project, we plan to focus on the following topics:

1. *Review of what is known about carnivores in the GEL*

We will gather available information on previous carnivore work conducted throughout the GEL. Sources will include peer-reviewed journals, books, EEI archives, the EIS, Namibian Scientific Society and colleagues. The purpose of this review is to obtain a detailed understanding of historic carnivore work, identifying which topics have been studied, which species have been focused on and where knowledge gaps exist that can inform future research priorities. We anticipate to submit the output of this literature review to the Namibia Journal of Environment for publication.

2. *Land mapping in the GEL*

The GEL comprises a variety of land tenures and land uses that influence large carnivore fitness and persistence. Within a 40 km buffer of ENP boundaries, we will map important land attributes, including, land use and tenure (historical and current), types of fences, wild and domestic prey occurrence (with stocking rates), waterhole distribution (if possible), conflict and the resulting attitudes toward and tolerance of carnivores, benefits derived from carnivores, and also presence of potential disease vectors such as non-vaccinated domestic pets. These attributes will be complemented with others that can be derived via remote sensing (e.g. habitat structure and NDVI). This project part will require a combination of field work and remote sensing.

3. *Analysis of data previously collected by the EEI: GPS data for lions and spotted hyaenas*

The EEI has been collaring lions and spotted hyaenas as part of their large carnivore monitoring programme. This part of the project is focusing on the analysis of available GPS location data.

   a. *Spatial ecology of lion and spotted hyaenas in ENP*

This project will focus on home ranges and movement parameters of both species. Work on home ranges will included size and seasonal variation, overlap between individuals and between seasonal ranges of the same individuals. We will compute the following metrics: average speed, total and net displacement at different time scale and path tortuosity. We will determine if these metrics differ between species and individuals, and if factors such as season, distance to water, moon phase or habitat type affect them.

Work on spotted hyaena home ranges will be included in a comparative study of their spatial ecology along a gradient of rainfall (ENP, Khaudum NP, Kavango East and Zambezi regions and Hwange NP) under the umbrella of the EEI large carnivore monitoring programme. Work on lion

will include GPS tracking data from ENP, ORC and the Namibian Lion Trust and will investigate the effects of land use and fences on lion spatial ecology.

b. Habitat selection on lions and hyaenas in ENP

Based on the GPS data collected by the EEI, this project will focus on habitat selection in both lions and spotted hyaenas in ENP. A vegetation map of ENP is available (published in 2017) at a 230 x 230 m resolution. We will investigate habitat selection using resource selection functions, compare habitat selection patterns between the two species and determine if factors such as season, prey density, distance to water and moon phase affect habitat selection.

c. Movement of lions in the vicinity of ENP fence

This project will focus on lion movement metrics with specific regard to ENP's boundaries. Questions will include how often carnivores come into close proximity of the fence, how many times they obey fence boundaries or 'bounce away' from them, and how often transgressions occur and where? These analyses will reveal fence effectiveness in terms of containing lions within the park and, thus, preventing conflict outside. This project will also utilise lion GPS data previously collected from Ongava Game Reserve and the Namibian Lion Trust.

4. Collaring of large carnivores in core study areas

The EEI has identified leopard and brown hyaena as species for which very little knowledge is currently available. We thus aim to intensify capture and GPS-tracking of these species. We anticipate trapping and tagging leopards and brown hyaenas on Ongava Game Reserve, in ENP and on different private farms bordering ENP. Simultaneously, the GPS-tracking of cheetahs throughout the landscape will continue, aligning with research already being carried out by the IZW Cheetah Research Project in collaboration with the MEFT.

5. Camera trap and call-up survey of large carnivores on farms bordering ENP

We plan to conduct a preliminary survey at waterholes during the 2021 dry season to assess the presence and relative abundance of carnivores on private farms along the southern boundary of ENP. This pilot study will gather initial data to assist in the planning of detailed research questions and tracking strategies. During the first part of the survey, we will deploy camera traps for three weeks at permanent waterholes across different properties. This will be followed by audio call-up surveys (near baited camera stations) to achieve more homogenous spatial sampling and improve the identification of individuals of uniquely identifiable species.

6. Water sampling

Beginning in 2021, water samples (2 x 50 ml) will be collected from both artificial and natural water sources (permanent and seasonal waterholes) through the landscape. These will be used to assess water quality in terms of chemical composition and disease transmission/infection risk. Sampling of artificial waterholes will be carried out twice annually, once at the end of the wet season (April-May) and once at the end of the dry season (September-October). Natural waterholes will mainly be sampled during the wet season.

If research will or may reasonably expected to negatively impact on the environment an environmental impact assessment must be submitted including the manner in which such impact will be negated or mitigated

This research is not expected to negatively impact on the environment. Sample extraction will not negatively impact or deplete the material source (animals in terms of tissue samples, and water sources in terms of quantity) as only minor amounts are collected. Based on previous experience, we anticipate only temporary effects from capture and tagging of carnivores. Carnivore immobilisations will be conducted by a professional team including a wildlife veterinarian or a para-veterinarian registered with the Veterinary Council of Namibia. As much as is feasible, research will be conducted non-invasively.

Technical institute, official agency or academic institute in Namibia involved in the research

Etosha Ecological Institute
Ministry of Environment, Forestry and Tourism
Ongava Research Centre
Leibniz Institute for Zoo and Wildlife Research
Namibian Lion Trust
University of Namibia Veterinary School & Biology department
Namibian University of Science and Technology
International universities for specific topics with limited Namibian capacity

Significance/benefits or expected benefits of research with specific reference to benefits/significance to Namibia and/or Namibians (if any)

We anticipate that this programme will produce important knowledge on ecology of large carnivores that will be relevant for their conservation in Namibia. Large carnivores are an important source of income both through consumptive and non-consumptive tourism in Namibia. At the same time, large carnivores are also a primary driver of conflict. A better understanding of their ecology in and around protected areas, and the factors affecting their number and distribution, will be highly beneficial for future management strategies.

This programme will involve Namibian students, researchers and universities through various collaborations, for instance providing training opportunities for UNAM vet students in chemical restraint (induction, monitoring, recovery, sample collection etc). This programme will also provide opportunities for local students to work alongside international colleagues, enhancing their experience as well as future collaborations between Namibian and international institutions.

Name, affiliated institution and/or country of applicant's collaborators on research

Collaborator	Affiliation	Specific interests
Werner Killian Marthin Kasona	Etosha Ecological Institute	Human-wildlife conflicts, disease, spatial ecology, intraguild interactions, predator-prey interactions
Kenneth Uiseb Uakendisa Muzuma	Directorate of Scientific Services of the Ministry of Environment, Forestry and Tourism	Human-wildlife conflicts, conservation, policy development
Dr. Matt Hayward	University of Newcastle, Australia	Predator-prey interactions, intraguild interactions, influence of environmental variables, meso-carnivores
Dr. Marion Valeix	Laboratoire de Biométrie et Biologie Evolutive CNRS, Université Lyon 1, France	Behaviour, spatial ecology, predator-prey interactions, waterhole ecology, influence of environmental variables, intra-guild interactions
Dr. Simon Chamaille-James	Centre d'Ecologie Fonctionnelle et Evolutive CNRS, Montpellier, France	Behaviour, spatial ecology, predator-prey interactions, waterhole ecology, influence of environmental variables, communication
Dr. Bettina Wachter Dr. Jörg Melzheimer	Leibniz Institute for Zoo and Wildlife Research, Germany Cheetah Research Project, Namibia	Disease, immunology, genetics, intraguild interactions, spatial ecology, influence of environmental variables, human-wildlife conflicts, communication
Dr. Ortwin Aschenborn Dr. Mark Jago	University of Namibia, Veterinary School	Parasitology, disease ecology (carnivores and herbivores)
Tammy Hoth	Namibian Lion Trust	Human-wildlife conflicts, spatial ecology, conflict mitigation
Dr. Dipanjan Naha	Wildlife Institute of India	Human-wildlife conflicts, conflict mitigation, risk modelling

Confirmed collaboration with Dr. Wendy Turner (USGS, Wisconsin Cooperative Wildlife Research Unit, University of Wisconsin, Madison) on specific topic areas as applicable.

Anticipated output and format of output (i.e. report, product, etc) and expected date on which output will be available

We will produce annual research progress reports as well as a general progress and activity update. As data, results and specific analyses accumulate, programme outputs can be used to inform management planning and future research priorities.

We also expect to produce peer-reviewed publications in international journals, as well as popular articles/press releases.

We anticipate taking part in workshops and present results from this programme at conferences both at the national and international levels.

Finally, we will supervise national and international academic theses, e.g. MSc and PhD projects.

Budget / Research funding and sources

In the initial stages, the programme will be self-funded through the contributions of different partner organisations. Once a research permit has been secured, international funding agencies will be approached for project-specific funding such as tracking equipment, sampling consumables, operational costs, vehicles and student stipends.

Potential opportunities for obtaining initial, project specific funding include National Geographic Society Big Cat Initiative, NEDBANK Go Green fund, British Ecological Society, Rolex Foundation, SPOTS Foundation, Van Tienhoven Foundation, Bosch Foundation, VW Foundation, as well as several dozen student scholarship programmes.

Any other information the applicant considers relevant to submit to the Commission which is not covered by this Form

The EEI has previously fitted spotted hyenas, lion and black-backed jackal with iridium-satellite collars from 2016-2020 throughout the ENP as part of a larger study on carnivores, i.e. the Large Carnivore Monitoring Program in and around Etosha National Park, Namibia (NCRST Auth. No. 2018050701). The Chief Conservation Scientist of the EEI, MEFT, is the Principal Investigator of this project.

Within this project, the following objectives have been identified as priorities for carnivore conservation in and around ENP.

1. Fit GPS satellite tracking devices to and mark individual carnivores inside the park.
2. Analyse home ranges and movement patterns of carnivores inside the park.
3. Determine lion and hyaena population distribution and abundance inside the park.
4. Establish carnivore prey preference to assess feeding ecology and predator-prey interactions inside the park.
5. Monitor human-wildlife conflict along park boundaries and on neighbouring farms to identify areas and animals with high conflict risk.
6. Conduct disease surveillance and health status assessment.

This proposal builds on current EEI work and expands its focus.