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„Impact assessment of fences and land use on landscape permeability for African elephants (*Loxodonta africana*) south of Etosha National Park, Kunene Region, Namibia"

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Abstract

Where farmers and elephants share a landscape, human-elephant conflicts are common. Fences are popular to prevent elephants from accessing farmland but they restrict the animals' natural movement patterns. In this study, the cumulative impact of both game-proof fences and land management on the landscape permeability for elephant movement is evaluated for communal and commercial farmland and the south-western part of the Etosha National Park in Namibia.
An interdisciplinary approach served to understand the local human-elephant interactions and to assess the impediment of landscape connectivity, driven by socio-economic activities and natural landscape features. Semi-structured interviews were conducted with freehold farmers and experts. Participatory mapping provided for the location of fences and information on farm management while GPS records of seven collared elephants were used to investigate habitat preferences. Least-cost analysis was used to evaluate the connectivity between identified areas of elephant preference.
The interview results suggest that in this area, elephant-farmer interactions may be seen as a conflict over natural resources. The geospatial data analysis revealed that game-proof boundary fences combined with a certain land management do not inhibit connectivity completely but rather shift corridors and potential conflicts locally. This suggests that individual and uncoordinated measures are unlikely to succeed in long-term conflict mitigation. A coordinated landscape-wide approach to align elephant movement requirements and human economic activities, based on local stakeholder and (scientific) expert knowledge, might be an alternative to provide a peaceful coexistence between elephants and humans.

Zusammenfassung

Dort, wo sich Elefanten und Menschen einen Lebensraum teilen, kommt es nicht selten zu Konflikten. Zur Konfliktprävention sollen unter anderem Zäune beitragen, welche Tiere von bestimmten Flächen ausschließen, gleichzeitig jedoch auch Wanderungsmöglichkeiten negativ beeinflussen können. In vorliegender Arbeit wird untersucht, welchen kumulativen Einfluss wildtiersichere Zäune und anthropogene Landnutzung auf die Durchgängigkeit einer Landschaft für Elefantenbewegungen haben. Das Untersuchungsgebiet umfasst namibisches Kommunal- und Privatland sowie den südwestlichen Teil des Etosha Nationalparks.
Durch einen interdisziplinären Ansatz konnte einerseits ein grundlegendes Verständnis der Interaktionen zwischen ansässigen Farmern und Elefanten geschaffen und andererseits die Auswirkungen sozioökonomischer Aktivitäten und naturräumlicher Begebenheiten auf die Möglichkeiten für Elefanten, sich im Gebiet fortzubewegen, bewertet werden. Hierzu wurden zum einen semi-strukturierte Interviews mit Experten und Farmern sowie eine partizipative Kartierung von Landnutzung und Zäunen durchgeführt. Zum anderen wurde anhand von GPS-Daten besendeter Elefanten der Einfluss einzelner Parameter auf die Habitatselektion bestimmt. Schließlich mündeten diese Erkenntnisse in eine Kostenentfernungsanalyse (*Least-Cost-Analysis)*, anhand derer die Konnektivität ausgewählter Gebiete evaluiert wurde.
Die Interviewergebnisse zeigen, dass die Interaktionen zwischen Farmern und Elefanten durch einen Konflikt um natürliche Ressourcen beeinflusst werden. Der räumlichen Analyse zufolge wird die funktionelle Konnektivität auf Landschaftsebene durch Wildtierzäune und Wild- und Weidemanagement nicht komplett unterbunden, jedoch werden potenzielle Korridore und damit möglicherweise Konflikte räumlich verlagert. Folglich ist anzunehmen, dass individuell geplante unkoordinierte Maßnahmen zur Konfliktprävention und -minderung keinen langfristigen Erfolg erzielen werden. Stattdessen könnte ein koordinierter Managementplan auf Landschaftsebene, erarbeitet auf Grundlage des Wissens lokaler Akteure und (wissenschaftlicher) Experten, zu einer konfliktärmeren Koexistenz von Menschen und Elefanten beitragen.

Table of Content

List of figures **11**
List of tables **12**
1 Introduction **13**
2 Study area, research context and goals **14**
2.1 Research goals **14**
2.2 Namibia: geography, biodiversity conservation and utilization of natural resources **15**
2.3 Research context and study area: geographical characteristics and tenure structure **17**
2.4 Elephants: ecology, conservation, benefit to biodiversity and relation to humans **19**
2.4.1 Ecology and movement behaviour 19
2.4.2 Current conservation status and range 20
2.4.3 Role within the ecosystem 21
2.4.4 Human-elephant interactions 21
3 Methods **26**
3.1 Empirical research in Namibia **26**
3.1.1 Semi-structured interviews and observation of group discussion 26
3.1.2 Participatory mapping 28
3.2 Post-processing of field work data **29**
3.2.1 Digitalization of maps and preparation of geodata 30
3.2.2 Digitalization of interviews 30
3.3 Geospatial data analysis **32**
3.3.1 Home range estimation 32
3.3.2 Assessment of input variables 33
3.3.3 Suitability analysis 36
3.3.4 Corridor identification and comparison 37
4 Results **42**
4.1 Current farm management and fencing **42**
4.2 Human-elephant interactions **44**
4.2.1 Perceptions on elephant behaviour 44
4.2.2 Characteristics of conflicts 45
4.2.3 Current measures to reduce conflicts 47
4.2.4 Long-term strategies for conflict mitigation 48
4.3 Singular impact of each driver **49**
4.3.1 Preferred vegetation and terrain conditions 49
4.3.2 Home range analysis 50
4.3.3 Preferred land management and the influence of fences 52
4.4 Suitability analysis: Determination of core areas **53**
4.5 Corridor analysis **55**
4.5.1 Current conditions in comparison to a natural landscape 57
4.5.2 Fencing scenarios 58
5 Discussion **59**
5.1 Dynamics of human-elephant interactions **59**
5.2 Cumulative impact of fences and land management on the permeability of the landscape **62**
5.3 Limitations of the study and recommendations for future research **64**
6 Conclusion **68**
7 References **71**
8 Appendices **83**

Appendix 1 – Information on interviews conducted in field phase 2019 83
Appendix 2 – Questionnaire: expert interviews 85
Appendix 3 – Questionnaire: farmer interviews 86
Appendix 4 – Participatory mapping: field maps 91
Appendix 5 – Cross-validation: maps sent to experts 92
Appendix 6 – Cross-validation: exemplary response from experts 92
Appendix 7 – R Script: home range estimation 93
Appendix 8 – R Script: calculation of the monthly NDVI median from 2000 to 2019 95
Appendix 9 – R Script: cumulative distribution of NDVI 101
Appendix 10 – R Script: cumulative distribution of slope 104

List of figures

Figure 1: (a) Administrative regions in Namibia for orientation purpose, (b) precipitation gradient and (c) altitudes represented by the digital elevation model (DEM), extracted from Kaseke et al., 2016). 15

Figure 2: Study area entailing different land tenure types: communal conservancies, freehold farms, state-protected national park and Hobatere Concession. 17

Figure 3: Proportion of land tenure types of total study area with predominating freehold/resettlement farms 18

Figure 4: (a) Geographical elephant distribution limited to the northern part of Namibia and (b) population estimates from 2000 to 2015 indicating a positive trend for Namibia (CITES 2016a) 20

Figure 5: Workflow of the study, beginning with the empirical phase and leading to the comparative description of calculated corridors. 27

Figure 6: NDVI and slope in and around the study area. 34

Figure 7: Monthly NDVI median from 2000 to 2019, indicating seasonal patterns in vegetation availability. 37

Figure 8: Example of corridor identification, modified after (McRae and Kavanagh, 2017). 38

Figure 9: Workflow of corridor analysis (dark brown: applied tools; light brown: outputs). 40

Figure 10: Result of participatory mapping; fences are present in freehold areas and surrounding ENP, different management activities are creating a mosaic in the study area; 1 – Ethosha Heights Game Reserve (all enclosed and neighboring polygons managed as one entity), 2 – Hirabis, 3 – Teschendorf, 4 – Ohorongo Game Reserve, 5 – Pionier, 6 – Kaross, 7 – Bruno, 8 – Bergvallei. 42

Figure 11: Damage on infrastructure caused by elephants, (a) damaged cattle fence, (b) dent on dam, (c) drinking spot for cattle flooded by water from damaged infrastructure, (d) garden furniture pushed over by elephants, (e) broken solar panel, (f) water pipes torn apart by elephants in search for water, sources: photos taken by individual farmers (d,e) and own photographs (a-c, f). 46

Figure 12: Measures applied by local farmers to mitigate their conflict with elephants, (a) stones to protect pipes at a dam, (b) booby trap to scare of elephants (blue wire leading to a dam to the left), (c) wildlife-proof fence at the southern boundary of ENP (own photographs) 47

Figure 13: Cumulative distribution of (a) NDVI and (b) slope values. Data obtained from a spatial overlap of raster products and elephant GPS records 50

Figure 14: Individual home range estimations and GPS records before the background of land management. 51

Figure 15: Density of GPS records in different management types within the 95% home ranges of each elephant. 52

Figure 16: GPS records in the vicinity to farm Hirabis, indicating the effectiveness of electrified game-proof fences as deterrent (location of the farm depicted in Figure 10). 53

Figure 17: Maps presenting the suitability of the landscape as elephant habitat, calculation based on Table 7 54

Figure 18: Results from the corridor analysis in a landscape without game-proof fences and land management (Nat) and the actual landscape (Real), (a) Cost-weighted distances to the nearest core area,

(b) mosaicked least-cost corridor maps, and (c) the comparison of corridors cut to 25 and 10 cost-weighted kilometres, respectively. 56

Figure 19: Results from the corridor analysis in a landscape with a continuous fence line to the west (S1) and at the southern border of ENP (S2), (a) Cost-weighted distances to the nearest core area, (b) mosaicked least-cost corridor maps, and (c) the comparison of corridors cut to 25 and 10 cost-weighted kilometres with the actual environment (Figure 18), respectively. Legend to be found in Figure 18. 57

Figure 20: Contextualization of the dominant variables influencing human-elephant interactions within the study area, modified after Shaffer et al. (2019); variables of humans and elephants have an impact on the conflict characteristics while framed by different press and pulse disturbances. 60

Figure 21: Feedback loop on fence construction indicating self-reinforcing shift of problems 64

List of tables

Table 1: Interview characteristics, conducted during the field phase in 2019; for more detailed information on the particular interviews see Appendix 1. 28

Table 2: Requested attributes in the process of participatory mapping. 29

Table 3: Translation of land use information to management categories. 30

Table 4: Elephant records used for home range analysis (collar ID identically used as elephant ID)(MET 2019). 32

Table 5: Input variables used for geo-spatial analysis. 35

Table 6: Description of landscapes used for corridor analysis. 41

Table 7: Percentiles of cumulative distribution of NDVI and slope values and resulting boundaries of classes for suitability and corridor analyses. 49

Table 8: Home range sizes in hectares; HR50 = 50% home range, HR95 = 95% home range. 52

Table 9: Cost-weighted distances (in cost-weighted kilometres) and lengths of least-cost paths (in kilometres), corridor area calculations and their intersecting area (in hectares). 55

1 Introduction

According to the International Union for the Conservation of Nature (IUCN), approximately 26% of the assessed mammalian species are currently threatened with extinction, worldwide (IUCN, 2020b). Also in Namibia, wildlife populations continued to decline until the government devolved utilization rights over game to private landowners in 1975 and to communities that established a conservancy in 1996 (Barnes and DeJager, 1996; Government of the Republic of Namibia (GRN), 2003). The background of these developments is the aim of Namibia to conserve nature through sustainable utilization of wildlife as also stated in the Namibia Vision 2030 (GRN, 2004). The opportunity to receive benefits through hunting and tourism created an incentive to protect wildlife for land users (Ministry of Environment and Tourism, MET; now acting as Ministry of Environment, Forestry and Tourism, MEFT, 2018a). Moreover, Namibia is one of the few countries that integrated the sustainable use of natural resources into their constitution (GRN, 2014).

Overall, the country's economy highly depends on its natural resources and sees great opportunity in tourism, especially connected to wildlife (GRN, 2008). In this regard, one of the best-known species is the African savannah elephant (*Loxodonta africana*). These species also decreased in numbers, but populations were seen to recover in Namibia in the recent years (Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 2016a). Actually, elephant populations not only increase in protected parks but also in areas that are inhabited by humans. In particular, outside of protected areas such as the Etosha National Park (ENP), elephants frequently migrate (Leggett, 2006). In many cases, however, sharing a landscape with large mammals that often wander around in large family groups is a challenge for land users. In areas where elephants occur, newspapers frequently report unpleasant encounters between humans and elephants (e.g. Schrader, 2019). Researchers and conservationists have assessed and are still examining the different dimensions of these so-called human-elephant conflicts (HEC) (Hoare, 2000, 2012; Osborn and Parker, 2003; DeMotts and Hoon, 2012). Different strategies were employed to prevent and mitigate these conflicts. Evaluations reveal that there is no "one-size-fits-all solution", but measures have to be adapted to the particular landscape and the specific dynamics of the interactions between resource users and elephants (Denninger Snyder and Rentsch, 2020).

In Africa, fences not only function to control livestock movement but also to prevent elephants or other wildlife from using a specific portion of the landscape (Ferguson and Hanks, 2010). McGranahan (2008) examined that Namibian commercial farmers construct fences mostly for livestock management purposes, while to a smaller extent to restrict wildlife movement. Since Namibian communal areas are prohibited from using fences, this option is not available to communal farmers (Government of the Republic of Namibia (GRN), 2013). However, the fences might pose considerable direct threats to the individual fitness of wildlife, e.g. through direct collision with these hard barriers (Ferguson and Hanks, 2012; Jakes *et al.*, 2018). Moreover, the resulting loss of connectivity may cause a considerably negative impact on ecosystems (Løvschal *et al.*, 2017; Jakes *et al.*, 2018). In this regard, Jakes *et al.* (2018) indicated the lack of knowledge on the consequences of fence construction. In particular, they outlined the importance of understanding the cumulative effect of fences on wildlife. They assumed that population demographics as well as ecosystem processes might be drastically altered when barriers appear in a landscape.

Against this background, the results of this study were intended to make a contribution for a better understanding of the general landscape connectivity for elephant movement in the study area south and southwest of ENP. Through the comparison between the current landscape and hypothetical environments, the cumulative impact of fences and game management was assessed, using corridor analysis. This least-cost analysis builds upon a mixed-method approach: Participatory mapping outlined the location and the type of game-proof fences, while simultaneously information on farm management characteristics was obtained and used as a proxy for human practices in the ecosystem. Findings from interviews served to frame the understanding of the local human-elephant interactions. Location records of seven collared elephants were the foundation for the assessment of the singular effect of both natural and socio-economic variables on

the habitat preference of elephants. Integrated into the final corridor analyses, these individual impacts were evaluated in a combined way and on a landscape level.

The thesis begins with the presentation of the research question and its objectives, which precede the description of the research area. The subsequent section provides background knowledge on the ecology, distribution, importance and endangerment of elephants as well as on human-elephant interactions including measures for conflict prevention and mitigation. It also explains the motivations for the construction and the advantages and disadvantages of fences. Subsequently, the methodology used within this study is explained and the results are presented. Finally, the discussion and conceptual embedding of the results follow, before the work concludes with a summary of the main outcomes of the study and an outlook for future management regarding human-elephant interactions.

2 Study area, research context and goals

Both, in Africa and Asia, the co-existence of elephants and humans is often fraught with challenges. Within the Namibian-German research project ORYCS (Options for sustainable land use adaptions in savannah ecosystems: Chances and risks of emerging wildlife-based management strategies under regional and global change), elephants are regarded as one of the focal species when looking at wildlife management. The following subsections will frame the research question and goals of this study. Furthermore, the geographic characteristics of Namibia and its land use structure will be introduced. The research project ORYCS, under which umbrella this study is conducted, and the study area will be presented. Finally, the last subsection will provide for background knowledge on the current research state on elephant ecology, the elephants' conservation status, their importance for the ecosystem as well as findings on the human-elephant relations and on fencing issues.

2.1 Research goals

Within the Elephant Management Plan (MET 2007b, p. 11), Namibia's government sets the goal "to carry the maximum number of elephants that is consistent with the conservation of biological diversity and the wishes of those primary stakeholders who have elephants on their land". This is a challenging task, as it encompasses social, ecological and economic objectives. While conflicts shall be reduced, benefits from elephants to people and the conservation of this species outside of protected areas shall be promoted.

It is evident that fences may be regarded as one of the most effective strategies to prevent human-elephant conflicts. However, Jakes *et al.* (2018) state that given the extent of fences worldwide, they received not nearly as much attention as roads and other linear infrastructure while showing a negative impact on wildlife. In this regard, the authors demand to "study fences as a broad-scale infrastructure that has widespread influence" (Jakes *et al.*, 2018, p. 310). This thesis is dedicated to the impact of fences on the landscape permeability for elephant movement with strong emphasis on the cumulative effect that according to Jakes *et al.* (2018, p. 310) is still not sufficiently understood on the landscape level, though crucial to "develop and implement practical solutions for sustaining wildlife and ecosystems in balance with social needs". They suggest the utilization of spatial fence data to assess the impact of fences on migration pathways. Closing these knowledge gaps may help to alter the fence systems and thus support ecological functions (Jakes *et al.*, 2018).

In order to address the current land use change from conventional livestock farming to game management in Namibia (Mannetti *et al.*, 2019) and to account for the heterogeneity of the management foci within the study area, the cumulative impact of fences is not regarded in isolation but in combination with prevalent land management, leading to the overall research question:

To which extent do socio-economic factors cumulatively impact the landscape permeability for elephants in the area south-west of ENP?

In this regard, through semi-structured interviews and geospatial data analysis on landscape connectivity, two goals are to be achieved:

1. **Provision of an understanding of the dynamics of human-elephant interactions within the study area and depiction of applied measures as well as future ideas on how to mitigate and prevent conflicts (qualitative assessment);**
2. **Assessment of the cumulative impact of fences and land management on landscape permeability for elephants within the study area (quantitative geospatial assessment)**

2.2 Namibia: geography, biodiversity conservation and utilization of natural resources

A large portion of Namibia's topography consists of a mostly flat and wide plateau at altitudes ranging from 900 to 1,300 metres above sea level. Lower altitudes occur only towards the coast, along rivers and in the south of the country (Mendelsohn *et al.*, 2003, p. 39)(Figure 1c). Namibia is characterized by low and unpredictable rainfall, which qualifies it as one of the driest Sub-Saharan countries experiencing frequent droughts. Furthermore, high rates of evaporation and evapotranspiration are caused by low humidity, high temperatures and intense solar radiation. On the other hand, temperatures may fall below freezing point during night times in winter (MET, 2010; Turpie *et al.*, 2010).

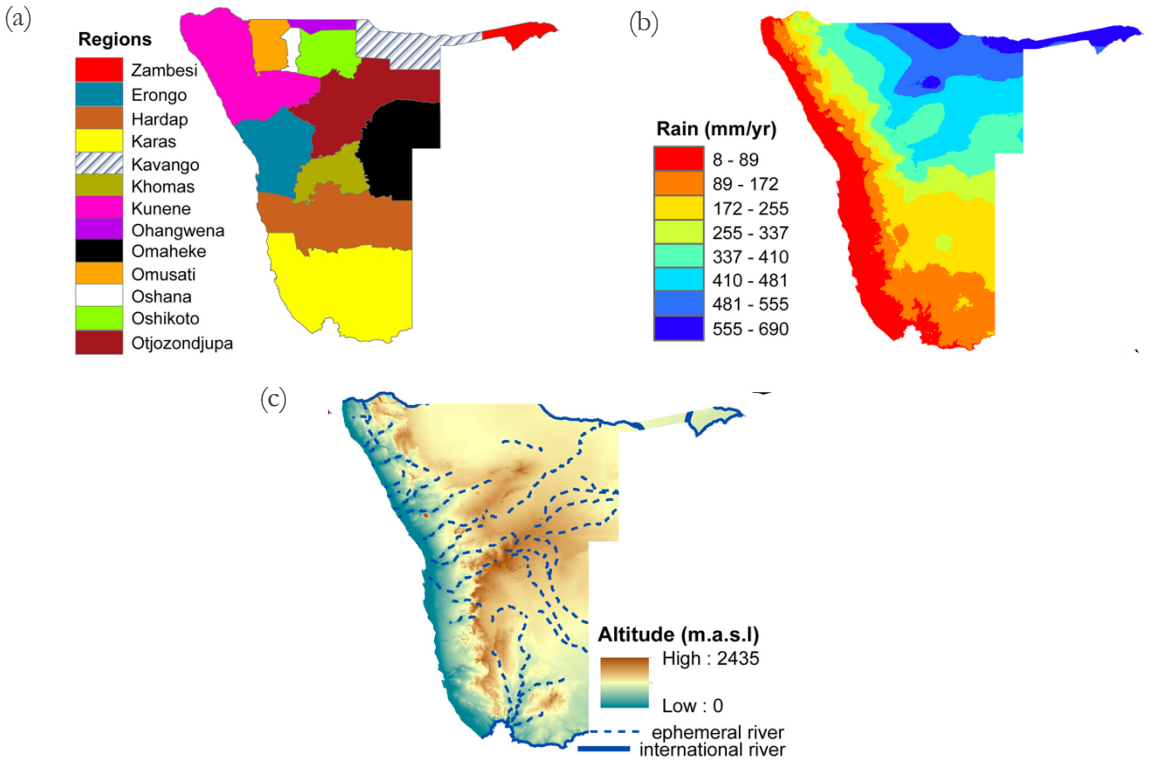


Figure 1: (a) Administrative regions in Namibia for orientation purpose, (b) precipitation gradient and (c) altitudes represented by the digital elevation model (DEM), extracted from Kaseke *et al.*, 2016).

Vegetation abundance and structure follow the north-east to south-west gradient of rainfall with increasing precipitation in the north-eastern parts of Namibia (Figure 1b) (Mendelsohn *et al.*, 2003). 22% of Namibia's area is classified as desert, 8% as dry sub-humid and 70% as arid and semi-arid (MET, 2020a, p. 7). Most of the country's area is made up of tree-and-shrub savannah whereby summer rainfalls, fires and grazing pressure from wildlife are the factors mainly influencing this biome (Mendelsohn *et al.*, 2003). These ecosystems are inhabited by a variety of mammalian species that are adapted to dry landscapes. Belonging to the 'big game', springbok, kudu, mountain and Burchell's zebra, elephant, hartebeest, giraffe and gemsbok are important tourist attractions and hunted for trophy or meat. Carnivores occurring in Namibia are lions, leopards, cheetahs, wild dogs and both spotted and brown hyaenas (Mendelsohn *et al.*, 2003; Lindsey *et al.*, 2013). Overall, Namibia's wildlife is a major tourist attractor, so that in 2017, the number of tourist arrivals in Namibia was recorded at 1,499,442, following a positive trend over the last years (MET, 2018b, p. 6).

Albeit the agricultural sector accounts for only 3.2% of the national Gross Domestic Product (GDP) (Van Schalkwyk and Hoffman, 2016, p. 2, referring to information of the Namibia Statistics Agency 2014), the largest proportion of the land is used for agricultural purposes. Moreover, the sector employs about one third of the country's workforce, has a direct impact on the livelihood of 70% of the population and is essential for food security (MET 2020a, p. 30). In 2004, the freehold sector accounted for 76% and the communal areas for 24% of the Gross Agricultural Product (GAP) (Mendelsohn, 2006, p. 10). The largest contributions came from meat products (59%), cereals (14%), grapes (5%) and dairy products (3%) (Mendelsohn, 2006, p. 10). Livestock farming is composed of cattle, sheep, goats and poultry (Mendelsohn *et al.*, 2003). Namibia's government recognized the economic potential of wildlife and hence devolved utilization rights of game to local people. By means of the Nature Conservation Ordinance, Act 4 of 1975, freehold farmers who privately own a piece of land were granted the ownership of the game being on their farm and enclosed with a game-proof fence. By an amendment of this act in 1996, partial rights were also granted to communal communities who established conservancies. These are gazetted by the government and activities on such communal land is coordinated by a conservancy committee representing the residing community (GRN, 2003). Following the concept of community based natural resource management (CBNRM), wildlife is managed locally on behalf of the State and the benefit generated by doing so shall be equally distributed to the conservancy members (MET 2010, 2013b). Benefits from wildlife through devolution of utilization rights may be seen as incentives to conserve local wildlife populations. This approach of conservation through sustainable utilization by effective local management led to an increase of wildlife populations (Barnes and DeJager, 1996; Turpie *et al.*, 2010; MET, 2018a). In 2016, wildlife use and tourism in combination accounted for 3.5% of the total GDP (Van Schalkwyk and Hoffman, 2016, p. 2, referring to information of the Namibia Statistics Agency 2014).

Although the income sources and the required management differ between game farming, livestock farming and tourism, the success is restricted by rainfall and land managers have to deal with its uncertainties. Projections from the Intergovernmental Panel on Climate Change (IPCC) indicated "high warming rates" and a "drying signal in the annual mean" rainfall for Namibia (Niang *et al.*, 2015, pp. 1209–1210). Moreover, both droughts and floods may occur more frequently (Niang *et al.*, 2015). For instance in 2013, the government of Namibia declared a state of emergency due to a persistent drought that caused food insecurity for an estimated one third of the country's population (Wilhite, Sivakumar and Pulwarty, 2014). Climate change impacts on the natural resources are predicted to lead to annual losses of 1.0 to 4.8% of the GDP (Reid *et al.*, 2008, p. 460).

2.3 Research context and study area: geographical characteristics and tenure structure

This study is part of ORYCS, an inter- and transdisciplinary joint Namibian-German research project funded by the German Federal Ministry of Education and Research (BMBF) within the funding measure SPACES-II (Science Partnerships for the Assessment of Complex Earth System Processes, 2nd call). The project is a follow-up initiative from the project OPTIMASS which investigated geosphere and biosphere feedbacks in order to provide for a sustainable rangeland management. ORYCS focusses on wildlife management strategies on communal and commercial farmland in Namibia. The aim is to assess the risks and options of wildlife management to contribute to the farmers' adaptation to climate change not only in African savannah ecosystems but worldwide (University of Potsdam, 2016; Blaum *et al.*, 2018). This study is embedded within the ORYCS framework to understand human-elephant interactions in combination with connectivity ecology. As such, the thesis is affiliated to the work package on social-ecological assessment. The working group follows a transdisciplinary approach and therefore, includes the local knowledge of people living in the study area. The author of this study is part of a tandem master's programme in which a Namibian and a German student complement and support each other, especially during the field phase.

The study area considered by the ORYCS project is situated in the country's north, the Kunene Region. It was spatially defined by the ORYCS project with the interest of including land use types relevant to wildlife management. In this regard, freehold land in the east, communal conservancies in the west and the ENP in the north are covered (Blaum *et al.*, 2018). For this research, the study area was adapted and includes the conservancies ≠Khoadi-//Hôas and //Huab, as well as the south-western part of ENP. //Huab and the selected freehold farms in the east and the south guarantee to cover the majority of the elephant records that were used for the geospatial analysis within this study.

Outside of ENP, the area of interest (Figure 2) lies within the constituencies Sesfontein, Khorixas, Kamanjab and Outjo (Mendelsohn *et al.*, 2003). It covers a total of 1.7 million hectares with a north-south and east-west extent of approximately 143 and 155 kilometres, respectively. The area almost reaches the

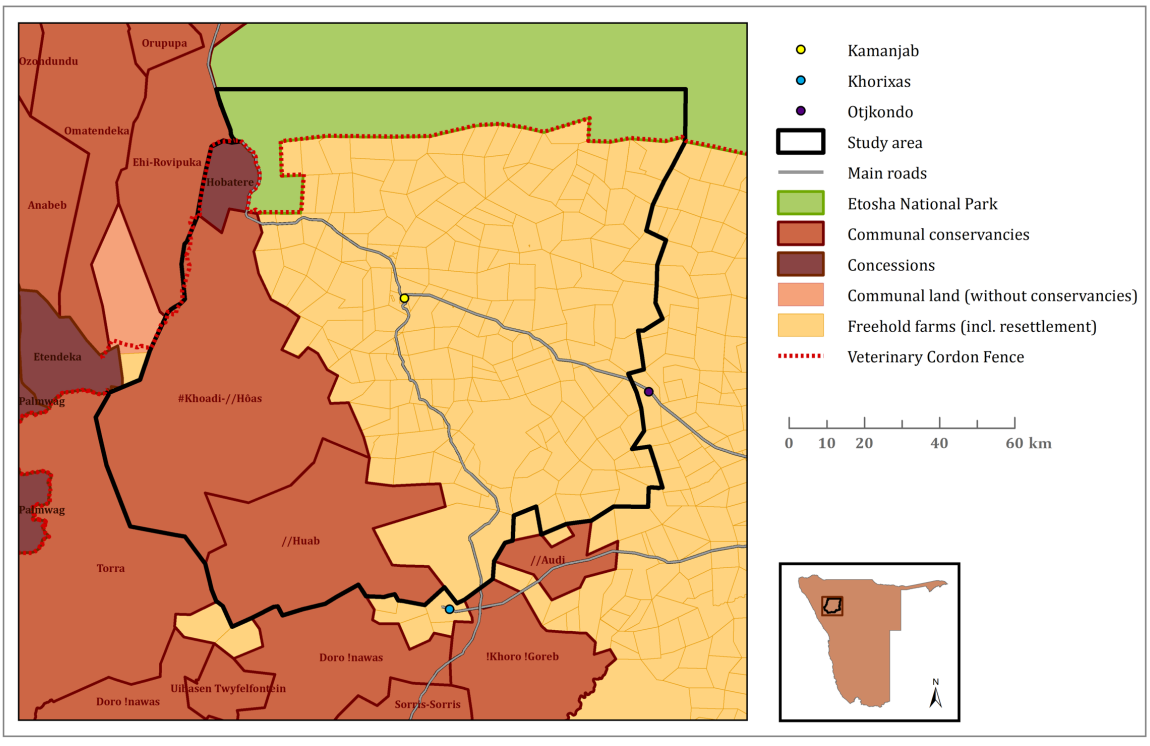


Figure 2: Study area entailing different land tenure types: communal conservancies, freehold farms, state-protected national park and Hobatere Concession.

town of Khorixas in the south and the village Otjikondo in the east. The semi-arid to arid region receives between 100 and 350 mm of rainfall on average per year (Mendelsohn *et al.*, 2003, p. 84) and is dominated by Acacia tree-and-shrub savannah. This sub-biome is generally characterized by occasional trees and shrubs in extended grassland and is represented by two vegetation types: the Karstveld with mixed woodlands as dominant plant structure and Western Highlands where grassland overweighs tree occurrence and which covers the southwestern part of the study area (Mendelsohn *et al.*, 2003). The area is located at an altitude of approximately 540 to 1,650 metres above sea level (Watkins, 2000). Besides various minor ones, two major ephemeral rivers characterize the study area: The Hoanib River has its source west of the town of Kamanjab flowing to the northwest and the Huab River starting northeast of Kamanjab and leading to the southwest straight to the sea (Mendelsohn *et al.*, 2003).

Farmers in the study area are engaged in livestock farming, semi-nomadic pastoralism, hunting and tourism (Mendelsohn, 2006). As presented in Figure 3, the area comprises different land ownership structures that are representative for Namibia. Freehold farmers privately own their farms, typically commercially operating game or livestock farming or being engaged in both (Mendelsohn, 2006). In the course of the national land reform process, the State is buying land from these farmers to provide it for the settlement by previously disadvantaged Namibians. By doing so, the State follows the objective to equitably distribute land and its natural resources (GRN, 1998, 2017). Freehold areas and resettlement farms cover approximately 57% of the entire study area (Figure 3).

State-owned land used as communal conservancies is located in the west of the study area. While commercial farming mostly seeks to maximise production, communal farmers usually do not invest greatly into fertilizers and equipment, specifically due to limited financial resources, but are rather engaged in subsistence farming (Mendelsohn *et al.*, 2003; Mendelsohn, 2006). Hobatere Concession is located on communal land and granted by the government. Concessionaires are allowed to use plant and/or animal resources, commercially. Hobatere is a wildlife-oriented concession and offers tourism activities with the purpose to enable business activities and economic development for local communities (Roe, Grieg-Gran and Schalken, 2001; GRN, 2008). While on a commercial farm, only the farmer's family and some worker families live, ≠Khoadi-//Hôas is inhabited by about 5.083 people and //Huab by 1,384 people (NACSO, 2020). Both conservancies make up approximately 30.9% of the study area while ≠Khoadi-//Hôas covers 20.1% and //Huab 10.8%.

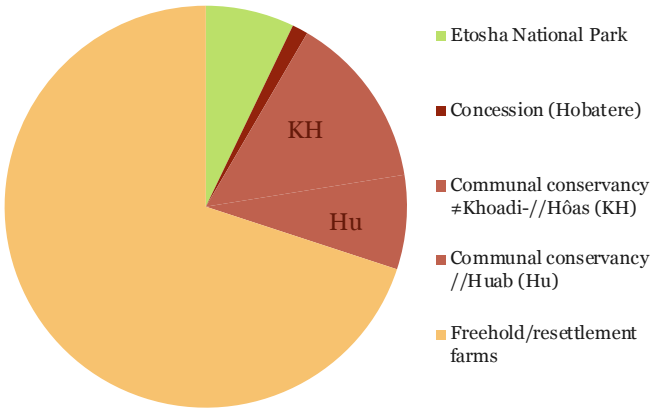


Figure 3: Proportion of land tenure types of total study area with predominating freehold/resettlement farms

ENP accounts for 10.2% and belongs to the country's protected area owned by the State. Any utilization of natural resources is prohibited except for activities coordinated by the MET (GRN, 2003). The park is surrounded to the south and west by a double fence: One line represents the boundary fences of neighbouring farms and communities, while the second one is a Veterinary Cordon Fence which was finalized in 1973 with the intention to be game-proof and used to protect the foot- and mouth-disease- and contagious bovine pleuropneumonia-free zone south of the fence which is required for the export of beef (Berry, 1997; Bishi and Kamwi, 2008; Scoones *et al.*, 2010). This so-called Red Line follows the northern boundary of Hobatere Concession and proceeds southwards along the western boundary of ≠Khoadi-//Hôas before leaving to the west (Mendelsohn *et al.*, 2003).

2.4 Elephants: ecology, conservation, benefit to biodiversity and relation to humans

Elephants are Africa's unique mega-herbivores. Various studies provide a comprehensive picture on their characteristics and social behaviour (e.g. van Aarde *et al.*, 2008). Due to their height and weight they have always played an important role within the ecosystem, hence are called 'ecosystem engineers'. Elephants have a long history on the African continent, however, the attitudes towards them have always differed. Hoare (2000, p. 34) describes this issue as follows: "Depending on one's values and one's situation, elephants may be considered as innocent and loveable, dangerous and destructive, or valuable and exploitable." The animals are seen as competitors or culprits causing damage and threatening lives on the one hand while on the other hand help to generate income by hunting and tourism (Naidoo *et al.*, 2016). They are seen as an inherent value within Africa's identity and Namibia's elephant populations are rising (CITES, 2016a). In order to secure elephant populations and increase the tolerance of people living coexistent with them, different management and mitigation strategies have been applied and evaluated in both Asia and Africa (Denninger Snyder and Rentsch, 2020).

2.4.1 Ecology and movement behaviour

As bulkfeeders, African savannah elephants (*Loxodonta africana*) have a high intake of plant material and hence, rather avoid to use areas with low availability of food (Olff, Ritchie and Prins, 2002). African elephants show a strong sexual dimorphism in body sizes: With an average shoulder size of 2.6 metres, female elephants are on average 23% smaller than bulls for which a mean of 3.2 metres was calculated (Larramendi, 2015, p. 550). In Etosha National Park, elephant bulls were recorded to have a shoulder height of 3.45 metres and in general weight up to 6 tons while the highest weight record of an Angolan elephant was 10 tons (Smithers, Apps and Abbott, 2012). Due to their size and weight, elephants lose a high amount of their available energy when even using minor slopes. Wall, Douglas-Hamilton and Vollrath (2006) revealed that the density of elephants in terrain of steeper slopes indeed decreased significantly.

On average, a four-ton elephant has to feed approximately 162 kilograms of wet vegetation per day to satisfy its energy demand. This is an equivalent of 42 kilograms of dry food (Petrides and Swank, 1965; cited by Wall, Douglas-Hamilton and Vollrath, 2006). Their competitive advantage is the extraordinary unselective diet: While grazers are mostly restricted to grass, elephants are able to switch to browsing behaviour including plant components like fruits, leaves, bark, branches, sedges, reeds and even roots and wood. Elephants focus on available grass in the wet season while mostly feeding on woody plants during the dry season (Olff, Ritchie and Prins, 2002; Smithers, Apps and Abbott, 2012). In order to satisfy the sodium and trace element demand, they furthermore eat soil, salt encrustations and rocks. Being not selective, they can occur where water and forage is provided: floodplains, grassland, woodland and tree savannah (Smithers, Apps and Abbott, 2012).

Elephants are migratory-nomadic and cover wide ranges when in search for forage areas and drinking spots (CITES, 2016a). They usually drink once a day, a bull approximately 120 litres (Smithers, Apps and Abbott, 2012, p. 157). However, they may survive three to four days without any water intake (Smithers, Apps and Abbott, 2012, p. 157). Observations show that an increasing density of potential drinking spots as well as heterogeneous landscapes led to a decreasing size of utilized area (Chamaillé-Jammes, Valeix and Hervé, 2007; de Beer and van Aarde, 2008). Water and vegetation availability vary seasonally and so does the elephants' movement behaviour: While they disperse further in the wet seasons to estimated more than 100,000 km² in Namibia (CITES, 2016a), elephants inhabit a distinct and smaller area during the dry months of the year (Smithers, Apps and Abbott, 2012). They move approximately 6km/day in dry landscapes while approximately only 3 km/day when being in the wettest environments (Loarie, Aarde and Pimm, 2009). Observations of savannah elephants in different southern African countries and in the Etosha National Park

revealed that the differences in movement behaviour differ less in generally wet seasons when water is permanently available. In the course of the day, elephants are less active in the midday avoiding heat and covering in the shade of trees to protect their skin (Loarie, Aarde and Pimm, 2009). They are more active during night when conducting regular treks to water points and are crepuscular, in general (Loarie, Aarde and Pimm, 2009).

2.4.2 Current conservation status and range

Populations on the African continent are estimated to decrease by 8% per year (Chase *et al.*, 2016, p. 14), except for Southern Africa where population records indicate a steady increase since the 20th century (UNEP *et al.*, 2013). Today, the African elephant is listed as vulnerable to extinction on a global scale on the IUCN Red List (Blanc, 2008). In particular poaching still poses a threat to elephant populations in many African countries (Wittemyer *et al.*, 2014). In the long term, habitats are lost or fragmented, standing opposite to the elephants' need for large areas. These circumstances are caused by increasing human populations with a higher demand for land, deforestation and agricultural development. These disturbances may increase in effect when weak laws and poor governance meet inadequate wildlife management. Furthermore, civil wars, prevalent poverty and corruption negatively affect the conservation of elephant populations (UNEP *et al.*, 2013).

Findings of the continent-wide Great Elephant Census in 2014 and 2015 estimate a current population size of around 350,000 African savannah elephants in 18 countries excluding South Sudan, Central African Republic and Namibia. This number is expected to represent around 93% of the total number of elephants in these countries (Chase *et al.*, 2016, p. 16). According to the African Elephant Status Report of 2007 (Blanc *et al.*, 2007, p. 112), Southern Africa represents an important region for elephants with approximately 39% of their total range. Estimates state that more than 290,000 elephants inhabit Southern Africa (IUCN, 2020a) which is the only region with a steadily increasing population as compared to the continent as a whole (UNEP *et al.*, 2013).

Aerial surveys in 2015 showed that the main elephant populations of Namibia comprise 22,711 individuals (CITES, 2016a, p. 4) and it is estimated that approximately 50% of the country's elephant range is located in proclaimed protected areas (CITES, 2016a, p. 8). However, for Kunene Region, the last estimate was only in 2009 and led to an estimate of 352 elephants. In 2015, Etosha National Park entailed 2,810 elephants (CITES, 2016a, p. 4). While historically, elephants inhabited the entire country in low densities, today, their range is restricted to the North (Figure 4a). Ehi-Rovipuka, ≠Khoadi-Hôas, //Huab as well as the freehold farms of interest cover this range. Simultaneously, due to a steady population increase and the construction of artificial drinking spots, they are able to inhabit areas they were absent before. Their current range is the

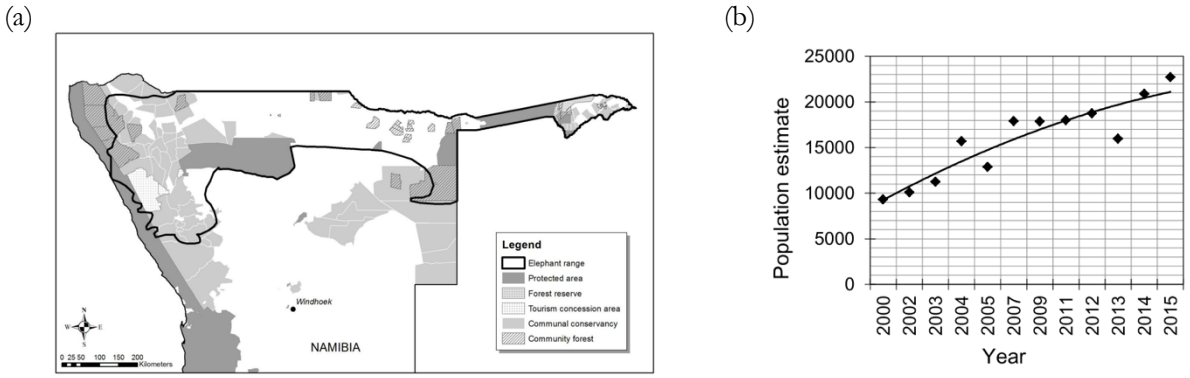


Figure 4: (a) Geographical elephant distribution limited to the northern part of Namibia and (b) population estimates from 2000 to 2015 indicating a positive trend for Namibia (CITES 2016a)

largest of the last century within Namibia, forming a viable population. Figure 4b presents recent estimates on elephant population based on aerial surveys. It shows a clearly positive trajectory leading to the highest estimate ever recorded in Namibia (CITES, 2016a).

2.4.3 Role within the ecosystem

For about 3 million years, elephants are inhabiting the African continent, in co-evolution with their environment and other species. As large mammals, they play an integral role within the ecosystem and promote biodiversity (Kerley *et al.*, 2007). Megaherbivores function as ecosystem engineers on different scales influencing various processes: due to their size, trampling and foraging behaviour, they directly influence vegetation (Owen-Smith, 1988; Ripple *et al.*, 2015). Shaffer *et al.* (2019) therefore express the need to conserve a healthy elephant population, as they function as keystone species.

In areas with a climax vegetation of woodlands, elephants help to create a patchy environment consisting of shrubland. This is important for other browsing species like for example impalas (*Aepyceros melampus*) (Rutina, Moe and Swenson, 2005) and black rhinos (*Diceros bicornis minor*)(Landman and Kerley, 2014). Likewise, large predators find easier conditions to hunt smaller ungulates after elephants thinned out the vegetation (Tambling *et al.*, 2013). On the patch scale, a more diverse and complex environment and therefore new habitats for small vertebrates like lizards are created when the number of damaged trees is increasing due to a high density of elephants (Pringle, 2008). This modification also provides new space for germinants to sprout (Owen-Smith, 1988). In ENP, the impact on woody plants was observed to be especially high in the vicinity to water sources (de Beer *et al.*, 2006).

Moreover, elephants modify the landscape when digging for underground water and moving surface material by trampling (Haynes, 2012). Finally, elephants significantly contribute to the long-distance dispersion of seeds (Campos-Arceiz and Blake, 2011). Kerley and Landman (2006) suggest that a decline of population scale may result in a cascading effect on the entire ecosystem with its variety of species. Nonetheless, the scale on which a high density of elephants may affect the environment must be considered. Moreover, in some cases it is difficult to determine the impact of each factor on tree population patterns alone when elephants, fires, drought, disease and other browsers have a combined impact on vegetation (Kerley *et al.*, 2007).

2.4.4 Human-elephant interactions

The relation between elephants and people clearly shows different facets. Twine and Magome (2007) emphasize the elephants' iconic value that contributes to Namibia's identity (Carruthers, 2010) and their use as clam totems and names as they are associated with power and royalty (Twine and Magome, 2007). The size and royalty of these animals also hold an aesthetic value which is manifested in the great popularity of elephants amongst visitors and thus, contribute positively to the economics within the tourism sector (MET, 2007b) and the recreational satisfaction of people (Twine and Magome, 2007). As still appreciated as symbols of the past, elephants from the 'wild Africa' found their way into marketing strategies that bring to mind the old times characterized by "great game hunters and explorers" (Twine and Magome, 2007, p. 209). Furthermore, people empathize with elephants as they are seen as "intelligent, social and long-lived creatures" (Twine and Magome, 2007, p. 209).

Approximately 70% of the continent-wide elephant range lies outside of protected areas (Chase *et al.*, 2016). Here, humans and elephants show the same habitat preferences (Twine and Magome, 2007) and frequently, share one landscape with challenges for both humans and elephants as they compete for the same resources (Denninger Snyder and Rentsch, 2020). This interaction can be considered as human-elephant conflict (HEC), politicized and emotionally charged (Twine and Magome, 2007). In Namibia, human-wildlife

conflict is officially described as "any event in which wild animals harm, destroy or damage human life or property (including damage to or destruction of crops), or in which wild animals are injured, captured or destroyed as a result of a perceived threat to humans or their property" (MET 2018a, p. 5). In particular, people living adjacent to protected areas bear high costs when elephants are entering agricultural landscapes which also applies to Namibia where neighbouring residents often do not have the economical means to cope with conflicts (MET, 2007a; Mackenzie and Ahabyona, 2012). Reports on incidents of HEC increased in all countries of Southern Africa (Cumming and Jones, 2005) and due to "on-going and future changes to land use, conservation policy, economic markets, and climate" humans and elephants will have to share more shrinking resources (Otiang'a-Owiti *et al.*, 2011; cited by Shaffer *et al.*, 2019, p. 6).

In Namibia, conflicts mostly arise around the competition for water resources and due to crop raiding by elephants as increased elephant populations expand their range into communal and freehold farmland (MET, 2018a). Artificial waterholes constructed for livestock made the area south and west of the ENP habitable for elephants as they find access to water (Hunninck *et al.*, 2017). Conflicts in north-west Namibia manifest most commonly in damage to infrastructure for water provision like windmills and water pipes, as well as to fences on farmland. High costs emerge as well when water for livestock and household use has to be pumped after a herd of elephants emptied the water reservoir. Other losses may result through physical threats like killed livestock or human injury or death (Cumming and Jones, 2005; Schnegg and Kiaka, 2018). Likewise, increasing conflicts pose a threat to elephant conservation as elephants' movement routes are confined due to the expansion of human activities. Movement which is relevant for the survival of individuals, gene flow in metapopulations and the occupation of new areas, is regarded as a worldwide endangered phenomenon (Wilcove and Wikelski, 2008; Bauer and Hoye, 2014; Panzacchi *et al.*, 2016). By analysing the concentration of faecal glucocorticoid metabolites, Hunninck *et al.* (2017) proved a higher psychological stress level of elephants outside of ENP and they observed significantly smaller herd sizes and lower occurrence of calves in that area.

In science, the facets and characteristics of HEC were already examined in Asia and Africa (Thouless, 1994; Hill, 1998; Hoare, 1999). Thouless (1994, p. 119) stated that "understanding the nature and extent of conflict under different circumstances" are crucial for conservation. Shaffer *et al.* (2019) for instance, emphasized interdisciplinarity as crucial to find sustainable long-term solutions and thus, developed a conceptual approach, which may be used to develop successful management strategies for human-elephant coexistence. When humans and elephants are supposed to coexist, costs have to be reduced and benefits increased resulting from the presence of elephants (Thouless, 1994). In order to reduce these levels of conflicts, different measures were implemented in Asia and Africa. Researchers reviewed these mitigation measures and concluded that the integration of farmers into the process of developing these strategies is a requirement for successful conflict reduction as conflicts have local characteristics (e.g. Osborn and Parker, 2003; Hoare, 2015; Denninger Snyder and Rentsch, 2020). The following subsections will introduce selected conflict mitigation measures on different scales giving a critical view on their implementation and success. The approach of fencing will also encompass other motivations for construction due to its societal and ecological complexity.

2.4.4.1 Policy framework on national and international level

Namibia committed to the conservation of elephants (MET, 2007b; Matinca, 2018) and is contracting party of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) which was signed in 1973 and came into force in 1975. This international treaty is an agreement between 183 countries to regulate the trade of over 35,000 wild species and their products for conservation purposes by preventing their over-exploitation through international trade. The parties see the conservation of species within their countries as responsibility of peoples and the State and therefore, are obliged to integrate the agreements of the CITES conferences of parties into their national legislation (Bowman, Davies and

Redgwell, 2010; Matinca, 2018). Species are grouped into three appendices, whereby the listing of the African elephant is controversially discussed. Currently, the regional elephant populations are listed in different appendices: Populations in Botswana, South Africa, Zimbabwe and Namibia are part of Appendix II and as such may enter limited sustainable domestic trade when authorized. The remaining populations belong to Appendix I as these are regarded as threatened by extinction and thus, are not approved for international trade. However, all ivory is regarded as part of Annex I and therefore, is prohibited to being traded internationally (CITES, 2016b).

In Namibia, elephants are under protection (GRN, 2003), however, the government is authorized to determine an annual number of permits for trophy hunting based on wildlife monitoring programmes in accordance with CITES regulations (MET, 2013a). In 2016, 90 elephant trophy hunting permits were issued for the entire country (Matinca, 2018). The acknowledgement of communal conservancies is another mechanism to provide for benefits of the co-existence with elephants. For 2013, Naidoo *et al.* (2016, p. 635) calculated that more than 50% of the overall trophy hunting income in communal conservancies was contributed through the hunt of elephants, based on the assumption that 13,300 dollars have to be paid for one animal. Schnegg and Kiaka (2018, p. 105) discovered that only "a small fraction of the revenues from community-based tourism, however, remains in the communities, and relatively few people profit from these revenues directly". Another instrument is the zonation of conservancies in areas for hunting, farming, locals, tourism and wildlife (Matinca, 2018). Namibia also recognizes the role of traditional authorities through the Traditional Authorities Act of 2000 (GRN 2000) and Communal Land Boards (GRN, 2013) to provide for the settlement of locals only outside of wildlife corridors (Matinca, 2018).

2.4.4.2 Local and regional human-elephant conflict mitigation tools

Within the scope of international and national restrictions, sub-populations of elephants may be regulated and controlled regionally. Likewise, farmers protect their livelihood from elephants locally. Such approaches are applied continent-wide and may be implemented through active and passive methods. Active measures entail direct action or intervention on animals (Cumming and Jones, 2005). As such, culling is a very controversially discussed method and may have two different objectives according to the South African Department of Environmental Affairs and Tourism (2008): First, by destroying a defined number of individuals, the size and the growth rate of a whole population is intended to be reduced. Second, selecting one individual observed to cause problems shall prevent future incidents with humans. In Namibia, the MET may declare an elephant as a problem causing animal and allow a landowner/lessee or a conservancy to shoot it (GRN, 2003). Slotow *et al.* (2008, p. 399) describe culling as "the only realistic mechanism to reduce population size in the short term if this is necessary to achieve specific management objectives". At first glance, these operations seem reasonable, however, there are some arguments against it: First, reducing the density of elephants in an area potentially increases the availability of biomass for each remaining individual that may, under these conditions, breed at maximal rate, followed by an increasing growth rate (Caughley, 1983; cited by Slotow *et al.*, 2008). Second, with the removal of experienced and older individuals which are often favoured for hunting activities due to their size, social knowledge influencing the entire group is lost (McComb *et al.*, 2001). Third, speaking of post-traumatic stress disorder (PTSD), culling events may negatively influence stress levels of remaining elephants and decrease resilience of witnessing calves that may result in stress-reactive aggressive behaviour when matured, which may increase the number of problem causing elephants as a result (Bradshaw *et al.*, 2005). Almost identical short-term stress levels are observed in the course of translocations when individuals are transported from areas where humans and elephants live closely together to protected areas (The African Elephant Specialist Group in collaboration with the Re-introduction and Veterinary Specialist Groups, 2003; Slotow *et al.*, 2008; Viljoen *et al.*, 2008). Stress may also be observed amongst the remaining individuals of the herd (The African Elephant Specialist Group in collaboration with the Re-introduction and Veterinary Specialist Groups, 2003) and studies revealed that problem causing elephants belonged to an incomplete family group (e.g. Grobler *et al.*, 2008). Fernando *et*

al. (2012, p. 8) regard translocation as being driven by "public and political pressure" while target areas are sparse (Grobler *et al.*, 2008) and elephants were observed leaving the areas they were brought to. This was followed by intensified conflicts in new areas and an increased elephant mortality rate. Hence, translocation neither contributes to the HEC mitigation nor to elephant conservation (Fernando *et al.*, 2012).

Elephants may also be disturbed in order to deter them from property, like for instance through trip alarms (O'Connell-Rodwell *et al.*, 2000). However, O'Connell-Rodwell *et al.* (2000) stated that elephants get used to disturbances. Furthermore, this operation may be dangerous and therefore, requires trained personnel (Nelson, Bidwell and Sillero-Zubiri, 2003). Another direct approach is immuno-contraception (Bertschinger *et al.*, 2018). While contraception is reversible, vasectomy of male elephants is not and therefore, is suggested to be applied only after being considered carefully (Garaï *et al.*, 2018). Both are invasive methods which are used to thwart population growth and hence, declines only appear with a long time delay (Cumming and Jones, 2005).

Passive approaches are favoured by a number of stakeholders as these are not lethal and therefore, ethically more justifiable. However, mortality may also occur not apparent at a first glance but indirectly (Cumming and Jones, 2005). With the attempt to repel elephants from farm or agricultural land, moats and ditched have been created to prevent elephants from entering a farm and agricultural plots. However, due to erosion, these structures require high maintenance efforts and are only applicable in areas without high rainfalls (Omondi, Bitok and Kagiri, 2004; Grant *et al.*, 2008). Studies have shown that aerial spraying of chili (*Capsicum*) extracts deter elephants effectively without causing aggressive reactions (Osborn, 2002). Chili may also be applied to fences, though associated with high costs compared with traditional measures and intensive labour. The efficiency is assessed as being highly variable (Denninger Snyder and Rentsch, 2020). Bee hives are less labour intensive (Denninger Snyder and Rentsch, 2020) and proved to be a good measure as elephants appeared to be sensitive to the buzzing sound and the stings of the insects (King, Douglas-Hamilton and Vollrath, 2007; King *et al.*, 2009).

On the broader scale, the distribution of elephants is manipulated by the creation of artificial water spots. This method is a complex and controversial issue and subject to various studies. It is evident that due to a higher (artificial) water supply, the movement distribution patterns of elephants are altered as they may move further away from rivers. Conclusively, elephants may increasingly use areas where beforehand, no water was available (Purdon and van Aarde, 2017). Thereby, the impact of elephants on the ecosystem might on the one hand be homogenised and/or on the other hand have tremendous effects on vegetation when being confined to a smaller area (Loarie, Aarde and Pimm, 2009). Likewise, during dry season, foraging pressure is exerted to areas where elephants usually would not be roaming (Loarie, Aarde and Pimm, 2009). In contrast, the spatio-temporal variability in space utilization induced by the reduction of artificial water sources might even have positive outcomes like heterogeneity of the savannahs induced by migrating elephants (Kohi *et al.*, 2011; Purdon and van Aarde, 2017).

2.4.4.3 Motivations, benefits, disadvantages and efficiency of fences

Game-proof fences play a major role in the human-wildlife-interface, spatially separating wild animals and people to avoid conflicts and thus, increase tolerance towards wildlife (Grant *et al.*, 2008; King *et al.*, 2017). Apart from that, other intentions motivate actors to construct different types of fences: visualizing boundaries to other properties or countries, managing and protecting resources through livestock control, conserving areas inhabited by endangered species and regeneration of degraded areas through elimination of disturbances by intruders (Kotchemidova, 2008; Jakes *et al.*, 2018). In Namibia, ownership and hunting rights are bound to the implementation of fences: according to the Nature Conservation Ordinance, Act 4 of 1975 as amended (GRN, 2003, Section 29), the owner of a farm only owns huntable game if the farm "is enclosed with a game-proof fence or an adequate fence or of any piece of land which is not less than one thousand hectares in extent and enclosed with a game-proof fence". By 1980, over 7,000 kilometres of

fences to restrict livestock and/or game movement were counted in Namibia (Scoones *et al.*, 2010, p. 137). One example of comprehensive fencing is the Veterinary Cordon Fence that divides Namibia in a northern and a southern part. The area south of this "red line" is declared to be free of the foot-and-mouth disease and contagious bovine pleuropneumonia. Beef originating from here may enter international markets, as opposed to the regions north of the fence (Bishi and Kamwi, 2008; Scoones *et al.*, 2010). This north-south divide can partly be traced back to the German colonial occupation of the region (Kössler, 2015). Today, the northern control zone is dominated by farmers on communal areas who are excluded from international beef trade markets (Bishi and Kamwi, 2008; Scoones *et al.*, 2010).

In some landscapes, fences were counted to be even more extensive than roads as they are installed not only by governmental authorities but also private landowners (Jakes *et al.*, 2018). Even when constructed for conservation purposes, these vertical structures may have negative impacts on wildlife, in particular to non-focal species, on smaller and larger scales (Jakes *et al.*, 2018). Direct negative effects on the health state of animals may occur when animals are physically confronted with fences: animals may lose hair, get injuries or even die by colliding with the fence. Mortality may also occur when animals get stuck in fences and suffer from predation or starvation, like for instance observed in the Namib desert (Hauptfleisch and Urban, 2017). Searching for a passage through multiple fences (Jakes *et al.*, 2018; Seidler, Green and Beckmann, 2018) goes along with stress, high energy costs and hence, decreasing individual fitness. The separation of new-borns from mothers or herds as they are not able to cross fences, may lead to a decreasing population size (Harrington and Conover, 2006). On a broader scale, fencing areas may decrease habitat availability in a landscape. This is particularly dramatic for species that have to migrate in order to find feeding grounds (Løvschal *et al.*, 2017). Similarly, when not able to migrate, animals like elephants get 'bunched up' at fences leading to increased pressure on the vegetation (Owen-Smith *et al.*, 2006; Loarie, Aarde and Pimm, 2009). Within a fenced area, edge effects of fences may occur, driving the elephants to the central part and there, increasing pressure onto the ecosystem (Vanak, Thaker and Slotow, 2010).

Due to their size, it is challenging to find structures that successfully prevent elephants from crossing. For instance, the Veterinary Cordon Fence shows breakages by elephants which can facilitate the spread of diseases (Grant *et al.*, 2008). Various studies conclude that the effectiveness of fences as barriers mostly depend on their design, constant maintenance and prompt repair of damaged sections, the location of fences in relation to surrounding landscape characteristics and the elephant density (Kioko *et al.*, 2008; Kesch, Bauer and Loveridge, 2015). O'Connell-Rodwell *et al.* (2000) observed that only electrified fences succeeded to reduce the loss of wildlife due to conflicts with humans in the long term and on the large scale. They also emphasize the importance of elephants to fear the fence and to frequently repair breakages. Furthermore, agricultural areas have to be totally fenced in, as the animals will quickly learn where to find the end of the fence and enter the area. Mutinda *et al.* (2014) even found that elephants broke fences after they learned that their tusks did not conduct electricity. The authors concluded that detusking would drastically reduce fence-breaking incidents. Other studies revealed that non-electrified barriers were generally ineffective, except when being combined with chili, while indeed being expensive (Nelson, Bidwell and Sillero-Zubiri, 2003; Sitati and Walpole, 2006). From their literature review, Nelson, Bidwell, and Sillero-Zubiri (2003, p. 13) even concluded that "electrified fences are perceived to be the best solution for human-elephant conflict". Denninger Snyder and Rentsch (2020) summarized that unelectrified fences bare low costs, however, show low efficiency and the risk that elephants become habituated. In contrast, electrified barriers are expensive to construct, and maintenance costs are high but indeed, show significant efficiency when maintained properly Denninger Snyder and Rentsch (2020). In this regard, Pekor *et al.* (2019, p. 73) describe fences as "likely to be a waste of both time and money" when the funding for the long-term maintenance and repair is not guaranteed. Finally, it has to be considered that fences might only shift problems: While elephants were excluded from a distinct area, increased conflicts occurred outside (Sitati and Walpole, 2006).

3 Methods

The study applies an interdisciplinary approach by combining social science perspectives with a geospatial data analysis: In order to understand how human-elephant interactions are structured, experts and local stakeholders were consulted through a socio-empirical survey in the study area and in Windhoek. Together with publicly accessible raster images on topography and vegetation, collected information on farm management and the identified location of game-proof boundary fences were fed into a geoinformation system. By analysing the GPS records obtained from seven collared elephants and by creating suitability maps based on the above-mentioned data and findings from the interviews, core areas were identified which served together with resistance raster images in a further step as input for the final corridor analyses. These resistance raster images were altered to create different hypothetical landscapes. By comparing the corridors, the cumulative impact of game-proof boundary fences and land management types was assessed. The detailed workflow in Figure 5 serves as guidance through this study.

3.1 Empirical research in Namibia

The empirical research phase took place in June and July of 2019. By interviewing both experts and farmers, the aim was to gather insights into wildlife management in Namibia, human-elephant interactions and the role of fencing from different viewpoints. Furthermore, a farmers' meeting was attended to observe discussions between government officials, freehold and resettlement farmers on human-elephant interactions. Each interview in the study area included participatory mapping to update the current knowledge on farm boundaries and to complement original spatial data with information on farm management and the location and type of game-proof fences.

3.1.1 Semi-structured interviews and observation of group discussion

Quantitative and qualitative interviews are a common social science method used in conservation science to assess perceptions and viewpoints of stakeholders (Young *et al.*, 2018). As a combination of quantitative and qualitative techniques, semi-structured interviews serve as a tool to assess factual information that is comparable from one interview to another while providing space for qualitative questions to pick up interesting aspects during a discussion (Bryman, 2016). Hence, semi-structured interviews were conducted with experts working on local, regional and national levels as well as freehold farmers directly living coexistent with wildlife (Table 1). All interviews were recorded via field notes.

Most expert interviews were conducted in cooperation with one researcher from ORYCS and complemented the surveys of the local farmers. The first three interviews, however, were taken individually, based on the questionnaire in Appendix 2 and in particular, served to frame the present issues around wildlife management, fences and human-elephant interactions. Using the outcomes from these expert interviews and results from previous literature research, a comprehensive semi-structured questionnaire for the upcoming interviews in the study area was drafted in cooperation with the ORYCS team. Being the first survey within the project, the questionnaire for the farmer interviews included items/questions that were of particular importance for the ORYCS project. It comprised questions on land management, human-wildlife-interactions, perceptions on wildlife, issues around fencing and knowledge about elephant behaviour and movement in the particular area. Information on the kind of farming and the type of the farm boundary fences were part of the participatory mapping process (see Section 3.1.2).

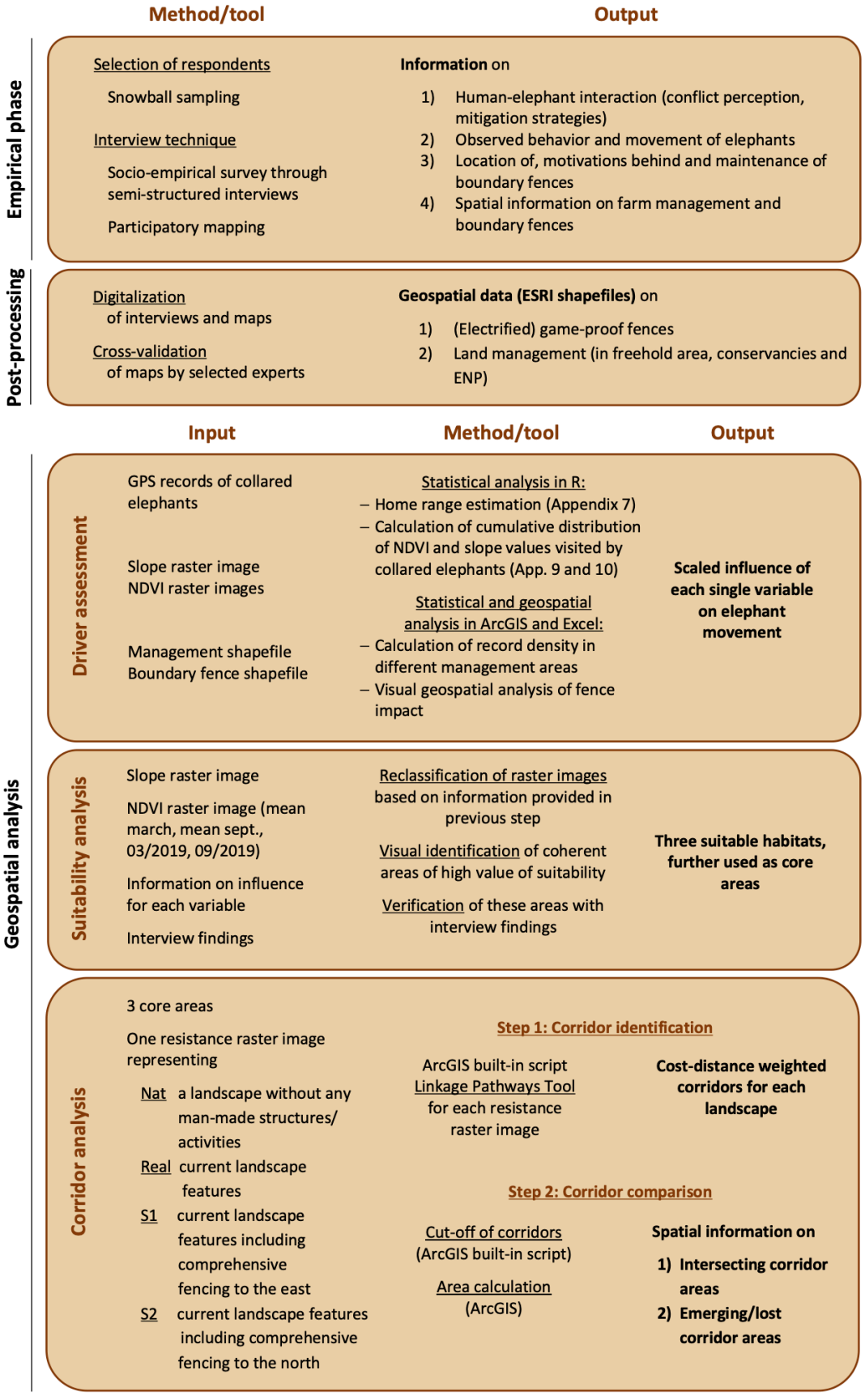


Figure 5: Workflow of the study, beginning with the empirical phase and leading to the comparative description of calculated corridors.

Table 1: Interview characteristics, conducted during the field phase in 2019; for more detailed information on the particular interviews see Appendix 1.

Semi-structured interviews			
Respondents	**Number of respondents**	**Characteristics of respondents**	**Interviews characteristics**
Experts	9	Experts from NGOs, associations, universities, management of communal conservancies, MET, management of ENP	Semi-structured interviews, qualitative (Appendix 2)
Experts	2	Government officials with knowledge on local farms	Contribution to the participatory mapping process
Freehold farmers	11	Farmers living and working around Kamanjab	Semi-structured interviews, qualitative and quantitative (Appendix 3)
Group discussion			
Farmers' meeting	Approx. 30 participants	Topic "problems with elephants", participants: freehold and resettlement farmers, officials of MET and Veterinary Service; further described as "elephant meeting"	Author as observant taking notes

Due to time constraints, only a small set of farmers could be interviewed. Eleven freehold farmers were selected consecutively by snowball sampling (Newing, 2010). Asking respondents about other potential interviewees amongst their neighbours appeared to be an effective way to get an idea about their farm management practices prior to approaching them. Overall, it was aimed to interview farmers engaged in livestock farming, game management and tourism. In the beginning of each interview, the farmers were informed about the overall project context, the topic of the interview and the confidentiality of their personal information. Apart from one farmer and one expert interview in German, the language during the interviews was English. Most of the surveys were conducted by the author together with the partner from the tandem master studies programme with the exception of two interviews that were accompanied by another ORYCS colleague and one interview which took place without a second project member.

In addition to the individual interviews, the attendance of a farmers' meeting with the ministry allowed to observe discussions around the human-elephant conflicts occurring in the area around and between Kamanjab and Outjo.

3.1.2 Participatory mapping

To adequately determine how human activities such as land management and game-proof fences affect elephant movement recent spatial data was required. Mendelsohn *et al.* (2003) comprehensively mapped Namibia including boundaries of commercial farms (Namibian Chamber of Environment (NCE), 2020). However, the data was considered to be at least partly outdated. As it was not possible to map farm management and boundary fences by satellite imagery, participatory mapping was considered adequate for the study.

The International Fund for Agricultural Development (IFAD) (2009, p. 6) defines participatory mapping as "a map-making process that attempts to make visible the association between land and local communities

by using the commonly understood and recognized language of cartography". Participatory mapping is applied world-wide on different levels providing maps that may entail detailed information on infrastructure and land use-occupancy (IFAD, 2009). Also in conservation studies, participatory mapping is one of the methods that is often carried out in combination with interview techniques (Young *et al.*, 2018).

Using available geodata (shapefiles) on the (i) commercial farms, (ii) the communal conservancies and (iii) the ENP (NCE, 2020) a map with farm boundaries and farm names was printed twice in DIN A1 format and the respondents were asked individually to update boundaries, farm names, mark out game-proof boundary fences and type of land use (Table 2). Camp fences installed for livestock management were not sampled. For orientation issues, the map also included main roads and the location of communal conservancies. The background map showed information on terrain from Open Street Map. Due to time constraints, it was not feasible to visit each farm in the study area. Notwithstanding, allowing respondents to give information about their neighbours and other farms in the region provided for a greater spatial coverage where no farms could be visited. Moreover, two local experts added their knowledge to the map (E10 and E11 in Appendix 1). The mapping process was always accompanied by at least one of the tandem master students who inquired additional explanatory information from the respondents.

With respect to the internal land use structure within the communal conservancies of the study area, the spatial zonation of the communal conservancy ≠Khoadi-//Hôas was utilized (NACSO, 2012). As this zonation pattern was unavailable for //Huab conservancy, the entire conservancy was classified as game management area since hunting activities contribute noticeably to the conservancy's financial returns (NACSO, 2017).

Table 2: Requested attributes in the process of participatory mapping.

Attribute	Options	Background
Land use (Multiple choices possible)	– Hunting (trophy, shoot and sell, own consumption) – Livestock (e.g. cattle) – Tourism (both consumptive and non-consumptive)	Increased faecal stress hormone levels of elephant bulls and herds after being present at a hunt (Burke *et al.*, 2008) Behaviour change to avoid risk, e.g. foraging at night, higher walking speed during daytime (Douglas-Hamilton, Krink and Vollrath, 2005)
Game-proof boundary fencing (to be drawn in the map)	– Game-proof fences – Electrified game-proof fences – Assumption: every other farm surrounded by livestock-proof fence that elephants may overstep	Variation in efficiency of different fence types (see Section 2.4.4.3): electrified fences are assumed to function more successfully as deterrents than non-electrified fences

3.2 Post-processing of field work data

The fieldwork output was processed to serve for further analyses. In this regard, the following subsections provide a brief description of (i) how the participatory mapping results were digitized and transformed to spatial data and (ii) how the interviews were transcribed and made accessible for content analysis.

3.2.1 Digitalization of maps and preparation of geodata

The geospatial information, which was added to the printed maps during fieldwork (Appendix 4), was digitalized to shapefiles and validated through a review process by three local experts. More detailed, the procedure of digitalizing the data may be differentiated into four steps: (i) the spatial adaption of the current shapefiles representing freehold farms and communal conservancies, (ii) the creation of one shapefile including information on boundary fences, (iii) the validation of updated data by experts, and (iv) the translation from land use to management categories. As a result, two shapefiles were generated: The first representing the land management as spatial polygons and the second showing polylines for game-proof and electrified game-proof boundary fences.

The shapefile on commercial farms that was initially used to create the field map was edited according to the respondents' statements and by using additional analogue cartographic material from the Directorate of Survey and Mapping of Namibia (1914 Kamanjab Map, 3rd edition of 2002, Private Bag 13182, Windhoek, Namibia). The ≠Khoadi-//Hôas polygon was divided into different areas according to the conservancy's zonation plan (NACSO, 2012). Inconsistencies between all three shapefiles were eliminated by adjusting commercial farm boundaries to the national park and the communal conservancies polygons. Subsequently, based on the farm and conservancy boundaries, game-proof and electrified game-proof fences were digitalized as a polyline shapefile.

During the field phase, three farmers were selected who appeared to be well connected with their neighbours and have a good overview over the area around their farms. They received access to a map in PDF format (Appendix 5) and a list assigning land use options to tick for each particular farm. Two farmers answered the request and gave their feedback on the mapping results (Appendix 6). Subsequently, the information on land use was categorized into three different groups, further defined as 'management types' (Table 3). For five farms, no information on land use was available. Considering the descriptions of the farming systems in the area by Mendelsohn (2006), they were assigned to livestock management.

Table 3: Translation of land use information to management categories.

Management types	Description
Game management	Management focus on game, including hunting, e.g. for population regulation purposes
Livestock management	Management focus on livestock, hunting may take place but only with a small amount and/or for own use only (biltong hunt, hunting with shoot and sell permits)
No hunting	Areas without any hunting activities, e.g. protected areas, management focus mostly on tourism, frequently with tourism facilities; in communal conservancy: wildlife zone

3.2.2 Digitalization of interviews

The field notes were digitalized and served as primary material for further analysis. In this regard, qualitative content analysis was carried out (Mayring and Fenzl, 2014). To understand the human-elephant interactions, relevant information was extracted using a coding approach (Young *et al.*, 2018): Categories were developed in a deductive way to code the digitized interview material. While processing the texts, codes were adapted and extended inductively when new information appeared. Finally, the coding scheme considered the following main categories:

- estimated herd and population size in the study area,
- observed movement behaviour,
- incidents perceived as problems by the respondents,
- current mitigation and response measures,
- discussed strategies to mitigate future human-elephant conflicts,
- motivations for installing fences and their effect on wildlife, and
- damage on and maintenance of fences.

The findings were used to frame the human-elephant interaction dynamics and to provide baseline information on the decision-making process within the subsequent geospatial data analysis.

3.3 Geospatial data analysis

The geospatial data analysis may be differentiated into (i) the creation of four two-dimensional spaces which represent the project region being characterized by different landscape characteristics, and (ii) the application of a corridor analysis within these landscapes. Based on the GPS records from the collared elephants, preferences on habitat features were derived. This information served to prepare the framework of and requirements for the final corridor analyses. More precisely, habitats were identified, which were considered as suitable and therefore, determined as core areas, and resistance surfaces were calculated. The analyses in the different environments and the comparison of their outputs were intended to reveal insights into the effect of socio-economic structures on the permeability of the landscape within the study area. Calculations were conducted with ArcGIS (ESRI 2018), R (R Core Team - R Foundation for Statistical Computing, 2019), R Studio (RStudio PBC, 2019), QGIS (QGIS Development Team, 2019) and Excel (Microsoft Corporation, 2020).

3.3.1 Home range estimation

Telemetry data of seven collared female elephants roaming the study area, most likely in family groups, served to determine the elephants' general habitat preferences and the resistance of the landscape for the species (MET, 2019). An overview is given in Table 4 indicating if the animals primarily roamed west (W) or east (E) of the main road leading from Kamanjab to Khorixas. The data used in this study covers 13 months in total, between October of 2018 and October of 2019. There is only one larger data gap for one elephant (collar ID: 0BCD) from 08/06/2019 to 08/08/2019 whose cause is unknown. As there are different time intervals of one and four hours between two recorded GPS fixes, the numbers of records utilized for analysis differ amongst the individuals.

Table 4: Elephant records used for home range analysis (collar ID identically used as elephant ID)(MET, 2019).

ID	0BCD	4F9F	3ECO	C2C5	4ED4	6366	BCD4
No. of GPS records	8,499	9,246	2,329	2,349	2,347	9,415	2,296
interval	1h	1h	4h	4h	4h	1h	4h
location	E	W	E	E	W	E	W

A frequently used method to analyse the space use of animals is the calculation of utilization distribution (UD) and home ranges (e.g. Ofstad *et al.*, 2016; Froy *et al.*, 2018; Knüsel *et al.*, 2019). UD "is defined as the two-dimensional relative frequency distribution for the points of location of an animal over a period of time" (Van Winkle, 1975, p. 118) or in other words, differentiates regions according to a probability density function that defined the animal's use of space (White and Garrott, 1990; Getz *et al.*, 2007). In this study, UD was calculated based on a least-square cross-validation algorithm within the R function *kernelUD* which is part of the package *adehabitatHR* (Calenge and Fortmann-Roe, 2020). Here, the UD is determined as the "bivariate function giving the probability density that an animal is found at a point according to its geographical coordinates" (Calenge and Fortmann-Roe, 2020, p. 33). This calculation is based on the bivariate kernel density estimation for all observation points (GPS records) as described by Worton (1995). Kernel density distribution may be seen as a "smooth curved surface" for every record with the highest probability at the location of that specific point. All surfaces of each point are combined to estimate the probability distribution for the sum of all observations (ESRI, 2020a).

Given the resulting isopleths, kernel home range contours were extracted by using the R function *getverticeshr* (Calenge and Fortmann-Roe, 2020). Home ranges are defined as "the minimum area in which an animal has some specified probability of being located" (Calenge and Fortmann-Roe, 2020, p. 33). Practically, they appear as calculated isopleths/contours represented as polygons that enclose a defined percentage of the available movement records. For each elephant and the entire time period of 13 months, the 95% and 50% home range polygons were calculated. The 95% home range is derived from 95% isopleths of the probability distribution. Hereby, points that only show short excursions of the animal are excluded. The core habitat of an individual is usually represented by the 50% isopleths (Kernohan, Gitzen and Millspaugh, 2001; Gitzen, Millspaugh and Kernohan, 2006; Chirima and Owen-Smith, 2017). The applied script is attached in Appendix 7.

3.3.2 Assessment of input variables

Both, environmental and socio-economic variables were used to assess the habitat suitability of and the permeability for movement within the study area (Table 5). The aim of this working step was to determine, how suitable or permeable each cell is in terms of a particular variable, respectively.

As presented in Section 2.4.1, various factors influence habitat selection and movement possibilities of elephants such as water and food availability as well as terrain conditions. However, the following analysis only includes two environmental variables, namely slope and vegetation (Figure 6). Although the distribution of water points plays an important role in the movement behaviour of elephants (Loarie, Aarde and Pimm, 2009; Cushman, Chase and Griffin, 2010), the available spatial data was insufficient for the study area (see Section 5.3).

For the purpose of depicting the spatial vegetation distribution and its temporal signal over time, several potential data products exist. The soil-adjusted vegetation index (Huete, 1988) is regarded as adequate for sparsely vegetated areas, but it requires extensive local calibration (Pettorelli *et al.*, 2005). Within other studies (Bailey *et al.*, 2004; Bonn, Storch and Gaston, 2004; Duffy and Pettorelli, 2012; Osipova *et al.*, 2018), the Normalized Difference Vegetation Index (NDVI) proved to be an adequate measure to determine the relationship between primary productivity and species richness. Being accessible in high resolution, NDVI was used as a proxy for availability of vegetation within this study. NDVI is derived from satellite imagery using the bands that record near-infrared and red light reflected from vegetation. More precisely, it is calculated by the red/near-infrared reflectance ratio (NIR – RED)/(NIR + RED) (Myneni *et al.*, 1995; Pettorelli *et al.*, 2005). Applying the Google Earth Engine (Gorelick *et al.*, 2017), monthly NDVI was calculated based on the bands of Landsat 5, 7, 8 and MODIS satellite data using a code provided by Sassik (2019). Each month resulted in one raster image with a cell resolution of 30 metres. Every raster cell was assigned with one NDVI value calculated by the median of all available bands within the concerning month.

While vegetation changes on a temporal and spatial scale, topography is considered a static variable. For this study, one-band raster images generated during NASA's Shuttle Radar Topography Mission (SRTM) in 2000 were acquired in a resolution of 30 by 30 metres (Watkins, 2000). The raster image cells included the particular elevation and were merged to entirely cover the study area. Subsequently, the slope for each raster cell was calculated as the maximum rate of change from the specific cell to its neighbouring cells in ArcGIS. This maximum change in elevation was given in degrees (ESRI, 2016).

To determine the relationship between the collared elephants and their environment, all GPS records were assigned with the (i) NDVI value of the particular month and the (ii) value for slope of the underlying raster cell. For each variable, the empirical cumulative distribution and subsequently, the 20th, 40th, 60th, 80th and 100th percentiles were calculated (Appendices 9 and 10). These values were partly used as class boundaries for suitability and corridor analyses.

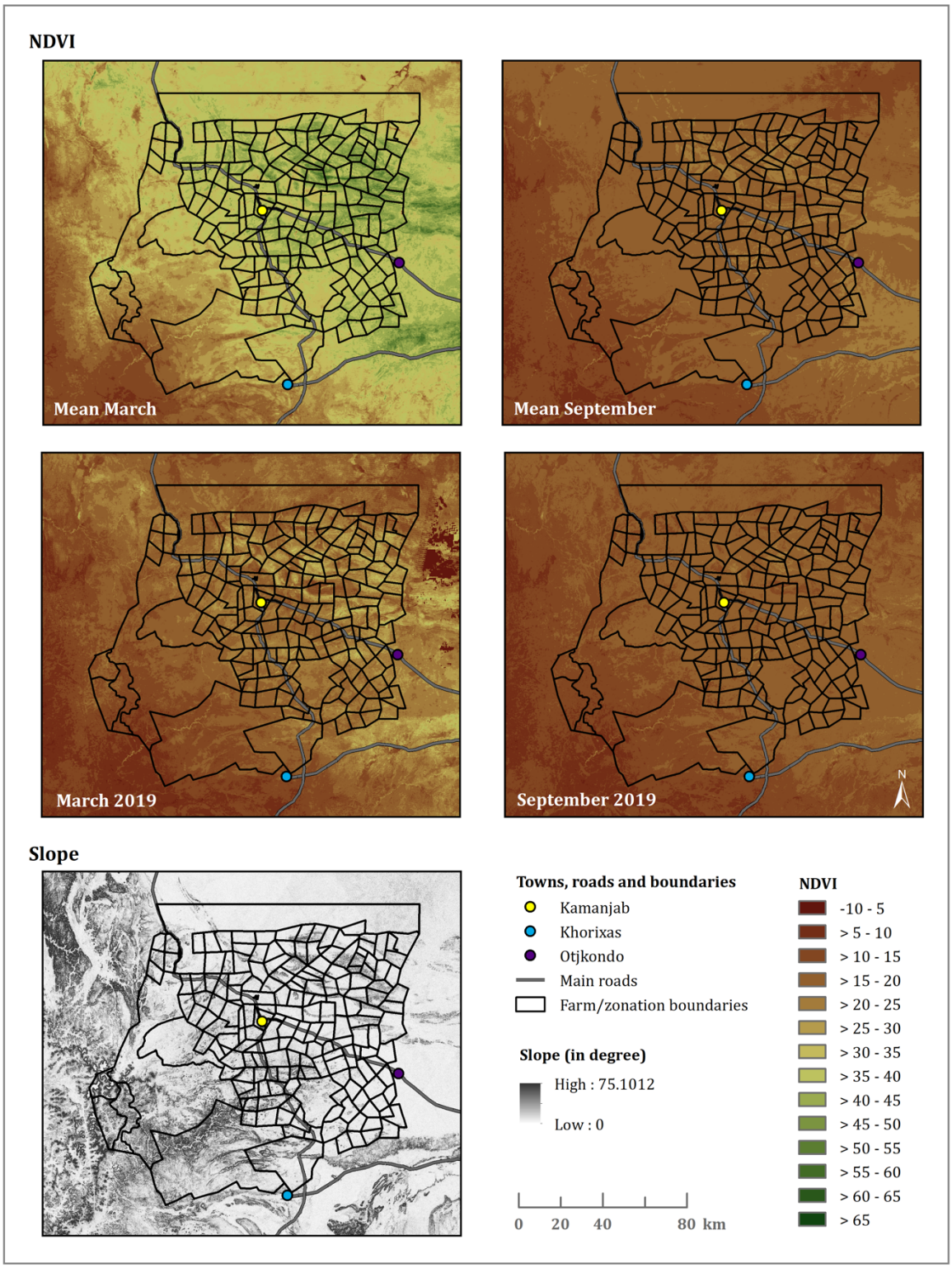


Figure 6: NDVI and slope in and around the study area.

Table 5: Input variables used for geo-spatial analysis.

Natural variables		
	Slope *static and continuous variable*	**Vegetation** *dynamic and continuous variable*
Index	highest-resolution topographic data generated from NASA's Shuttle Radar Topography Mission (SRTM) in 2000	NDVI (normalized difference vegetation index) on a monthly basis, calculated by Landsat 5, 7, 8 and MODIS satellite data: value range from -100 to 100
Source	30-Meter SRTM Tile Downloader (Watkins, 2000)	Google Earth Engine (Gorelick *et al.*, 2017)
Format	One-band raster images (.tif) Resolution: 30 metres	12-band raster images (.tif): one band for each month representing the average monthly NDVI value (median); resolution: 30 metres
Socio-economic variables		
	Management *static and categorical variable*	**Fences** *static and categorical variable*
Index	1 = game management 2 = livestock management 3 = no hunting (e.g. tourism)	2 = electrified game-proof fence 1 = game-proof fence (not electrified) 0 = no or livestock-proof fence
Source	Commercial farm boundaries provided by project lead, amended according to field study findings (see Section 3.2.1)	Generated by author, location adjusted to amended management shapefile
Format	Shapefile converted to one-band raster image (.tif)	Shapefile converted to one-band raster image (.tif)

While NDVI and slope values are continuous variables, management and boundary fence types are categorical. Thus, for these factors different methods were applied. The aim was not a metric but an ordinal scale, indicating which type was more suitable or more permeable, respectively. The assessment of management focussed on the records within the 95% home range. For each individual elephant, the following index was calculated for every management type:

$$Index = \frac{\text{absolute number of records within the management type}}{\text{the total area of that management type within the home range}}$$

To get an idea of how effective game-proof and electrified game-proof fences inhibit elephant movement, GPS tracks (connected point fixes) and their intersections with fence polylines were extracted. The hypothesis was that the more fence crossings (polyline intersections) are observed, the more permeable a certain fence type is and vice versa. Detailed observations on GPS records in the proximity of game-proof fences combined with interview findings on their effectivity were supposed to allow for conclusions on the permeability of singular fences.

Before being used in the suitability and corridor analysis, the shapefiles on management and fences were converted to raster images by using the ArcGIS tool *Feature to Raster* (Store and Kangas, 2001). Together with the slope raster image, their extent and spatial resolution were aligned to the NDVI raster images in QGIS. After clipping to the study area, four raster images with the same cell size, identical offset in grid and extent were generated.

3.3.3 Suitability analysis

The protection of important habitats is a major goal within nature and biodiversity conservation. This, however, needs knowledge about the habitat requirements of target species. These requirements are regarded as factors that determine the suitability of habitat (Beier, Majka and Jenness, 2006). Suitability may be measured by an index which is "a unitless variable describing the priority of the habitat with respect to the needs of the species (or group of species) under consideration" (Store and Kangas, 2001, p. 81). In this study, large areas of the highest suitability were identified based on the natural landscape features (vegetation availability and slope) and chosen as core areas, as they are considered to have a high importance for elephants (Osipova *et al.*, 2018). It has to be noted that current patterns in vegetation, as represented by NDVI, are actually a combined result of natural conditions and long-term human activity. Since near natural vegetation conditions are, however, not available to be included in the current habitat suitability analysis, the actual NDVI patterns are considered as representing the natural state for the following analysis.

In ArcGIS, both raster images (NDVI and slope) were reclassified into five groups determined by the previously defined percentiles (Section 3.3.2). As a result, the cells of both images were replaced by values from 1 to 5 representing the information on how suitable the cell was in terms of slope or vegetation availability, respectively (ArcGIS tool *Reclassify*). In a next step, the resulting raster images were combined to one image by using the ArcGIS tool *Weighted Overlay*. This tool is a commonly used overlay analysis approach, sums up the raster cell values (ESRI, 2020b) and may account for the importance of the different variables influencing habitat suitability as applied in other studies (e.g. Store and Kangas, 2001). In this study, both variables were assumed to have 50% of importance as no information on different weighting was available. Every raster cell within the study area was consequently assigned with a number that represented its suitability as elephant habitat considering the landscape characteristics slope and vegetation availability.

This analysis was conducted four times with the same slope but different vegetation raster images. The months March and September were considered to adequately account for the seasonality of climate in the region (Figure 7, calculation procedure in Appendix 8). In this regard, on the one hand, March and September 2019 were considered to represent the situation in a very dry year that, furthermore, covered the time period of recorded elephant movement data. On the other hand, two raster images entailing the March and September NDVI values averaged over the last 20 years were used. In this way, the habitat suitability in the exceptionally dry year 2019 could be compared and validated with the patterns in an averaged 'normal' year. This guaranteed that selected core areas are not only applicable for the circumstances of that exceptional year but represent suitable habitat conditions over a longer period of time.

Within every resulting raster image, the most suitable coherent areas were depicted visually. By comparing all raster images and including interview findings on elephant movement and preferred regions, three comprehensive areas with high suitability were assumed to be important for elephants and hence, selected as core areas within the subsequent corridor analyses.

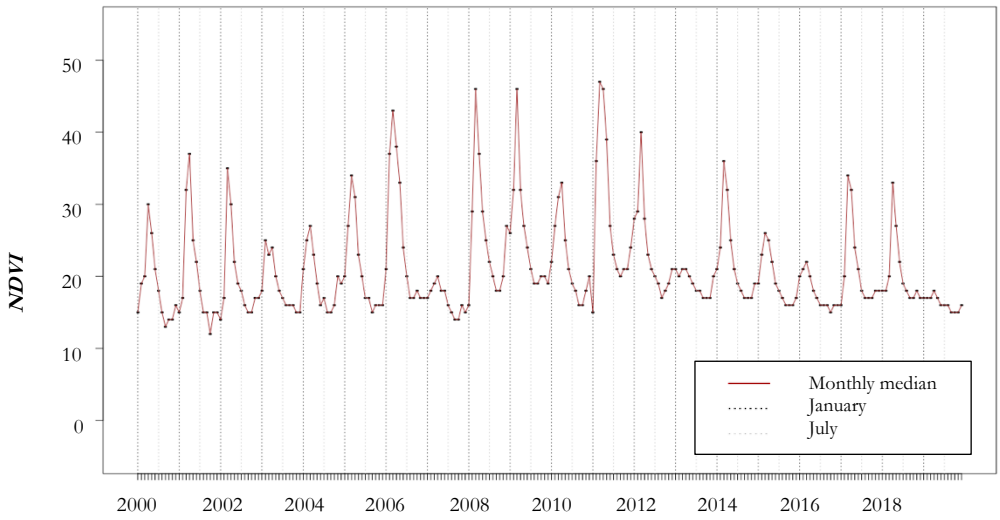


Figure 7: Monthly NDVI median from 2000 to 2019, indicating seasonal patterns in vegetation availability.

3.3.4 Corridor identification and comparison

To which degree a region facilitates or inhibits movement between patches is measured by landscape connectivity (Taylor *et al.*, 1993). Connectivity influences the ability of species to adapt and expand their home ranges to changing environment in the long-term. Therefore, increasing connectivity may promote biodiversity conservation (Saura and De la Fuente, 2002) and can be measured by cost-weighted distance. In this regard, Beier, Majka, and Jenness (2006) defined cost or resistance as a "pixel attribute that quantitatively represents the difficulty of moving through the pixel for a particular focal species". B. H. McRae and Kavanagh (2017) translated resistance as energy costs, the risk of mortality or the difficulty for moving across the particular cell. Cost-weighted distance is the "distance between points that reflects the difficulty of moving between them" (Beier, Majka and Jenness, 2006, p. 1), thus, it may be seen as an extension of the Euclidean distance as the costs of each cell is considered.

For the calculation, permeability was regarded as quantitatively identical to suitability and as the complement to resistance (Beier, Majka and Jenness, 2006). More specifically, a cell with high suitability value was assumed to afford lower movement costs, hence, cost may appear as reversed suitability value ranges. The underlying concept is that animals make decisions on movement and habitat selection based on the same rules (Beier, Majka and Jenness, 2006). Although there is some critic about this approach (Keeley *et al.*, 2017; Scharf *et al.*, 2018), it was used in several other studies before (Beier, Majka and Jenness, 2006; Chetkiewicz and Boyce, 2009). Within this study, this approach was perceived to capture the landscape resistance to the possible extent.

Within this research, the functional connectivity between focal landscape patches was determined. More specifically, the movement behaviour of the individuals was perceived as a response to the structure of the landscape and its resources. Various other studies applied the *Linkage Mapper Version 2.0.0* in combination with *Circuitscape* (*Circuitscape. Publications.*, no date). Different scripts were designed by a team around Brad McRae to analyse wildlife habitat connectivity (*About the LinkageMapper Team*, no date). This methodological approach was considered suitable to depict especially the influence of fences in a landscape as they influence movement rather than habitat suitability. The following section will give background information about the general functionality of the tool and the application of the software within this study.

3.3.4.1 General functionality of Linkage Pathways Tool

As input, one shapefile including the core areas that are supposed to be connected and one raster image with each cell value representing resistance is required. First, the tool identifies neighbouring core areas by calling the ArcGIS tools *Cost Allocation* and *Euclidean Allocation,* which allocate every raster cell to the closest core area – either with regard to the Euclidean or the cost-weighted distance (Figure 8a). Furthermore, information on distance and adjacency is calculated for the second step, which generates a network of links connecting core area pairs that are used for corridor analysis with each link including its statistics (McRae and Kavanagh, 2017)(Figure 8b).

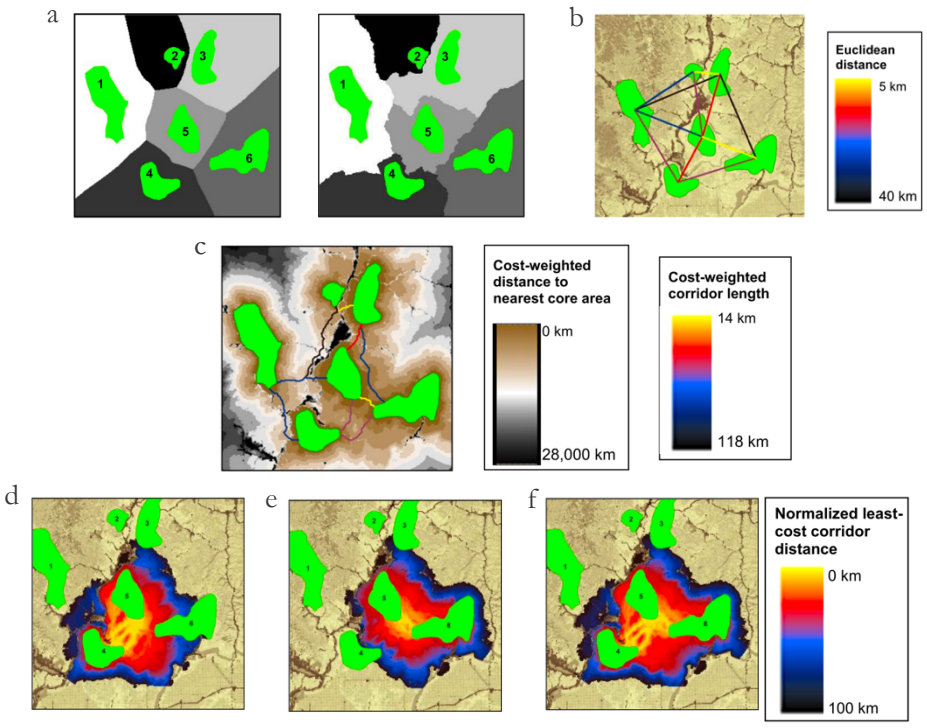


Figure 8: Example of corridor identification, modified after (McRae and Kavanagh, 2017).

Afterwards, based on the resistance raster image and for each core area, one cost-weighted distance raster image is calculated. Likewise, one single cost-weighted distance raster for all core areas is generated (Figure 8c). The value of one cell represents the accumulated cost-weighted distance to the nearest core area (McRae and Kavanagh, 2017). It is calculated based on both, Euclidean distance and on the values of the resistance raster image, assuming that with increasing resistance values, the cost distance for an animal to move from that cell to the core area increases (Washington Wildlife Habitat Connectivity Working Group (WWHCWG), 2010). The WWHCWG (2010) pictured the example of one particular cell x that is two cells away from a core area. They assumed that each of these cells has a resistance value of $r = 5$ and a size of 100 metres. Consequently, the accumulated cost-weighted distance r of cell x is 1.000, as

$$r_x = (5 * 100\,metres) + (5 * 100\,metres)\,.$$

However, if there would be a lower accumulated cost-weighted distance through another set of cells, cell x would be assigned with that value. This would be the case if, for instance, four other cells would only accumulate to a value of 400 cost-weighted metres in total, as cell x is connected to the core area by four other cells, each with a resistance value of 1:

$$r_x = (1 * 100\ metres) + (1 * 100\ metres) + (1 * 100\ metres) + (1 * 100\ metres)$$

Afterwards, based on these cost-weighted distance raster images, *Linkage Pathways Tool* creates least-cost-paths as output feature classes representing the route with the least accumulated resistance (McRae and Kavanagh, 2017). Figure 8c shows the total cost-weighted distance traversed by the linkage, selected from the least-cost path attributes.

Subsequently, least-cost-corridors for each core area pair are calculated by summing up the previously calculated cost-weighted distance raster images. Subtracting the distance of the least-cost path, these corridors are normalized in order to combine them into a single map (McRae and Kavanagh, 2017):

$$NLCC_{AB} = CWB_A + CDW_B - LCD_{AB}$$

$NLCC_{AB}$	normalized least-cost corridors
CWB_A	cost-weighted distance from core area A
CDW_B	cost-weighted distance from core area B
LCD_{AB}	cost-weighted distance accumulated among the ideal (least-cost) path connecting the core area pair

In the final step, these individual normalized corridor raster images for each pair are mosaiced by the ArcGIS mosaic function. Figure 8d exemplary depicts the normalized least-cost corridors for the core area pair 4 and 5, while Figure 8e for 5 and 6. The final corridor mosaic is shown in Figure 8f. It consists of raster cells, each assigned with the minimum value of all single corridor raster images. The values are cost-weighted distances as above and their range starts from zero for the best or least-cost path. They indicate, "how much more costly the (locally optimal) path between the core areas passing through each cell is relative to the (globally optimal) least-cost path connecting the core area pair" (McRae and Kavanagh, 2017, p. 15). In other words, the raster cells provide information on their relative value to provide connectivity between core areas. Thus, it is visualized which routes comprise more or fewer features that aggravate movement (McRae and Kavanagh, 2017).

3.3.4.2 Parametrization of the corridor analysis

Connectivity analysis was conducted for the mean September setting only, as this month is the one expected to be crucial for elephant-human interactions when resources are limited. Figure 9 shows the workflow for the corridor analysis which is outlined in this section.

In the first step ((1) in Figure 9), different resistance raster images were calculated by using the ArcGIS tools *Reclassify* and *Raster Calculation*. Each image represented one landscape as described in Table 6.

The percentiles from the cumulative distributions for slope and NDVI that served as class boundaries within the reclassification process for the suitability analysis were also applied to generate the resistance raster images used in the corridor analysis. However, in consideration of restrictions of the ArcGIS tool *Weighted Overlay*, the range of reclassified values was stretched from 1 (low resistance) to 10 (high resistance) in order to provide for a finer-scaled depiction of landscape connectivity in the least-cost corridor calculation. Furthermore, the range was reverted as described in the beginning of Section 3.3.4 and by Beier, Majka and Jenness (2006).

When considering a hypothetical movement path through a cost landscape, linear structures such as fences only change the entire accumulated cost weight distance to a small extent, if they are weighted on the same scale from 1 to 10 like the factors slope and vegetation. As literature confirms, however, game-proof fences

indeed affect landscape permeability for elephants (Section 2.4.4.3). In this regard, McRae and Kavanagh (2017) suggested to use significantly higher values for hard linear barriers like fences, as for instance applied by Osipova *et al.* (2018).

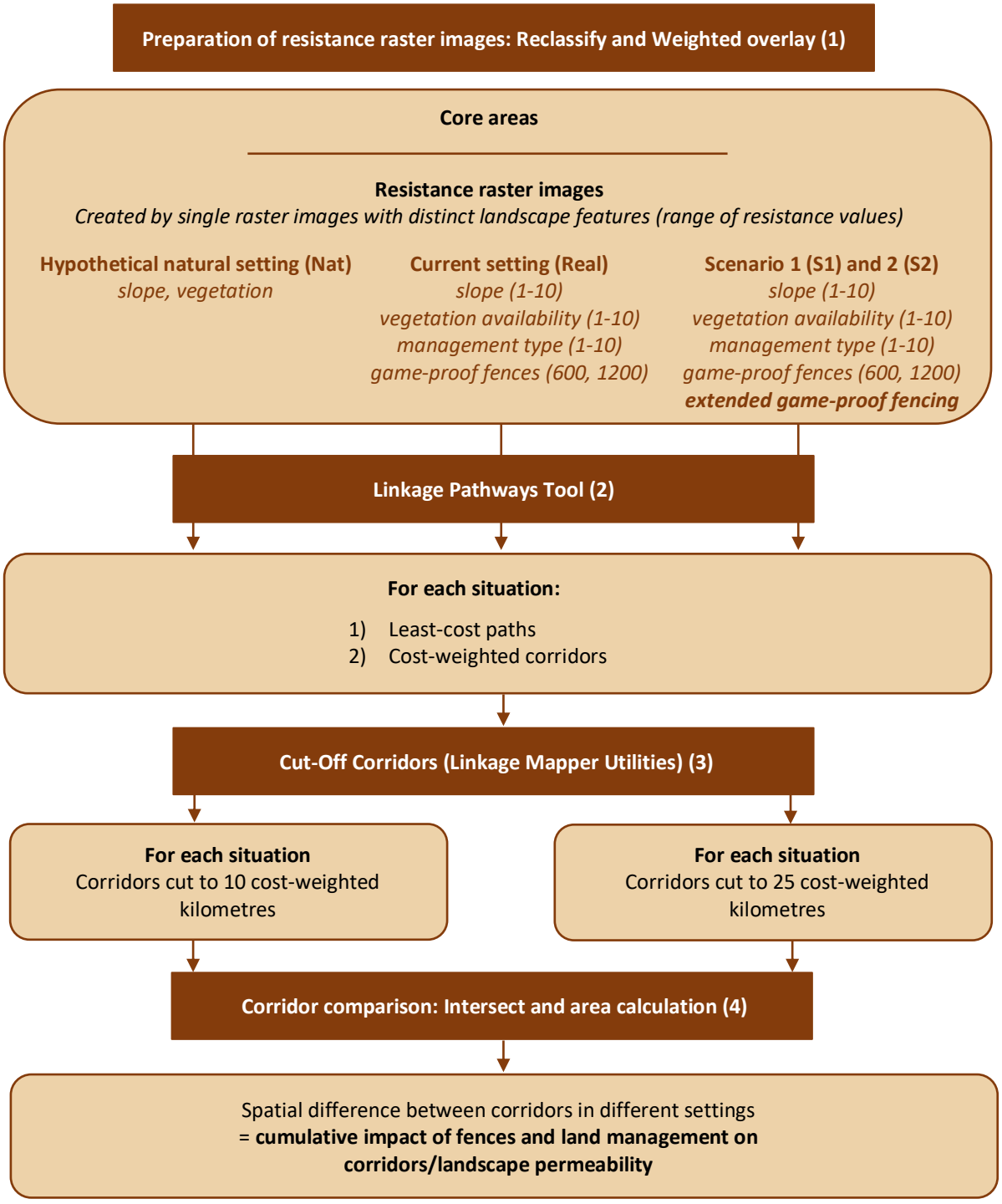


Figure 9: Workflow of corridor analysis (dark brown: applied tools; light brown: outputs).

Table 6: Description of landscapes used for corridor analysis.

Landscape abbreviation	Description
Nat	Hypothetical landscape with natural features only (slope and vegetation availability)
Real	Landscape with current features (slope, vegetation, land management and current fences)
S1	Theoretical future scenario (slope, vegetation, land management, current fences and added fences to the west), discussed strategy at farmers' meeting (FM)
S2	Theoretical future scenario (slope, vegetation, land management, current fences and added fences to the north), discussed strategy at farmer's meeting (FM)

In order to find an appropriate resistance value for game-proof and electrified game-proof fences, an adaptive approach was chosen. Different resistance raster images were iteratively tested with increasing resistance values for raster cells that represented fences while each raster image contained the same values where fences were absent. For cells including a game-proof fence, information on slope, vegetation and management was ignored and the cell was assigned with the predefined resistance value for fences, only. For reasons of simplicity, resistance values for game-proof fences were always half the resistance of electrified fences, as the interviews results and the literature indicate that non-electrified fences are less effective than electrified ones. Based on each generated resistance raster image, *Linkage Pathways Tool* was run providing the least-cost paths (LCPs) between each pair of core areas. The resistance surfaces were adapted until no LCP crossed any electrified game-proof fence.

The final resistance value ranges of the different variables are depicted in the first output box of Figure 9. These singular resistance raster images for each variable were finally combined using the ArcGIS tool *Weighted Overlay* (step 1 in Figure 9) with equal importance of each feature to create four different resistance raster images (representing each landscape as listed in Table 6).

In the second step ((2) in Figure 9), *Linkage Pathways Tool* identified least least-cost paths and cost-weighted corridors based on each resistance raster image. McRae and Kavanagh (2017) recommend clipping the corridors to a cost-weighted width (step 3 in Figure 9). However, as the literature review did not reveal trustworthy information on values for that combination of elephant corridors, the size of the study area and the value range of the resistance surfaces, the cut-off value was iteratively tested. Eventually, 10 and 25 cost-weighted kilometres were considered to adequately represent the corridor areas most important for elephant movement. Each corridor raster image was cut to both widths. In the last step ((4) in Figure 9), the corridors clipped to 10 and 25 cost-weighted kilometres, respectively, were intersected using the ArcGIS tool *Intersect*. Intersected areas and those not overlapping were used as metrics to determine the accumulated impact of game-proof fences and land management on the landscape permeability.

4 Results

This section presents the results, structured as follows: First, the findings from the participatory mapping serve to provide a deeper insight into the current management and the characteristics of and issues around boundary fences (4.1). Secondly, light will be shed on the outcomes on human-elephant interactions (4.2) before proceeding to the geospatial data analysis. Here, the outcomes around the input variables (4.3) and the identified core areas will be outlined (4.4). Finally, this section concludes with the comparison of the identified corridors (4.5).

4.1 Current farm management and fencing

The respondents showed a great willingness to participate in the mapping process. They readily contributed with their knowledge about their and other farmers' management and boundary fences. However, it is important to recognize the small set of interviews which provide for the mapping of landscape elements and an exploratory survey but do not allow for conclusions on the general opinion of stakeholder groups.

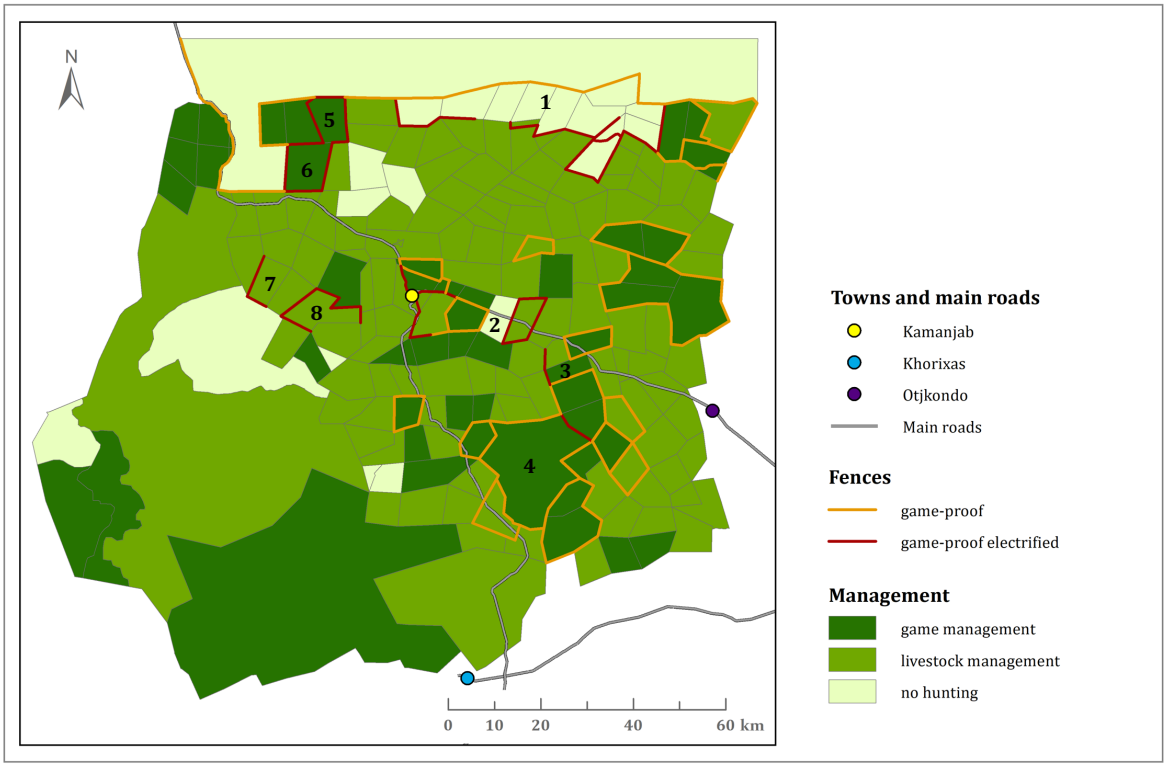


Figure 10: Result of participatory mapping; fences are present in freehold areas and surrounding ENP, different management activities are creating a mosaic in the study area; 1 – Ethosha Heights Game Reserve (all enclosed and neighboring polygons managed as one entity), 2 – Hirabis, 3 – Teschendorf, 4 – Ohorongo Game Reserve, 5 – Pionier, 6 – Kaross, 7 – Bruno, 8 – Bergvallei.

As far as is known, this map is the first accessible landscape-wide overview of wildlife-proof fences and land use on private land in the area of interest and might function as base for further research in the study area. The information on farms and fences show valuable insights into the landscape characteristics that emerge from human activities (Figure 10). Farms without first-hand information from respondents were classified as livestock management areas according to the farming system descriptions of the area's freehold areas by Mendelsohn (2006). Outside the communal conservancies, 47 farms are engaged in game

management, 118 in livestock management while partially practicing some hunting, e.g. for own use (see Table 3) while 17 farms follow strategies that do not include any hunting activities. For the whole study area of about 904,000 hectares the predominant management category is livestock management (58.2%), followed by game management (29.0%). On about 12.8% of the study area no hunting is conducted.

Game-proof boundary fences appear to be important infrastructure within the study area. Commercial farmers expressed different motivations for boundary fencing: (i) keeping wildlife inside the farm (F1, F7, F10), (ii) avoiding livestock to walk off and intermix with the neighbour's animals (F2, F6, F8), (iii) keeping game outside to protect grazing areas for livestock (F6) and (iv) preventing predation on livestock (F1). The first-mentioned motivation is also coupled to the regulation of the Nature Conservation Ordinance, Act 4 of 1975 (GRN, 2003), which states that utilization of game requires game-proof boundary fencing.

The result of the participatory mapping (Figure 10) shows that the southern boundary of ENP is surrounded by a game-proof fence which functions as Veterinary Cordon Fence, yet according to respondents (E1, E5, E8, F3) and newspaper articles (Namibia Press Agency, 2018), it is not properly maintained. Subsequently, the movement of infected animals cannot be prevented (F3, FM). Damage was said to be caused by mostly elephant excursions and people cutting holes in order to bring their livestock to favourable grazing spots within the park (E5). Repairing the whole length of the fence requires a tremendous amount of funding which is currently unavailable and is therefore not conducted comprehensively (E3, E5). Instead, the government was said to focus on those fences adjacent to resettlement and hunting areas (E5). As Etosha Heights Game Reserve offers tourism activities and accommodation south of the park without any hunting, the respondent assumes that this fence section is not a priority for the park management's maintenance activities (E5).

Farmers adjacent to the ENP mostly enclosed their farms: farmers in the very East of the study area surrounded their farms with game-proof fences while Etosha Heights Game Reserve constructed an electrified game-proof fence along its southern, western and eastern boundary. Likewise, two farmers in the West (Kaross and Pionier, see Figure 10) installed electrified boundary fences. Further south and bordering ≠Khoadi-//Hôas, two farmers partly constructed electrified fences (Bruno and Bergvallei, see Figure 10), with at least one still in the construction process. The commercial farm area east of the road connecting Kamanjab and Khorixas (the C35) is frequently permeated by game-proof fences. Electrified fences are found in the vicinity to Kamanjab, around the farm Hirabis, at the border of Teschendorf and in the Northeast of Ohorongo Game Reserve to prevent game from leaving in search for food and water (FM, Figure 10).

Experts mentioned that fencing might benefit wildlife, as for instance in parks without hunting, game is protected because people cannot enter (E1, E2). At the same time, fencing was described as the "death of wildlife" (E1) as it impedes migrations of species that need to find access to vital resources (E3, F2). Feeding game within a fenced property was described as domestication and as not solving the problem of absent vegetation in the long term (E1). The restriction of movement by fences would furthermore require population control by hunting when the carrying capacity within the fenced-in area is reached (E1). To make livestock-proof fences permeable for game like gemsbok, zebra, hartebeest and young kudu, farmers removed some strands of fences (F6). This way, damage on fences can be avoided which is mostly caused by game. Only one respondent reported the collapse of fences because of heavy rainfall, followed by emerging flash floods (F1, F11). Farmers reported giraffe bulls (F1, F5, F6, F7), black rhino males (F1) and other game fighting through fences (F3, F10), kudus interrupting electricity when jumping over them and elephants easily cross them if power was off (F5). Fence maintenance was hence often described as a constant challenge, being time-consuming and costly (F5, F6, F8). Farmers have to control the condition of the fences at least every week (F5, F7) or every month (F3), one farmer occupied workers to patrol each day (F11). One farmer reported to be able to maintain their fences properly (F3), while a second one only repairs the fences where his cattle currently graze (F8). Electrifying boundary fences were considered most acceptable, but still require some effort to repair (F5).

In the communal area, fences in general are prohibited, as they would exclude other people from using pastures for livestock grazing (E3). One conservancy respondent mentioned that electrified boundary fences towards commercial farms or conservation areas are a serious issue as they are close to homesteads and may pose a threat to people's lives, as for instance children may touch them (E6).

4.2 Human-elephant interactions

The following subsections[1] provide insights into the respondents' perceptions on elephant behaviour (4.2.1), conflict characteristics (4.2.2), current measures to prevent human-elephant conflicts (4.2.3) and discussed long-term strategies (4.2.4). The information provided builds on the qualitative material obtained from the interviews.

4.2.1 Perceptions on elephant behaviour

The respondents seemingly have a good knowledge on elephant ecology to specify their behaviour for the Namibian situation. Nevertheless, uncertainty persists with respect to the total number of individuals in the study area (E8, FM). An expert observed a general population increase amongst lions and elephants in the Kunene region, the latter even moving south to Erongo (E8). While respondents only perceived little problems for the time six years ago, during the last four years, human-wildlife conflicts intensified (E8). Though, estimates for the Kamanjab area suggest an elephant population of about 200 (F4, FM), the actual number of elephants is largely unknown and further aerial surveys are required, as indicated by one expert (E8).

Farmers have also felt that the local elephant population around Kamanjab is increasing (F8, FM). When being asked about the current number of elephants on their farms, respondents gave varying answers: Though for some farmers it was difficult to estimate the current number, as the elephants come and go occasionally or the farmers do not have the time to survey the area, observed herd sizes of 30 individuals were mentioned (F8). Estimated numbers of current elephants on the farms varied between 80 (on a tourism farm without any hunting, F11) and 10-40 (livestock management farm, F5). Another cattle farmer observed nine elephants while usually there were none on his farm (F6). One farmer perceived that while all other species populations were decreasing due to the current drought, elephant numbers were locally increasing (F8). Only one respondent observed a disappearance of elephants, suggesting the electrified boundary fence as the major reason, while in the past he estimated to have 30 elephants on his farm (F9). The elephant population is assumed to be a mix of individuals from Damaraland, the South and ENP (F9, F10). All farms in vicinity to the national park were reported to have been visited by elephants (e.g. E11). One government official mentioned that Etosha elephants would enter the commercial area through the resettlement farm east of Etosha Heights (E11). The farm in the west of the resettlement area (Pioneer, Figure 10) said not to have any elephants, possibly due to electrified fences (E11).

Elephant behaviour is said to be driven by a search for food, water and safety (F5, F8). The respondents confirmed the non-selective feeding behaviour by elephants as stated by Smithers, Apps and Abbott (2012): they feed on anything available like for instance, mopane, camel-thorn acacia (*Vachellia erioloba*) and white-thorn acacia (*Vachellia constricta*) when grass is absent (F10, E7). In early spring and late summers, they also feed on seeds and pods. They are able to dig for water and can remain one to three days without water (E7). Wherever they find enough food and are not confronted with competition, elephants may become resident (E8). Mountainous areas are no impediment for their movement as long as there are flat paths (F11). Particularly during drought events, the elephants are said to spread in search for food (E8). In the early rainy

[1] The following descriptions might not correspond to the actual facts but are rather supposed to reflect the subjective perception of the respondents.

season, they were perceived to move to the Northeast (F11). Multiple farmers observed the animals to generally approach areas that are further in the East as the area is considered less dry and thus providing more food (F5, F11, FM). One farmer in the very eastern part of the study area did not have elephants on his farm until March of 2018, while now they cause tremendous damage (F8).

A representative from ≠Khoadi-//Hôas perceived that there are herds freely moving around between Huab and ≠Khoadi-//Hôas (E6). Moreover, every conservancy is purported to have some resident elephants (E6). Additionally, elephants were said to persist droughts within the conservancies and leave again when the conditions improve (E6). On a broader scale, they were observed to partly use riverbeds like for instance Hoanib River to migrate between the regions north of Opuwo and south of Khorixas, through the conservancies and the Skeleton Coast Park (E6). A representative from one conservancy (E6) perceived that in the communal conservancies, the elephant population of the current size has never occurred before and that elephants were constantly present. He estimated that elephants would stay for two to three months before moving on. He saw the broken Veterinary Cordon Fence as a sign for the frequent use of the conservancies as elephant habitat.

4.2.2 Characteristics of conflicts

The Kamanjab region was introduced as a hot spot area, where human-wildlife conflicts are a prevalent challenge (E8). Seven farmers said that elephants were causing problems on their farm (F3, F4, F5, F6, F7, F8, F10). The interviews showed for some respondents that when compared to other conflict causing species, elephants were the greatest burden, even greater than predators (F4, F8, F10). None of the respondents did confirm that elephants in general are valuable for the environment on their farm. Problem causing elephants were said to be mostly young bulls, females with calves in danger and cornered elephants as these become aggressive when confined in a small place (E7, E8). According to some commercial farmers, elephants typically stayed on their farms between some hours and one week, often visiting during nighttime (F6, FM). Even though they sometimes quickly passed through to another farm, in that short period they caused significant damage (F5).

Once, 48 elephants destroyed the whole work of a lifetime within one week.
(based on fieldnotes from the farmers' meeting (FM), paraphrased statement of farmer engaged in game and livestock farming)

Damage on water infrastructure appeared on most of the farms (F4, F8, H8, Figure 11b, c, f). One farmer reported that damage occurs when families with their calves try to reach the water (F6) and an expert (E9) indicated that this conflict about water is especially serious in the event of occurring droughts. When digging for insects, baboons uncover pipes, which lie in the ground (F5). Due to their good sense of smell, elephants easily find theses pipes and destroy them in order to access the water (E1, Figure 11f). When drinking, one elephant was said to be capable of consuming the whole storage of water in just one night, leaving the farmers without water for their household and livestock (F8). Repairs take at least one day, and it is costly to refill it by pumping groundwater (F8).

A resettlement farmer (FM) emphasized that he was hit hard by elephants that destroyed the efforts from the last years. Furthermore, due to time-consuming repairs of infrastructure, farmers cannot complete feeding of their game during drought (FM). Besides water infrastructure, farmers reported damage on windmills, solar panels, cameras installed to document elephant occurrence, cribs and kraals (F3, F6, F8, FM, Figure 11c, e). When approaching kraals, cattle was observed to panic and being trampled by elephants (FM). Calves left the safe kraals and hence, risked being preyed by predators (FM).

Fences and elephants are incompatible where small areas are fenced in.
(based on fieldnotes from the interview with one farmer engaged in game farming (F10))

When moving, elephants have to cross several farm boundaries that are often fenced in or contain camp fences for livestock. When these fences get permeable after elephants damaged them (Figure 11a), predators may enter the area and livestock cannot be controlled anymore to practice sustainable grazing (F8, F9). Often, attempts to repair the fences or other damaged infrastructure were unsuccessful as only a few days after the maintenance elephants came back, destroying the infrastructure again (E6, FM). Providing a fence-maintenance team is time- and cost-consuming, especially as the damage occurs frequently. One respondent reported that one day in 2016, he had to repair 23 damaged sections (F11).

Farmers reported that in search for food, elephants entered gardens and hence, got very close to the farm-houses (F8, FM). Here, besides the damage (Figure 11d), the aspect of fear comes in. Farmers received calls from worried workers at night when these felt threatened by elephants (F8, FM). The respondents themselves reported also to be afraid of leaving the house when elephants were in the yard or garden (F8). Similar concerns were raised by a tourism farmer (FM).

Apart from infrastructure damage, several respondents observed a high impact of elephants on the environment (F3, F8, F11, FM). One farmer, for instance, reported severe damage on old giant trees with high touristic value (FM).

That damage on trees might be a sign of stress feeding as elephants are frightened by farmers.
(based on fieldnotes from a conversation with one respondent engaged in game farming (FM))

Instead of picking leaves, they pull over whole trees for a higher biomass intake in a shorter period (FM). Where elephants opened up fences, predators entered, and, therefore, rare species might disappear (F10). Resettlement areas were described as being free of any wildlife except of elephants (E7).

In the communal conservancies, a similar picture appeared. In ≠Khoadi-//Hôas, human-wildlife conflicts are currently the most pressing challenge due to the ongoing drought (E6). In addition to the loss of livestock, which affects most of the farmers, drying out water points in the co-wildlife areas cause the elephants to approach the farms. When arriving there, they empty water and damage pipes (E6).

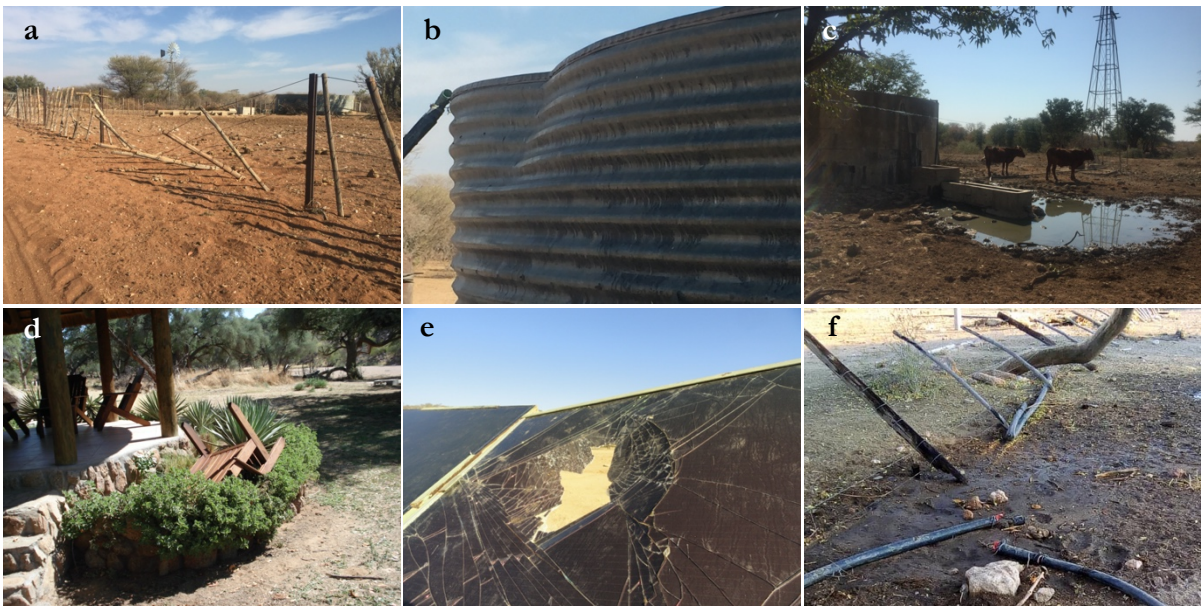


Figure 11: Damage on infrastructure caused by elephants, (a) damaged cattle fence, (b) dent on dam, (c) drinking spot for cattle flooded by water from damaged infrastructure, (d) garden furniture pushed over by elephants, (e) broken solar panel, (f) water pipes torn apart by elephants in search for water, sources: photos taken by individual farmers (d,e) and own photographs (a-c, f).

4.2.3 Current measures to reduce conflicts

Overall, the respondents mentioned a number of measures available to reduce conflicts with elephants. Among these, farmers implemented (i) direct deterring measures, (ii) strategies to provide elephants with alternatives and (iii) evaluated the governmental compensation schemes.

Deterrent measures are a common strategy to prevent elephants from accessing certain areas. Stones and tires are a cheap way to protect infrastructure, as they are uncomfortable with walking (F6, Figure 12a). One farmer installed booby traps on trees close to water dams and connected these through a wire with the dam (F8, Figure 12b). When elephants touch the wire, the trap is triggered and shoots gunpowder, causing a noisy acoustic signal that is intended to scare the elephants away. Warning shots were fired manually by other farmers when they were informed about approaching elephants (F6, F7) and elephants were observed to mostly move during night (F10, E7).

Fences are most often used to exclude elephants from specific areas (Figure 12c). Opinions about the effectiveness of fences differed depending on their condition and type. Some farmers (F5, F9) and an expert (E11) reported less problems on farms since these were enclosed with an electrified game-proof fence. One respondent installed a game-proof fence of 1.8 metres height with one electrified string and therewith successfully deterred elephants (F9) while another farmer perceives electrified fences as expensive and ineffective (F3). One farmer applied bags filled with 5 kilograms of chili every 10th metre which succeeded as a deterrent for elephants (F4).

Apart from direct deterring measures, strategies exist that try to offer elephants alternatives. Farmers, who tolerate elephants, left water for elephants to drink in order to protect their dams from destruction (F6). One livestock farmer did not electrify the corners of the farm so that elephants can pass without destroying the fence (F5). These fence sections were made of cable wire instead of steel wire so that they automatically spring up again. Since the implementation, the farmer did not have any problems with broken gates anymore. Another farmer mentioned the idea to create gates that would open for elephants only, so they can pass the fence without destroying it and without other wildlife species walking through (F11).

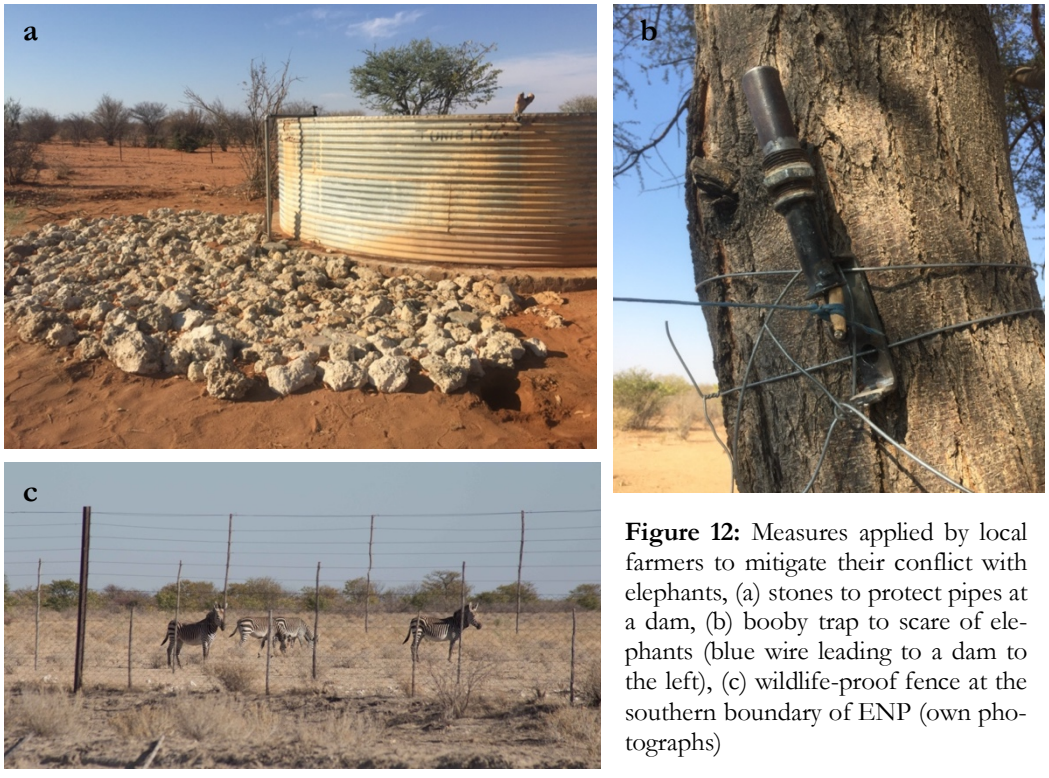


Figure 12: Measures applied by local farmers to mitigate their conflict with elephants, (a) stones to protect pipes at a dam, (b) booby trap to scare of elephants (blue wire leading to a dam to the left), (c) wildlife-proof fence at the southern boundary of ENP (own photographs)

Along these local measures implemented by farmers, governmental compensation schemes are a policy instrument to reduce human-elephant conflicts (MET, 2018a). The compensation mechanism provided by the government, however, did not have much support amongst freehold farmers (F5, F7, F10). The government was said to be not economically able to afford the investigation of every case and to provide more compensation funds (E1). In order to improve the compensation mechanism, one respondent (E8) mentioned the new Protected Areas and Wildlife Management Bill that shall delegate the power to declare an elephant as problem causing from the minister to the deputies. In regard of destroying a problem causing elephant, a concern was raised by one respondent that the identification of the individual was quite difficult resulting in a high risk to choose the wrong elephant (E3). Furthermore, there seems to be a long time delay between reporting and approval for action when the problem causing animal already left the farm (F9).

4.2.4 Long-term strategies for conflict mitigation

The challenge of elephant management is an omnipresent issue in Namibia (e.g. Schrader, 2019). In addition to the above-mentioned measures taken locally and on the governmental level, long-term strategies for conflict mitigation are discussed by the involved stakeholders. From the qualitative material, especially the participating observation of a farmers' meeting with MET (FM), different viewpoints can be identified on the suitability and effectiveness of respective strategies. In this regard, the following paragraphs will briefly present the stakeholders' viewpoints on (i) the control of elephant populations, (ii) the clarification of ownership over elephants and (iii) the establishment of a region-wide elephant management plan.

At the meeting, concern was raised that due to the lack of natural enemies, current elephant population might increase (FM). Elephants are unselective feeders (Smithers, Apps and Abbott, 2012), thus, an attendant of the farmers' meeting (FM) feared that all other selective wildlife species of high conservation value might have already disappeared when natural regulation due to vegetation degradation sets in. Amongst farmers, opinions on culling of elephants differed. At the farmers' meeting, the opinion that the number of elephants should be reduced was expressed, followed by a discussion about the concerns regarding culling and translocation. Reasons against those actions are said to be voices from the animals' rights movement (E2) as well as international pressure (F9) and the complexity of culling (E7). The identification of a problem-causing elephant is often uncertain (E7) and the loss of individuals within a herd may cause new problems when for instance older bulls are removed that used to teach younger males (F10). Translocation, on the other hand, was said to be only successfully facilitated when including all family members (FM).

Furthermore, the farmers (FM, F7) emphasized the unsolved question about ownership over elephants, which is seen as important because the owner of the elephants shall bear for damages. Moreover, due to current laws, the utilization of elephants for these specific farmers is prohibited (FM). If being allowed to consumptively utilize elephants, farmers would have an interest in conservation and more easily accept them (FM).

Currently, farmers established methods to cope with elephants on their farms individually. Participants of the farmers' meeting agreed on the preparation of a management plan providing immediate measures in regard of damages on infrastructure and environment as well as serving as a long-term strategy (FM). Focussing on the cooperation on local, regional and governmental levels, the plan shall be prepared by a working group that consists of experts from the government, external consultants and farmer representatives (FM). In this regard, an expert (E8) suggested a livestock-free zone in the vicinity of 50 kilometres to ENP. However, starting a tourism business was reported not to be possible for each farmer as capital, a good location and/or a special tourism attraction are required (F11). Only after five years, investments may be covered by revenues (F4). An experienced farmer mentioned that it takes some years to switch from livestock management to tourism and that ecotourism only works on a large area which can only be feasible if

farmers decided to jointly manage their farms (F11). The profit of trophy hunting within smaller areas might compensate costs due to wildlife presence (F11). Another suggestion was to expand protected areas like for example 'people's parks' which exclude livestock but give direct benefits to the inhabitants (E8). Furthermore, the designation as 'disease free status' shall be guaranteed by repairing the Veterinary Cordon Fence (FM).

A corridor approach was seen as an adequate strategy on the landscape scale (E7, E9) as for instance suggested by Lee and Graham (2006), Parren, De Leede and Bongers (2002) and Suksavate, Duengka, and Chaiyes (2019). An expert (E9) advised the identification of a corridor to be accompanied by extensive monitoring over years and by guaranteed funding mechanisms. These could include tourists paying for human-wildlife conflict measures in these areas. Early warning systems should enable farmers to react to the occurrence of elephants and communal farmers should be incorporated. If succeeding, monitoring, early warning systems, and utilizing the intrinsic value of elephants may additionally create jobs.

4.3 Singular impact of each driver

In order to determine the areas which were preferred by the collared elephants, the locations of the GPS records were related to the landscape characteristics. More precisely, correlations between the records and the variables slope and NDVI (4.3.1) were identified. Furthermore, the elephants' home ranges were estimated (4.3.2) to uncover preferred land management (4.3.3). Together with the assessed impact of singular fence lines on the movement of elephants (4.3.3), the findings were used in the suitability analysis to determine three core areas and to create resistance raster images for the least-cost analyses which follow in the subsequent Sections 4.4 and 4.5.

4.3.1 Preferred vegetation and terrain conditions

For identifying preferred vegetation and terrain conditions, the elephants' GPS locations were spatially overlain with NDVI and slope raster products. The sum of all GPS records within the period of October 2018 to October 2019 was 36,480. Based on these records, the cumulative distributions for NDVI (Figure 13a) and slope (Figure 13b) were calculated. Subsequently, the 0.2, 0.4, 0.6 and 0.8 percentiles were used as class boundaries for the suitability analysis and the calculation of the different resistance raster images (Table 7).

Table 7: Percentiles of cumulative distribution of NDVI and slope values and resulting boundaries of classes for suitability and corridor analyses.

	Percentiles	0.2	0.4	0.6	0.8	1.0
NDVI	Resulting class size	<16	>16 - 18	>18 - 21	>21 - 23	>23
Slope	Resulting class size	<1.31	1.31 – 2.00	2.00 - 2.80	2.80 - 4.00	>4.00

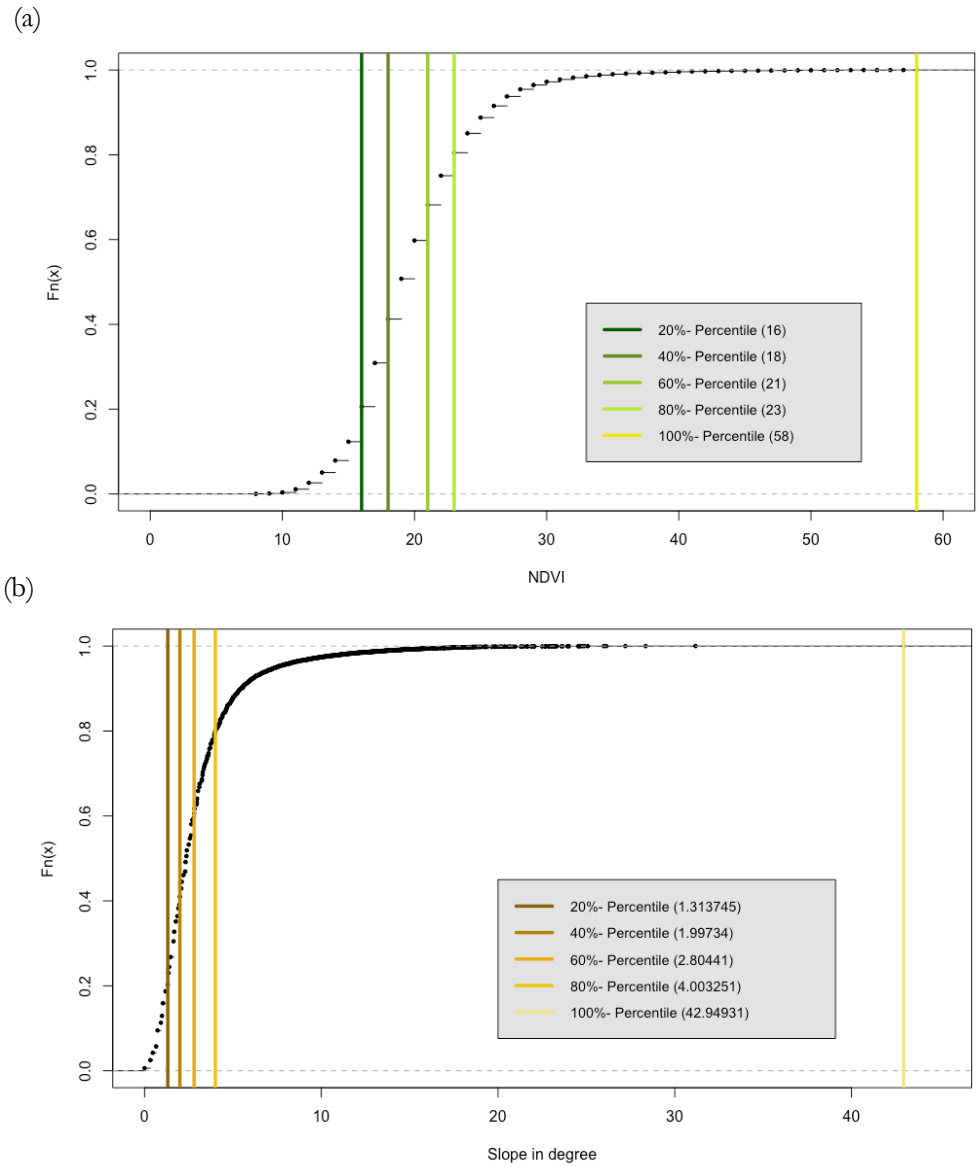


Figure 13: Cumulative distribution of (a) NDVI and (b) slope values. Data obtained from a spatial overlap of raster products and elephant GPS records.

4.3.2 Home range analysis

Only little empirical evidence is available to validate the respondents' outlined impressions on elephant movement as mentioned in Section 4.2.1. Nevertheless, movement data is available from MET for seven elephants and a period of 13 months that can be utilized to understand the local elephant population's behaviour. Figure 14 geographically depicts the estimated home ranges for each individual which are important in the process of driver assessment (Section 4.3.3). 50% home ranges comprised an average area of about 23,500 hectares, while the mean for 95% home ranges is 154,000 hectares (Table 8). The individuals 0BCD, 3ECO, C2C5 and 6366 had similar home ranges east of the road between Kamanjab and Khorixas. Though, only the 95% home range of 0BCD did not include the smaller part towards the northeast, all individuals had in common that both 50% and 95% home ranges were located on commercial farmland and were intersected by the road from Kamanjab to Outjo. Especially the 50% core home ranges of the four

individuals seem to overlap, considerably. The elephants 4ED4 and BCD4 had their home ranges mostly in communal conservancies (Figure 14). Here, one part of their 95% home ranges covers the wildlife zone of ≠Khoadi-//Hôas, while the majority of the 50% home ranges of both elephants were inside that area. Both elephants mostly moved within the borders of ≠Khoadi-//Hôas, whereas the 95% home range of elephant 4F9F encompassed both commercial and communal land. With 385,000 hectares, this elephant showed the largest 95% home range of all individuals (Table 8). The elephant cow's 50% home range is located in the south of the study area (Figure 14).

When comparing the home range sizes of the elephants moving in the east and those in the west, different averages occur. While the 50% home ranges of the elephants in the east covered an area of about 14,900 hectares on average, the size of the 50% home ranges of those individuals in the west is more than twice that size with about 35,000 hectares. This observation is also confirmed when considering the 95% home ranges: The average area was estimated to be 109,000 hectares for the individuals in the east, whereas elephants in the west utilized 215,000 hectares (Table 8).

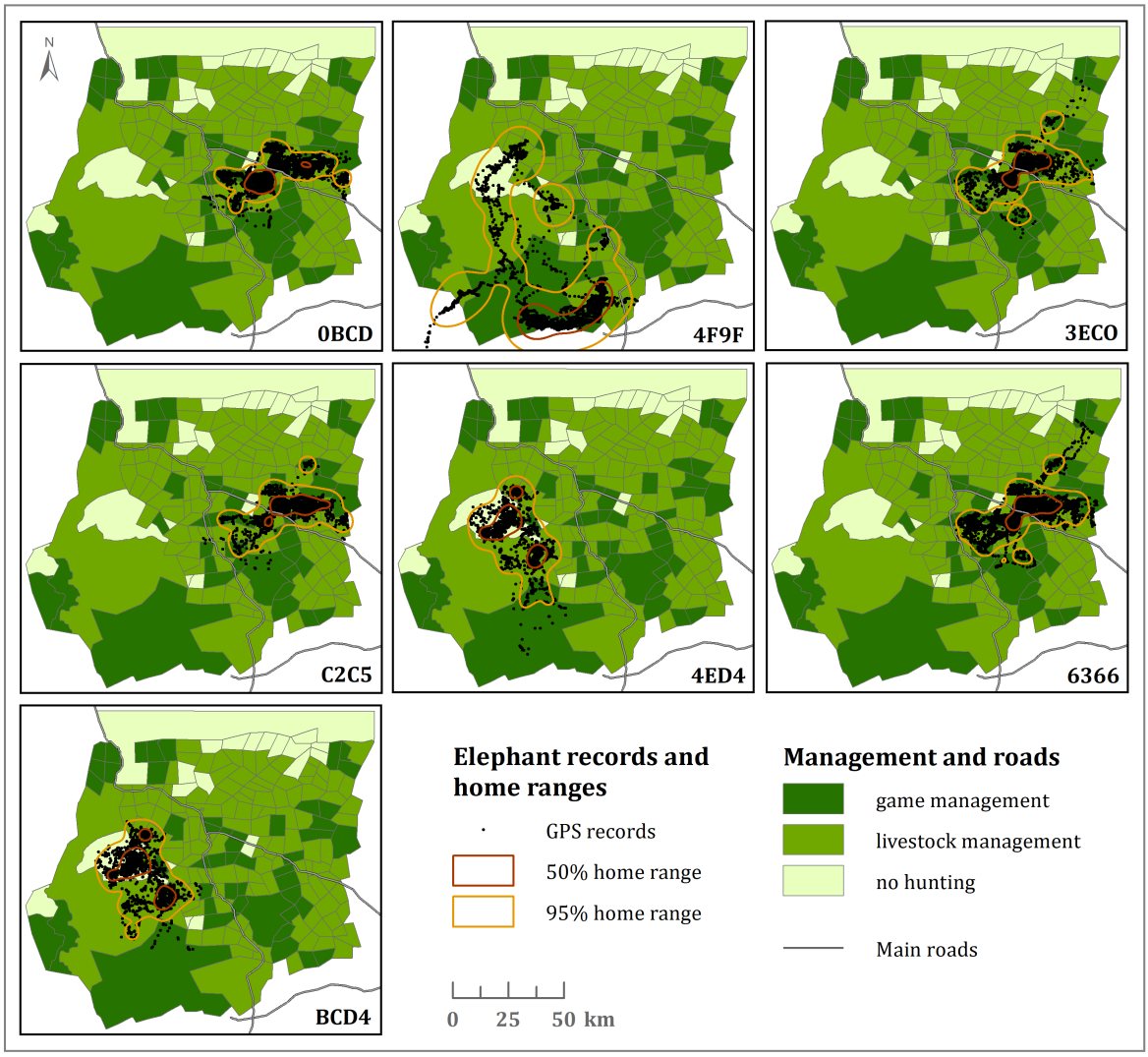


Figure 14: Individual home range estimations and GPS records before the background of land management.

Table 8: Home range sizes in hectares; HR50 = 50% home range, HR95 = 95% home range.

	0BCD	4F9F	3ECO	C2C5	4ED4	6366	BCD4	Mean
HR50	2,516.4	51,444.9	17,547.4	19,547.2	26,978.5	19,875.0	27,060.2	23,567.1
HR95	86,426.2	385,466.4	123,885.1	109,848.1	133,700.0	116,061.0	125,246.0	154,376.1
	Elephants in the east (mean)				Elephants in the west (mean)			
HR50	14,871.5				35,161.2			
HR95	109,055.1				214,804.1			

4.3.3 Preferred land management and the influence of fences

Figure 15 shows the density of GPS records per management type area within its 95% home range for each elephant, confined to the study area. First, it is evident that the density distribution for each elephant differs. In order to derive a statement on the preference of elephants, it is important to look at the home ranges and locations of GPS records of each individual elephant. The home ranges of the elephants with the identification codes 0BCD, 3ECO, C2C5 and 6366 only cover a small area where no hunting is practiced. Hence, a reliable statement whether they prefer or avoid this management type is not possible. However, all these elephants spent more time on farms with livestock than game management. The density distribution of elephant 4F9F is considered as unreliable as a large proportion of its home range covers the conservancy //Huab where no zonation plan was available. Therefore, two remaining elephants are expected to provide information on the relative preference of all three management types: 4ED4 and BCD4. Here, the record density was higher in regions where livestock management was practiced then on those areas with game management. Additionally, it is evident that in areas where no hunting takes place, an even higher density occurred. Thus, for further analysis, the preference of elephants in terms of management is regarded as being highest in areas without any hunting practices, followed by livestock management. Areas with game management are considered as less attractive to elephants. This gradient is a reasonable assumption as for instance, Lee and Graham (2006, p. 11) indicated that "some elephants responded to intense hunting by moving into protected areas and other secure refuges".

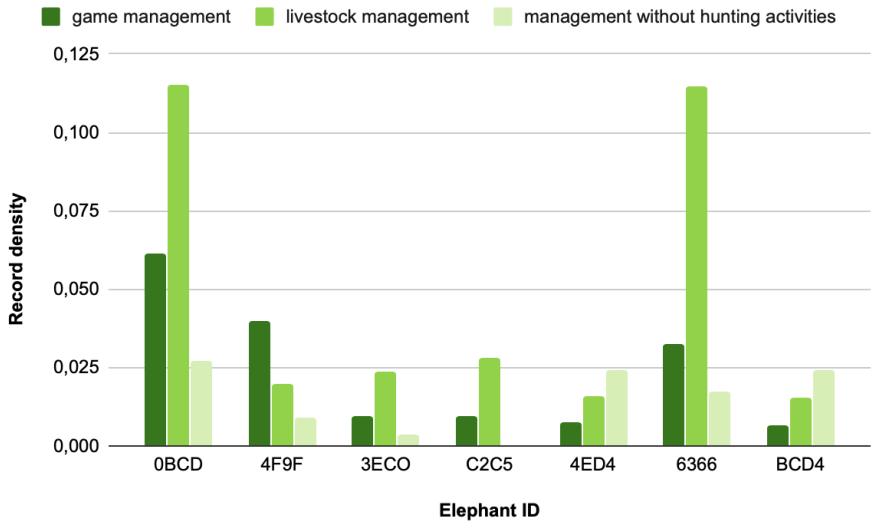


Figure 15: Density of GPS records in different management types within the 95% home ranges of each elephant.

Considering the effect of fences, the geospatial analysis revealed that elephant tracks more often crossed game-proof fences that were not electrified than those that were. While the data does not allow a sound statistical analysis on the permeability of fence types (e.g. small sample size, uneven spatial distribution and inaccuracy of GPS fixes), a qualitative analysis of elephant tracks had to be made. A closer look at the areas around electrified game-proof fences revealed for instance, that both elephants 3ECO and 6366 stopped their excursions in front of the south-eastern electrified boundary fence of Etosha Heights Game Reserve (location of reserve depicted in Figure 10, elephant records mapped in Figure 14). Furthermore, a closer look at the farm Hirabis proved the expected efficiency of electrified fences (Figure 16). Only few GPS fixes were recorded within the farm boundaries, possibly because of inaccurate positioning, unprecise location of the farm boundary or incomplete fence construction/electrification. As all other records indicate that elephants do not cross these fence lines to enter the farm area and as the farmer reported no conflicts with elephants since the fence was constructed, electrified fences are presumed to be a successful barrier against elephants. Some areas that were enclosed with non-electrified game-proof fences were intersected by elephant tracks. Therefore, game-proof fences without electricity are considered to have an impact as deterrents but with a lower efficiency than electrified ones.

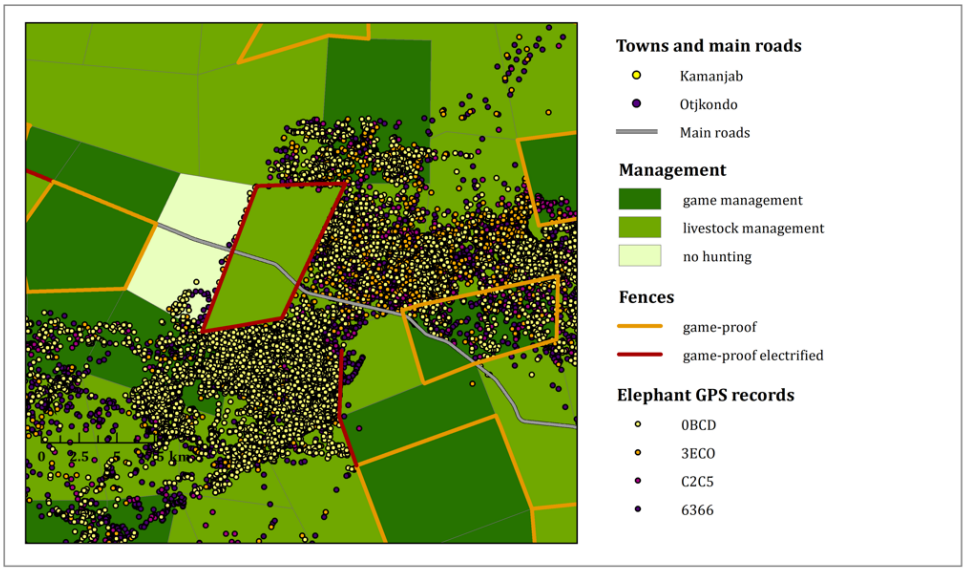


Figure 16: GPS records in the vicinity to farm Hirabis, indicating the effectiveness of electrified game-proof fences as deterrent (location of the farm depicted in Figure 10).

4.4 Suitability analysis: Determination of core areas

Habitat suitability is a key reference point for all further analyses as it allowed to identify core areas that were used in the corridor analysis. Habitat suitability was calculated based on the findings from the above-mentioned driver assessment and was derived for the end of the rainy period (September) and the end of the dry period (March) – the two seasonal extreme conditions (Figure 7 in Section 3.3.3). In this regard, both the mean conditions of March and September as well as for the specific year of 2019 were considered to provide a basis for core area determination.

Both, in the averaged September and the September of 2019, a generally lower habitat suitability was identified compared to the mean March and the March of 2019 (Figure 17). This correlates with the seasonality of the study area (Figure 7). Additionally, it is evident that in 2019, areas suitable as elephant habitats were fewer than in an average year. In general, the south-western part of the study area was seemingly least suitable as elephant habitat.

Based on the suitability maps and by integrating the interview findings, three core areas were determined (Figure 17). These areas were selected against the background of (i) the final habitat suitability classification, (ii) their protection status and (iii) the respondents' observations on elephant movements. One core area is located in the western study area, more precisely in the part of the conservancy ≠Khoadi-//Hôas where no hunting is allowed. Another core area was determined in the region of Etosha National Park, which is relatively suitable and provides a high degree of safety for elephants. This matches the observation of respondents that elephants move between the park and the adjacent farmland at this boundary section. As they also reported elephants to continuously extend their range towards the eastern part of the study area, the most suitable habitat in this area was determined as the third core area.

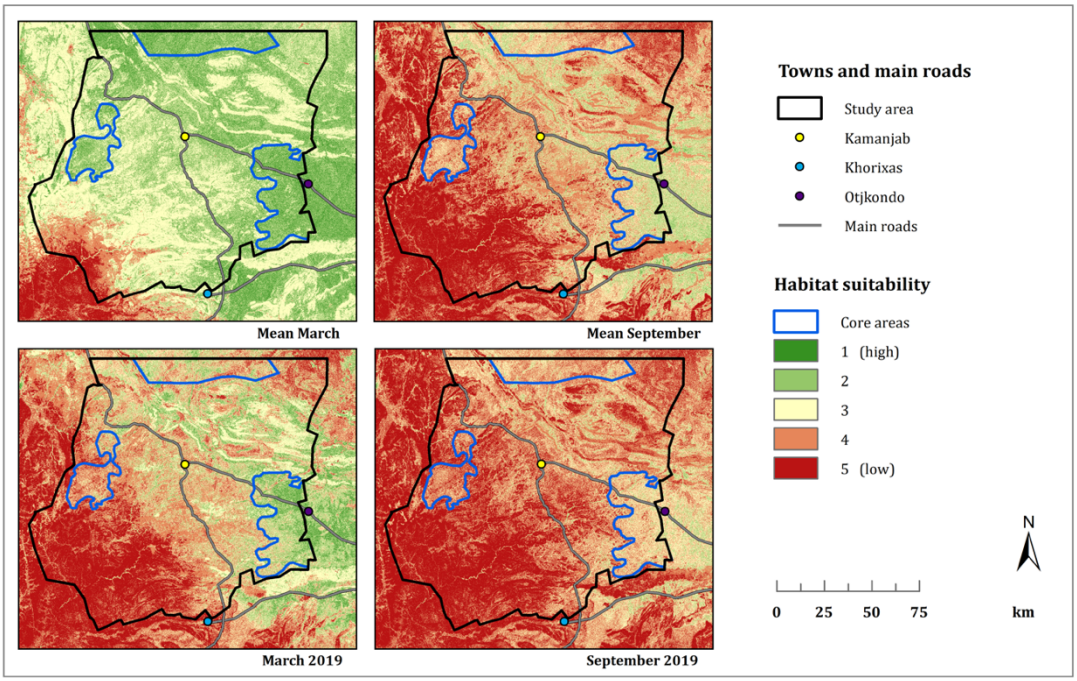


Figure 17: Maps presenting the suitability of the landscape as elephant habitat, calculation based on Table 7.

4.5 Corridor analysis

From the qualitative interview material and the quantitative metrics of habitat suitability and resistance, potential elephant movement corridors were calculated that connect the determined core areas. The following subsections will depict the changes on landscape permeability between the current status quo conditions and an environment without any fences and management practices (4.5.1), and two hypothetical fencing scenarios derived from the qualitative interview and observation findings (4.5.2).

To that effect, Figure 18 and 19 present the results graphically. First, the cost-weighted distances to the nearest core area are depicted (Figures 18a and 19a). The higher the value, the more costly is the movement to reach the nearest core area. A least-cost path (LCP) represents the track with least-cost distance between one core area pair. Table 9 includes the cost-weighted distance and the length of each least-cost path. Second, the maps present the location of corridors as calculated in relation to the least-cost paths (Figure 18b and 19b), thus, the corridors are to be seen in relation to the specific environment described by one resistance surface. Green areas show a higher permeability for elephants to move between each core area pair while vice versa grey areas represent a higher cost-weighted distance, which may be translated as being coupled with higher movement costs for elephants. Corridors, which are below 10 cost-weighted kilometres, are outlined in blue while those below 25 kilometres are framed in purple. The location of these cut-off corridors is comparatively depicted in Figure 18c and 19c, respectively. The darker green areas are overlapping corridor sections, while red ones are lost and lighter green areas emerge, when the landscape changes in its characteristics.

Table 9: Cost-weighted distances (in cost-weighted kilometres) and lengths of least-cost paths (in kilometres), corridor area calculations and their intersecting area (in hectares).

Cost-weighted distance of LCP between core area pair	Nat	Real	S1	S2
1 and 2	308,786.69	347,769.72	365,132.72	347,769.72
1 and 3	139,048.09	145,740.88	145,740.88	145,740.88
2 and 3	205,767.91	271,097.66	271,097.66	273,701.63
LCP lengths between core area pair	Nat	Real	S1	S2
1 and 2	69,627	91,847	91,847	91,847
1 and 3	32,533	41,937	41,937	41,937
2 and 3	48,872	62,292	62,292	56,086
	Area within 10 cost-weighted km		Area within 25 cost-weighted km	
Corridor area				
Area Nat	167,608		417,282	
Area Real	183,524		377,523	
Area S1	181,995		374,942	
Area S2	163,110		343,256	
Area of intersect				
Nat – Real	49,938		273,463	
Real – S1	181,938		374,914	
Real – S2	160,416		342,328	

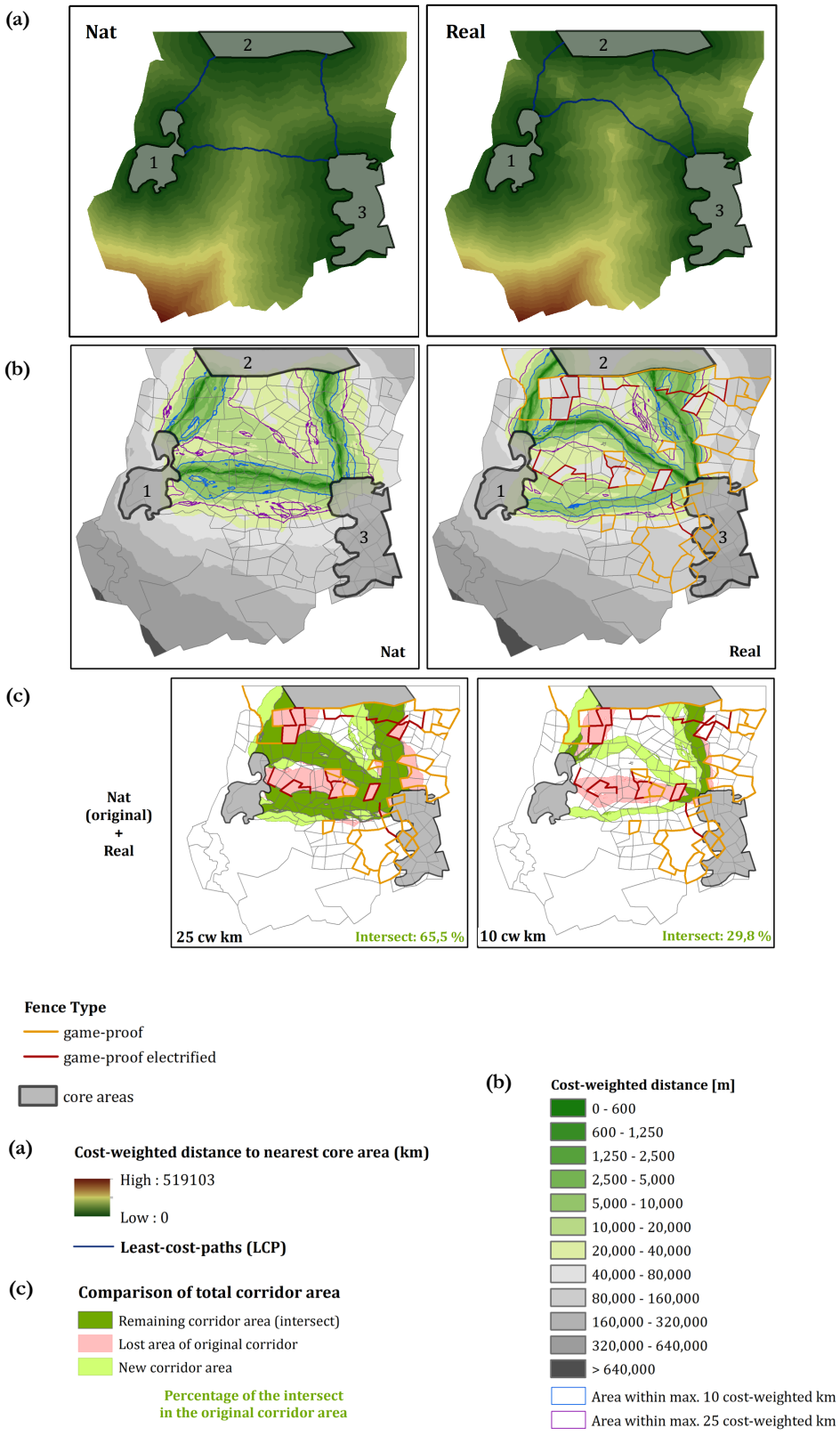


Figure 18: Results from the corridor analysis in a landscape without game-proof fences and land management (Nat) and the actual landscape (Real), (a) Cost-weighted distances to the nearest core area, (b) mosaicked least-cost corridor maps, and (c) the comparison of corridors cut to 25 and 10 cost-weighted kilometres, respectively.

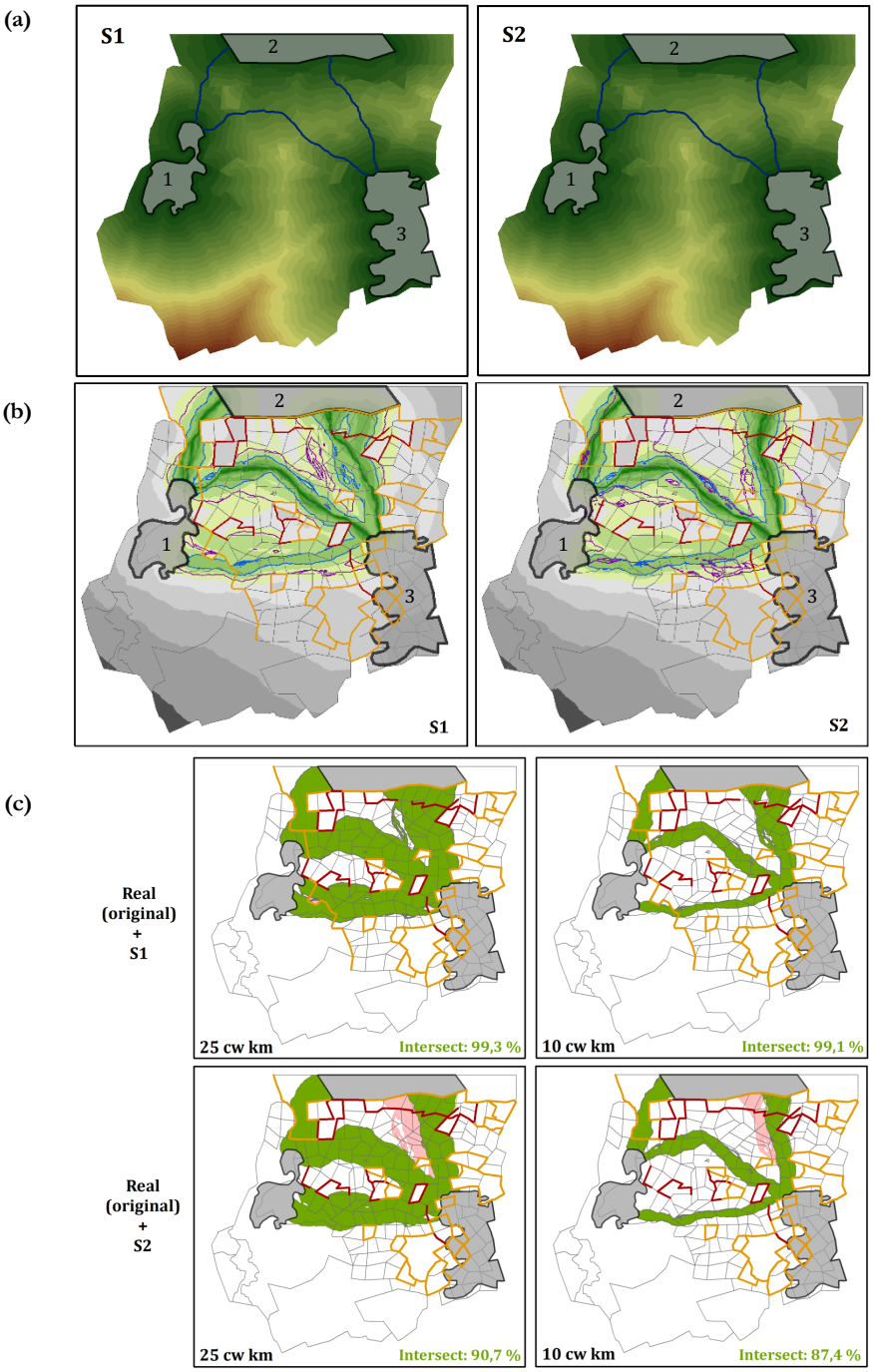


Figure 19: Results from the corridor analysis in a landscape with a continuous fence line to the west (S1) and at the southern border of ENP (S2), (a) Cost-weighted distances to the nearest core area, (b) mosaicked least-cost corridor maps, and (c) the comparison of corridors cut to 25 and 10 cost-weighted kilometres with the actual environment (Figure 18), respectively. Legend to be found in Figure 18.

4.5.1 Current conditions in comparison to a natural landscape

In an area without any socio-economic barriers and deterrents, cost-weighted distance in general increases with distance to core areas (Figure 18a, Nat). Irregularities emerge from terrain characteristics and differences in vegetation availability. The picture changes in areas with farms that are enclosed with game-proof fences and where game and livestock management is practiced while the impact of linear game-proof fences

seems to be higher than the management on two-dimensional areas (Figure 18a, Real). Each LCP changes its location in the altered environment: The LCP between core area 1 and 3 circumvents all boundary fences, thus both, its length and cost-weighted distance increases (Table 9). These higher values are also observed for the LCPs while still intersecting the southern national park boundary fence. The LCP connecting core area 2 and 3 leads through the unfenced passage south of Etosha Heights Game Reserve and the LCP between core area 1 and 2 shifts to the national park further west, probably due to the lower costs in this protected area (Figure 18a, Real). The associated corridor between these core areas is also confined to this part of the national park, possibly as to the east, game-management area with electrified game-proof fences impedes connectivity (Figure 18b, Real) whereas in a natural environment (Figure 18a and b, Nat) both, the LCP and the corridor of least-cost distance would lead through this area. The corridor between core area 2 and 3 splits with least resistance around the corresponding LCP through the unfenced section, where resistance decreases and leads to a low cost-weight distance when moving through this passage (Figure 18a and b, Real). The most obvious corridor shift is observed between core area 1 and 3. One corridor follows the connecting LCP while another corridor is shifted to the south, similarly circumventing farms that are surrounded by game-proof fences – regardless if electrified or not. These exhibit a higher cost-weighted distance due to the heavy resistance (Figure 18a and b, Real).

The change in the total area of the clipped corridors is quantitatively presented in Table 9. With a total of around 417,300 hectares, the corridors cut to 25 cost-weighted kilometres (further addressed as wider corridor) in a landscape without socio-economic structures (Nat) have the largest extent. In the 'real' environment, the area of these wider corridors decreases significantly to about 377,500 hectares with 65.5% of the previous corridor area remaining. The difference in the location of the central corridors (used as synonym for corridors cut-off to 10 cost-weighted kilometres) is even greater, as only 29.8% remained. In other words, 70.2% of the corridor area changed their location indicating that socio-economic structures cumulatively have a high impact on the connectivity when integrated into the landscape.

4.5.2 Fencing scenarios

When the existing situation (Figure 18a, Real) is complemented by additional non-electrified game-proof fences to the west (S2), the cost-weighted distance in the east of core area 1 increases (Figure 19a). However, the LCPs do not change their location and length. Only the path connecting core area 1 and 2 shows an increased cost-weighted distance (Table 9). The intersection of the cut-off corridors revealed that despite the additional fences, least-cost corridors still lead through the continuous fence line indicating that circumventing it in the south would increase the costs for movement considerably. To be described in numbers, from the corridors in the actual landscape (Figure 18c, Real), 99.3% and 99.1% of the wider and central corridors, respectively, conserve their location when a continuous fence line exists in the west.

Comprehensive fencing to the north (S2) closes the former passage through Etosha Heights Game Reserve and thus, the pattern of cost-weighted distance to the nearest core area in and south of this tourism-based association of farms changes (Figure 19a and b, S2). Most obvious is the eastward shift of the LCP connecting core area 2 and 3, where the path is also located in a natural environment. Likewise, the corridor of least resistance shifts to that location as seen in Figure 19b and c. In total, 90.7% of the wider corridors in the current landscape remain, while at least 87.4% of the central corridors persist. These remaining portions are largely those connecting core area 1 with core area 2 or 3, respectively. Here, the LCP metrics do not change except for the LCP leading through Etosha Heights Game Reserve whose length and cost-weighted distance increases due to the additional fence section (Table 9).

5 Discussion

In this chapter, the results of the empirical surveys and spatial analyses are put into context to answer the overall research question on the cumulative impact of fences and land management on the permeability of the landscape for elephant movement. First, the results of the interviews will be embedded in the concept of (Shaffer *et al.*, 2019), which was adapted to adequately contextualize the different variables that form the human-elephant interactions in the study area (5.1). Second, the focus is directed specifically towards fencing as one deterrent measure, given that the study area is parcelled out by areas of different management practices (5.2). From an elephant perspective, the extent to which opportunities for movement are provided in the landscape and the linkage to human-elephant interactions is discussed in this subsection. Lastly, limitations and opportunities to optimize the empirical survey and the spatial analyses will be outlined (5.3).

5.1 Dynamics of human-elephant interactions

Understanding the dynamics of the human-elephant interactions within the study area is a central goal of this research in order to generate basic knowledge for further research into mitigation of this problem. In general, interactions between humans and wildlife may be predominantly positive or negative (Twine and Magome, 2007). Twine and Magome (2007) assessed that inside of protected areas, the interactions were of a positive nature, however, they also mentioned that outside, sporadic conflict events may negatively influence the residents' attitude towards elephants. For the area of interest, the results revealed that the perception of local farmers towards elephants was mostly negative. However, there seems to be a gradient between livestock farmers and those who are engaged in tourism activities experiencing negative impacts but also benefitting from the presence of elephants. This conflict identification is in line with other studies that assessed the conflict potential between farmers and elephants (e.g. Hill, 1998; Sitati *et al.*, 2003; Adams *et al.*, 2017). This conclusion on the conflict character was drawn from different factors: (i) The farmers living in the rangeland south of ENP mostly perceived the population as too large. (ii) Except for one, all interviewed farmers having elephants on their farm ranked them as significant problem species. (iii) Attendants of the farmers' meeting reported numerous problems occurring around elephants, which supports the perception that these interactions are characterized as conflicts. The identification of the interactions' nature and the drivers for this rather conflicting relation between elephants and humans is crucial when attempting to understand decision-making by individual farmers and the management of communal conservancies. In this way, entry points for conflict identification, prevention and mitigation may be set. This section will determine the conflict dynamics as base for further research.

It is clear that the conflict in the study area is driven by the competition around natural resources like water, food and space as also described in various other studies (O'Connell-Rodwell *et al.*, 2000; Nelson, Bidwell and Sillero-Zubiri, 2003). Shaffer *et al.* (2019) also regarded the conflict between humans and elephants as the result of resource competition. They frame it as a conceptual model of coupled natural and human systems, which focuses on the varying resource availability on a spatial and temporal scale and is also applicable for the area around Kamanjab. In this subsection, the conceptual framework will be used to descriptively depict the drivers that explain the characteristics of human-elephant conflict in the study area as derived from the respondents' statements while discovering interconnections between these variables.

Figure 20 shows the adapted concept of Shaffer *et al.* (2019). Human-elephant conflict is regarded as influenced by variables around humans and elephants, which both rely on the same natural resource base to fulfil their needs. Besides these variables that emerge from both species directly, other circumstances may influence the intensity, timing and geographical location of conflicts. Shaffer *et al.* (2019) sum up these factors as pulse/press disturbances. However, this study revealed that these disturbances also influence the humans' and elephants' actions and perceptions. Thus, the figure of Shaffer *et al.* (2019) is adapted insofar as disturbances are not seen as components equal to human and elephant variables but rather as a scenery or

framework in which humans and elephants act and react. Within the study area, these disturbances may be categorized in (i) drought events (D1), (ii) conservation policies (D2), (iii) access to international meat markets (D3) and (iv) (international) tourism (D4). To which extent these disturbances influence human and elephant variables and consequently human-elephant conflicts will be explained in the following paragraphs.

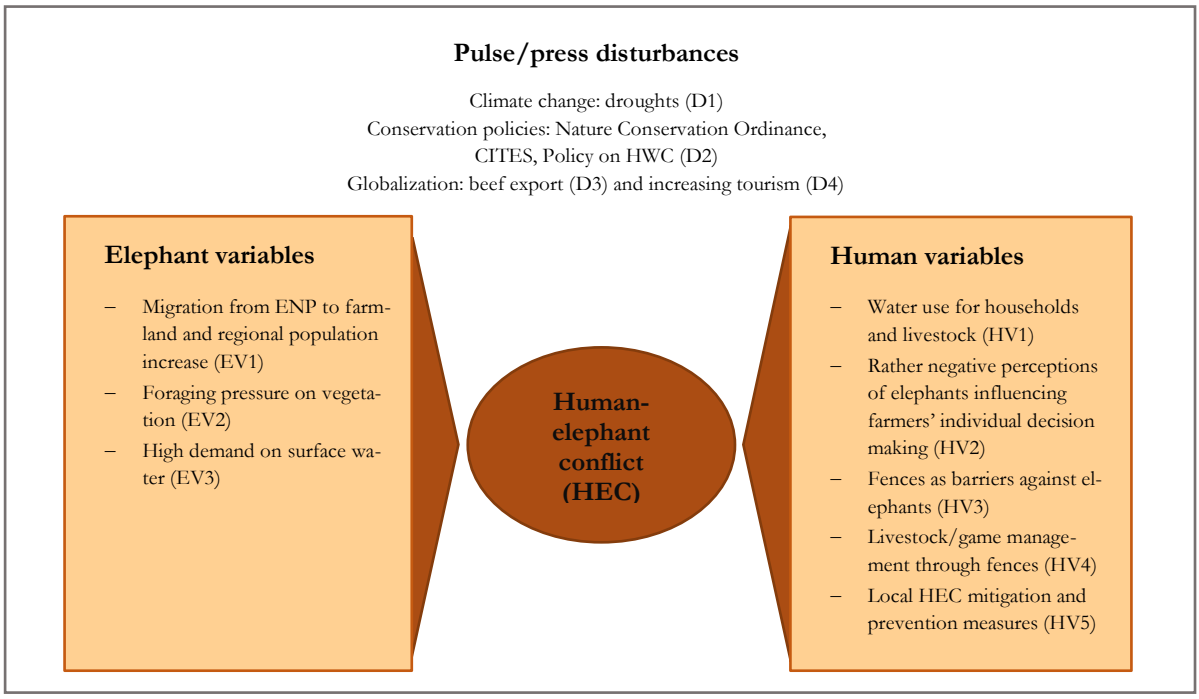


Figure 20: Contextualization of the dominant variables influencing human-elephant interactions within the study area, modified after Shaffer *et al.* (2019); variables of humans and elephants have an impact on the conflict characteristics while framed by different press and pulse disturbances.

When looking at the elephant population, the spatial context has to be considered. Twine and Magome (2007, p. 223) state that "one of the clearest spatial risk factors is distance from the boundary of the protected area". Indeed, respondents reported that elephants frequently use specific farms and communal area in the south and southwest of ENP (EV1). This supports the analyses of Leggett (2006) who examined the records of various collared elephants in this area. Furthermore, the population is perceived as increasing which might exacerbate the conflict regarding the resource competition (EV1). Moreover, elephants forage on ancient trees (EV2) that are regarded as integral part of the landscape and hence have a high touristic value.

Resource competition focusses primarily on water. Farmers and conservancies constructed boreholes and dams from which they obtain water for their household and livestock (HV1). Elephants that drink this water and destroy water infrastructure are perceived as culprits. Due to the elephants' high water demand (EV3), affected farmers and communities bare high costs to refill these reservoirs. Especially in drought years (D1) when surface water is scarce and groundwater levels are low, this conflict around water is exacerbated due to the shrinking resource base. The drought in the 2018/2019 agricultural season (Food and Agriculture Organization of the United Nations, 2019; Masawi, 2019) proved to be a major challenge for Namibia's population as reported in various news headlines (Namibian Press Agency, 2019; Nghinomenwa, 2019; Shikangalah, 2020). An expert (E8) assumed that conflicts might decrease when the drought is overcome.

This competition over limited resources causes the majority of the farmers to have a rather negative perception of the current elephant population (HV2). Besides financial burdens, unexpected encounters with elephants that approach farmhouses in search for food and water, contribute to the conflicting interactions.

As these conflict incidents occur frequently, farmers might suffer from psychological stress being constantly alerted to discover damage caused by or encounters with elephants. Moreover, none of the farmers who were asked confirmed that elephants would have an environmental benefit within their area. These perceptions drastically influence the stakeholders' decision-making. Government, therefore, is challenged to achieve acceptance of strategy plans, i.e. on human-elephant conflict and conservation. Thus, the drafting and implementation processes have to be persuasive, well-communicated and based on early and comprehensive integration of local stakeholders.

However, farmers who offer wildlife-based touristic activities like safari drives might have a higher tolerance towards damage caused by elephants as they also experience benefits through the presence of the animals. The study area may be seen as a mosaic of parcels with different management practices and thus, intensity and occurrence of conflicts might differ. Those who practice livestock farming do not directly benefit from elephants except from revenues distributed through the conservancy committee. Their individual decision-making is primarily influenced by agricultural interests around livestock, whereas farmers engaged in tourism activities, might decide for the benefit of elephants. The government supports the sustainable development of the tourism sector. Indeed, Namibia has an increasing number of international visitors (MET, 2018b, MET, 2020b) that are attracted by the country's unique wildlife (D4). This might possibly lead to a shift from conventional livestock management towards tourism-oriented land uses in the area south of the national park and hence, also change the local stakeholders' perception on elephants.

Policies and laws (D2) also influence the occurrence of conflicts as they regulate the decision-making of actors and determine guidelines on elephant conservation. One important policy that limits the hunting and trade activities of individuals, is CITES. This international agreement regulated the trade of ivory and culling to promote the conservation of Africa's elephant populations. The Nature Conservation Ordinance, Act 4 of 1975 (GRN, 2003), as amended several times, prescribes specific zonation plans for communal conservancies. These plans may include areas exclusively reserved for wildlife and may lead to conflict prevention as land is subdivided for different land uses. Furthermore, the National Policy on Community-based Natural Resource Management (MET, 2013b) aims at the generation of benefits to communal farmers and hence, at a higher tolerance of individuals towards elephants. The Revised National Policy on Human-Wildlife Conflict (MET, 2018a) shall, amongst others, provide for a framework to compensate farmers under different regulations for damage, human injury and loss of life caused by elephants. In the study area, however, this compensation scheme did not impact the farmers' perceptions on elephants considerably as it is not practical in its implementation.

The Nature Conservation Ordinance also gives incentives to farmers engaged in wildlife-based management to enclose their farms with wildlife-proof fences as thus, they receive the ownership over the wildlife on their farm. Moreover, local stakeholders choose game-proof fences as measure to prevent elephants from approaching the resources on their farm (HV3). As literature suggests (Ferguson and Hanks, 2012; Jakes *et al.*, 2018), these fences, however, pose a threat to elephant movement and fitness. Likewise, they are one manifestation of the conflict itself, as elephants frequently break these, which results in high labour and financial costs for farmers. Moreover, fence damages inhibit controlled game and livestock management (H4).

This is especially obvious in terms of the Veterinary Cordon Fence that may be seen as the manifestation of the influence from an international policy framework. In the course of globalization, farmers started to export beef from Namibia to European countries (D3). The import permits are targeted to meat from the disease-free zone, which is separated from the north by the Veterinary Cordon Fence. Particularly freehold farmers are engaged in the exporting beef meat industry and therefore, have a high interest in a proper state of the fence (Scoones *et al.*, 2010; Van Schalkwyk and Hoffman, 2016). In this regard, elephants crossing the fences when entering or leaving ENP, indirectly pose a threat to the livestock sector. Moreover, predators preying on livestock may enter to farmland when elephants opened up passages. In summary, especially the conflict between elephants and local farmers engaged in livestock farming in close proximity to the ENP

boundary is indirectly exacerbated by the European regulations on meat import. Another factor influencing the conflict dynamics is the (international) tourism.

Moreover, the interviews revealed that farmers applied a variety of local measures to prevent and mitigate conflicts with elephants (HV5), including fence construction as described above (HV3). The strategies may be regarded as part of individual decision-making and are mostly deterrents commonly used in other areas of southern and eastern Africa (Mbaiwa and Mbaiwa, 2006; Ferguson and Hanks, 2012). Some measures successfully serve to prevent damage and potentially dangerous encounters on a particular farm. However, for some reasons it is questionable whether these measures serve to mitigate human-elephant conflict in the long-term: First, construction and maintenance of deterrents like game-proof fences or booby traps are labour-intensive and time-consuming. Furthermore, methods such as warning shots may pose psychological stress on individual elephants. This may cause stress feeding and thus, damage on vegetation and infrastructure. Human-induced elevated stress levels might also cause higher aggression potential towards humans and consequently exacerbate conflicts, unintentionally. This statement would support the findings of Hunninck *et al.* (2017) who examined an indicator for stress in the feces of elephants outside the ENP and suggest that anthropogenic disturbances might pose a threat to the long-term survival of elephant population outside of protected areas. In general, it is evident that applied measures rather focus on the symptoms of the conflict rather than the drivers, i.e. competition over resources.

5.2 Cumulative impact of fences and land management on the permeability of the landscape

The methodological approach and the analyses applied in this study build upon a limited set of elephant movement data as well as selected environmental and socio-economic variables. Therefore, the results are considered as preliminary and it is not recommended to use the findings for political decision-making. However, it may function as a first approach to spatially assess the cumulative impact of socio-economic structures on the landscape permeability for elephants within the savannah ecosystem of Namibia.

From the participatory mapping it is evident that different land management activities are practiced – mostly livestock but also game farming and, to a smaller extent, tourism without any hunting activities. There are also various hybrid livelihood strategies. Suggestions that farming in certain regions is moving away from livestock farming towards wildlife-based practices were made. This shift is perceived to mitigate human-elephant conflicts as wildlife-based management might be more compatible with the presence of elephants than livestock-dominated management. Wildlife-based management might encompass comprehensive game hunting as well as photo tourism. While both management strategies are accompanied with more tolerance towards elephants, their impact differs. In this study, hunting is assumed to have a negative effect on the well-being of elephants and thus, these areas might pose higher costs to animals.

In regard of the other socio-economic structures assessed in this study, fences are essential for successful rangeland management for livestock as cattle, sheep and goats may be guided to allow vegetation to recover from grazing pressure. The perceived importance of fences supports the interview findings from McGranahan (2008) and are key strategies according to Tainton (1999). The reason for the construction of taller game-proof fences is to prevent elephants and other wildlife species from entering or leaving specific areas. As indicated in the previous section, these fences play a major role for farmers within the study area. Electrified fences were reported to be more successful as deterrents to elephants than non-electrified ones.

Until now, fencing is not centrally coordinated but individually decided by private farmers. The findings of this study revealed that the functional connectivity between the core areas generally persists when fences are constructed and management is intensified towards livestock and hunting activities, as elephants may choose other areas to move to. These changes in location and spatial extent could be visualized through the

calculation of cut-off corridors. Of the wider corridors (25 cost-weighted kilometres) one third remained while more than two thirds of the central corridor with least-cost distance of 10 kilometres changed their locations when comparing the landscape without fences and human-induced management. The difference might be even greater when compared with a landscape entirely unaffected by humans, as in these results, NDVI is already influenced by human presence. Yet, the calculated connectivity still might be very optimistic as various other aggravating factors, e.g. water absence, individual dissuasive measures, occupation by other elephant herds, were not recognized in the analyses. Furthermore, these corridors might have been used frequently by resident herds, thus, finding alternative corridors might be accompanied with energy loss in the course of search.

These findings correlate with the study of Osipova *et al.* (2018) on the functional connectivity of the Borderland area between Kenya and Tanzania for elephants. They conclude that on a landscape scale, no fragmentation is to be expected with additional fences, however, locally the connectivity might be reduced. South of ENP, this becomes especially evident when looking at the corridor between the western and the eastern core area: Although the functional connectivity persists, the area directly between the core areas completely loses its function as priority corridor area. Here, in particular game-proof fences decrease connectivity. In the transboundary region of Botswana, Namibia and Zambia, Cushman, Chase and Griffin (2010, p. 365) also analysed that veterinary fences have a "dominant effect on landscape connectivity for elephants". In other words, they assessed that cost distance increased, which might result in the isolation of specific areas.

For testing of continuous fencing, i.e. from ENP to the south, the least-cost analysis revealed that the corridor still intersects the fence line. Obviously, the additional costs generated through the fence do not reduce permeability to an extent that would cause elephants to circumvent the linear barrier in the south. With memory and knowledge on forage grounds and movement routes passed from one generation to another (McComb *et al.*, 2001), elephants probably would not simply respect continuous lines of fences when they have no forage on that side of the fence. Populations of long-lived animals first have to adapt their behaviour to the new circumstances until the next generations benefit from successful experience. Thus, the population's fitness might decrease in the first years after comprehensive fence construction (De Waal, 2001; cited by Grant *et al.*, 2008).

Lastly, it is questionable if this method would be justifiable in terms of conservation. Conservation practitioners agree on the importance of movement for restoring and stabilizing populations of elephants and other wildlife species (e.g. Chase and Griffin, 2009). Negative effects of a landscape-wide comprehensive fence are assessed in various studies on the Veterinary Cordon Fence, both in Namibia and Botswana (Martin, 2005; Mbaiwa and Mbaiwa, 2006; Ferguson and Hanks, 2012). Furthermore, considering the social aspects, this fence line would represent a separation of communal and privately-owned land that probably is not desirable in a country that is still challenged by the restoration of equality after the colonial era (GRN, 2017).

One farmer reported to not have any conflicts with elephants anymore since he enclosed his farm with an electrified game-proof fence (F9). For his individual management, this may be regarded as a success to prevent human-elephant conflict as elephants do not forage on and drink of the resources within the boundaries of the farm. However, seen in the larger context of conflict prevention and mitigation, the suitability of uncoordinated fence construction as adequate method therein has to be questioned.

Reflecting upon the above-mentioned points, Figure 21 provides a conceptualization to show the feedbacks of uncoordinated individual fencing decisions and overall conflict occurrence. The figure depicts a feedback loop that might emerge when elephant-proof fences are constructed as an individual decision by land users. Farmer A receives disadvantages from the presence of elephants on his/her farm, e.g. damage on water infrastructure or on trees, and therefore, weighs up the different measures to reduce these disservices. Assuming he/she chooses to construct an efficient boundary fence, elephants will avoid this farm. Regarding

the landscape as one entity however, these elephants will not simply disappear but alter their movement to approach resources in other parts of the area. This might be a protected area where elephants are accepted, but also rangeland that is utilized by another farmer. This farmer B might never have had any problem with elephants or tolerated few conflict incidents while now, a higher number of elephants cause a higher disservice to farmer B. According to his/her experience, management objectives, value system and the characteristics of human-elephant encounters, farmer B will assess the new situation, and – like farmer A earlier – decide on different mitigation strategies. If he/she constructs new fences, the elephants are up to decide if ignoring the barriers, which for farmer B will result in high costs for construction and maintenance, or to move to another area where additional farmers might be affected.

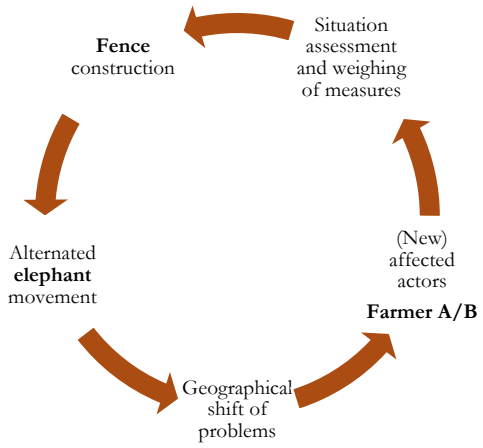


Figure 21: Feedback loop on fence construction indicating self-reinforcing shift of problems

In this regard, it has to be considered that through one farm fence, not only farmer B but multiple other farmers might be affected when elephants change their movement as a response to this new barrier. Before this background, fences that were constructed by individual actors neglecting or simply not knowing about the cumulative consequences on the landscape level might exacerbate human-elephant conflicts on other farms, as also Osipova *et al.* (2018) conclude. At this point, it has to be emphasized that farmers not simply ignore consequences but instead, without additional support conduct farm-based practices in their individual favour.

A landscape plan on elephant management and coordinated land management combined with fence construction that is based on shared practical experience and scientific knowledge might mitigate intensity and frequency of conflict events for the benefit of more than just one actor. Through the definition of areas where the movement of elephants is tolerated, corridors might connect protected areas such as the ENP and conservancy wildlife zones and thus, contribute to their individual fitness and population survival. This approach of a land use and large-scale management plan is not new, but recommended by different other studies, like for instance by Graham *et al.* (2009). In this regard, fences do not necessarily have to be seen as obstacles but also as potential measures for the implementation of the plan such as the guidance of elephants towards provided corridors.

This study indicates that the least-cost distance analysis can be a powerful methodological approach to locate areas of high and low connectivity and the influence of fences before construction, when considering the cumulative impact of several landscape components. When findings shall be viable for political decision-making regarding the establishment of a landscape plan, future research should aim to refine the approach and analyses with consideration of their current limitations as outlined in the subsequent section.

5.3 Limitations of the study and recommendations for future research

Linkage Mapper is a powerful tool to identify the location of corridors within a landscape. With the identification of the relative corridors in each environment, a comparison was possible to draw conclusions on the cumulative effect of game-proof fences and land management. However, it is important to keep in mind that the method has its limits and was applied with some restrictions. These limitations and concerns may be grouped into (i) data availability and selection, (ii) demarcation of the study area, (iii) restrictions in the process of input variable assessment and core area definition and (iv) limitations of the corridor results.

Likewise, the interdisciplinary approach entailing semi-structured interviews and the participatory mapping process enabled the acquisition of information, which was crucial for the preparation of the corridor analysis as well as the understanding of the human-elephant interactions within the region of interest. Yet, different aspects have to be accounted for when drawing conclusions concerning the research question (v). Further outlined in this section, these restrictions also point out opportunities to enhance this study for future research.

First, the limited number of environmental parameters as background data has to be considered. Literature clearly suggests that water crucially influences population dynamics and distribution (Wittemyer, 2001; de Beer *et al.*, 2006; Chamaillé-Jammes, Valeix and Hervé, 2007; Harris *et al.*, 2008). However, for the study area, reliable information on artificial water holes and detailed data on the location of ephemeral rivers was unavailable. In order to enhance the results' viability, it is suggested to map or request geospatial data on these features as their integration might be valuable. For instance, De Boer *et al.* (2013), considered water availability for a continent-wide calculation to understand spatial differences in elephant densities and occurrence. Furthermore, in terms of terrain, the factor slope can be complemented with elevation as in higher altitudes, there might be lower temperatures, which helps the elephants to control their body temperature (de Boer *et al.*, 2013).

In this study, NDVI served as proxy for vegetation availability. In order to further account for forage biomass, NDVI might be combined with the Net Primary Production (NPP) index. Besides the biomass, vegetation structure should also be taken into account when depicting a comprehensive picture on habitat preference and landscape resistance as for instance the availability of shade differs therein (Olff, Ritchie and Prins, 2002; Harris *et al.*, 2008; de Boer *et al.*, 2013). By using airborne vehicles, colleagues from ORYCS are currently obtaining details on vegetation structure as reference for the classification of vegetation patterns in the study area. Leggett (2006) indicated that the fruit mature of *Faidherbia albida* triggered the movement of elephants rather than the availability of water. Therefore, the date of fruit mature might be an important component influencing the distribution of elephants in the study area. Additionally, soil characteristics such as soil fertility, nutrient status and soil water holding capacity might have an effect on elephant abundance, as assumed by De Boer *et al.* (2013) and Khaemba and Stein (2000), respectively. De Boer *et al.* (2013) also suggest that there was a negative correlation between human and elephant density. For this study, integrating population density with census data and livestock rates as a proxy for human presence might reveal interesting differences between communal and freehold area (de Boer *et al.*, 2013). Livestock numbers for instance, are gathered at the Veterinary Service of Namibia.

Moreover, one has to keep in mind that the boundaries of the study area were aligned to the borders of the commercial farms and communal conservancies, though elephants move in and out of this area. The analyses of Leggett (2006) revealed that elephants use a wide range, hence, the study area may not be regarded as isolated from the surrounding area.

The derivation of habitat suitability and landscape resistance proved to be an approach that successfully contributed to the corridor analysis to depict the cumulative influence of socio-economic factors such as fences and land management. However, some restrictions are evident. For the impact of singular fences on local movement of elephants a semi-quantitative approach had to be chosen as the animals' GPS tracks between fences did not depict reality. This approach might be improved through further experience obtained in additional interviews with land users that constructed fences. The empirical survey showed that fences can be categorized into livestock- and game-proof fences, with the latter sub-divided into electrified or non-electrified. Yet, their state differs. This has to be accounted for as elephants might cross sections that are perceived as being maintained when in reality, they are broken and therefore do not pose a barrier for elephants. In this regard, it is considered as valuable information to more precisely ask about the success of maintenance and to know about the construction period and the finalization date. Moreover, further details on fence characteristics might help to assess the impact on elephant movement more reliably.

Elephant family groups show a high social complexity (van Aarde *et al.*, 2008) with each individuals gathering considerable ecological information about the landscape which is crucial for survival (Foley, Pettorelli and Foley, 2008) and which they are able to transmit over large distances to avoid foraging of multiple herds on one vegetation corridor (Garstang, 2004). However, these individual experiences, especially of matriarchs leading the herd, could not be accounted for, as the GPS records of all individual were pooled for further processing. This happened due to little knowledge about the herd size, in-group constellation and individual behaviour of the collared elephants. But indeed, spatial memory is regarded as relevant in the movement behaviour of animals (Fagan *et al.*, 2013). Additionally, the elephants' selection on habitat might also be influenced by the presence of other elephant herds (e.g. Garstang, 2004). Little is known about the behaviour and distribution of those herds, albeit collared elephants might choose their habitats with the intention to avoid encounters with other herds. Observations on individual behaviour, additional interviews or the collaring of a larger number of elephants in areas that were not visited by the already collared individuals might support the understanding of the distribution of the GPS records. Likewise, it is suggested to also collar bulls as for now, the derivations of habitat selection from records are based on the behaviour of elephant cows only. In fact, according to previous studies, females and males show different foraging and movement behaviours (Smit, Grant and Whyte, 2007; Shannon *et al.*, 2010; de Knegt *et al.*, 2011) and reactions on human activity like settlements (Harris *et al.*, 2008). Furthermore, aerial game counts might give an idea on the abundance and distribution of the elephants within the study area.

Regarding the core area determination, no information was available on the weighting of the different factors and thus slope and NDVI were regarded as equally important. Each factor was examined in isolation but Aarts *et al.* (2008) state that cross-correlation between different environmental factors might be a problem in the analysis of habitat preferences. Through resource selection function (Hebblewhite and Merrill, 2007; Chetkiewicz and Boyce, 2009; Abrahms *et al.*, 2017), step selection function and path selection function (Zeller *et al.*, 2016; Osipova *et al.*, 2018; Suksavate, Duengkae and Chaiyes, 2019) the influence of different factors might be identified and thus, their impact integrated into the suitability and corridor analysis. Moreover, Calenge (2006) indicate different functions that can be applied by the R package *adehabitat* which is the predecessor of the R package *adehabitatHR* used in this study for home range estimation.

Additionally, expert opinions could complement the quantitative assessment that was based on GPS records only, with concrete knowledge and experience on habitat preference and movement behaviour of elephants in the specific region. This was conducted for instance by Castilho *et al.* (2015) who examined the landscape permeability for cougar and jaguar. Consultations of specialists provided for values representing resistance of land use/land cover classes for animal movement. Specific expert knowledge might also help to extent the conclusions on the preference and resistance of different land management types, which are currently only based on the records of two collared elephants. This is crucial as the selection of core areas are strongly influencing the outputs of the corridor analysis.

The current results reveal information on the location of corridors with a predefined width of 10 and 25 cost-weighted kilometres. With additional expert knowledge a more valuable and sound width might be chosen when intending to specifically identify realistic corridors to be included in land planning. The ArcGIS tool *Pinchpoint Mapper* might also contribute to the understanding of the importance of the different corridor sections to either sustain the connectivity of the overall network between all core area pairs or between each individual pair. Portions with high current density would represent areas that have a high conservation value with regard to the connection of the core area pairs (McRae, 2017). This analysis also becomes rather relevant in the decision-making process on the implementation of corridors.

The applied least-cost analysis is only able to depict the situation in one month, in this study in September with vegetation patterns averaged over the last 20 years. In order to see the change in other months, same calculations would have to be conducted which is a time-consuming process. However, a more powerful tool to take into account the temporal dynamics is agent-based modelling. With that approach, like for instance provided in the software NetLogo (Wilensky, 1999), not only dynamic developments on a defined

time scale but also individual elephant behaviour may be considered. Calculations run before the background of a two-dimensional space, which reflects environmental factors that may change over time.

Lastly, light has to be shed on the design and process of the socio-empirical interviews and participatory mapping. It stands out, that besides the two conservancy representatives, only experts and freehold farmers were interviewed. Due to the difficult accessibility of the communal farms as reported by Enzerink (2017), combined with limited time, financial restrictions and language barriers, the focus of the survey was put on land users on private farm area. Furthermore, the interviews served as source for qualitative information and do not call for generally valid statements representing every resident's opinion but rather to understand the general setting of human-elephant interactions, the issues around fencing, and to gather background information for a first corridor analysis. However, comprehensive information based on structured quantitative interviews could validate assumptions drawn for the analysis approach. As elephants are an issue in the whole study area, interviews should be conducted both in freehold and communal land, not least to integrate also communal farmers that feel left behind in the process of decision-making as indicated by respondents.

Participatory mapping may be regarded as a successful tool to receive valuable information on spatial socio-economic landscape characteristics. Nevertheless, the interviewees' different knowledge levels complicated the process. In this regard, approaching experts with a comprehensive overview over the region was a crucial quality criterion. Albeit the farmers provided their best knowledge on the farm boundaries and management, the information might not be entirely up to date. In this regard, a closer cooperation with the responsible offices that collect relevant data might support the updating process of the map.

6 Conclusion

This research aimed to assess the cumulative impact of socio-economic structures on the permeability of the area south of ENP and to frame the dynamics of elephant-human interactions. In order to adequately address the social-ecological dimension inherent to this issue, an interdisciplinary methodological approach was chosen. Based on a qualitative assessment of interviews, the current interaction between land users and elephants was evaluated as a conflict around natural resource competition and as primarily framed by conservation policies, climate change, increasing tourism and international trade structures.

In particular, through participatory mapping, geospatial data on socio-economic landscape characteristics (game-proof boundary fences and land management), was obtained from local actors. The geospatial and statistical analysis on the natural terrain and vegetation characteristics facilitated the identification of potentially preferred areas for elephants within the area. The connectivity between these core areas was calculated for landscapes that differed in terms of fence existence and location as well as land management practices.

The analyses revealed that socio-economic landscape features cumulatively have a considerable impact on the permeability between these areas. The most obvious decrease in connectivity was observed when game-proof fences (especially electrified fences) and land management were integrated in a landscape that was characterized by natural features only: Former corridors were shifted to areas without fences and high-impact game management. Adding hypothetical fence sections, as tested for two scenarios, revealed local changes in landscape connectivity. However, overall functional connectivity within the landscape persisted.

This combination of empirical findings, GPS records from telemetry and different geospatial data analysis procedures may be seen as a first approach to generally depict the connectivity within the study area based on socio-economic and ecological parameters. By including additional background data on the natural environment and socio-economic components as well as referring to a larger number of elephant GPS records, the analyses might be enhanced and lead to more viable conclusions on potential corridors for wildlife movement. Moreover, the assessment of the correlation between habitat preferences and movement behaviour may be improved through more sophisticated statistical analyses. Obtaining additional knowledge from experts and land users might provide for further knowledge on elephant behaviour, the efficiency of different fence types and processes around human-elephant interactions. Likewise, scientific material for nature conservation practitioners is recommended to be more accessible providing for an increased reliance on scientific insights (Young and Van Aarde, 2011).

The interviews revealed that currently, farmers mostly practice mitigation methods in isolation without knowledge of their cumulative effect on the landscape-level. Through the analyses, the cumulative impact of multiple individually constructed fences was determined for a larger scale. Likewise, some concerns against the long-term efficiency and financial feasibility of these local measures were raised. In this regard, a holistic landscape approach is regarded as one option to sustainably mitigate the conflicting relation between farmers and elephants. The intention to develop a localised elephant management committee (FM) has been a positive first step towards achieving this. When coordinated on a landscape level, the already applied local strategies might benefit more successfully to the overall strategy of conflict mitigation. Indeed, landscape conservation and integrated park management is one specific objective of the National Policy on Protected Areas' Neighbours and Resident Communities to establish corridors for the viability of wildlife and to provide for sustainable biodiversity conservation through adapted management on adjacent areas (MET, 2013c).

Future management plans should be developed through a transdisciplinary approach involving cooperation and open communication between local and national stakeholders as also suggested by Matinca (2018). At the same time, there is a need not only to consider ecological conditions, but also to evaluate governance structures, i.e. social practices, perceptions and values. With stakeholder involvement, peaceful coexistence between land users and elephants may be achieved and elephant populations sustainably conserved.

Namibia regards large-scale networks of landscape conservation as crucial for successful responsiveness towards climate change (MET 2013c). Due to the differences concerning protection status, land tenure and management, the analyses in the study area might be seen as an example region for savannah ecosystems in southern Africa. Considering climate change effects which are already obvious for southern Africa (Niang *et al.*, 2015), resource competition is expected to increase as a consequence of altered precipitation and temperature patterns. Thus, conflicts might arise while simultaneously, wildlife has to adapt, i.e. through movement or migration. In this regard, the Aichi Target 11 (SCBD, 2016, p. 1) promotes the expansion of conservation areas that should "be well-connected to the wider landscape or seascape using corridors and ecological networks to allow connectivity, adaptation to climate change, and the application of the ecosystem approach". Connecting protected areas over cultivated rangeland is a challenging but crucial process to sustainably conserve wildlife populations.

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8 Appendices

Appendix 1 – Information on interviews conducted in field phase 2019

Expert interviews		
Respondent (pseudonym)	**Field of expertise/affiliation**	**Method**
E1	Science, university	Semi-structured interviews, qualitative (Appendix 2)
E2	Hunting association	Semi-structured interviews, qualitative (Appendix 2)
E3	Science, university	Semi-structured interviews, qualitative (Appendix 2)
E4	Non-governmental organisation	Semi-structured interviews, qualitative (Appendix 2)
E5	Government official, science	Semi-structured interviews, qualitative (Appendix 2)
E6	2 conservancy representatives	Semi-structured interviews, qualitative (Appendix 2)
E7	Non-governmental organisation	Semi-structured interviews, qualitative (Appendix 2)
E8	Government official	Semi-structured interviews, qualitative (Appendix 2)
E9	Non-governmental organisation	Semi-structured interviews, qualitative (Appendix 2)
E10	Government official	Consultation within the process of participatory mapping (see Section 3.1.2)
E11	Government official	Consultation within the process of participatory mapping (see Section 3.1.2)
Farmer interviews		
Respondent (pseudonym)	**Type of farming (as ticked by respondent)**	**Method**
F1	Livestock farming and tourism	Semi-structured interview, qualitative and quantitative (Appendix 3), 30 minutes
F2	Livestock farming	Semi-structured interview, qualitative and quantitative (Appendix 3), 95 minutes
F3	Livestock farming and hunting	Semi-structured interview, qualitative and quantitative (Appendix 3), 90 minutes
F4	Livestock farming and tourism, farming tourism	Semi-structured interview, qualitative and quantitative (Appendix 3), 60 minutes
F5	Livestock farming	Semi-structured interview, qualitative and quantitative (Appendix 3), 85 minutes
F6	Livestock farming (and hunting)	Semi-structured interview, qualitative and quantitative (Appendix 3), 180 minutes
F7	Hunting	Semi-structured interview, qualitative and quantitative (Appendix 3), 120 minutes
F8	Livestock farming (and hunting)	Semi-structured interview, qualitative and quantitative (Appendix 3), 170 minutes

F9	Livestock farming	Semi-structured interview, qualitative and quantitative (Appendix 3), 180 minutes
F10	Hunting, has livestock from another farmer on his property	Semi-structured interview, qualitative and quantitative (Appendix 3), 165 minutes
F11	Livestock farming and tourism	Semi-structured interview, qualitative and quantitative (Appendix 3), 150 minutes
Group discussion		
FM	Respondents applying livestock and/or game management and/or engaged in tourism; officials of MET	Observant participation of protocolling interviewers

Appendix 2 – Questionnaire: expert interviews

Overall introduction
1. Please describe how your work is connected to wildlife management in Namibia.
2. What are the most important challenges in human-wildlife interactions? Specifically considering large herbivores and predators interacting with freehold and conservancy farmers?
Focus on elephants in the North
3. Please outline the relationship between wildlife (in particular with elephants) and freehold farmers in the south of Etosha National Park (ENP). Which role does the ENP play?
4. In which way did the land resource management change over the last decades in the area south of ENP?
Role of fencing
5. Which perception do commercial farmers have on fencing?
6. Where do you see benefits of fencing – in general and in the area south of ENP?
7. Are there disadvantages of fencing – in general and in the area south of ENP?
8. What do you know about the elephant herds in this area? What are the key factors that determine movement of elephants in this area (water, vegetation, predators, hunting, etc.)?
9. In which way are fences influencing the elephants' and other species' movements? How would wildlife migrate if there were no fences?
10. What do you think about the economic feasibility of sufficiently maintaining fences – for the commercial farmers as well as for the administration of ENP?
Outlook
11. What do you think has to happen in order to motivate commercial farmers to remove fences?
12. In your opinion: Which is the best solution to mitigate the human-elephant conflicts in the area?

Appendix 3 – Questionnaire: farmer interviews

Questionnaire

Embedded in the project **ORYCS** – Options for sustainable land use adaptions in savannah systems: Chances and risks of emerging wildlife-based management strategies under regional and global change (*https://www.uni- potsdam.de/orycs/)* Project coordination: University of Potsdam, Plant Ecology and Nature Conservation (Germany)

Personal Data

Interview No. _____

Name of Farm _____

Name of Respondent _____

Age ____ Sex ____

Living/working on farm for _____ (years)

Contact number/e-mail (optional) _____

Interviewers:
Time:
Location:

Personal data (e.g. age, sex, name) will not be linked to the respondent in any publication.

Research Data

The respondent agrees that quantitative data (locations, number of livestock, wildlife etc.) may appear in publications and be used for the creation of maps. *X Yes* *O No*

If there is any sensitive data gathered in the interview, the respondent may mention restrictions concerning publication at any point.

Type of Farming

O Only livestock farming
O Livestock farming and hunting
O Only hunting
O Livestock farming and tourism
O Only tourism
O Hunting and tourism
O Livestock farming, tourism and hunting

1. **Livestock**: Which animals belong to your farm? How many individuals of each are there?

Livestock animals	Number of animals	
	currently	usually
Cattle		
Sheep		
Goats		
Horses		

Donkeys		
Others (_____)		

O There is no livestock on my farm.

2. **Wild animals**: Which mammal species are on your farm, both regularly and occasionally? Please estimate the average number of animals.

Wildlife species	Curr.	Usua.	Wildlife species	Curr.	Usua.
Black-faced impala			Kudu		
Burchell's zebra			Ostrich		
Hartmann's mountain zebra			Red hartebeest		
Black wildebeest			Roan		
Blue wildebeest			Sable antelope		
Common duiker (did road counts)			Steenbok		
Eland			Springbok		
Elephant			Warthog		
Gemsbok			Waterbuck		
Giraffe			Cheetah		
Lion			Hyaena (brown/spotted)		
Leopard			Jackal		
Caracal			Baboon		
Rhino			Caracal		

3. **Hunting**: Which animal species were hunted on your farm in the last 5 years? Please note the number of each species per year (as an average over the last 5 years) and the time of hunting.

Wildlife species hunted	Average number per year	Months when hunting took place

O There was no hunting on my farm.

4. What kind of **water points** do you have on your property? Please map their location.

No. on map	Type of water point	Natural / artificial	Open / fenced in	Active / not active	Additional information (e.g. rotation)

5. Are there **animals that cause problems** on your property and/or are a threat to your livelihood? Please name those 'problem animals', note in which way they cause problems and how much of a problem it is to you (0 = no problem, 10 = very severe problem).

Problem causing animals	Occurring problems	Scale (0 – 10)

Ask for: Elephant, Lion, Leopard, Cheetah, Brown hyaena, Spotted hyaena, Caracal, Black-backed jackal, Chacma baboon

6. What do you do to **prevent** those problems?

7. How do you **react** when incidents with those problem causing animals occur?

8. Do you **benefit** from wildlife? If yes – in which way?

9. Describe the **boundary fences** of your farm. Please map their type and location.

10. What are your **reasons** for your type of boundary fencing?

11. Which sections of the boundary fences of your property need to be **repaired regularly**? Why do these sections need maintenance on a regular basis?

12. How much **time and costs** do you invest to maintain the boundary fences?

13. Please answer the following questions with **Yes** or **No**.

	Yes	No
Do your boundary fences help to mitigate your conflict with wildlife?		
Are you able to maintain the existing boundary fences so that they are proof?		
Are you planning to build new fences?		
Do you use internal fences for your livestock? Average size of fenced area:		
Do you see disadvantages in fences? _____		
Do you generally think that elephants are valuable for the environment of your area?		

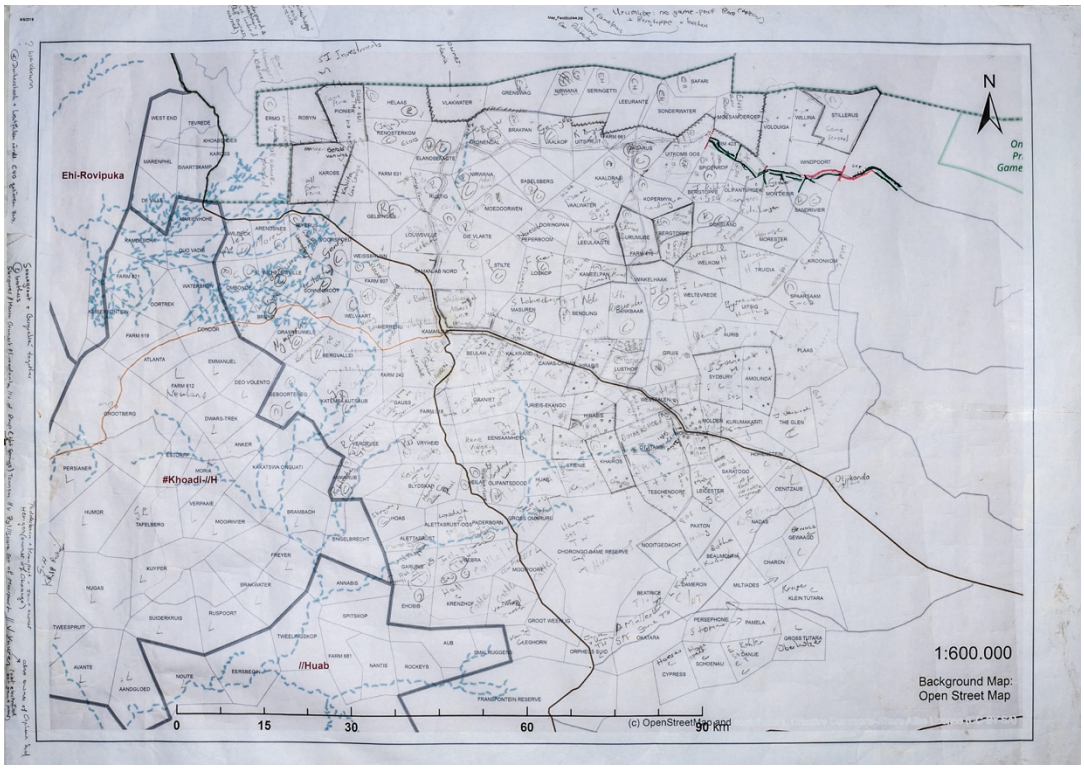
14. What do you know about the **elephants' (and other species) movements** on your property and the surrounding area (e.g. foraging and feeding patterns, waterholes they use for drinking, seasonal movement and activity over the day, information about individual herds/animals)?

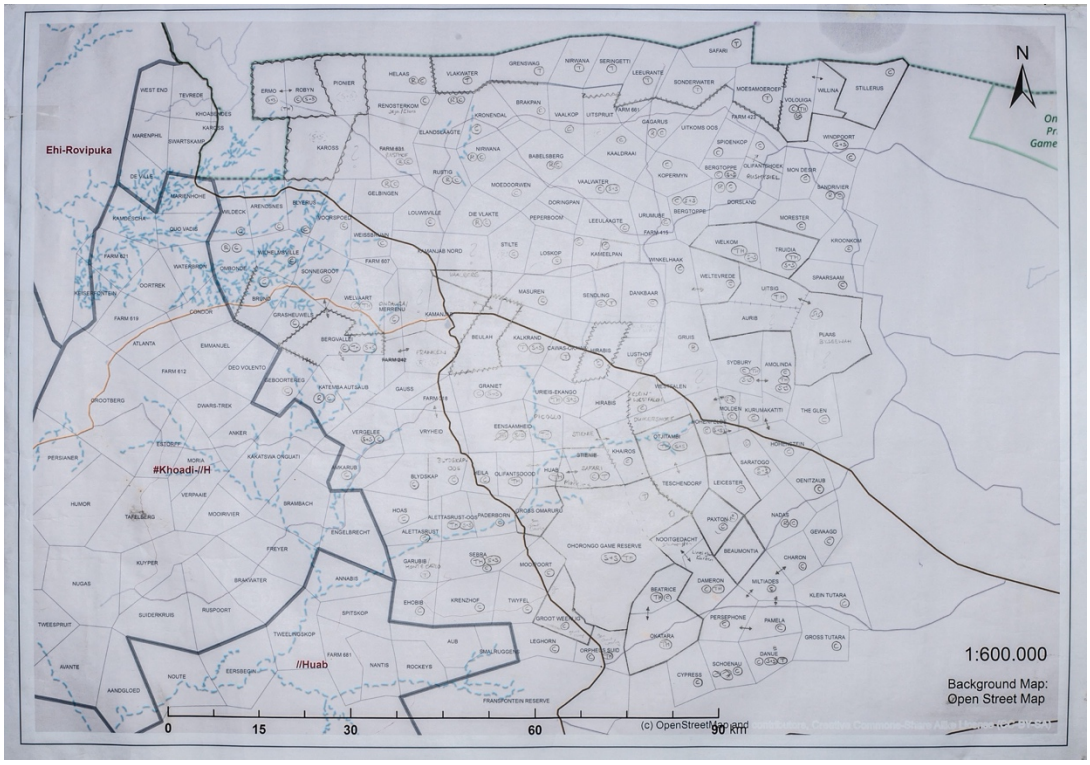
15. What do you think about concepts like the one of **Etosha Heights** where they removed fences to manage wildlife and other natural resources across the borders of several farms? What do you think about sharing your resources with your neighboring farmers?

16. Which **format of presenting** the results of the ORYCS studies as a report back to you is most suitable for you?

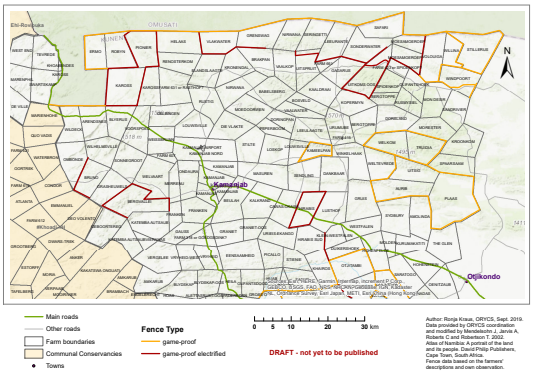
Additional notes

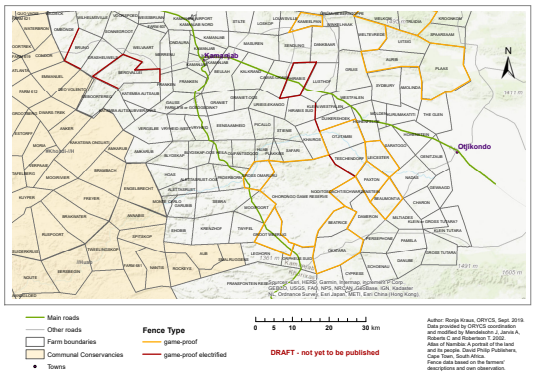
Appendix 4 – Participatory mapping: field maps

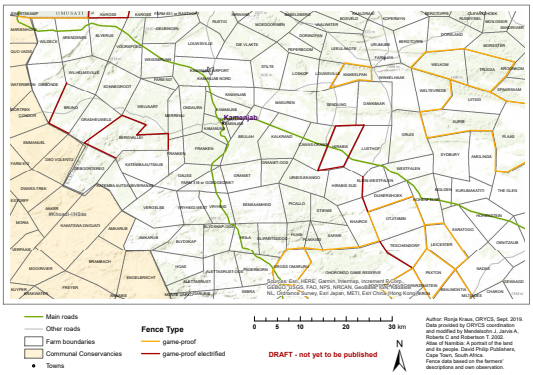




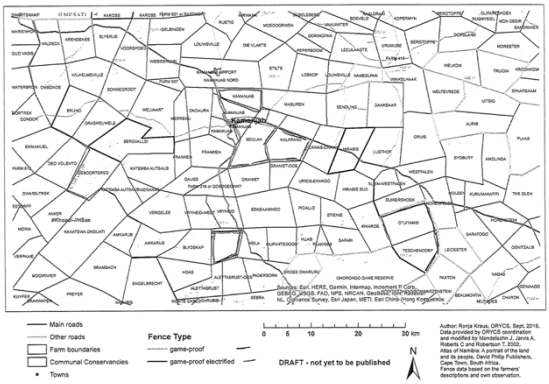
Appendix 5 – Cross-validation: maps sent to experts







Appendix 6 – Cross-validation: exemplary response from experts



OID	ANNOTAT	Tourism	Trophy	ShootSell	HuntOwnUse	Cattle	Resettlement	
49	ALETTASRUST	0	0	0	0	1	0	✓
57	ALETTASRUST-OOS	0	1	1	0	0	0	
119	AMKARUB	0	0	0	0	1	0	
21	AMOLINDA	0	1	1	0	1	0	✓
66	ARENDSNES	0	0	0	0	1	0	✓
23	AURIB	1	1	1	0	0	0	
75	BABELSBERG	0	0	0	0	1	1	✓
100	BERGTOPPE (north)	0	0	1	0	1	0	✓
101	BERGTOPPE (south)	0	0	1	0	1	0	✓
99	BERGVALLEI	0	1	1	0	1	0	
27	BEULAH	1	0	1	0	1	0	✓
118	BLYDSKAP	0	0	0	0	1	0	
135	BLYDSKAP-OOS	0	0	0	0	1	0	
67	BLYERUS	0	0	0	0	1	0	✓
120	BOSVELD	0	0	1	0	1	0	✓
84	BRAKPAN	0	0	0	0	1	0	✓
62	BRUNO	0	0	0	0	1	0	✓
4	CAWAS-OKAWA	1	0	0	0	0	0	
24	DANKBAAR	0	0	0	0	1	0	✓
73	DIE VLAKTE	0	0	0	0	1	1	✓
32	DORINGPAN	0	0	0	0	0	0	✓
39	DORSLAND	0	0	0	0	1	1	
129	DUIKERSHOEK	0	0	0	0	0	0	
112	EENSAAMHEID	0	0	0	0	0	0	
81	ELANDSLAAGTE	0	0	0	0	1	1	✓
76	ERMO	0	1	1	0	1	0	✓
125	FARM 318 or GOEDGEDINK?	0	0	0	0	0	0	
50	FARM 375	0	0	0	0	0	0	
51	FARM 415	0	0	0	0	0	0	
59	FARM 607	0	0	0	0	0	0	
70	FARM 631 or RASTHOF?	0	0	0	0	1	1	✓
92	FARM 661	0	0	0	0	0	0	
53	FARM 423 or SPIOENKOP?	0	0	0	0	0	0	✓
17	FRANKEN (west)	0	0	0	0	1	1	✓
106	FRANKEN (east)	0	0	0	0	1	1	✓
35	GAGARUS	0	0	0	0	1	1	✓
29	GAUSS	0	0	0	0	0	0	
58	GEBOORTEREG	0	0	0	0	1	0	
69	GELBINGEN	0	0	0	0	1	1	✓
14	GEWAAGD	0	0	0	0	1	0	
111	GRANIET	0	0	1	0	1	0	✓
134	GRANIET-OOS	0	0	1	0	1	0	✓
61	GRASHEUWELS	0	0	0	0	1	0	✓
85	GRENSWAG	1	0	0	0	0	0	✓
0	GROSS OMARURU	0	1	0	0	0	0	✓
19	GRUIS	0	0	0	0	0	1	
48	HEILA	0	0	0	0	1	0	✓
79	HELAAS	0	0	0	0	1	1	✓
5	HIRABIS	0	0	0	0	1	0	✓
2	HIRABIS SUD	0	0	0	0	0	0	✓
30	HOAS	0	0	0	0	1	0	
9	HOHENFELDE	0	0	0	0	0	0	✓
7	HOHENSTEIN	0	0	0	0	1	0	
113	HUAB	0	1	0	0	1	0	
122	KAALDRAAI	0	0	0	0	1	0	✓
110	KALKRAND (cheetah fence)	1	0	1	0	0	0	✓
107	KAMANJAB NORD	0	0	0	0	0	0	
121	KAMEELPAN	0	0	0	0	1	0	✓

Appendix 7 – R Script: home range estimation

SCRIPT PREPARATION

```
setwd("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/12_Elephant data/ANALYSIS/FOR_R")
install.packages("adehabitatHR")
library("adehabitatHR")
install.packages("adehabitatHS")
library("adehabitatHS")
install.packages("maptools")
library("maptools")
install.packages ("rgeos")
library("rgeos")
install.packages ("rgdal")
library("rgdal")
library("utils")
```

DATA PREPARATION

 # 1 # prior to table import: all irrelevant columns removed in Word Excel; dec = "." and 1000's = ","

```
0BCD_gps <- read.csv2("0BCD _longlat.csv", head = TRUE, sep = ";")
4F9F_gps <- read.csv2("4F9F_longlat.csv", head = TRUE, sep = ";")
3ECO_gps <- read.csv2("3ECO_longlat.csv", head = TRUE, sep = ";")
C2C5_gps <- read.csv2("C2C5_longlat.csv", head = TRUE, sep = ";")
4ED4_gps <- read.csv2("4ED4_longlat.csv", head = TRUE, sep = ";")
6366_gps <- read.csv2("6366_longlat.csv", head = TRUE, sep = ";")
BCD4_gps <- read.csv2("BCD4_longlat_corr.csv", head = TRUE, sep = ";")
```

 # 2 # create spatial points variable lon & lat: R recognizes these columns as geographic coordinates

```
0BCD _sp <- SpatialPoints(0BCD _gps[c("Longitude", "Latitude")])
4F9F_sp <- SpatialPoints(4F9F_gps[c("Longitude", "Latitude")])
3ECO_sp <- SpatialPoints(3ECO_gps[c("Longitude", "Latitude")])
C2C5_sp <- SpatialPoints(C2C5_gps[c("Longitude", "Latitude")])
4ED4_sp <- SpatialPoints(4ED4_gps[c("Longitude", "Latitude")])
6366_sp <- SpatialPoints(6366_gps[c("Longitude", "Latitude")])
BCD4_sp <- SpatialPoints(BCD4_gps[c("Longitude", "Latitude")])
```

 # 3 # Make sure the variable is projected as CRS = WGS84

```
proj4string(0BCD _sp) = CRS("+init=epsg:4326")
proj4string(4F9F_sp) = CRS("+init=epsg:4326")
proj4string(3ECO_sp) = CRS("+init=epsg:4326")
proj4string(C2C5_sp) = CRS("+init=epsg:4326")
proj4string(4ED4_sp) = CRS("+init=epsg:4326")
proj4string(6366_sp) = CRS("+init=epsg:4326")
proj4string(BCD4_sp) = CRS("+init=epsg:4326")
```

DATA PROCESSING

 # 4 # kernel density estimate via kernelUD function

```
0BCD.kde <- kernelUD(0BCD_sp, h="href", grid = 6000)
4F9F.kde <- kernelUD(4F9F_sp, h="href", grid = 6000)
3ECO.kde <- kernelUD(3ECO_sp, h="href", grid = 6000)
C2C5.kde <- kernelUD(C2C5_sp, h="href", grid = 6000)
4ED4.kde <- kernelUD(4ED4_sp, h="href", grid = 6000)
6366.kde <- kernelUD(6366_sp, h="href", grid = 6000)
BCD4.kde <- kernelUD(BCD4_sp, h="href", grid = 6000)
```

 # 5 # turn the KDE image into a raster file

```
0BCD.kde.raster <- (raster(as(0BCD.kde, "SpatialPixelsDataFrame")))
4F9F.kde.raster <- (raster(as(4F9F.kde, "SpatialPixelsDataFrame")))
3ECO.kde.raster <- (raster(as(3ECO.kde, "SpatialPixelsDataFrame")))
C2C5.kde.raster <- (raster(as(C2C5.kde, "SpatialPixelsDataFrame")))
4ED4.kde.raster <- (raster(as(4ED4.kde, "SpatialPixelsDataFrame")))
6366.kde.raster <- (raster(as(6366.kde, "SpatialPixelsDataFrame")))
BCD4.kde.raster <- (raster(as(BCD4.kde, "SpatialPixelsDataFrame")))
```

 # 6 # Plot for visualization

```
plot(0BCD.kde.raster)
plot(4F9F.kde.raster)
plot(3ECO.kde.raster)
plot(C2C5.kde.raster)
plot(4ED4.kde.raster)
plot(6366.kde.raster)
plot(BCD4.kde.raster)
#Optionally: overlay the GPS records
plot(0BCD _sp, add = T, col="blue", type = "p")
plot(4F9F_sp, add = T, col="blue", type = "p")
plot(3ECO_sp, add = T, col="blue", type = "p")
plot(C2C5_sp, add = T, col="blue", type = "p")
plot(4ED4_sp, add = T, col="blue", type = "p")
plot(6366_sp, add = T, col="blue", type = "p")
plot(BCD4_sp, add = T, col="blue", type = "p")
```

 # 7 # Export the kernel density as a rasterized geo tiff

```
writeRaster(0BCD.kde.raster, "0BCD_kderaster6000.tif", overwrite = TRUE)
writeRaster(4F9F.kde.raster, "4F9F_kderaster6000.tif", overwrite = TRUE)
writeRaster(3ECO.kde.raster, "3ECO_kderaster6000.tif", overwrite = TRUE)
writeRaster(C2C5.kde.raster, "C2C5_kderaster6000.tif", overwrite = TRUE)
writeRaster(4ED4.kde.raster, "4ED4_kderaster6000.tif", overwrite = TRUE)
writeRaster(6366.kde.raster, "6366_kderaster6000.tif", overwrite = TRUE)
writeRaster(BCD4.kde.raster, "BCD4_kderaster6000.tif", overwrite = TRUE)
```

 # 8 # home range kernel density estimation (95%)

```
0BCD _hr95 <- getverticeshr(0BCD.kde, percent = 95, unin = "m", unout = "km2")
4F9F_hr95 <- getverticeshr(4F9F.kde, percent = 95, unin = "m", unout = "km2")
3ECO_hr95 <- getverticeshr(3ECO.kde, percent = 95, unin = "m", unout = "km2")
C2C5_hr95 <- getverticeshr(C2C5.kde, percent = 95, unin = "m", unout = "km2")
4ED4_hr95 <- getverticeshr(4ED4.kde, percent = 95, unin = "m", unout = "km2")
6366_hr95 <- getverticeshr(6366.kde, percent = 95, unin = "m", unout = "km2")
BCD4_hr95 <- getverticeshr(BCD4.kde, percent = 95, unin = "m", unout = "km2")
```

 # 9 # home range kernel density estimation (50%)

```
0BCD _hr50 <- getverticeshr(0BCD.kde, percent = 50, unin = "m", unout = "km2")
4F9F_hr50 <- getverticeshr(4F9F.kde, percent = 50, unin = "m", unout = "km2")
3ECO_hr50 <- getverticeshr(3ECO.kde, percent = 50, unin = "m", unout = "km2")
C2C5_hr50 <- getverticeshr(C2C5.kde, percent = 50, unin = "m", unout = "km2")
4ED4_hr50 <- getverticeshr(4ED4.kde, percent = 50, unin = "m", unout = "km2")
6366_hr50 <- getverticeshr(6366.kde, percent = 50, unin = "m", unout = "km2")
BCD4_hr50 <- getverticeshr(BCD4.kde, percent = 50, unin = "m", unout = "km2")
```

 # 10 # export of home ranges as shapefiles

```
writeOGR(0BCD _hr95, dsn = ".", layer = "0BCD_hr95", driver="ESRI Shapefile")
writeOGR(4F9F_hr95, dsn = ".", layer = "4F9F_hr95", driver="ESRI Shapefile")
writeOGR(3ECO_hr95, dsn = ".", layer = "3ECO_hr95", driver="ESRI Shapefile")
writeOGR(C2C5_hr95, dsn = ".", layer = "C2C5_hr95", driver="ESRI Shapefile")
writeOGR(4ED4_hr95, dsn = ".", layer = "4ED4_hr95", driver="ESRI Shapefile")
writeOGR(6366_hr95, dsn = ".", layer = "6366_hr95", driver="ESRI Shapefile")
writeOGR(BCD4_hr95, dsn = ".", layer = "BCD4_hr95", driver="ESRI Shapefile")

writeOGR(0BCD _hr50, dsn = ".", layer = "0BCD_hr50", driver="ESRI Shapefile")
writeOGR(4F9F_hr50, dsn = ".", layer = "4F9F_hr50", driver="ESRI Shapefile")
writeOGR(3ECO_hr50, dsn = ".", layer = "3ECO_hr50", driver="ESRI Shapefile")
writeOGR(C2C5_hr50, dsn = ".", layer = "C2C5_hr50", driver="ESRI Shapefile")
writeOGR(4ED4_hr50, dsn = ".", layer = "4ED4_hr50", driver="ESRI Shapefile")
writeOGR(6366_hr50, dsn = ".", layer = "6366_hr50", driver="ESRI Shapefile")
writeOGR(BCD4_hr50, dsn = ".", layer = "BCD4_hr50", driver="ESRI Shapefile")
```

Appendix 8 – R Script: calculation of the monthly NDVI median from 2000 to 2019

 # INPUT: 19 raster files with 12 bands, one band for each month (acquired from Google Earth Engine)

SCRIPT PREPARATION

```
setwd("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegetation/NDVI_2000_2019")
install.packages("sp")
install.packages("raster")
install.packages("rgdal")
library(sp)
library(rgdal)
library(raster)
```

DATA PREPARATION

OUTPUT: 12(bands)*20(years) TIFs from original images (2000-2019)

 # 1 # Import raster layers and create one raster image for each band

```
multiLayerRaster2000 <-stack("ndvi_30m_2001.tif")
nlayers(multiLayerRaster2000)
```

```
                                    # Check the number of bands
for(i in 1:nlayers(multiLayerRaster2001))
                                    # for layer/band 1 to 12 do the following
{
  band<-multiLayerRaster2000[[i]]
                                     #save raster in a separate file
  writeRaster(band,paste(filename ='ndvi2000_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2001 <-stack("ndvi_30m_2001.tif")
nlayers(multiLayerRaster2001)
for(i in 1:nlayers(multiLayerRaster2001))
{
  band<-multiLayerRaster2001[[i]]
  writeRaster(band,paste(filename ='ndvi2001_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2002 <-stack("ndvi_30m_2002.tif")
nlayers(multiLayerRaster2002)
for(i in 1:nlayers(multiLayerRaster2002))
{
  band<-multiLayerRaster2002[[i]]
  writeRaster(band,paste(filename ='ndvi2002_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2003 <-stack("ndvi_30m_2003.tif")
nlayers(multiLayerRaster2003)
for(i in 1:nlayers(multiLayerRaster2003))
{
  band<-multiLayerRaster2003[[i]]
  writeRaster(band,paste(filename ='ndvi2003_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2004 <-stack("ndvi_30m_2004.tif")
nlayers(multiLayerRaster2004)
for(i in 1:nlayers(multiLayerRaster2004))
{
  band<-multiLayerRaster2004[[i]]
  writeRaster(band,paste(filename ='ndvi2004_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2005 <-stack("ndvi_30m_2005.tif")
nlayers(multiLayerRaster2005)
for(i in 1:nlayers(multiLayerRaster2005))
{
  band<-multiLayerRaster2005[[i]]
```

```
  writeRaster(band,paste(filename ='ndvi2005_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2006 <-stack("ndvi_30m_2006.tif")
nlayers(multiLayerRaster2006)
for(i in 1:nlayers(multiLayerRaster2006))
{
  band<-multiLayerRaster2006[[i]]
  writeRaster(band,paste(filename ='ndvi2006_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2007 <-stack("ndvi_30m_2007.tif")
nlayers(multiLayerRaster2007)
for(i in 1:nlayers(multiLayerRaster2007))
{
  band<-multiLayerRaster2007[[i]]
  writeRaster(band,paste(filename ='ndvi2007_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2008 <-stack("ndvi_30m_2008.tif")
nlayers(multiLayerRaster2008)
for(i in 1:nlayers(multiLayerRaster2008))
{
  band<-multiLayerRaster2008[[i]]
  writeRaster(band,paste(filename ='ndvi2008_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2009 <-stack("ndvi_30m_2009.tif")
nlayers(multiLayerRaster2009)
for(i in 1:nlayers(multiLayerRaster2009))
{
  band<-multiLayerRaster2009[[i]]
  writeRaster(band,paste(filename ='ndvi2009_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2010 <-stack("ndvi_30m_2010.tif")
nlayers(multiLayerRaster2010)
for(i in 1:nlayers(multiLayerRaster2010))
{
  band<-multiLayerRaster2010[[i]]
  writeRaster(band,paste(filename ='ndvi2010_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2011 <-stack("ndvi_30m_2011.tif")
nlayers(multiLayerRaster2011)
for(i in 1:nlayers(multiLayerRaster2011))
{
```

```
 band<-multiLayerRaster2011[[i]]
 writeRaster(band,paste(filename ='ndvi2011_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2012 <-stack("ndvi_30m_2012.tif")
nlayers(multiLayerRaster2012)
for(i in 1:nlayers(multiLayerRaster2012))
{
 band<-multiLayerRaster2012[[i]]
 writeRaster(band,paste(filename ='ndvi2012_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2013 <-stack("ndvi_30m_2013.tif")
nlayers(multiLayerRaster2013)
for(i in 1:nlayers(multiLayerRaster2013))
{
 band<-multiLayerRaster2013[[i]]
 writeRaster(band,paste(filename ='ndvi2013_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2014 <-stack("ndvi_30m_2014.tif")
nlayers(multiLayerRaster2014)
for(i in 1:nlayers(multiLayerRaster2014))
{
 band<-multiLayerRaster2014[[i]]
 writeRaster(band,paste(filename ='ndvi2014_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2015 <-stack("ndvi_30m_2015.tif")
nlayers(multiLayerRaster2015)
for(i in 1:nlayers(multiLayerRaster2015))
{
 band<-multiLayerRaster2015[[i]]
 writeRaster(band,paste(filename ='ndvi2015_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2016 <-stack("ndvi_30m_2016.tif")
nlayers(multiLayerRaster2016)     # Check the number of bands
for(i in 1:nlayers(multiLayerRaster2016))  # for layer/band 1 to 12 do the following
{
 band<-multiLayerRaster2016[[i]]
 writeRaster(band,paste(filename ='ndvi2016_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2017 <-stack("ndvi_30m_2017.tif")
nlayers(multiLayerRaster2017)
```

```
for(i in 1:nlayers(multiLayerRaster2017))
{
 band<-multiLayerRaster2017[[i]]
 writeRaster(band,paste(filename ='ndvi2017_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2018 <-stack("ndvi_30m_2018.tif")
nlayers(multiLayerRaster2018)
for(i in 1:nlayers(multiLayerRaster2018))
{
 band<-multiLayerRaster2018[[i]]
 writeRaster(band,paste(filename ='ndvi2018_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}

multiLayerRaster2019 <-stack("ndvi_30m_2019.tif")
nlayers(multiLayerRaster2019)
for(i in 1:nlayers(multiLayerRaster2019))
{
 band<-multiLayerRaster2019[[i]]
 writeRaster(band,paste(filename ='ndvi2019_month',i,format ='.tif', sep=''),by-
layer=TRUE, suffix='i')
}
```

 # 2 # prior to calculation each raster image was renamed in MacOS Finder to have the correct order for statistic calculation, e.g. ndvi2016_1.tif renamed to ndvi2016_01.tif; to avoid manual edition, add formatC(width=2) in future calculations

 # 3 # Original raster stacks (e.g. ndvi_30m_2001.tif) were moved to another folder in MacOS Finder

DATA PROCESSING

 # 4 # create vectors which in the end shall result in a data frame

```
mean_vec <- vector()
median_vec <- vector()
min_vec <- vector()
max_vec <- vector()
perc25_vec <- vector()
perc75_vec <- vector()
monthly_ndvi_raster = list.files(pattern=".tif")
                                # list all TIFs in the folder
```

 # 5 # statistics (i.e. mean, median, min, max, 25-percentile, 75-percentile) calculated

```
i = 1
for(i in 1:length(monthly_ndvi_raster))
                                # do the following for 1:240
{
 temp_raster <- raster(monthly_ndvi_raster[i])
                                # create a temporal raster layer for the first/second/etc
```

```
  mean_vec <- append(mean_vec, cellStats(temp_raster,  stat = 'mean', maxpix-
  els=ncell(temp_raster), na.rm=TRUE))
                                # add the values from the vector mean_vec # mean_vec
                                are the statistics of the temporal raster (created before)
                                using the values of all pixels
  min_vec <- append(min_vec, cellStats(temp_raster,  stat = 'min', maxpix-
  els=ncell(temp_raster), na.rm=TRUE))
  max_vec <- append(max_vec, cellStats(temp_raster,  stat = 'max', maxpix-
  els=ncell(temp_raster), na.rm=TRUE))
  median_vec <- append(median_vec, quantile(temp_raster, 0.50, maxpix-
  els=ncell(temp_raster), na.rm=TRUE)[[1]])
                                # same as above, by adding [[1]] we exclude "50%" as
                                we do not want to add it to our data frame
  perc25_vec <- append(perc25_vec, quantile(temp_raster, 0.25, maxpix-
  els=ncell(temp_raster), na.rm=TRUE)[[1]])
  perc75_vec <- append(perc75_vec, quantile(temp_raster, 0.75, maxpix-
  els=ncell(temp_raster), na.rm=TRUE)[[1]])
  print(paste0('We are at No.: ',i))
}

# 6 # create a data frame from the vectors
stats_df <- data.frame(Mean = mean_vec,
                       Median = median_vec,
                       Max = max_vec,
                       Min = min_vec,
                       Perc25 = perc25_vec,
                       Perc75 = perc75_vec)
stats_df_t = t(stats_df)
                                # transpose -> first column is name of statistic variable
month <- substr(monthly_ndvi_raster,5,11)
                                # select 5th character to 11th character (=year and
                              month)
colnames(stats_df_t) = as.characters(month)
                                # give the columns these name names
stats_df_t_t <- t(stats_df_t)
                                # transpose again: row names = statistic variable, first

# 7 # export data frame as csv
write.csv(stats_df_t_t,file='stats_ndvi_2000_2019_t.csv')

# 8 # visualize results in a chart
statistics_ndvi <- read.csv("stats_ndvi_2000_2019_t.csv", header=TRUE)
plot(statistics_ndvi$X,
    statistics_ndvi$Median,
    ylab= "NDVI values",
    xlab= "Months",
    type= "l",
    col= "darkgreen",
    ylim = c(-5,55))

lines(statistics_ndvi$Median, col="brown")
                                # plot a line between the points
```

```
abline(v=c(seq(1,240,6)), col=c("black", "gray58"), lty=c(3,3), lwd=c(1, 1))
                                    # plot vertical lines for each January and each July

legend(185, 8, legend=c("Monthly median","January","July"), col=c("brown", "black",
"gray58"), lty=c(1,3,3), cex=0.8, bg ="white")
```

Appendix 9 – R Script: cumulative distribution of NDVI

INPUT

- *folder "GPS_NDVI_monthlysorted" containing sub-folders "0BCD", "4F9F", "3ECO", "C2C5", "4ED4", "6366", "BCD4"*
- *each sub-folder containing one shapefile with records from one month (from 10/2018 to 10/2019) (e.g. 0BCD_2019_05.shp for May of 2019)*
- *13 TIFs representing NDVI values, one for each month (from 10/2018 to 10/2019) (e.g. 01_10_2018.tif)*

SCRIPT PREPARATION

 # Based on Script from Appendix 7

DATA PROCESSING

 # 1 # create csv file with all NDVI values of the cells in which the GPS records fall

```
name_vec <- c("0BCD", "4F9F", "3ECO", "C2C5", "4ED4", "6366", "BCD4")

    i = 1,
    for (i in 1:length(name_vec))   # do the following for every elephant (= "0BCD", "4F9F",
                                    "3ECO", "C2C5", "4ED4", "6366", "BCD4")
    {
      setwd (paste0("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/O-
    RYCS_Sicherung/03_GIS_Data/03_Vegetation/GPS_NDVI_monthlysor-
    ted/",name_vec[i]))
                                    # choose folder of the particular elephant

      prePOINTS_list <- list.files(pattern = ".shp")
                                    # list all files in this folder that are shapefiles/end with
    „.shp"
                                    # problem: .shp AND .shp.xml are selected

      shp_noshpxml <- seq(1,length(prePOINTS_list),2)
                                    # solution: creating a vector (= 1 3 5 7 etc)

      POINTS_list <- prePOINTS_list[shp_noshpxml]
                                    # only the shapefiles are selected
```

```
TIF_list <- list.files(pattern=".tif")
                                # list all 13 TIFs in this folder


final_list=list()
                                # create list that will be filled with loop; final list will in-
                                clude 13 elements each point assigned with the particular
                                NDVI value of the corresponding TIF

j = 1
for(j in 1:13)
                                # going to run until 13, in order to cover 13 months
        {
          monthly_ndvi       = raster(TIF_list[j])
                                # load the first NDVI raster image
          monthly_points     = readOGR(POINTS_list[j])
                                # load the first shapefile
          new_monthly_points  = extract(monthly_ndvi,monthly_points)
                                # returns the NDVI value of the raster image for the cells
                                in which a particular point falls
          final_list         = append(final_list,new_monthly_points)
                                # add these NDVI values to a final list

                                # output: list with all NDVI values for 13 months for one
                                individual elephant
          }

ndvi_all_indiv      <- data.frame(matrix(unlist(final_list), nrow=length(final_list), by.
row=F))
colnames(ndvi_all_indiv) <- "NDVI_value"
write.csv2(ndvi_all_indiv, file = "ndvi_all_indiv.csv")

}

                                # Output: ndvi_all_indiv.csv for every elephant in the ele-
                                phant's folder
```

 # 2 # in MacOS Finder: ndvi_all_indiv.csv manually renamed to ndvi_all_[code].csv

 # 3 # import these csv files

```
0BCD _ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicher-
heitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegeta-
tion/GPS_NDVI_monthlysorted/0BCD/ndvi_all_0BCD.csv", header = TRUE)

4F9F _ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicher-
heitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegeta-
tion/GPS_NDVI_monthlysorted/4F9F/ndvi_all_4F9F.csv", header = TRUE)

4F9F _ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicher-
heitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegeta-
tion/GPS_NDVI_monthlysorted/4F9F /ndvi_all_4F9F.csv", header = TRUE)
```

```
C2C5_ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegetation/GPS_NDVI_monthlysorted/C2C5/ndvi_all_C2C5.csv", header = TRUE)

4ED4_ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegetation/GPS_NDVI_monthlysorted/4ED4/ndvi_all_4ED4.csv", header = TRUE)

6366_ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegetation/GPS_NDVI_monthlysorted/6366/ndvi_all_6366.csv", header = TRUE)

BCD4_ndvi_df <- read.csv2("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/03_Vegetation/GPS_NDVI_monthlysorted/BCD4/ndvi_all_BCD4.csv", header = TRUE)


ndvi_df_allgps <- rbind(amahle_ndvi_df, bandile_ndvi_df, corne_ndvi_df, dalitso_ndvi_df, kagiso_ndvi_df, lesego_ndvi_df, thapelo_ndvi_df)
                                                    # all entries


# 3 # calculation of the cumulative distribution of the slope values

 V = ecdf(ndvi_df_allgps$NDVI_value)

  perc20_cumveg <- quantile(V, 0.2)
  perc40_cumveg <- quantile(V, 0.4)
  perc60_cumveg <- quantile(V, 0.6)
  perc80_cumveg <- quantile(V, 0.8)
  perc100_cumveg <- quantile(V, 1.0)


# 4 # visualization of cumulative distribution
  plot(V,
       xlab = "NDVI",
       cex = 0.5,
       xlim = c(0,60))

abline(v=c(16,18,21,23,58), col=c("darkgreen","olivedrab", "yellowgreen", "olivedrab2", "yellow2"), lty=c(1,1,1), lwd=c(3.5, 3.5, 3.5))

legend(33, 0.45,legend=c("20%- Percentile (16)","40%- Percentile (18)","60%- Percentile (21)","80%- Percentile (23)","100%- Percentile (58)" ), col=c("darkgreen","olivedrab", "yellowgreen", "olivedrab2", "yellow2"), lty=1:1,lwd=c(3.5, 3.5, 3.5, 3.5, 3.5), cex=0.9, bg ="gray90")
```

Appendix 10 – R Script: cumulative distribution of slope

SCRIPT PREPARATION

```
setwd("/Volumes/KrausRonja1/Sicherheitskopien/06102019_RonjaKraus2/ORYCS_Sicherung/03_GIS_Data/05_SRTM/Slope")
```

DATA PREPARATION

 # 1 # prior to table import and creation of data frame: attribute table of each shapefile was assigned with a new attribute (column), namely the slope value of the raster cell underlying the specific GPS record (in ArcGIS)

```
slope_df_0BCD <- read.csv2("0BCD_slope.csv", header = TRUE, sep = ";", dec=",")
slope_df_4F9F <- read.csv2("4F9F_slope.csv", header = TRUE, sep = ";", dec=",")
slope_df_3ECO <- read.csv2("3ECO_slope.csv", header = TRUE, sep = ";", dec=",")
slope_df_C2C5 <- read.csv2("C2C5_slope.csv", header = TRUE, sep = ";", dec=",")
slope_df_4ED4<- read.csv2("4ED4_slope.csv", header = TRUE, sep = ";", dec=",")
slope_df_6366 <- read.csv2("6366_slope.csv", header = TRUE, sep = ";", dec=",")
slope_df_BCD4 <- read.csv2("BCD4_slope.csv", header = TRUE, sep = ";", dec=",")
```

 # 2 # combining previous data frames to one single data frame

```
slope_df_all <- rbind(slope_df_0BCD, slope_df_4F9F, slope_df_3ECO, slope_df_C2C5, slope_df_4ED4, slope_df_6366, slope_df_BCD4)
```

 # 3 # export of data frame to csv, as no statistics can be calculated when data frame contains characters

```
write.csv2(slope_df_all, file = "slope_df_all.csv", append = FALSE, sep =";", col.names= TRUE)
```

 # 4 # Excel: all columns deleted except Count_rev (= number of entry) and RASTERVALU (= slope in degree) -> only_slope_all.csv); import as data frame that only includes numbers

```
onlyslope_all_df <- read.csv2("only_slope_all.csv", header = TRUE, sep = ";", dec=",")
```

DATA PROCESSING

 # 5 # calculation of the cumulative distribution of the slope values (= RASTERVALU)

```
P = ecdf(onlyslope_all_df$RASTERVALU)
perc20_cumslope <- quantile(P, 0.2)
perc40_cumslope <- quantile(P, 0.4)
perc60_cumslope <- quantile(P, 0.6)
perc80_cumslope <- quantile(P, 0.8)
perc100_cumslope <- quantile(P, 1.0)
```

 # 6 # visualization of the cumulative distribution of the slope values (= RASTERVALU)

```
plot(P,
    main = "Cumulative distribution of slope values underlying the GPS records",
    xlab = "Slope in degree",
    cex = 0.5,
    xlim = c(0,45))
```

```
abline(v=c(1.313745,1.99734,2.80441,4.003251,42.94931), col=c("darkgoldenrod4",
"darkgoldenrod","darkgoldenrod2","gold2", "khaki"), lty=c(1,1,1), lwd=c(3.5, 3.5, 3.5))
legend(20, 0.45,legend=c("20%- Percentile (1.313745)","40%- Percentile
(1.99734)","60%- Percentile (2.80441)","80%- Percentile (4.003251)","100%- Percentile
(42.94931)" ), col=c("darkgoldenrod4", "darkgoldenrod","darkgolden-
rod2","gold2","khaki"), lty=1:1,lwd=c(3.5, 3.5, 3.5, 3.5, 3.5), cex=0.9, bg ="gray90")
points(ecdf(onlyslope_all_df$RASTERVALU))
```