At a crossroads: African elephant conservation, climate change and community-based management

by

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Candidate's Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author’s knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Rachael Bina Gross Date: 25/10/2023

Acknowledgement of Country and Land/s

I acknowledge that I live, work, and have completed this Ph.D. on stolen land, waterways and skies. I am a settler who was born on Gundungurra Country, moved to Ngunnawal/Ngunawal Country and have done research on a species distributed across the wide and diverse lands of many African nations. I have, and will continue to, benefit from political, ecological, and humanitarian systems that actively oppress the Indigenous peoples of these lands and their knowledges. My Ph.D. has been written in a colonial institution that rejects and denies the ancient knowledge, sciences, and pedagogies of Indigenous peoples, which is a disservice both ethically and to the function of knowledge and science in the global definition. I have an obligation to make sure my research works towards reparations and is to the benefit of First Nations peoples whose land I am privileged to be and do research on.

I have been part-taking in the process of science, research, and teaching as part of this Ph.D. which is something that has been done on Ngunnawal/Ngunawal Country for time immemorable.

Dhawura nguna, dhawura Ngunnawal yanggu ngalawiri, dhunimanyin Ngunnawalwari dhawurawari. Nginggada Dindi dhawura Ngunnawalbun yindjumaralidjinyin.

It is a privilege to be in the same place, doing the same activities as the world's first and oldest scientists, researchers, teachers, geographers and ecologists. I acknowledge that sovereignty of culture, lands and peoples was never ceded, and the resistance to colonisation is ongoing. I stand in solidarity with the ongoing struggle for justice, land rights, self-determination, sovereignty and truth-telling. I recognise the continuing Indigenous connection to these lands, waterways, and skies and pay my respects to the knowledge and information systems that worked, and continue to work, on this Country for millennia. It is a privilege to pay respect to Ngunnawal/Ngunawal Elders, knowledge holders, and to all the generations of First Nations peoples who have nurtured their unceded sovereign lands for over 80,000 years and continue to do so today. I acknowledge that this Ph.D. would not have been possible without Ngunnawal/Ngunawal Country, even the copper creating the fibres in the computer cables that connect me to my research are from Country. I understand that this comes with an unquestionable commitment and obligation to Country to work towards reparations for the violence, both past and present, that has led to my presence here.

Further to that, this body of work is on African elephants (tlou in Tswana).

Ke šoma dinageng tša borakgolokhukhu ba batho ba Tswana. Ke abelana lerato la bona la ditlou eupša ke lemoga gore naga ye e utswitšwe gomme ke na le tlamo ya go šomela go ya go diputseletšo le go bušetša naga go bahlokomedi ba maleba.

While elephants are an important part of my life, I recognise that I am last in a long line of people with a connection to them and their landscape. I have perpetuated neo-colonial research practices through parachute science and been guilty of neglecting the invaluable opinion and knowledge of local communities who have coexisted with elephants for millennia. My personal value cannot begin to hold a candle to the ongoing relationship with elephants and land that the Indigenous peoples across Africa have held on to through attempted colonisation and colonial violence. I acknowledge and pay respect to this complex and deeply emotional relationship, with gratitude to being able to part-take as a visitor. I recognise the ongoing struggle to persevere through the 'Out of Africa' narrative and endeavour to restore landscapes and livelihoods in the wake of colonialism.

My research has benefitted endlessly from the time, patience and knowledge of First Nations people for which I am grateful and recognise the burden of emotions and effort that has gone into helping me on this journey. I do not take this lightly and I hope that this thesis, and proceeding publications, can show how I am working towards reparations and ensuring lands and the wonderful creatures within are more strongly connected or reconnected with their traditional custodians.

Positionality Statement

This section and statement are to inform the reader of this work of my positionality in relation to my research. Science and research can never be fully objective, there is always something that has led you to choose a topic, method or approach. Knowing the positionality of the person presenting the work provides critical insight into the objectives of the research, and how the work has been shaped by how the writer relates to their work. This is also a reflection of how my approach and work has changed in response to the pandemic, and the process of decolonising my mind and research, which has shaped the final product of my thesis as something significantly different from how I started. This reflection on personal growth and personal history provides critical perspective on how and why I have done this research and written this thesis.

Firstly, I write this Ph.D. and body of work as a white settler with indelible privilege and benefits from living on and researching lands marred by colonisation with a violent history and a violent present. I am a white, fully abled, heterosexual and cisgender woman and have benefitted entirely from the privileges that provides. I am a geographer, ecologist and science communicator trained within the confines of a strictly colonial institution. Bar one course during my undergraduate degree, I have no formal training in Indigenous sciences and my background is predominantly in Western biological and environmental sciences. I am well educated, but my rural background has not been conducive to understanding or learning about anything to do with the Country I am or have been on. Coming from a colonial education system, I recognise that I was allowed and encouraged to be ignorant, indoctrinated by colonial systems and actively contribute to the oppression of Indigenous peoples in both 'Australia' and Africa. Yet as I finish my Ph.D., I see that it has fundamentally changed to reflect the reality of working with nature – the only ethical and effective way forward is decolonial and community-centred.

I also recognise that I hold unique positionality as a grandchild of refugees and Shoah (Holocaust) survivors (ז"ל/may their memory be a blessing). I am a non-practising Ashkenazi Jewish woman/yenta and am proud of my ethnicity and heritage. Both my grandparents and the small remnants of their family were refugees of the Shoah. I am here as a testament to their perseverance, sacrifice and suffering and have an obligation to continue their fight for autonomy and self-determination. I have come to understand that the research I do must be a continuation of my families fight for justice, freedom and survival. As part of a refugee diaspora living and working on stolen lands, my aim is to pursue research in a framework that honours my families struggles for freedom and justice for *everyone*.

My research and position are influenced by several factors. Some factors are innate, like my privilege to be able to do a Ph.D. and work on a charismatic species. Some factors are intentional, like going down the path of decolonial methods and ontology. Those factors are influenced by my background as an ecologist, a woman, and as an Ashkenazi Jew. My obligations towards doing research ethically are grounded in my experience of being in a minority, loving and befriending people in minorities and seeing their oppression and working on a species and landscape decimated by colonialism. For me, as a researcher, a Ph.D. student and a Jew writing this body of work, it always comes back to the core values of tikkun olam (repair the world/תִּיקּוּן עוֹלָם), tzedakah (righteousness/צדקה), chessed (kindness/שחמט) and 'never again' (keynmal mer/קיינמאל מער). For wildlife, for ecosystems, and for all First Nations peoples. There is no environmental justice without social justice and I try to emulate this in this thesis and by providing the reader with my positionality in relation to this body of work.

Part of my PhD journey has been decolonising my mind and my research, which led to me to be co-editor on a book (in-prep with ANU Press) called '*yindyamarra*: Pursuing Decoloniality in Academia One School at a Time'. As an editor, I co-wrote the editorial but also contributed a chapter called "Out of Africa" which is essentially an extended positionality statement and provides more context on the work I have done in Africa and how it has changed. I have included this piece of work as an appendix (Appendix 4) to this thesis with the reviewer comments and commentary included.

Acknowledgements

It takes a village to raise a child and this Ph.D. is as close to baring a child as I'll likely ever come. As such, there is a whole village of people to thank.

I would like to start by thanking my supervisory panel; Rob Heinsohn, Bruce Doran and Rosie Cooney. Firstly, thank you all for letting me meet or keeping me updated on your dogs! Bruce and Rosie, thank you for your time, expertise and patience. I appreciate the critical and constructive conversations we have had and your input into making my research more robust and helping me become a better researcher. Rob, you have truly gone above and beyond what any student could ever expect from a supervisor. Supporting your research group through a pandemic, while also trying to get through yourself, is no small feat and I think I may have dropped the Ph.D. when fieldwork became impossible if it wasn't for your endless patience and kindness. I appreciate that you took on a student from outside your research group with an overly ambitious project and did so with grace, passion and expertise. You have always made me feel like my health, wellbeing and happiness came before the Ph.D. and that in itself makes you a one-of-a-kind supervisor. Thank you for your compassion, kindness and sharing a passion for Africa. I am so lucky to have learnt so much from you and look forward to sharing a few more hot chocolates together in the years to come.

In the professional sphere, thank you Katie Liesinger and Pat Werner for your knowledge and academic support throughout the research process. Thank you also to Veenita Vido, Mitchelle D'lima and Rosie Stevens for your professional help and support and above else, the ever-friendly faces, the warm laughs, cranky rants and all the good food.

Teaching has been a highlight of my Ph.D. and I hope my career will continue in a space where I can educate (and learn from) students. I'd like to thank Rob Heinsohn, Matt Brookhouse and Ben Scheele for encouraging me in the teaching sphere and providing space for me to specialise, grow and refine my skills as an educator.

A project on a continent so far away and so inaccessible due to the pandemic is not possible without the help and knowledge of people on the ground. Thank you to Kenneth Uiseb (Namibian Ministry of Environment and Tourism) and Mike Chase and Kelly Landen (Elephants Without Borders) for your knowledge, willingness to collaborate and critical data that contributed to this Ph.D. I would also like to thank my colleagues Michael Wellington and Fang Yuan from Geoscience Australia who helped turn one of my datasets into an interactive and openly accessible dashboard through Digital Earth Africa.

While I did not sit within a research group, I was graciously welcomed into two that shaped this Ph.D. and research into what it is. Firstly, the ANU African Studies Group who provided me with critical and constructive thoughts and discussions on my work. My work doesn't mean much if it is not respectful and useful to Africans, and I appreciate the time many of you took to listen and discuss my work and that I was privileged to learn so much from all of yours. In particular, thank you Margaret O'Callaghan for providing the perfect place to live and write a Ph.D. and the constant reminder to KISS…keep it simple, stupid! Secondly, the Fenner Decolonial Research and Teaching Circle. Being allowed into a space created for and led by Indigenous researchers has by far been the most valuable and important part of my Ph.D. journey. The yarns, shared content and relational accountability has been invaluable to decolonising my mind, my research and my life. To have a safe space where I can make mistakes, learn from them and do better in the decolonial area has made this research what it is. In particular, I must thank kate harriden as a colleague, conspirator and a friend. Thank you, kate, for listening to, inspiring and pushing me to do and be better. I look forward to many more walks with dogs, sharing sweet snacks and decolonising the academy with you for a long time to come marambangbilang woman.

Now into the personal sphere! While a Ph.D. is meant to be challenging, I faced a lot of extra challenges along the way. Losing my fieldwork to the pandemic, while also trying to navigate a pandemic, took a huge toll on my research and me as I did this Ph.D. specifically for the fieldwork component. During this time, we also fought both bushfires and floods at my childhood home and I went on a long, arduous journey diagnosing and trying to manage chronic health issues. All on top of doing a Ph.D., which was fun sometimes and exceptionally hard for others. Throughout it all, I received support from far and wide, and from all over the world and I'm very grateful to be able to say that.

Firstly, my Fenner colleagues. I have been at the Fenner School for 10 years and in that time, have come to befriend and adore so many people. Thank you for all the impromptu coffees, yarns in the corridors, commiseration in mutual suffering and rush for free food at every chance. Being surrounded by like-minded, charismatic and kind people makes the world of difference to a workplace and Fenner is a special concoction of those people that have made my professional and academic life a wonderful and enjoyable thing. Cheers!

Secondly, my endlessly patient and supportive friends. Toby, Zoë, Ash, Leah, Kris, Nat, Sabine, Caitlin, Renée, Danu, Christine, Brittany, Jacqui, Ginny, Rory and Claire – there are no words. Thank you for laughs, the tears, the distractions, the hugs, my nieces and nephews, your kindness, your support, your patience and for loving me and letting me love you. Also, thank you to my Uncle Holger for your cross-continental lifetime of love and support and a quiet spot in regional Germany to make apple juice and write my thesis. A special thank you to both Matt and Aaron for joining me on this academic journey since Honours and for showing me the true spectrum of conversations ranging from superior vegetables and deltoids through to thoughts and critiques that genuinely shaped and improved my research. Thank you both for being ridiculous, being kind in your own ways and for putting up with me as an office mate and a friend.

I have been lucky to have a close group of people who are collectively the loves of my life that have made both me and this project better and taught me what platonic love, support and family can be. Thank you/toda Emily, Meena, Jessie and Oli. You are kin. Toda for making me laugh endlessly, reminding me that there are bigger things in life than the Ph.D. and unconditionally supporting me through this journey. Your patience, love, kindness, support and laughter has made my life so full and wonderful. I am looking forward to so many more times of being couch potatoes, laugh/crying, impromptu adventures and quality time with you all. And to end my acknowledgements of those who aren't family, thank you Lachlan for your patience, support and love, I am lucky to have it. Here's to many more birds to watch, food to eat and laughs to have.

Lastly, I have to acknowledge and thank my family. There are several people who won't be able to read this research or see the work I have done yet I am where I am because of their suffering, perseverance and sacrifice. My life and my work are a testament to theirs and all they survived so I could thrive and I do not take it lightly. I hope they know, wherever they are, that my grandparents (John and Bina), great-uncle (Morris) and great-aunt (Bella) that I am eternally grateful and proud to represent the family they created. In particular, toda/mulțumesc to my grandfather. It is the highest honour and privilege to become the second Dr. Gross in the family. Thank you for passing down your love of science, your intelligence and your power for compassion and kindness.

Importantly, to my family who have been here to love and support me. Thank you to my sister, Sarah. We have had ups and downs and all arounds, but you have always unconditionally supported me even if you're not sure what I even do. You also brought my niece, Willow, into my life for which I will always be grateful. Little Willow – thank you for reminding me that there are always more important and bigger things in life, I'm lucky to be your auntie and I will forever share my cheese with you. And the most important acknowledgement of them all, thank you/toda to Mum. A life like mine, and a career choice like this, cannot happen without unconditional love and support and that is all I have ever received from you, unwaveringly, in abundance. You have been there for every break though and every break down and I am here today because of you. You believed in me when I was 5, and you believe in me now and I am honoured to share my successes with you because of it. Please know this Ph.D. is a Gross family effort and I could not have done it without you. Thank you for being a zaftig yenta matriarch to look up to and love.

A last little note to acknowledge the elephants. What a privilege to study them, be with them and research them. Thank you for being wondrous, complex and more-than-human and a constant source of inspiration and motivation during such difficult circumstances. We have a lot to learn from elephants, and from the people that have coexisted with them for millennia.

לֹא עָלֶיךָ הַמְּלָאכָה לִגְמֹר וְלֹא אַתָּה בֶן חוֹרִין לְהִבָּטֵל מִמֶּנָּה

Lo alecha ham'lacha ligmor. V'lo ata ben chorim l'hibatil mimena.

It is not your duty to finish the work of the world, but neither are you at liberty to desist from it.

Abstract

The African elephant (*Loxodonta africana*) is threatened by habitat destruction, illegal killing and human-elephant conflict. Their susceptibility to climate change, especially drought conditions across their distribution, is less well documented. Elephants are likely to struggle with increasing air temperatures and decreasing precipitation because they are biophysically susceptible to heat stress, largely because they cannot sweat and are highly dependent on surface water. As drought conditions across sub-Saharan Africa intensify in duration and severity, elephants are inhibited from adapting to the changing conditions by their poor thermoregulatory mechanisms and from being confined to protected areas. Climate-specific research is also lacking which limits options for informing management and policy. Using both a meta-population approach and case studies, this thesis seeks to explore how elephants are responding spatially to climate change induced drought, how their responses will impact the landscapes around them and how their relationships with local human communities may shift or be shifting. In this thesis, I aim to address these research aims using literature (Chapter 2 and 6) and systematic (Chapter 3) reviews, remote sensing (Chapter 4) and Geographic Information Systems and GPS movement data (Chapter 5). Chapter 1 is an Introduction to the thesis.

Chapter 2 explores the biophysical susceptibility of elephants to drought and thus climate change. The chapter shows that elephants are unusually susceptible to climate change-induced drought from a cellular to a landscape level. It also shows that current management strategies, such as artificial water holes and conservation fencing, can amplify conservation issues. It concludes that elephants need room to move between sources of surface water and that climate change needs to be factored into elephant management.

Chapter 3 is a systematic review of ecological research published on elephants from 2000 to 2020. It evaluates whether the recent scientific research on elephants is diverse enough to inform managers across the species' range and identifies important gaps and biases. The results show that elephant research is significantly biased towards a few small elephant populations. These biases may lead to management strategies overly dependent on misrepresentative information from a small, non-representative subset of the meta-population. I conclude that the biases may be a result of poor accessibility and systemic conservation research barriers. I recommend theoretical research frameworks built around need instead of accessibility and meaningful community collaboration to overcome barriers and biases.

Chapter 4 develops a continent-wide index model of habitat suitability for elephants using remotely sensed satellite data. The model predicts areas of increased human-elephant conflict because of resource depletion and shows the role and importance of smaller protected areas in

the future of elephant migration and habitat refuges. Habitat suitability, inside core protected areas, is mostly mid-range while the 10km buffer zones around protected areas have mid-high habitat suitability. Further, smaller protected areas have higher habitat suitability than their larger counterparts and higher potential for elephants to continue to use, or start using, zones outside protected areas. I conclude that the risk of human-elephant conflict is increasing because the buffer zones around protected areas are of high value for elephants. I recommend investment in wildlife corridors and community-based management including trans-frontier areas and contiguous protected areas to help manage this.

Chapter 5 uses GPS collar data for eight elephants across the Kavango-Zambezi Transfrontier and Tuli regions to track occupancy time in different habitat types and quality under climate extremes. It shows a clear response by elephants to climatic conditions and how drought-specific climate conditions can impact how they use their habitat and the likely implications. Precipitation has the strongest influence on elephant habitat use. Elephants may be using forests as heat refuges and spent more time in human dominated landscapes. In forests, increased occupancy time may cause damage and in human-dominated spaces may lead to escalating human-elephant conflict. I again recommend investment in wildlife corridors, community-based management and trans-frontier areas/contiguous protected areas.

Chapter 6 summarises my research findings and lists my overall conclusions, including the significance and limitations of my research. I include a sub-section on community based natural resource management (CBNRM) as the key management recommendation. It discusses how colonisation changed the relationship between humans and nature in Africa, pitting people against wildlife which is a problem perpetuated by current research methods and conservation strategies. I conclude that CBNRM is not a singular solution but a multi-faceted approach which can be improved by committing and investing by becoming truly community focused, with emphasis on the most ethical and sustainable options in elephant conservation.

Four overarching conclusions from my thesis are as follows. First, climate change will continue to intensify drought conditions and conservation issues across the distribution of elephants. Second, elephants are already responding to drought conditions and incidentally interacting more with humans. Third, elephants are, and will continue to, spend more time outside protected areas in human-dominated spaces. Lastly, elephant research and management work largely within frameworks still dominated by colonial attitudes which are not conducive to adaptive or integrative policy for droughts, climate change and landscape-level environmental changes.

Table of Contents

List of Acronyms and Abbreviations

CBNRM: Community-based natural resource management

CGLS: Copernicus Global Land Satellite

ESA: European Space Agency

FAO: Food and Agriculture Organisation

GIS: Geographic Information Systems

GPS: Global Positioning System

HEC: Human-elephant conflict

HWC: Human-wildlife conflict

HSM: Habitat Suitability Model

IUCN: International Union for Conservation of Nature

NASA: National Aeronautics and Space Administration

NPR: National park/reserve

PA: Protected area

UN: United Nations

Chapter 1:

Introduction

The Anthropocene, beginning during the Industrial Revolution, has initiated the sixth mass extinction of wildlife and natural landscapes across the world[1–3]. This has led to most continents experiencing a biodiversity extinction crisis where species richness and evenness, particularly among priority species, are declining while populations of invasive and introduced species increase[3,4]. While species extinction occurs naturally, and life on Earth has experienced five previous mass extinction events, this extinction event caused by human activity is happening thousands of times faster than the background rate[3]. Loss of wildlife, particularly keystone and priority species, leads to economic, cultural and ecological losses on an exponential scale[5]. Further, many species are critical for agriculture and food systems across the world. The livelihoods of humans hinge on the maintenance and survival of biodiversity[3].

The global biodiversity extinction crisis has led to ongoing conservation challenges for many species. Among the primary causes of species decline are habitat destruction and fragmentation, overexploitation of natural resources and climate change[6]. At the core of these challenges is wildlife facing rapidly decreasing access to resources and space, which in turn increases the likelihood of intra- and interspecific competition, malnutrition, starvation or dehydration, and causes disruption to the function of species in landscapes and the relationships within[1,2,7,8]. In particular, keystone and other high priority species may no longer be reaching their carrying capacity or optimum functional numbers in landscapes, which has a trickle-down effect on the other wildlife[1,2,6]. This allows invasive and introduced species to arrive and/or thrive in the opening of new niches made available by their decline. This causes further changes in the landscape that affect the wildlife dependent on the primary species[5].

Resource decline is analogous with the effects of drought, particularly moderate to severe drought. Drought is characterised by extended periods of increased ambient air temperatures and decreased precipitation and is driven largely by the El Nino phenomenon[9,10], a cycle that occurs roughly every seven years where temperatures of the sea surface in the central and eastern Pacific Ocean become significantly warmer[9–11]. The specific climatic and hydrologic parameters and definition of drought are not black and white, but are categorised as the same characteristics of warmer air and less rain[12–14]. Climate change is a shift in overall meteorological, climatic and hydrological systems across the planet as a result of the greenhouse effect increasing the average temperatures of water, air and atmosphere. Increasingly severe droughts and drought conditions are one of the implications of global climate change[15–17]. While droughts have occurred naturally in the climate record, the intensity and longevity of droughts is worsening across much of the Southern Hemisphere, particularly in Australia and Africa[15,17,18]. On a regional scale for wildlife, drought depletes critical resources, such as foliage and surface water, at an accelerated pace and creates competition for those resources[14,19]. Many species are already endangered due to their inability to compete and being less resilient to landscape and resource changes[20,21]. Pressures such as drought on species like this exacerbate the pressure on their survival. Further, animals that are more sensitive to heat and heat stress, primarily mammals, are also susceptible to the effects of drought as longer periods of higher ambient air temperatures puts biophysical pressure on their metabolism to maintain homeostasis and offload heat with increasing incoming environmental heat[22]. With increased intensity of weather events as a result of climate change, many continents such as Africa, have been and will continue to experience intensifying drought conditions which in turn puts pressure on resources available and the species, vulnerable or not, that need them.

Examples of these conservation challenges can be seen throughout most continents but may be more apparent in the most biodiverse regions. Prime examples occur across the landscapes of Africa. The Anthropocene had an amplified effect on many African nations due to the aforementioned issues in combination with European colonisation[8,23]. While Africa is renowned for its many charismatic and flagship species, particularly megafauna, most have experienced drastic population declines since colonisation[24]. Colonisation introduced the ivory and illegal wildlife trade, trophy hunting and destroyed many symbiotic relationships between local human communities and wildlife[25,26]. In particular, the introduction of colonial protected areas that have strictly enforced boundaries, limited migratory species from being able to move between resources by fragmenting their habitat and fencing them in[11, 12, 13]. Megafauna, in particular large herbivores, migrate to different habitats and regions depending on resource availability which has also allowed them to adapt to climate driven resource changes[27]. African wildlife, especially megafauna and big game, need space to move and rotate between resource patches, establish and maintain territories and avoid negative interactions with humans[28–30]. The fragmentation of most African landscapes due to colonisation, establishment of protected areas and human population expansion limits space and opportunity for movement for megafauna[31–33]. Habitat fragmentation also impinges on connectivity between conservation spaces for wildlife so moving between them is dangerous or difficult for wildlife[34–36]. As a result, some megafauna populations are overpopulating some protected areas, overusing resources and interacting more with human populations as they seek resources[37–40]. These factors all lead to a decline in habitat quality and resource availability in protected areas and the increased likelihood of wildlife leaving the confines of protected areas to seek critical resources and move into overlapping spaces with humans where the chances of human-wildlife conflict increase, causing harm or death to both parties[41–44].

While habitat fragmentation and human population growth are steadily increasing and have been an issue in the conservation space in Africa for many decades, climate change is rapidly becoming a bigger driver of resource decline in sub-Saharan Africa[45,46]. Savannah regions, particularly in eastern and southern Africa, have been experiencing varying levels of moderate to severe range drought across the last 3 decades[47–49]. Drought, characterised by periods of ongoing high ambient air temperature and low precipitation[50], not only causes increasing heat stress in wildlife but depletes water and forage, sometimes permanently[51]. While drought is a natural part of semi-arid and temperate landscapes, global changes in water and weather systems as a result of climate change are causing droughts in the southern hemisphere to become longer and more intense[17,52]. With resource depletion leading to increasing human-wildlife interactions, and by extension conflict, it is critical to understand how drought and climate change affect the movement and habitat use of megafauna to best understand how to manage their response and the landscape.

This thesis examines how megafauna, specifically elephants (*Loxodonta africana*), are responding to climate change induced drought. It examines how their response to drought impacts their survival, how their relationship with local human communities might change, and how designing policy and management frameworks inclusive of climate change is a major conservation challenge. Elephants are keystone species[53] that play a critical role in African ecosystems as ecosystem engineers[54] and have immeasurable cultural, ecological and economic value but their populations have dropped by 98% from 27 million (19th century) to ~415,000 (2016) since colonisation[55,56]. The two primary causes of elephant decline, habitat destruction and poaching, are directly attributable to European colonisation and , indirectly, as a consequence of the large contribution from the western world to climate change[55–57]. While habitat destruction and fragmentation and poaching are well studied and considered in the literature, how elephants respond to drought is poorly understood but increasingly problematic. The theoretical framework of this thesis was anchored in six chapters with associated aims and research questions.

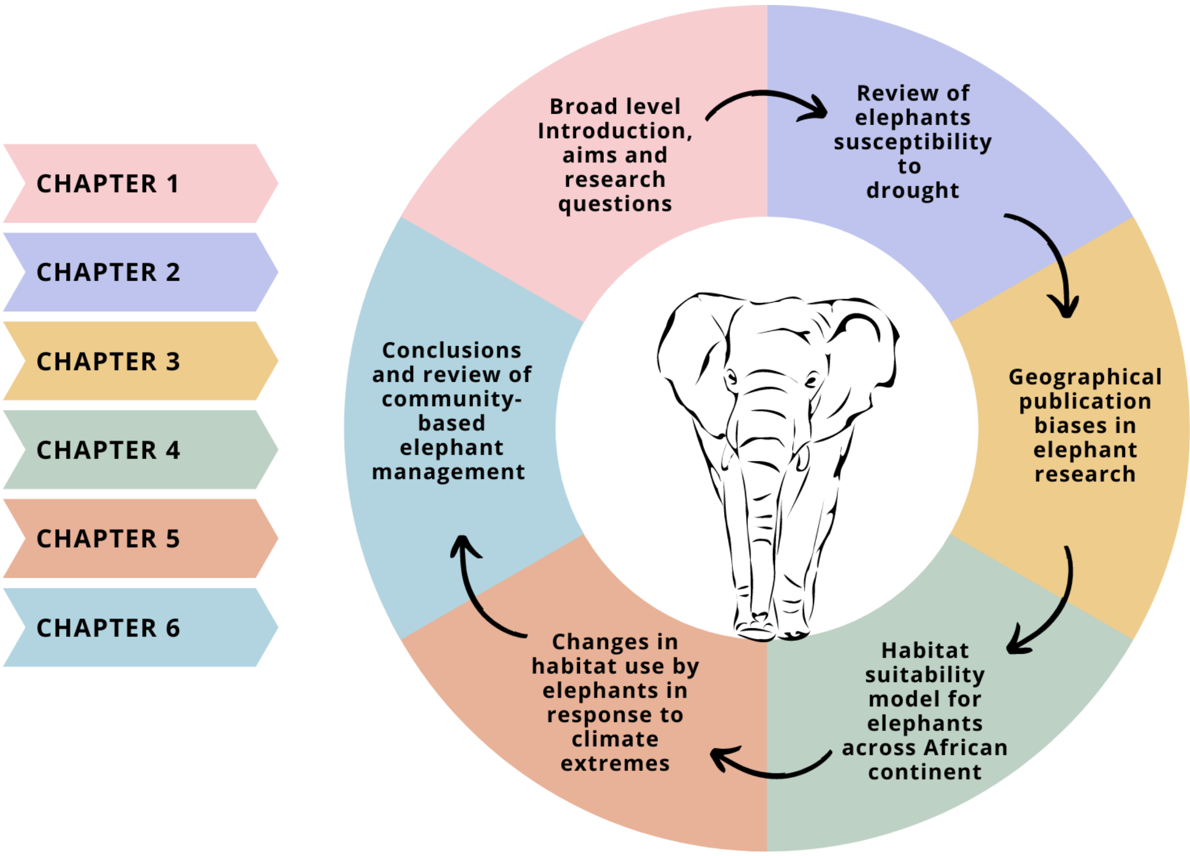

Figure 1: A visual representation and summary of each chapter in this thesis and how they lead into each other.

Chapter one: *Introduction*

Chapter two: *Climate change is the elephant in the room.*

This chapter is a literature review on the biophysical susceptibility of elephants to drought and thus climate change with a focus on policy. Given the novelty of the research area, the review aimed to gather what is known of elephants responding to climate change and highlight key research gaps that the rest of the thesis aims to fill. The review thoroughly interrogates what is known of how and why elephants experience heat stress, how they are biophysically inhibited to respond to drought conditions and how and why they are so dependent on surface water for survival. The chapter shows that elephants are susceptible to climate change-induced drought from a cellular to a landscape level. A simplified version of this chapter has also been published in *The Conversation*.

Chapter three: *Elephants not in the Room: Systematic Review Shows Major Geographic Publication Bias in African Elephant Ecological Research.*

This chapter is a systematic review of all academically published ecological research on elephants from the years 2000 to 2020. I was aiming to evaluate whether the recent scientific research on elephants is geographically diverse enough to inform managers and policy makers across the species' range. It further aimed to identify gaps and biases in research on elephants, determine the implications of any research biases, and make recommendations for future research. This chapter has been published in *Diversity*.

Chapter four: *A Continent-wide Habitat Suitability Model for the African savannah elephant (Loxodonta africana).*

This chapter consists of a continent-wide index model of habitat suitability for elephants across Africa using remotely sensed satellite data from CGLS-100 (ESA), NASA, FAO, UN and IUCN. I was aiming to highlight patches of landscape likely to become overused by elephants, predict areas of increased human-elephant conflict as a result of resource depletion and understand the role and importance of smaller protected areas in the future of elephant migration and habitat refuges. I further aimed to understand patterns of relative habitat suitability and elephant distribution to best predict elephant movements and the implications of this in the future. The model shows how likely elephants are to leave protected areas in response to declining resources and shows the current habitat quality. Analysis on elephant habitat at this scale and resolution has not been previously attempted. This dataset is being transformed into an interactive dashboard being published through Digital Earth Africa (DE Africa), Geoscience Australia (GA). The script has been completed, tested and approved by the DE Africa executive team and is in the final stages of review by the technical team and higher authorities in GA. Once approved, DE Africa and I will be proposing the model to ESRI to transform the code and console into an interactive dashboard for less experienced users.

Chapter five: *Shifting habitat preferences of African elephants (Loxodonta africana) in response to climate extremes.*

This chapter uses GPS collar data for eight elephants across the Kavango-Zambezi Transfrontier and Tuli regions from 2014 – 2019, provided by the non-government organisation *Elephants Without Borders*, to track occupancy time in different habitat types and quality under climate extremes focussing on air temperature, humidity and precipitation. This time period is pertinent as it was a time of moderate-severe drought in these regions. I aimed to show a definitive response by elephants to extreme climatic conditions, how drought-specific climate conditions can affect how elephants use their habitat, and the likely implications.

Chapter six: *Conclusions.*

Here I summarise my thesis findings and list my main conclusions including the significance of my results, the limitations of my thesis and the best directions for future research. The chapter also includes a long sub-section on management recommendations, which focuses specifically on community-based management natural resource management (CBNRM). Given that the management recommendation highlighted is CBNRM, this short review aimed to provide a past history, present state of and future outlook on CBNRM. The review aims to show how the relationships between humans and elephants has been fractured by colonisation and the role that colonial protected areas play in maintaining and enforcing this divide. Given the focus of my thesis on the possibility of elephants and humans interacting with each other more as a result of climate change, the review is pertinent to show the power of amplifying the voices and autonomy of the communities where the interactions will be occurring. In particular, the review outlines how CBNRM and climate change can concurrently be built into and considered in conservation policy and management moving forward.

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Chapter 2:

African elephants need better access to water to survive climate change.

A summarised version of this chapter was published in *The Conversation*:

Rachael Gross & Robert Heinsohn: Elephants Not in the Room: Climate change is leaving African elephants desperate for water. *The Conversation*. 2023.

https://theconversation.com/climate-change-is-leaving-african-elephants-desperate-for-water-191844

(Appendix 1)

2.1 Introduction

Megafauna and big game can experience the stressors of drought on a broad level and faster than some other species[15]. Drought causes increasing heat stress which can be amplified in larger bodied animals due to their size and volume and depletes the resource of which they need more to maintain their size[16]. Large species with lower surface area to volume ratio are particularly vulnerable to heat stress as they have a large volume creating metabolic heat and less surface area in which to release the heat back into their environment [6, 15, 29]. Of all the large species, some are particularly susceptible due to further biophysical restrictions to offloading this heat, such as African savannah elephants (*Loxodonta africana*, hereafter elephant)[6, 29].

Climate change is affecting large areas of key habitat for elephants, especially in southern and eastern African countries like Kenya, Zimbabwe, Tanzania and Botswana where elephant populations are largest [1–7]. Climate change manifests in these regions as increasingly severe and ongoing drought [8–12], characterised by higher temperatures and lower precipitation [13–15].

These conditions are increasingly unfavourable to elephants because of their unusual susceptibility to heat and water stress. This review aims to summarise what is known of elephant responses to drought on many biophysical and environmental levels and highlight critical knowledge gaps that may be key to future elephant management under climate change as drought increases their heat and water stress and threatens their survival.

2.2 Elephant population decline

Climate change is both adding to, and compounding, several serious threats to elephants. Elephants are listed as endangered (savannah elephant) and critically endangered (forest elephant) by the IUCN. Habitat loss and fragmentation, human-wildlife conflict and ivory poaching have already reduced elephant numbers across Africa by 98% (from ~20 million elephants to ~415,000) since the 19th Century [7,16]. Human activity alone has reduced the distribution of elephants and giraffes (*Giraffa camelopardalis*) by over half since the 19th century, primarily by causing severe habitat fragmentation [16–18].

There are three species of elephant; *Loxodonta africana* (African savannah elephant), *Loxodonta cyclotis* (African forest elephant) and *Elephas maximus* (Asian elephant)[19]. Until recently, *L. africana* and *L. cyclotis* were treated as the same species by taxonomists but the IUCN has since recognised them as two separate species and recategorised the savannah elephants as endangered and the forest elephants as critically endangered[19]. Elephants are the largest land mammal with African savannah elephants being the largest weighing 4 to 6 tonnes, can stand over 13 feet high and be over 24 feet long[20]. Elephants are herbivores with regional diets that is broad in vegetation and grass preferences but will also eat fruit, roots and agricultural crops[21]. Elephants require up to 135 kg of food and 225 L of water per day, which fluxes with their size and location[21–23]. Female elephants stay in herds of varying sizes, while males will leave the herds to be largely solitary between the ages of 12-18 when they sexually mature[24–26]. Females have long gestations and will birth one calf every 3-4 years, twins are rare and it is more rare for both to survive[27,28]. Elephants can live up to 80 years, with the average lifespan sitting between 55-70 years[29–32]. Forest elephants are distributed in fragmented parts of mainly Central Africa, particularly in heavier forested areas like the Democratic Republic of Congo[33]. Savannah elephants are more versatile and can be found across western, central, eastern and southern Africa with the biggest populations being in southern Africa[33]. Both species have largely gone extinct in northern Africa save a few dwindling populations[33]. Elephants on average will move 5-10 km a day but can go up 80 km in search of resources and can traverse several hundred kilometres when migrating as a facultative partially migratory species[34]. Elephants live in diverse habitats ranging from deserts in Namibia to heavily forested regions in Congo[33]. While the desert elephants are elusive and little is known, habitats for elephants generally require abundant forage, water and space to move[35–38]. As mentioned, elephants will move great distances for adequate resources, including into communities.

The elephant population decline is concerning both for elephants and other species that rely on their role in the ecosystem because elephant behaviour and movements shape landscapes around them to the benefit of other endangered species [39–42]. Their role as ecosystem engineers makes them a key determinant of the health and function of African ecosystems [43–48] and their decline has already had broad environmental effects [7]. Elephants also have high cultural and economic value on local, national and international scales and are one of the major sources of tourism revenue across Africa [49–51]. This is relevant for both forest elephants (*Loxodonta cyclotis)* found predominantly in central Africa, and the separate savannah elephant species (*Loxodonta africana,* also known as Bush elephants) that make up the remaining populations across southern, eastern and western Africa.

By virtue of their size and foraging habits, elephant movement inherently shape the landscape around them. They create semi-permanent cleared pathways as they move through the forest, which allows other smaller species (such as endangered Suni, *Neotragus moschatus,* in South Africa)[52–55]. Elephants are also seed and pollen dispersers through their dung and the wrinkles in their skin[54,56–58]. With enough time spent in a habitat, such as an open woodland or near a water source, elephants can flatten habitats which will eventually transform into grasslands and savannahs[59–61]. The decline of elephants has occurred so quickly that it is difficult to quantify how much elephant population decline has impacted the broader environment, especially give the diverse habitats that they live in. However, overpopulation of elephants in fenced reserves has clear impacts on other wildlife like habitat degradation, intense competition for resources and inter-specific violence[32,35,62].

2.3 The relationship between elephants and drought

Most research on elephants has focussed on their population decline as a result of poaching and human-elephant conflict but there are indications that climate change is also impacting their survival. For example in Zimbabwe, especially Hwange National Park, has seen increases in elephant deaths as a result of ongoing drought [63,64]. Further, in Botswana, ~300 elephants recently died of poisoning when uncharacteristically warmer water facilitated a cyanobacteria bloom [65]. There is also growing concern surrounding the increasing evolution and variation in zoonotic diseases. For example, elephants have a higher risk of contracting and spreading foot and mouth disease as a result of global warming [66].

Elephants' behaviour and movements are almost entirely dictated by water use and access, so it is crucial to understand how they respond to intensifying climate change-induced drought scenarios where their responses may have domino effects on other endangered species and ecosystems.

There is evidence that the susceptibility of elephants to drought conditions occurs on many biophysical levels, starting with water reliance. Adult elephants, on average, weigh between 3.5 and seven tonnes [67] and require up to 225 L of water per day to remain hydrated and can lose up to 10 per cent of their body water (427-516 L) in one hot (24^0C+) day [68]. Their size, thick impermeable skin, and lack of sweat glands [67,69,70] make them unusually susceptible to heat stress, especially during periods of sustained higher ambient air temperatures [71]. This is concerning as the intensity and duration of the current droughts across southern and eastern Africa, where most elephants live, is escalating due to climate change arising from shifts in global water cycles altering the timing and intensity of the El Niño and La Niña phenomena [7,9,72–76]. Droughts in some African regions have lasted more than 20 years and show no signs of easing [77].

2.4 Thermoregulatory limitations to heat stress.

Starting at a physiological level, elevated internal temperatures in endotherms can disrupt cellular, tissue and organ function and, in elephants, can cause illness, increased risk of predation due to dehydration and weakness, gestational deformity and death [78,79]. This makes effective heat dissipation imperative. Heat in an elephant's body is generated through metabolism, feeding and physical activity [80], and is also transferred from the environment by radiation, convection and conduction [81,82]. Lactation also creates significant metabolic heat [83], which can double water requirements in mammals [84]. After 22 months of gestation, energy and water deprivation during drought may harm the health of cows and stunt the growth of calves [85]. Elephants are more susceptible to complications due to heat stress than other endotherms because of the unique combination of their very large size with smaller surface area to volume ratio, thick impermeable skin that cannot perspire and living in largely arid environments. While they inevitably share responses to heat, processes of offloading heat and susceptibility to heat stress with many other mammals, their sheer mass significantly amplifies the issues and thus their susceptibility.

Elephants use many forms of behavioural thermoregulation, such as ear flapping, seeking shade, and minimizing activity but most avenues of heat loss require water [86,87]. These include the cooling effect of drinking and offloading metabolic heat by urinating and defecating [88]. However, their thick hide slows heat loss and their inability to sweat is a disadvantage [81,82,89]. Elephants rely on swimming and spraying the body with mud and water [90] to achieve the trans-epidermal evaporative cooling from the skin that many other species gain by sweating [69,81]. Elephants also have a low surface area to volume ratio that inhibits effective thermoregulation although this ratio is slightly improved by their large ears and deep skin wrinkles [81,82,91]. Lastly, elephants accumulate heat during the day, allowing body temperature to rise and dissipate it at night [87], but increasing ambient air temperatures during both day and night will limit the effectiveness of this mechanism.

In terms of foraging, herbivores also respond to high ambient temperatures by reducing food intake because digestion and associated processes are a major source of internal heat [22,34,80,92]. In large herbivores like elephants, feeding declines almost linearly with ambient temperature [80] and this reduces water intake from food and may leave individuals more reliant on external water [22]. Two further considerations arise when animals consume foliage rich in plant secondary metabolites. First, liver function is depressed at high temperatures and this can lead to temperature-dependent toxicity [80]. Second, some plant metabolites are thermo-disruptive and can generate additional heat [80]. These factors are likely to restrict the choice of browse at high ambient temperatures [80,93].

One potential management solution to the biophysical challenges related to foraging is the addition of plants capable of withstanding the physical impacts of elephants that will provide extensive shade close to water. This may both reduce impact on threatened ecosystems and provide areas for elephants to stay cool and reduce heat stress [90]. A more ambitious longer-term option may be to intensely monitor the vegetation structure of reserves and when needed, consider the reintroduction or introduction of more drought resistant vegetation that prioritizes high water and nutrient content and takes into consideration the need for diversity of plant-secondary metabolites [94]. This would reduce plant consumption rates, stress on the landscape, and allow elephants to reduce metabolic heat production and heat stress [80,94].

2.5 Water reliance in elephants

Elephant distribution in southern Africa and parts of eastern Africa is limited by the availability of large quantities of water [34]. Their movements are usually restricted to a 20 km radius of water sources and their home ranges become significantly smaller during the dry season [34,95–97]. Drought causes starvation and death among elephants mostly from reduced growth/survival rates in young when cows produce lower quantities and quality of milk and increased predation by other species [79,97,98]. For example, drought in Tarangire National Park was associated with higher mortality in young males and the calves of younger mothers [98]. The impact was reduced for those that had unfenced access to seasonal water sources [98]. Some desert adapted elephants have adapted to accentuated drought conditions, though the mechanisms are not well understood [84,99] but wrinkles in their skin play an important role in retaining and distributing water to engage trans-epidermal water loss [81,89]. Desert adapted elephants are still at risk from intensifying drought as the conditions can be amplified in deserts through low resilience to climatic disturbance [53,100,101], so these adaptation mechanisms may become less effective. Non-desert elephants (the majority of the population) seemingly will also not have the time nor capability to evolve desert-adapted traits at the current rate of environmental change [53].

A common management intervention is to introduce artificial water sources [95]. This is problematic because artificial water points are commonly sourced from supplies needed by local human communities and elephants can cause a shift in habitat quality and dynamics due to overuse of the areas around water as they rarely move more than 15 km from a water source during the dry season unless travelling between water sources [102–105]. Introduction of artificial water sources can magnify elephant presence and habitat use in these areas, increase competition with local communities for water and is a costly intervention that requires considerable spatial planning and ongoing management which may be difficult to achieve under strained budgets [106–108]. Waterholes are also hotspots for poachers who can capitalise on increased elephant usage by setting snares and traps or by poisoning the water [109,110]. Recent efforts by some parks to rotate artificial water sources periodically across the landscape suggest this may be an effective but short-term solution.

2.6 Fencing as a limiting factor in elephant responses to drought

Climate change induced modification to the amount and distribution of water sources in Africa increases the importance of wildlife mobility and landscape connectivity. Historically, during periods of drought, elephants migrated to water including sites known to have been used for tens or hundreds of years [34]. Such movements have been severely curtailed in many areas with the establishment of fenced protected areas [111–113]. Fences may include national park fencing, agricultural fences and community fencing which can impact elephant movement in varying ways. For example, all national parks with elephants inhabiting them in South Africa are heavily fenced, specifically to keep elephants and other wildlife restricted. There are many regions with a combined agricultural/elephant presence, for example, Amboseli National Park in Kenya, primarily have agricultural and community fences designed for deterring wildlife and to protect humans and livestock [112,114]. Fences around southern African protected areas were constructed in the last two centuries to represent colonial land ownership, separate local human populations from megafauna and to deter poachers [115]. However, modern fences cause edge effects, fragment habitats and have detrimental effects on elephant health and ecology [17,41,112,113]. Although there are calls to remove fences to restore animal movements in Africa, such actions need to consider repercussions in relation to human-wildlife conflict and tourism revenue.

While fences around reserves aim to protect elephants and other endangered species, some fenced reserves have elephant populations that may exceed carrying capacity. Habitat modification and change by elephants is a natural and critical part of shaping African landscapes [48,116–118], and many other species rely on elephants to create and maintain habitat [119–121]. However, with increasing intraspecific competition within fenced areas and the inability to move, habitat modification may be amplified or even occur in areas previously unaffected by elephants [35,62]. These fenced or fragmented reserves may struggle to maintain ecosystem balance and to manage the populations ethically and within the public eye as population control methods like culling prove controversial [122]. For example, Kruger National Park has been experiencing moderate drought and relies heavily on its elephants for tourism revenue but elephant density now appears to exceed carrying capacity, to the extent that it is causing considerable changes to the ecosystem [123,124]. The park exemplifies an increasingly common 'conservation stand-off' characterized by the conflicting conservation objectives. This is particularly evident in the context of land use pressures associated with intensifying drought [60,125]. Continued population control within fenced reserves remains necessary and culling remains controversial but effective [126]. In the context of drought and heat stress, the less intrusive method of using contraception to control elephant numbers [127] has the added benefit of reducing milk production and the additional heat stress this causes to elephant mothers but there can also be longer-term side effects for the cows that are not yet known as it is a new intervention method. The various ways of maintaining or control elephant populations in restricted areas is a deeply complex issue that is often clouded by the speculation and judgement of the public, especially when it involves elephants dying. As with any intervention methods, there are costs to benefits to all types of methods and not one method can be applied to all populations. The issue itself could be a series of separate theses due to this complexity.

Changes to elephant movement patterns in protected areas, particularly those which are fenced, can have major implications for ecosystems, especially when new 'elephant corridors' are created. Elephants act as landscape architects through their foraging habits and interactions with mature trees [37,61] and form corridors across landscapes. They are comprised of pathways generally clear of trees, bushes and shrubs that lead them between water, food and social locations [61]. Although formed via destruction of vegetation, traditional elephant corridors (created before fences were erected) are low impact as they are well-established parts of the landscape [61]. As with the intervention methods, the issue of fencing is not black and white and is complex and diverse depending on the type of fence, the location and the landscape it is in. The issue of fencing is discussed in more detail through several other chapters of this thesis.

As resources become limited, elephants will need to find more places to forage and more places to seek shade which is likely to lead to the creation of more elephant corridors when they are restricted to a small area. Disturbance from new elephant corridors is problematic. Invasive plants often follow the elephants as seeds in dung and on the skin. Also, forest/woodland canopy cover decreases as a result of elephant-induced environmental modification in these corridors, potentially resulting in colonization by grasses and other species adapted to direct solar radiation [48,56]. Elephant corridors also provide access to endangered ecosystems by meso- and megaherbivores [61,128]. Large herbivores with broad diets that browse woody vegetation, like elephants, may pose a risk to plant species with limited regeneration capability and species that rely on them to survive [128,129].

An obvious but controversial action to help water-deficient elephants in southern and parts of eastern Africa is to remove fencing and allow them to move more between ephemeral resources, ideally with access to more pre-established wildlife corridors. Wildlife corridors have been shown to be of great benefit to the megafauna of India and the United States and would increase mobility of much of Africa's wildlife, including elephants [130–132]. Within fenced reserves, spatial analysis can also be used to identify vulnerable habitats where elephants should be excluded. To achieve this however, some areas may need to be allocated to increased habitat modification by elephants. However, such action exposes surrounding communities to more conflict with elephants, increases accessibility of poachers to elephants and jeopardizes tourism revenue because elephants are harder to locate.

One largely underestimated dimension is the ability of local communities to implement effective conservation strategies. These communities, while smaller at the time, coexisted with a much larger (>50 fold) population of elephants for thousands of years and there are many current examples across Africa where community-based projects have reduced human-wildlife conflict, decreased poaching rates and increased revenue [133,134]. The privatization and annexation of land by governments of many areas with elephants has led to the exclusion of local communities despite their significant knowledge and traditional management practices and left them with few incentives or resources to protect elephants [135,136]. By working with and providing incentives to local communities, removing fences may be less difficult [137–139]. Examples of successful unfenced areas with high-level community engagement are the community conservancies across Namibia and the CAMPFIRE projects in Zimbabwe [107,140–143].

2.7 Conclusion

Climate change, especially the increasing frequency and severity of droughts, is of great concern for elephants and many other species. Current management practices including fencing and artificial water sources appear to be unsustainable and highlight the frequent lack of resources available to managers [144]. There is also a clear gap in the research needed to understand the potentially irreversible impacts of climate change on elephants and their ecosystems. A clearer understanding of how elephants respond to climate change may improve understanding of how other species will fare, especially other related large mammals like rhinoceroses (*Rhinocerotidae*) and hippopotamuses (*Hippopotamus amphibious*). Both species share with elephants an inability to sweat, have thick impermeable skin and inhabit increasingly hot and dry environments [145–147]. Similarly, this review focuses on the African savannah elephant *(L. africana*) because they are bigger and live in more drought prone areas than their sister-species the forest elephant (*L. cyclotis*) which is critically endangered [67]. However, forest elephants have the same biophysical limitations to heat stress so increasing ambient temperatures across Africa [72,92,148] may eventually become a threat to their survival as well.

Conserving elephants in a climate scenario of prolonged drought will increasingly rely on the introduction of spatial and population planning specific to the drought/elephant interaction and the movement towards reinstating community-based management wherever possible. Inaction will lead to further elephant population decline, adverse impacts on ecosystem health and stability, and major economic losses. Management, policy shifts and conservation implementation require adequate funding and resourcing, which the conservation sector chronically lacks [144], so investment from governments and international organisations will be key. With continuing drought across Africa, and elephants more likely to breach their biophysical capabilities to stay cool, pre-emptive action and mitigation are crucial for their survival. Climate change may be the ‘elephant in the room’ and while much of the focus pivots around the ivory trade and habitat loss, Africa may lose one of its most iconic, essential and culturally significant species as a victim of persistent drought and an inability to cope with the lack of water.

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Chapter 3:

Elephants not in the room: systematic review shows major geographic publication bias in African elephant ecological research.

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3.1 Abstract

African savannah elephants (*Loxodonta africana*) are a keystone species in African ecosystems. As a result of increasing anthropogenic pressure, elephant populations have declined significantly in the last two centuries. Research on a broad sample of these populations is necessary to inform management strategies over a range of environmental and socio-political conditions. In order to evaluate the current state of literature that is informing evidence-based management and conservation of elephants, we systematically reviewed all research published on the ecology of African elephants from the last 20 years (492 publications). We contrasted the geographic distribution of published research against the 2016 IUCN elephant census. We found several statistically significant biases in the geographic distribution of elephant research. South Africa has 4.54% of the total elephant population and accounted for 28.28% of all research publications. Kenya has 5.49% the total elephant population but accounts for 20.6% of the research. Conversely, Botswana has 31.68% of the total elephant population but accounts for only 9.29% of the research and Zimbabwe has 19.89% of the total elephant population with only 10.50% of research. We also found that 41.85% of areas with ~60,100 elephants have not had any research published on their populations in the last 20 years. This publication imbalance may encourage management strategies that are overly dependent on misrepresentative information from a small subset of the elephant population. We recommend that (1) marginalised areas with large elephant populations (e.g., Botswana and Zimbabwe) should receive higher priority for future research, (2) new research and proposals should design theoretical frameworks to account for and overcome the present biases, and (3) local community-based management approaches should be prioritised and amplified in order to overcome the barriers to conducting research in priority areas.

Keywords: research bias; African elephant conservation; *Loxodonta africana*; community-based management; conservation; policy

3.2 Introduction

The conservation and management of African savannah elephants (*Loxodonta africana*, hereafter elephant) has been a focus of research for decades. Elephants play a significant role in maintaining and shaping ecosystems across their distribution in Africa[1]. They are a major keystone and umbrella species meaning that their activities affect other wildlife, many of which are endangered[1,2]. Elephant meta-populations in Africa, including the forest elephants (*Loxodonta cyclotis*), have declined significantly since, and due to, European colonisation throughout the 19th century. African savannah elephants are listed as endangered and forest elephants as critically endangered by the International Union of the Conservation of Nature (IUCN)[3,4]. Declines in elephant meta-populations are largely attributed to colonial anthropogenic factors, including hunting for the illegal ivory trade and conflict with humans[4]. Climatic changes, including increasing surface temperatures and more severe drought conditions, are also increasingly prevalent stressors for elephants[5–16].

Currently, 84% of African savannah elephants reside within Protected Areas [PAs][4]. Fenced areas generally experience population increases because wildlife are more protected from negative human interactions[17], although PAs also have high levels of elephant mortality linked to illegal killing[4,17]. Elephants can attract much needed revenue, with wildlife tourism garnering US$38 billion across Africa in 2018 and attracting more than 67 million international tourists across the continent[18]. While most PAs are not fenced many that are report elephant populations that are reaching and, in some cases breaching, their contested [19–24] carrying capacity[25–27].

Landscapes that have elephant populations that are over carrying capacity can undergo major ecosystem change[3,25,28,29]. Elephants can cause permanent changes to old growth trees and riparian systems and inhibit ecosystem regeneration [30–37]. These effects can largely be attributed to their habitat use and foraging habits[5,38]. They also compete with many species of mega- and mesoherbivores for these resources[39–41]. Elephant overpopulation is a landscape scale conservation problem. Many fenced PAs, which are generally small patches of fragmented landscape, are subject to overpopulation by elephants[27] and are experiencing difficulty in maintaining healthy ecosystems with managers struggling to control populations ethically and within the public eye[27]. The ecosystem change is exacerbated by the fact that PAs are often home to other vulnerable and endangered species that are at risk from elephant induced habitat change[2]. Outside of fenced PAs, elephant populations continue to decline due to lack of protection and increasing human-elephant conflict[4,42–44]. Their decline in outside areas could lead to shifts in ecosystem function and quality and disrupt the ecological function and maintenance of landscapes outside of PAs.

The conservation of elephants is critical from both an economic and environmental perspective but adding the uncertainty of the future under the effects of climate change means there is a critical need to fully understand the remaining meta-population to inform the best management strategies appropriate for each region. It is becoming evident that current strategies to manage elephants are economically and ecologically inefficient, largely due to the increasing pace of environmental change and chronic underfunding and lack of resources in the conservation sector[45].

Peer-reviewed research is a key input into conservation policy and management[46]. However, recent studies have shown a bias in research on conservation management strategy[47,48]. A study has also recently shown that knowing the current state of research for conservation is essential for effectively coordinating future research efforts[46]. Basing policy and management on information that is not representative of a specific context may lead to inappropriate or ineffective strategies[49].

The purpose of this paper is to evaluate whether the recent scientific research on elephants available to managers and conservationists is geographically diverse enough to inform managers across the species' range. We aimed to identify gaps and biases in research on elephants, determine the implications of any research biases, and make recommendations for future research. We systematically reviewed all peer-reviewed published material on elephants from the last 20 years (492 papers) and contrasted the results against the 2016 IUCN Elephant Census. Our hypotheses were as follows. First, there will be a geographical bias in published research towards countries with established elephant research units/non-government organisations and better accessibility to elephants, such as South Africa, Kenya and Botswana. Second, there will be a large proportion of the elephant meta-population that has not been studied recently, for example in less politically stable countries such as Zimbabwe that have pre-existing systemic barriers to research such as funding and administrative limitations.

3.3 Materials and Methods

3.3.1 Data Collection

We systematically reviewed all available peer-reviewed research on elephants over 20.5 years from 2000 until mid-2020. Search engines used were Google Scholar, Scopus, Web of Science, and the Australian National University Library Supersearch Engine. We filtered by date range (1 January 2000–30 July 2020) and article type. Media and creative pieces were omitted because they can be speculative and subjective. To ensure we reviewed all relevant literature, we did not use refining search terms like "ecology" so as not to exclude any work and reviewed all research pertaining to elephants and refined the data upon completion. We used the search terms "African elephant", "*Loxodonta africana*", "African savannah elephant", "savannah elephant", "*Loxodonta*" and "*africana*". We defined ecology as any interaction or relation to elephants and their environment as this is the main factor that will shape and change elephant behaviour and movement in the future. Research on basic biology and non-environmental biochemistry, physiology and captive specimens was not recorded as it is feasible for these topics to be extrapolated to a wider population based on a single or captive population. For each relevant article, we recorded the title, authors, year of publishing, country/countries, whether the area was partially, fully fenced or unfenced, whether the area was transfrontier, if the area is privately or publicly owned and/or managed and the name of the area or reserve. We also recorded the topic of the research within five categories that we believe represent the most pertinent issues in elephant conservation. Definitions of these categories can be found in Table 1. We have used three categories for some topics as most options are not simply binary (e.g., fenced or not fenced). If the data for a category was not available, they were excluded from specific calculations but included in the overall calculations. For example, if one of the studies took place in a park where the fencing status is not clear, it was omitted from the analysis relating to fencing but included in the overall review based on country and PA. If a paper covered more than one topic, then it was recorded under both topics. We reviewed research published in all languages assuming non-English papers would appear by using the scientific name, and variations (aforementioned), as a search term.

Table 1. Definitions of each category used to refine this systematic review.

Category	Sub-Category	Definition
Fencing	Fully fenced	The area is fully enclosed by a fence capable of confining elephant movement
	Partially fenced	The area is partially enclosed by either wildlife management or agricultural fencing or contains internally fenced areas
	Unfenced	The area is unfenced or lacks fencing adequate to inhibit elephant movement
Frontier	Transfrontier	The area intersects several countries and nations
	National frontier	The area is fully within the boundaries of one country
Management	Government	The area is under the funding and management of the government or a governmental body/ies, includes community managed areas
	Private	The area is privately owned and managed
	Joint	The area is managed by both the government/community and privately
	Ecology	The article is focused on how elephants interact with or impact the environment around them
	Behaviour	The article is focused on how and why elephants behave in certain ways and how those behaviours have changed
	Climate interactions	The article is focussed on how the varying aspects of the climate interact with elephant survival and livelihood
	Illegal Killing	The article is focused on the impact of, history or predictions of illegal killing of elephants, including for both commercial savanna meat and ivory

We did not record work on the African forest elephant (*Loxodonta cyclotis*) as research on that species is limited due to high risk from political unrest in the countries they reside within[50,51]. We included countries with a crossover zone between the species such as Uganda but excluded parks with the *L. cyclotis* species and to our knowledge there are no PAs with both species present. We limited the search to the last 20 years because the main interest was understanding how elephants need to be managed in changing environmental conditions coinciding with the major topics we investigated (Table 1) where research preceding this time period may be less relevant to contemporary elephant ecology[52–54]. Unimpeded elephant populations can also double naturally within 10 years[55,56] and the illegal killing rate/ivory trade fluctuates annually so evidence from elephant populations that is more than 20 years old may not be comparable to modern studies or as relevant for policy formation.

We then reviewed the 2016 International Union for the Conservation of Nature (IUCN) Elephant Status Report[3], which included a continent-wide elephant meta-population survey from 2015. We believe this report to be the most reliable and recent dataset on meta-populations of elephants across Africa. The report is the first and latest continent-wide survey of its kind. From this report, we extracted the total estimate across all countries as well as meta-population estimates for each country and for each area surveyed. We used the estimate of 415,428 as the total number of individuals in the elephant meta-population. We grouped a set of small PAs under "Other Private Reserves". These comprise a series of reserves bordering Kruger National Park in South Africa that were grouped together in the Census (Maremani, Kwandwe, Kariega and Balule, Timbavati, Umbabat and Klaserie).

3.3.2 Data Analysis

We calculated the proportion of African elephants that resided within each country as a percentage, and used the estimates provided by the report. We calculated the results against the provided upper and lower limits of the confidence interval to ensure there were no notable discrepancies or outliers influencing the results.

We then took the total number of papers published per country and per area/reserve and calculated it as a percentage of the total. We contrasted the available list of areas surveyed by the census against the list of reserves where research had been conducted to indicate which places had not had research done.

To test if there were statistically significant biases present between countries, we standardised the meta-population to 100% to exclude the *L. cyclotis* species and calculated the number of papers that should have been published for each country if it had been based on that country's proportion of the elephant meta-population. We conducted Chi-Squared tests on this data, omitting Eritrea as its elephant population is extinct. This process was then repeated with data related to the specific PAs, the fencing status of PAs and the custodianship of land which elephants inhabit. A data summary is available in Appendix 2.

3.4 Results

We recorded over 8000 published articles and analysed 492 that were considered relevant under our criteria. There were 14 papers published in areas not surveyed in the census which are not counted in the results on biases in PAs but counted in the analysis by country. There were 28 papers (5.69%) that took place in multiple parks/countries and 4 papers (0.81%) that were published in transfrontier parks that were counted in all of the analyses where applicable. There were four papers recorded that were published in languages other than English, two in French and two were in Portuguese. A list of the articles included in this analysis can be provided on request.

3.4.1 Distribution of Published Research

The countries with the highest proportion of research on elephants published in the last 20 years were South Africa (28.3%) and Kenya (20.6%); these had, respectively, 4.5- and 5.5% of the total meta-population (Figure 1). The countries with the highest elephant numbers were Botswana (31.7% of total) and Zimbabwe (19.9%) and these published 9.3% and 10.5% of research respectively. There was a highly significant statistical difference between the actual number of papers published and the number that would have been published in each country if based on its proportion of the total African elephant meta-population ($\chi^2 = 964.55$, $p < 0.001$, 17 d.f.).

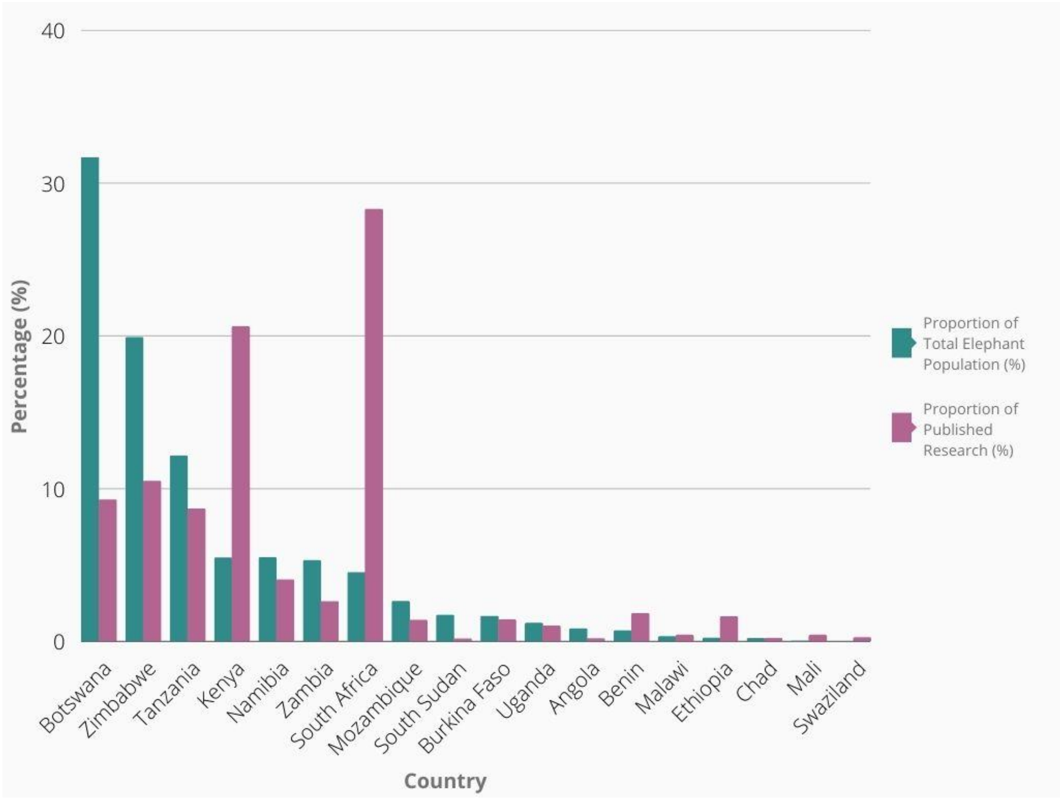

Figure 1. Research and populations by country.

3.4.2 Research and Populations by Protected Areas

3.4.2.1 Highest Proportion of Research

The PAs with the most research on elephants published over the last 20 years were Kruger National Park (12.2%) and Other Private Reserves (9.7%) which are all located around Kruger National Park. Both areas are in South Africa and have 4.5% and 0.6%, respectively of all elephants (Figure 2). Addo Elephant Park, Pilanesburg Provinicial Reserve and Tembe Elephant Park are also in South Africa and all show a large proportion of research given their elephant population sizes. As in Figure 1, Kenya is also overrepresented in the research as the Laipikia-Samburu and Amboseli Ecosystems have considerable research and small elephant populations. There was a highly significant statistical difference between the actual number of papers published and the number that would have been published in each PA based on its proportion of the total African elephant meta-population (χ^2 = 2564.03, $p < 0.001$, 12 d.f.).

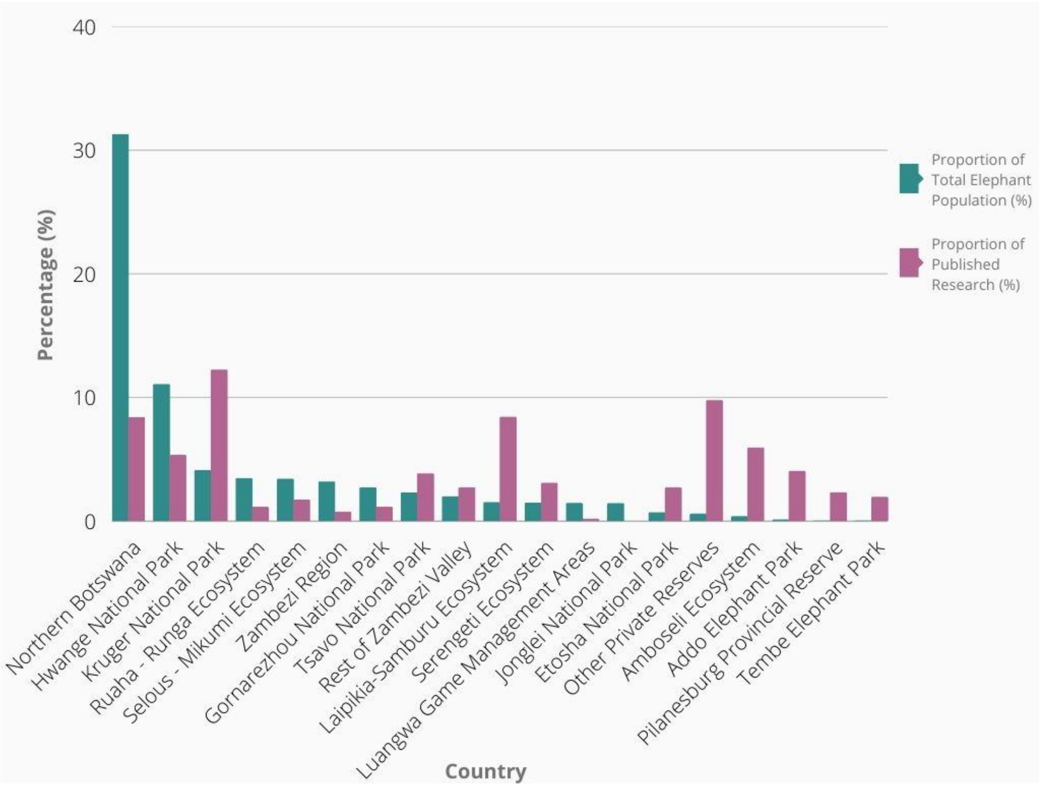

Figure 2. Research and populations by National Parks & Reserves and Protected Areas (NPR/PAs).

3.4.2.2 Highest Proportion of the Elephant Population

The PAs with the highest elephant populations are Northern Botswana (31.3%) and Hwange National Park in Zimbabwe (11%) and have produced 8.4% and 5.3% of elephant research over the last 20 years (Figure 2). Other PAs underrepresented in the research are the Ruaha-Runga Ecosystem in Tanzania and the Zambezi Region in Zambia. There was a highly significant statistical difference between the actual number of papers published and the number that would have been published in each PA had it been based on proportion of the total African elephant meta-population ($\chi^2 = 3828.44$ $p <$ 0.001, 51 d.f.).

3.4.3 PAs with and without Research

Countries with small elephant populations like South Africa and Namibia have small percentages of the elephants that have not been studied. Countries with high populations including Zimbabwe, Mozambique and Angola, show up to 80% of PAs with elephants that have not had research published about them over the last 20 years (Figure 3). Countries with low populations and high political conflict, especially Senegal, Niger and Eritrea, have the highest percentage of population not studied (Figure 3). These countries, plus the next most understudied places, are all within Central and Northern Africa.

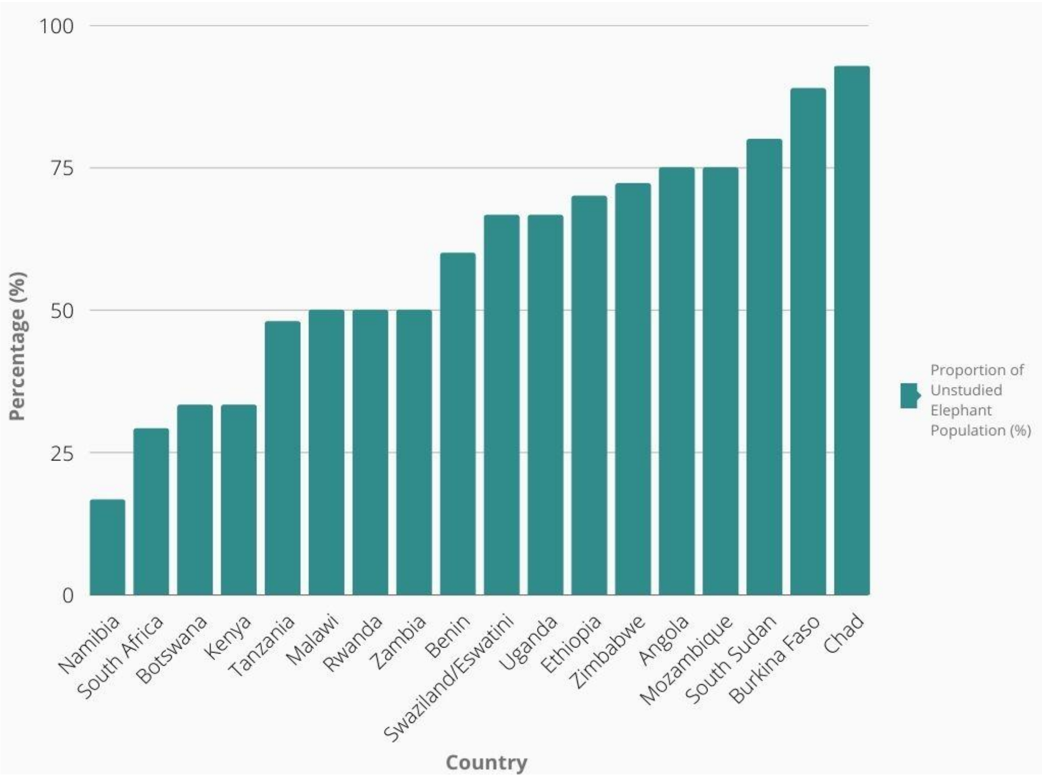

Figure 3. Percentage of PAs by country where no research on elephants has been published over the last 20 years.

In the last 20 years, 40.8% of PAs with elephants have not had any research published. This equates to ~68,500 elephants that have not been studied by researchers over the last 20 years.

3.4.4 Fencing and Custodianship of Elephant Habitats

A large proportion (43.3%) of research on elephants in the last 20 years took place in unfenced PAs and reserves, followed by partially fenced (30.6%) and fenced PAs [26.1%]. Comparatively, 7.5% of elephants reside in fenced reserves, 64.4% in partially fenced PAs and 28.2% in unfenced PAs (Figure 4). There was a highly significant statistical difference between the actual number of papers published and the number that would have been published in fenced, partially fenced, and unfenced PAs if based on the proportion in each of the total African elephant meta-population ($\chi^2 = 324.65$, $p < 0.001$, 2 d.f.).

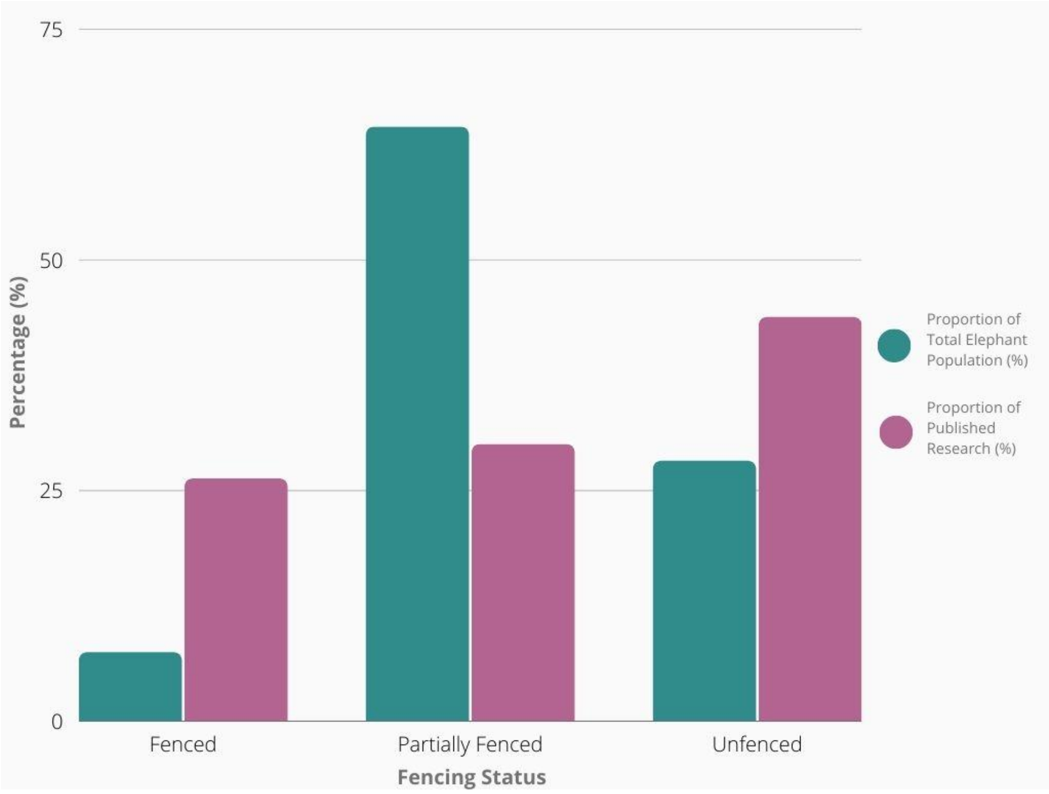

Figure 4. Percentage of research versus proportion of elephant population occurring in fenced, partially fenced and unfenced reserves (PAs).

The majority (52.6%) of research on elephants in the last 20 years took place in PAs publicly owned and managed by the government/state, followed by co-owned and managed PAs (30.4%) and privately-owned reserves (17%). Most research on elephants has occurred in government-managed PAs that account for 6.1% of the total elephant population. Comparatively, jointly managed PAs have 65% of the total elephant meta-populations, followed by publicly managed PAs with 28.9% of the meta-population with private reserves managing 6% of the total meta-population. There was a highly significant statistical difference between the actual number of papers published and the number that would have been published in each category of custodianship if based on the proportion in each of the total African elephant meta-population ($\chi^2 = 268$, $p < 0.001$, 2 d.f.).

3.4.5 Research Topics

The majority of research (41.5% and 30.1% consecutively) on elephants has been on the topics of Ecology and Behaviour in the last 20 years. Human-elephant conflict is the third most common topic at 15.7%, followed by Climate (7.1%) and Poaching (5.7%). The research topic percentage in each country can be found in Appendix 2.

3.5 *Discussion*

Published research on African elephants over the last 20 years has shown potentially concerning geographical and population bias. We define geographic bias as more published research coming from certain countries and regions, and population bias as more published research coming from certain PAs within those countries. A significant geographical bias is evident as more research on elephants is being published in certain countries, predominantly South Africa and Kenya, where elephant populations represent a smaller proportion of the total across Africa than other countries such as Botswana and Zimbabwe (Figure 1).

Further, a significant population bias is present in favour of elephant populations within parks such as Kruger National Park, Associated Private Reserves (both in South Africa) and Amboseli National Park (Kenya) (Figure 2). Researchers on these parks have produced a large amount of published research on elephants compared to the size of the elephant populations (Figure 2). In line with the geographic bias, much larger populations of elephants, for example in Northern Botswana and Hwange National Park (Zimbabwe), have less research published in proportion to their size (Figure 2). Further the geographic and population bias in elephant research reported here also shows that a large proportion of elephants have not been studied at all over the last 20 years. Most prominently, 40.8% of the PAs have not had any research published on their elephant populations over this period. The population bias is strongly supported by some countries [South Sudan, Burkina Faso, Chad, Eritrea and Senegal] having 80–100% of PAs that have had no research on elephants published (Figure 3).

The biases indicate that management and conservation of African elephants informed by research may not be based on regionally accurate evidence and data. While this review focuses on savannah elephants (*Loxodonta africana*), the results seem likely to apply to other vulnerable and threatened fauna in Africa. Similar biases can be seen in research on Africa's birds where research has been heavily influenced by accessibility[57].

The geographical bias towards Kruger National Park (and surrounding reserves), South African PAs and other high profile, tourist-oriented PAs may be of concern if these parks are not representative of other areas with elephants that rely on the same research. These parks have proportionately small populations that may not be indicative of the greater elephant meta-population. These elephants may not be exhibiting standard behavioural patterns[58,59]. High profile parks draw high numbers of tourists whom observe the wildlife at close range leading to human disturbance. For example, Kruger National Park alone draws ~1.4 million tourists per annum[60]. Tourists and safari staff can cause edge effects and aggressive and defensive behaviour amongst the elephants, and their presence can override aspects of habitat selection like foraging and water access[58,59,61,62]. Although research may be needed in these areas to understand the impact of tourism and management strategies in that context, its wider applicability may be questionable if it is used to create and shape ecological management strategies across the elephants' wide geographical and international range.

Geographical biases in research may be present for a variety of reasons, but there has been no analysis of why they occur for elephants. We identify and discuss the factors behind two key obstacles that may be leading to the biases in recent elephant research: accessibility and systemic conservation research barriers.

3.5.1 Accessibility

Countries with bigger and more established research centres, such as South Africa and Kenya, are more likely to have greater capacity for maintaining long-term databases and to facilitate the processes for obtaining research permits[63]. The research centres, particularly in South Africa, are usually financially and intrinsically linked to tourism areas[64] (e.g., Kruger National Park) so roads are well established, elephant movements are known and there are safe, inexpensive places for researchers to stay[63,65]. Accessibility also includes the perceived security of researchers. Whether a country is perceived as safe may affect formal research plan approval at the researchers' home institutions and access to research funding. This may be a particular problem with forest elephants (*Loxodonta cyclotis*) in Central Africa[50,51], and in countries that are deemed less safe due to political unrest like Zimbabwe[50,66].

Physical accessibility to elephants is a likely determinant of how researchers choose sites. For example, most of Botswana's elephants are free ranging and traverse the poorly accessible Kavango-Zambezi Transfrontier Area[3,67]. This is in stark contrast to South Africa where all elephants reside in fenced or partially fenced PAs so are mostly easily accessible[68]. These differences in accessibility could be leading to researchers preferencing easily accessed and more guaranteed data from elephants.

Politics also plays a role in the perception of security and accessibility of research. We define politics as the government's interactions with their conservation sector, particularly those involved with elephant management. For example, the last century in Zimbabwe has seen a civil war, land annexation[69], increased violence associated with illegal killing[70] and unstable politics[69] that have affected the accessibility to elephant research and the safety of researchers[70]. Most elephant research has occurred on government/state and combined private land (Figure 5). Poor security and accessibility are likely to affect the granting of research permits from home institutions, and thus limit the ability of researchers to enter countries like Zimbabwe. The difficulties of navigating the politics may be exacerbated by differences between countries. Despite 62.5% of elephants living in transfrontier areas[3], the countries involved often manage their elephant populations in different ways.

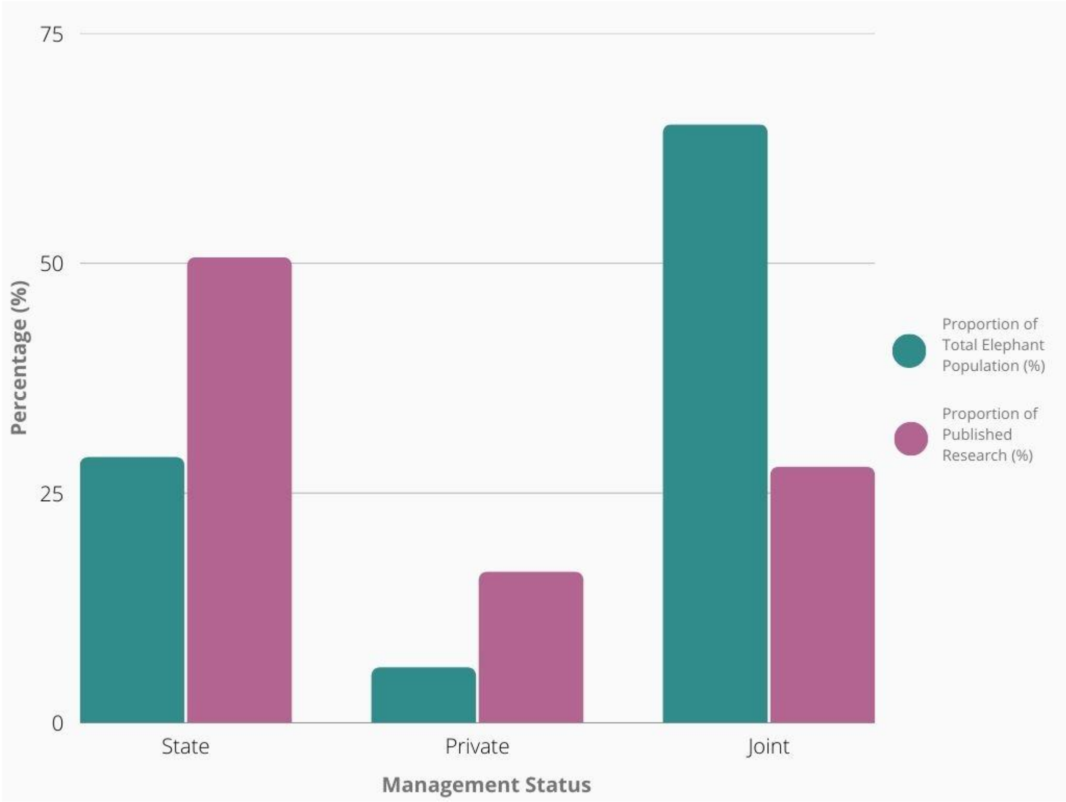

Figure 5. Percentage of research versus proportion of elephant population occurring in publicly managed, privately managed, or joint publicly/privately managed reserves [PAs].

Conservation research is chronically underfunded and highly competitive[47,71]. Established and well-funded research centres like Save the Elephants in Kenya, are likely to be more attractive to researchers than places without research infrastructure. The results show a bias towards these epicentres of elephant research e.g., Amboseli National Park, Kruger National Park and the Associated Private Reserves and Laipikia-Samburu Ecosystem (Figure 2). These places are relatively well funded[72], established and accessible[73] which makes them attractive to researchers because these factors keep costs low. They are however subject to high tourism levels and the elephant populations are likely to be more disturbed. The dependency of conservation on ecotourism is a common problem and has led to the prioritisation of certain conservation areas based on tourism value as opposed to biodiversity value[74,75].

3.5.2 Systemic Conservation Research Barriers

Biases in global conservation research are becoming more apparent[76]. Our results may partially be attributed to the general bias towards the English language seen in the conservation sector[77,78]. Most countries in Africa do not use English as a first language, however, English is an official language of both Kenya and South Africa[79]. The globally used and accepted scientific process of peer-reviewed research, which has been developed and implemented by Western culture and dominated by English speaking countries[80,81], may also inhibit non-English speakers from publishing research in scientific journals. Further, research shows that countries with higher Gross Domestic Product (GDP), more English speakers and higher security have more biodiversity research being published, despite not necessarily having higher levels of biodiversity[49]. For example, South Africa is an internationally recognised biodiverse country, but so too are countries with higher elephant populations such as Mozambique and Tanzania but they are characterised by lower GDPs, fewer English speakers and more perceived issues surrounding security.

Botswana appears to be an exception to the rule and its relative exclusion from elephant research is not explained by the above arguments. Botswana is considered a safe country, has high GDP, a high proportion of English speakers, and runs well established research units like Elephants Without Borders[82]. The low level of elephant research is likely to be linked to the low accessibility of its elephants as many live in the largely inaccessible Okavango Delta and Kavango-Zambezi Transfrontier Conservation Area, as well as having more strict conservation permit and research policies than surrounding countries in southern Africa [3,67].

Solutions to help overcome biases in research are available. Extra and conscious effort is required to conduct surveys and data collection in environmentally and spatially underrepresented areas, which can be done remotely with in-country partners and remote sensing technology[46]. This study provides the necessary basis for this approach at a broad level and identifies for example a clear need for more research on elephants in Botswana and Zimbabwe, particularly in Northern Botswana and Hwange National Park. Further suggestions have been made that research should be based on environmental variables that are important to the species based on previous research and field experience, instead of based on location and accessibility[46]. In the case of elephants, this could mean targeting variables such as water availability and feeding ecology, and temporarily favouring research sites in Botswana and Zimbabwe that best represent these variables. The bias can also be countered by using the most current IUCN African elephant survey to choose survey sites based on local population density and considering levels of disturbance to populations before initiating and publishing research.

A large amount of research on elephants (>50%) has occurred on fenced or partially fenced populations compared to the number of elephants these represent (Figure 4). Therefore studies, particularly on movement ecology, may not be indicative of the greater population that are truly free ranging, for example, in transfrontier areas. While removing fences is often not feasible in the short-term, more research is needed in transfrontier areas which account for 62.5% of the total elephant meta-population[3,83,84]. As wildlife mobility and movement become more essential with changing climate and within heavily fragmented landscapes, the role and existence of transfrontier areas is gaining greater prominence[83,85]. This review shows that only 0.76% of research on elephants in the last

20 years has occurred in transfrontier parks and 4.96% of research took places across multiple meta-populations in multiple countries.

The research topics also show bias towards the areas of Ecology and Behaviour (Figure 6). While this is largely to be expected in a study focusing on ecology, the lack of research on climate interactions and climate change is of concern given the major climatic changes over prime elephant habitat in Southern and Eastern Africa during and since the Millennium Drought[9,86]. Based on ecological and behavioural studies, we know that elephants are highly susceptible to heat stress due their size, an inability to sweat and poor heat transfer mechanisms[10]. They are also highly dependent on surface water and their movements are inhibited by their proximity to a water source[10]. Under a climate change-induced drought scenario, this threat to their survival [as well as how their response may impact other species and local communities] is imminent and understudied. While behavioural and ecological studies may help inform this management issue, an explicit and evidence-based understanding will be necessary to best prepare the landscape and associated managers for the impact. This is particularly relevant for areas like Botswana, where an unexpected cyanobacterial bloom as a result of higher average ambient temperatures killed ~300 elephants[87]. It is also relevant in Zimbabwe where the drought is ongoing and severe and has caused the death of 200 elephants already[8,88]. Drought and erratic weather events in Eastern and Southern Africa are predicted to increase in occurrence, severity and longevity[9,86]. Poaching is also underrepresented in the research given it is the primary cause of population decline, though it is possible that this information is more widely disseminated through government and NGO agencies, as opposed to peer-reviewed scientific publications.

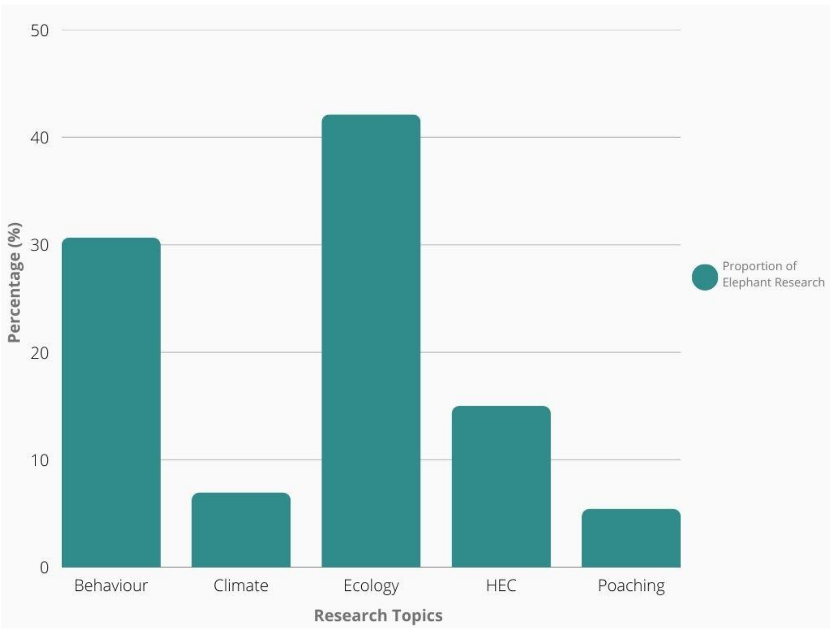

Figure 6. Percentage of total elephant research to which each topic contributes.

3.5.3 Limitations

This systematic review has several limitations as follows. First, we focused on ecology because of other aspects of biology and biochemistry are less likely to influence policy and management of wild elephant populations. We recognise that this may not always be the case and that there may also be biases in research areas outside of the field of ecology. Further, we have focused on literature (both as evidence and as data) on only elephants and understand that other factors may influence issues such as fencing. We believe that this was within the scope of our study on research biases but acknowledge there are further opportunities to expand and examine other research areas and topics.

We acknowledge limitations around the assumption that a study in a park represents all elephants in that area when in reality only a subset of the population may have been studied. Our aim was limited to identifying large scale biases and gaps as a starting point for examining research biases.

We also acknowledge that our omission of government reports and informal research from non-government organisations may have impacted this review. Given that many of these reports and data are not peer-reviewed, it is difficult to consider them objectively as part of this study and it is difficult to gauge how they inform elephant conservation practice. We acknowledge the likely importance of these reports, and encourage peer-review, publication, and wide-scale accessibility wherever possible.

Finally, we recognise that our assumption that elephants abide by the boundaries of countries and PAs does not reflect the reality of elephant movements. We used the population definitions provided by the IUCN elephant census and to the best of our knowledge this provides the most accurate population estimates available even if they do not necessarily capture the movements of elephant populations across borders and boundaries.

3.5.4 Management Recommendations and Future Research

The implications of this study could be discussed in various ways but we aim to present only the firmest conclusions. We recognise that it is not feasible or realistic for research to match elephant population size and only use the proportion of total elephant number as a rough guide to the extent of bias. In response we encourage researchers to consider choosing sites and populations based on the need for research as opposed to ease of access or other factors encouraging or discouraging conservation research.

We also encourage researchers to expand the topics they cover given that some research areas have become more important over time. These include human-elephant conflict and climate change which involve highly fluid issues relating to elephant management. We also recommend exploring the finer details of the administration around research permits such as cost, rules and legislation and conditions. A review of these independent variables may provide further insight into why the biases are present and help develop strategies to overcome them. Further, a lack of research in certain areas, such as climate change, may indicate they are novel areas of research and yet to reach high levels of publication.

The total African elephant meta-population has declined by 98% in the last 200 years, during European colonisation of the continent[4]. Considering that local communities have coexisted with significantly higher populations of elephants for millennia; site specific conservation research is likely to benefit from an increased role of local communities. While the human communities coexisting with elephants before colonisation were smaller, traditional knowledge and management is likely to hold great value to elephant conservation. This will help alleviate bias caused by lack of security and accessibility and make areas where research is difficult safer[89,90]. It will also provide access to a significant amount of historical data that can be drawn from local knowledge and traditional management practices. The ratio of research to elephant population is skewed on both public and jointly managed land (Figure 5), where it is evident that more research needs to occur on jointly managed land. While this may mean higher engagement of the private tourism sector, it is also an opportunity for collaborative community-based engagement and management in the future. Community based management and inclusion of local people in conservation in Africa has led to decreased illegal killing, decreased human-wildlife conflict and increased quality of life for local people[90–93]. An interdisciplinary and socially oriented research approach will become more critical when managing landscapes, people and wildlife at any scale as the climate continues to change, communities become more empowered and traditional knowledge regains value in the conservation space.

Although we have identified geographic and population bias, we do not wish to criticise the value of research that has been conducted, or the value of well-established and long-term monitoring programs which have been pivotal to understanding elephant ecology. In particular, we recognize that localised studies have great value for managing local populations (e.g., Kruger National Park). Our main recommendation is that researchers strive to overcome any inertia associated with these well-established programs and diversify according to where new research will have greatest impact. In the long term, this may lead to the establishment of more research centres and long-term monitoring opportunities as well as diversifying the evidence base available to managers and researchers.

3.6 Conclusions

The economic, cultural and ecological value of elephants is significant, and they are a high priority for conservation in Africa. This review indicates that the current literature is inherently biased towards PAs with elephant populations that are not necessarily indicative of the greater elephant meta-population. We propose that future research on elephants should be established so that these biases are acknowledged and their implications further explored and plans for pro-actively working towards overcoming bias are established. By addressing population and geographic publication biases in the evidence base for elephant research, we are likely to improve evidence-based management and conservation.

3.7 References

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Chapter 4:

A Continent-wide Habitat Suitability Model for the African Elephant.

The model is in preparation for publication by Digital Earth Africa, Geoscience Australia.

4.1 *Abstract*

African savannah elephants (*Loxodonta africana*) are a highly mobile and water-dependent species that play a keystone role in diverse habitats across their continental distribution. Elephant populations have dropped significantly since European colonisation and are now found largely only within IUCN protected areas. As human populations increase and climate change has varying effects across Africa, it is critical to understand the quality of habitat available to elephants and where the best quality habitat is in relation to protected areas. To assess habitat suitability for elephants across Africa, I created an index model using multiple satellite datasets merged with Weighted Linear Combination. The final product is a high-resolution and interactive habitat suitability model (HSM). The HSM shows that smaller protected areas have higher habitat suitability and the 5-10 km zones around protected areas have higher habitat suitability for elephants than the core protected areas. This raises concerns for where research and resources are being invested to study and protect elephant populations and whether it should be in smaller, less prolific protected areas. It also indicates an increased likelihood of human-elephant conflict if elephants are likely to enter the buffer zones around protected areas more often. I recommend researchers and managers use this information and model to inform community-amplified management and consider interrogating the IUCN protected area policies and implementations when investing time and money into elephant research.

4.2 *Introduction*

Climate change induced drought has increased in both severity and distribution across the parts of Southern and Eastern Africa[1–8] that are key habitat for the majority of African elephant populations[9]. As drought is characterised by increasingly high ambient temperatures and decreasing precipitation[2,10], this poses a significant risk to elephants who are highly susceptible to heat stress and are highly dependent on surface water[11]. Drought also drives landscape-wide resource depletion for elephants[12], other endangered species[13] and local communities[1]. As such, it is likely that elephants will need to increase their movement and expand their home ranges to find adequate resources. Chapter 1 of this thesis outlines this premise extensively. This may lead to increased elephant activity and movement outside of protected areas where 84% of the total population reside[14]. Given the establishment of protected areas during European colonisation led to the forced displacement of local communities into the areas immediately surrounding protected areas[15], it is possible that habitat use outside of protected areas may lead to more incidents of human-elephant conflict.

From an ecological perspective, elephants are ecosystem engineers[16] and play a keystone role in the landscapes they inhabit. Their foraging and semi-migratory behaviour creates and maintains habitat for both themselves and other vulnerable species[16–19]. As a flagship species, they also hold high national and international value in cultural, economic and ecological settings. As a result, their decline has had, and will have, far reaching consequences in each of these areas. Elephant populations have decreased by 98% in the last 200 years, largely due to the attempted colonisation of many African nations[14,20]. Elephant population decline is attributable to poaching for ivory, increased human-elephant conflict and the fragmentation and destruction of key elephant habitat[14,20]. Habitat fragmentation, in combination with the introduction of conservation fences, has led to hotspots of increased elephant populations in vulnerable landscapes[21–23].

There is a significant bias present in elephant research that favours large, tourism-heavy and easily accessible flagship reserves, such as Kruger National Park and surrounding reserves[24]. Research from those reserves may not necessarily reflect the reality of elephant ecology in under-represented regions and smaller reserves with large elephant populations such as Hwange National Park in Zimbabwe[24]. These less studied reserves may have higher habitat suitability for elephants due to less tourist and human influence so it is critical to establish their importance and whether they may become elephant refuges in the future.

While many aspects of elephant ecology are contentious, their foraging habits, water dependence and habitat spatial use by elephants are well documented and understood. It is also well understood how increasing habitat fragmentation and the growth of both demographic and agricultural systems will continue to impinge on elephant mobility and access to vital resources[21–23,25–27]. To best predict a change in habitat use in response to resource depletion, an understanding of the habitat suitability in areas where they exist is necessary.

While habitat suitability for elephants has been modelled at a local scale in some key areas[28–33], to date, a continent-wide suitability assessment grounded in satellite data has not been conducted and tools have not been developed which allow comparable assessments of habitat suitability on a continent-wide basis. Given the strong likelihood of increased elephant mobility, with anecdotal evidence that elephants are moving further for resources like water[34], it is critical to understand the quality of habitat within their current distribution to predict where they may move and how this may impact the landscape and its inhabitants. As such, I have used Geographic Information Systems (GIS) to model habitat suitability for elephants across their distribution in Africa using a range of factors representing optimal conditions as well as negative anthropogenic impacts. The model aims to understand habitat suitability in areas that elephants are likely to use more in the future and to understand the role and importance of smaller protected areas in the future of elephant migration and habitat refuges.

In this model, I aimed to firstly establish habitat quality within core protected areas (here defined by IUCN category 1 and 2 reserves) that elephants currently inhabit. Secondly, examine habitat suitability in zones surrounding the core protected areas given that buffer zones are likely to be increasingly important in the context of drought-induced resource depletion within core elephant habitat, Thirdly, establish a tool that allows predictions of when drought induced resource depletion within elephant habitat will lead to their increased movement outside of their designated protected areas. Lastly, to establish my tool's potential for informing policy related to the above issues for elephants, managers and local communities.

4.3 Methods

4.3.1 Study Location

This model consists of the parts of the African continent with known elephant presence across their distribution[20]. This includes the majority of Southern, Eastern, Central and Western Africa but excludes islands and much of Northern Africa. Figure 1 shows the current known elephant distribution.

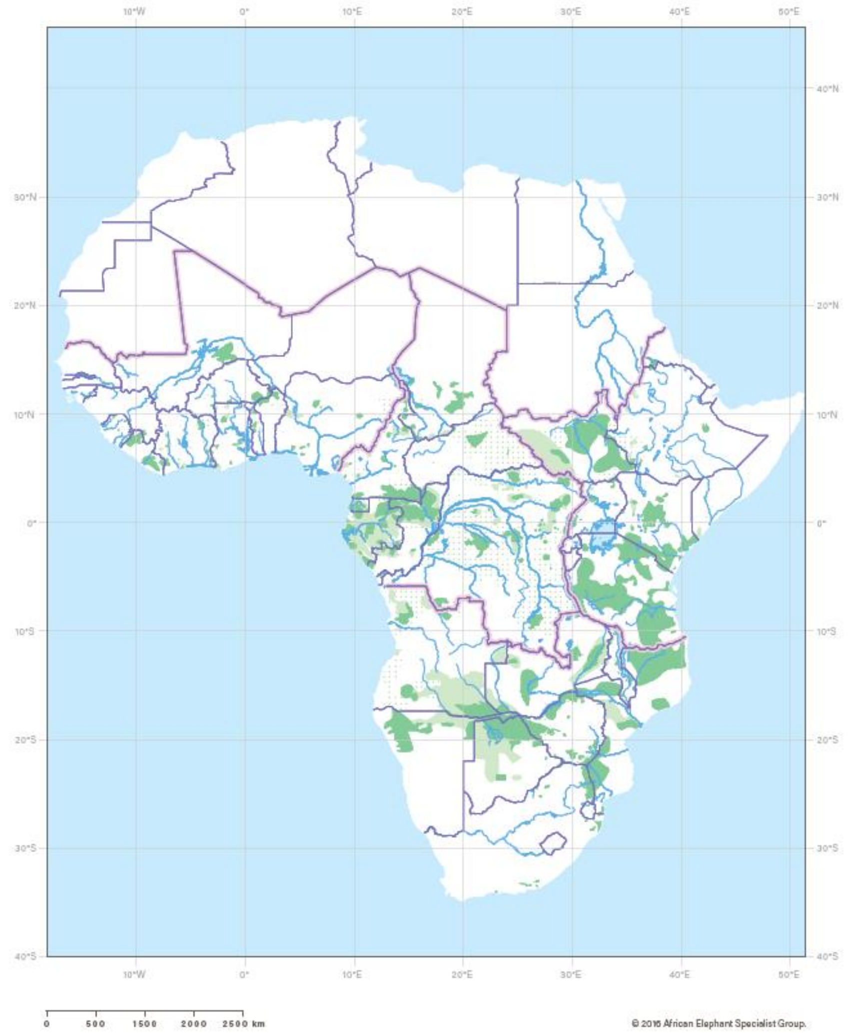

Figure 1: the current known distribution of African elephants. Dark green indicates confirmed distribution while light green indicates potential distribution as per the 2016 IUCN elephant census[14].

4.3.2 Study Species

African elephants are a keystone species, ecosystem engineer and the largest terrestrial animal[9]. In Africa, there are two recognised species of elephant: savannah elephants (*Loxodonta africana)* and forest elephants (*Loxodonta cyclotis*). While the final model shows habitat suitability across both species' distributions, the discussion of this paper will focus on *L. africana*. I believe that, while forest elephants are also water dependent, their interactions with humans[35] and interactions with more heavily forested environments requires different variable input weightings which can be achieved through the Digital Earth Africa platform where this dataset is to be published.

4.3.3 Data

Data were sourced from multiple sources, as outlined in Table 1. All data is open access, and from remote sensing sources.

Name	*Source*	*Components*	*Resolution*
Copernicus Global Land Service – Land Cover	European Space Agency	Closed forest, evergreen needle leaf Closed forest, deciduous needle leaf Closed forest, evergreen broad leaf Closed forest, deciduous broad leaf Closed forest, mixed Closed forest, unknown Open forest, evergreen needle leaf Open forest, deciduous needle leaf Open forest, evergreen needle leaf Open forest, evergreen broad leaf Open forest, deciduous broad leaf Open forest, mixed Open forest, unknown Shrubs Herbaceous vegetation Herbaceous wetland Bare/sparse vegetation Cultivated and managed Vegetation/agriculture (cropland) Urban/built up Permanent water bodies Seasonal water bodies Open sea	100 metres
Global Roads Open Access Data Set (gRoads)	Socioeconomic Data and Applications Centre – the	Roads	N/A (Vector)

	National Aeronautics and Space Administration		
Africa High Resolution Population Density Maps (CIESIN) (Sentinel-2)	Columbia University/ National Aeronautics and Space Administration/ United Nations – Spider	Human population density	60m
Africa's World Database on Protected Areas	The World Database on Protected Areas (WDPA)/ United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) and the International Union for Conservation of Nature (IUCN)	National Park and Protected Area borders IUCN category data	N/A (Vector)

Table 1: The names, sources, components and resolution of the variable inputs for this habitat suitability model

Satellite data for Africa, particularly on a continental level, is sparse and has low accuracy. However, the Copernicus Global Land Satellite (CGLS) dataset captures data at 100m resolution and has been validated at 74.6% accuracy (+-2.1%) with the most discrepancy being over West Africa (particularly the South-east, Sahel and Eastern Africa plateau)[36]. CGLS has the best cropland accuracy and is the best match to the Food and Agriculture Organisation of the United Nations (FAO) FAOSTAT dataset. Forest and grassland were also consistent across FAO[36]. Bare land and water had the highest accuracy[36]. Inaccuracy mostly came from vegetation with similar characteristics and class definitions but errors were unevenly distributed[36]. In Northern and Western Africa, forests were confused with shrubland and results in over/under estimation in forest/shrubland[36]. The CGLS data has been used for diverse uses across several other studies[36–41].

4.3.4 Data analysis

Data were processed and analysed using ArcPro, QGIS, Python and Microsoft Excel.

The spatial analysis is based on an index model created with Weighted Linear Combination (WLC). I chose this method because it allows the weight of each component of the model to have an overall weighting and to help create a more realistic influence and flexibility of the variables in the model. This ability is limited and inflexible in purely statistical models and when working with such a large area and amount of data, flexibility is critical for a realistic output. Initially, the CGLS tiles were reclassified into individual variables to create one raster for each habitat component, and some (such as closed forest mixed and closed forest unknown) were combined into one variable (Figure 3). The model used fuzzy logic to represent the attenuating effect of distance[42–44]. Fuzzy buffers were created for each input variable through calculating Euclidean distance, establishing a threshold, before standardizing and inverting the rasters[45]. Increasing proximity to anthropogenic factors (e.g. human population density and roads) detracted from habitat suitability scores, whereas reduced distance to key components of habitat (e.g. nearest permanent water) increased scores.

The components were combined into a single index model with WLC by assigning them a subjective but explicit weighting (Figure 3), with habitat quality represented on a continuous scale from 0 (low) to 1 (high). The borders of the NPRs and PAs were overlayed over the habitat suitability model and buffer zones of 5, 10, 20 and 30 km were created around the core area. The data were then tabulated and habitat quality within NPRs and PAs, and the surrounding buffer zones, was extracted. To show one application of the model, two case studies were selected for which data from the Habitat Suitability Model (HSM) was extracted for. I selected Botswana and Kenya as case studies due to their high elephant populations and relevance in the elephant research community. To keep this chapter succinct, only two country profiles were used but I encourage researchers to continue to use the HSM in this capacity as a zone-by-zone extraction method. Data were extracted from the HSM raster file and were exported to Microsoft Excel as an attribute table. Data for the habitat suitability rating for the core protected areas, buffer zones and different IUCN categories (Table 2) were used to calculate the results using a logarithmic scale and the exponential and linear trend functions.

Figure 2 provides a visualised example of my method of processing satellite data through to a suitability model in five steps.

Table 2: the definitions of each IUCN category.

Category	*Name*	*Definition*
Ia	Strict nature reserve	Strictly protected areas set aside to protect biodiversity and also possibly geological or landform features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of conservation values. Such protected areas may serve as indispensable reference areas for scientific research and monitoring.

Ib	Wilderness area	Protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and manages so as to preserve their natural condition.
II	National Park	Protected areas are large natural or near-natural areas, set aside to protected large-scale ecological processes along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
III	Natural monument or feature	Protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.
IV	Habitat or species management area	Protected areas aim to protect particular species or habitats, and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.
V	Protected landscape or seascape	A protected area where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value, and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI	Protected area with sustainable use of natural resource	Protected areas that conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

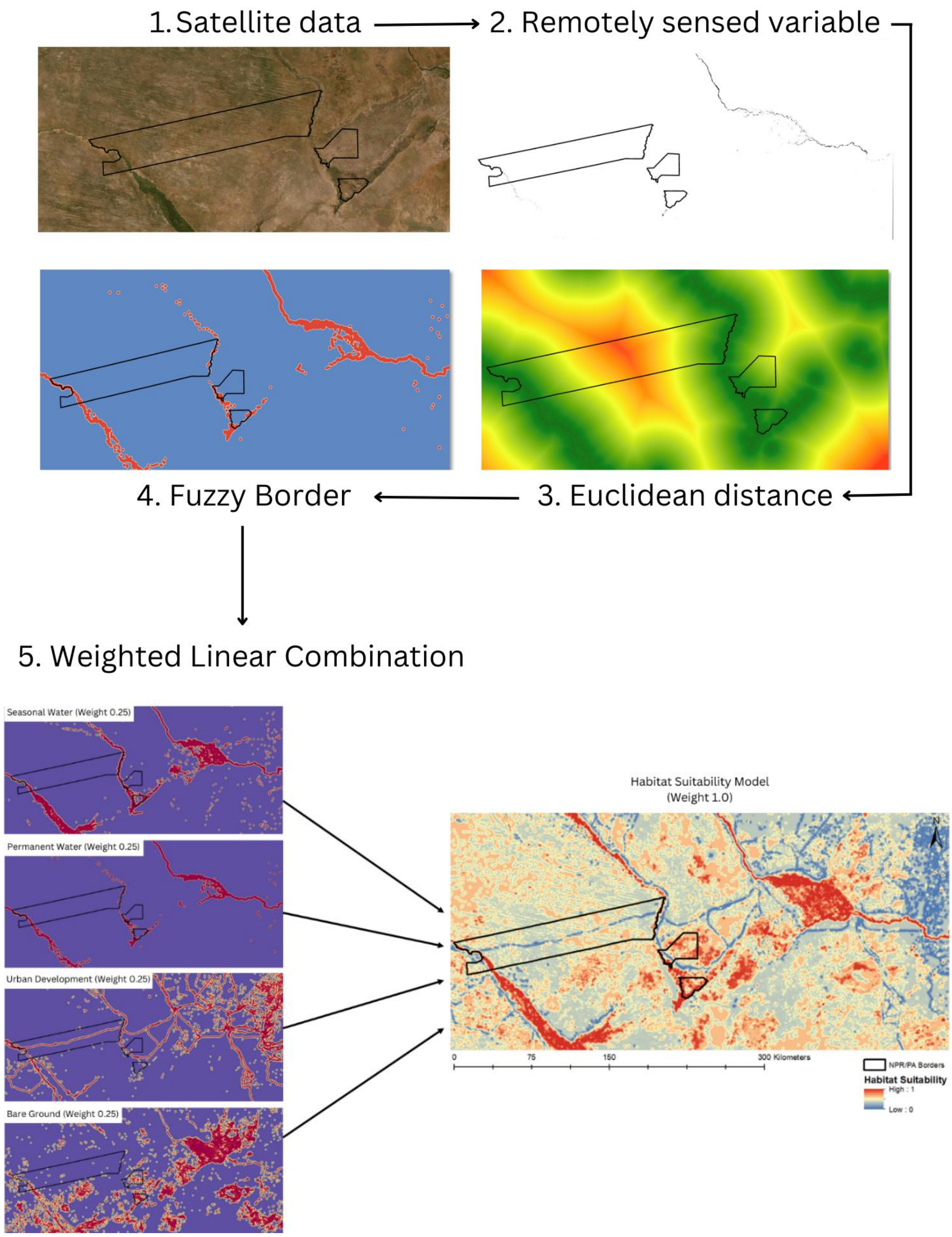

Figure 2: the five-step process used to transform remotely sensed satellite data to a suitability model using fuzzy logic, Euclidean distance and Weighted Linear Combination

To the best of my knowledge, a continent-wide *interactive* habitat suitability model grounded in satellite data does not yet exist for elephants or any other African species. Given the novelty of the approach and scale, I propose this model as baseline information for discussion and assigned even weights to the sub-models (Figure 3). As the model is live and interactive through Digital Earth Africa (DE Africa), users can adjust the weight and model compilation to suit their needs. I designated weighting in the WLC based on previous studies of elephant habitat use and preferences. Given the experimental nature of this model, and the flexibility to change the variables within the DE Africa platform, I used equal weighting in the models and sub-weighting. While literature can inform choosing different weightings, those weighting will be informed by specific regions and populations and not the metapopulation for which these results are catered to. The categories can be considered as having either positive or negative associations with elephant habitat. The positive sub-models are forests, other vegetation and both water variables. The negative sub-model is human presence. I assigned forests, all variables of both open and closed forests, as positive components of habitat as they provide shelter and forage for elephants[46–48]. The 'other vegetation' category also has two variables of higher value due to their foraging opportunities: shrubs/herbaceous vegetation and herbaceous wetland[49–51], while bare ground and sparse vegetation provides little to no good habitat qualities for elephants but I recognise is often the primary habitat type surrounding water sources. Water sources were also treated separately (permanent and seasonal) as they have strong influence over elephant movement and habitat use[34,52,53]. Lastly, the human presence model and the variables within are combined to have an equal weight to the other sub-models as interactions with humans and human-dominated landscapes requires more risk of conflict and competition for resources. For example, while crops may provide some forage for elephants, there is a high risk of conflict with farmers and agriculturalists which can result in physical harm or death of both elephants and humans[54].

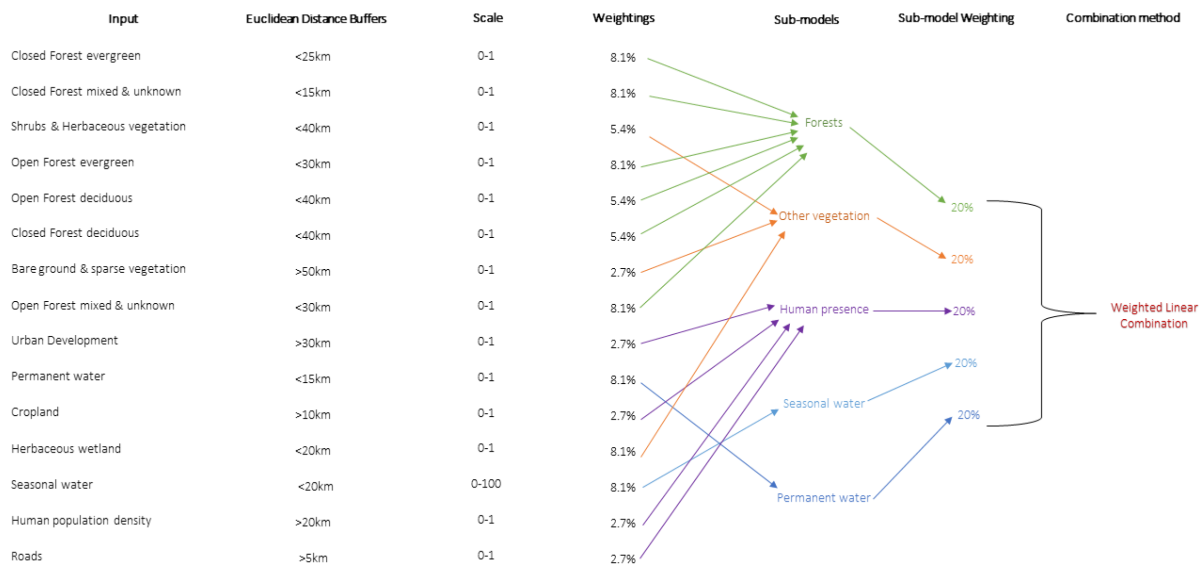

Figure 3: the input variables and associated values used for the analysis for the habitat suitability model.

4.4 Results

This model combines 25 habitat variables into a single model output showing habitat quality and suitability for elephants across their distribution over the African continent (Figure 4). The habitat suitability for elephants in and around protected areas across Africa is largely mid-range (Figure 5). On a continental scale, smaller protected areas have higher habitat suitability for elephants than larger areas (Figure 5). I recognise that there is wide scatter in the data points in this Figure, which is to be expected in a model of this size but may mean the trends are not necessarily as strong in reality as in the results. This is exhibited in both linear and exponential trends. Further, the 5- and 10 km buffer zones around core protected areas have high habitat suitability for elephants (Figure 6) as seen in the linear trend. When examining two case study countries, Botswana and Kenya, similar trends in the buffer zones can be seen where areas around protected areas are suitable elephant habitat (Figures 10 and 12). Botswana has higher habitat suitability in larger protected areas than smaller (Figure 8). In Kenya, parks exhibit even distribution of habitat suitability regardless of size (Figure 11). Though Figures 9 and 11 both indicate on the exponential trend that smaller areas have higher habitat suitability than their larger counterparts. Figure 9 indicates that habitat suitability in the buffer zones around protected areas are reasonably high, a trend we see across the results. I included Kenya and Botswana as country profile examples to show the diverse options available to elephant researchers in extracting and applying the data provided by the HSM.

Figure 13 indicates that IUCN category 1 and 2 parks have low suitability in the core areas, with the highest suitability being in the 5 km buffer zone surrounding them. The 10-, 20- and 30 km buffer zones are characterised by low habitat suitability. IUCN category 2, 3 and 5 parks have consistently high habitat suitability in the core areas and the 5- and 10 km buffer zones surrounding them. IUCN category 6 parks have the highest habitat suitability within the 5- and 10 km buffer zones surrounding protected areas. IUCN category ‘not reported’ and ‘not applicable’ parks have consistently lower habitat suitability across both the core areas and buffer zones. Lastly, contiguous protected areas have the highest habitat suitability in the 5- and 10-km buffer zones around core protected areas. Overall, IUCN category 3, 4 and 5 parks have the highest habitat suitability for elephants across Africa.

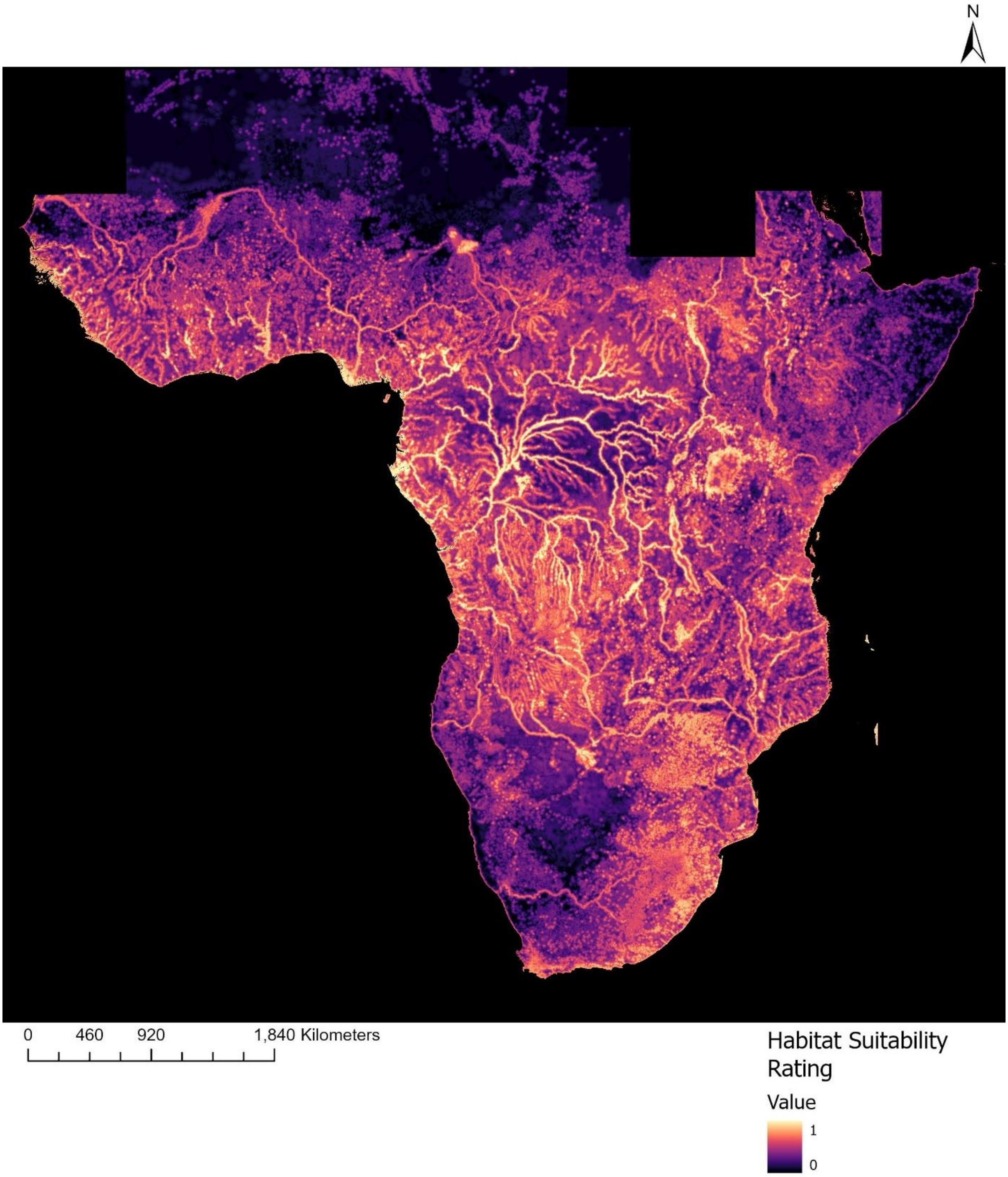

Figure 4: the model showing habitat suitability for elephants across their distribution on the African continent. Values in yellow (i.e., closer to the value of 1) are higher quality habitat, while values in purple (closer to the value of 0) are lower quality habitat.

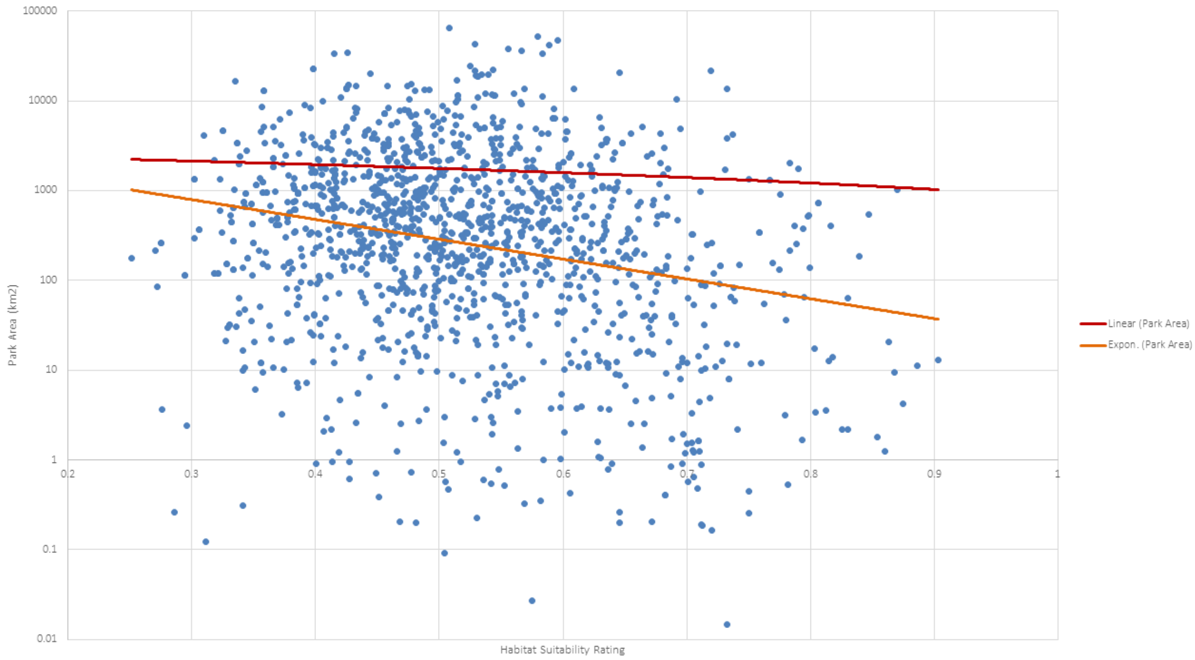

Figure 5: The linear and exponential relationships between the area of a national park/protected rea and the habitat suitability rating of those areas. Both the linear and exponential trends indicate that across Africa on average, smaller parks and reserves have higher habitat suitability for elephants. There is significant scatter which is to be expected with a model of this size.

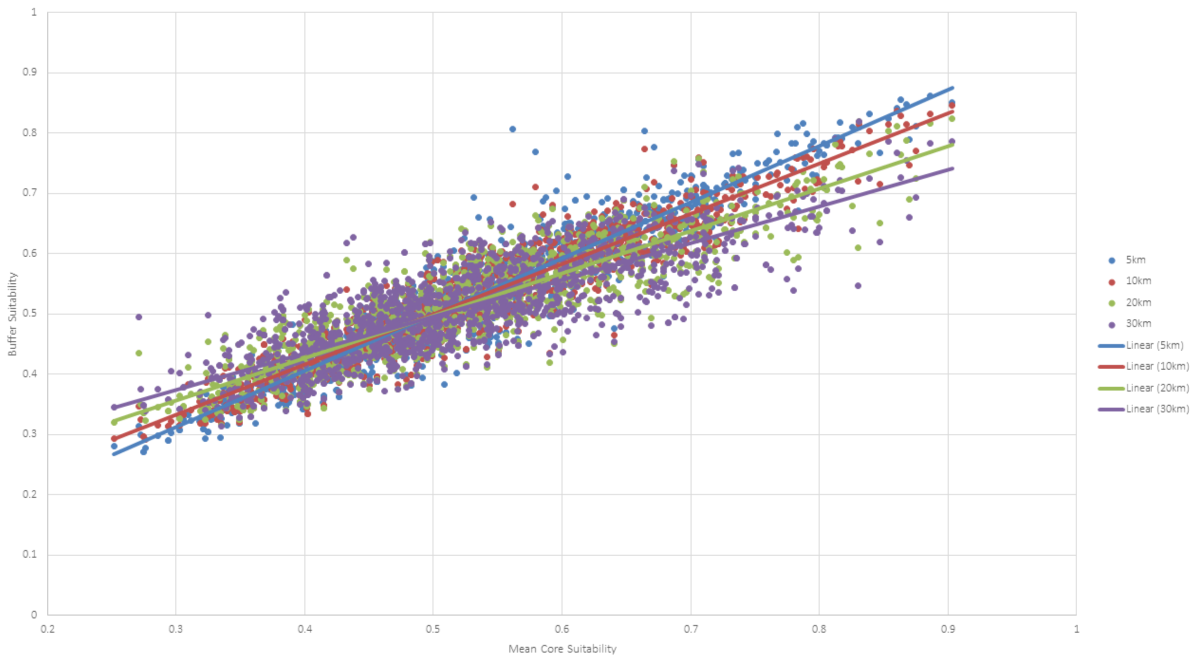

Figure 6: The linear relationships between the habitat suitability within 5, 10, 20 and 30 km buffer zones around protected areas and the habitat suitability rating of the core protected areas. The linear trends indicate that on average across Africa, habitat quality within the immediate buffer zones (5 and 10 km) around protected areas is suitable habitat for elephants.

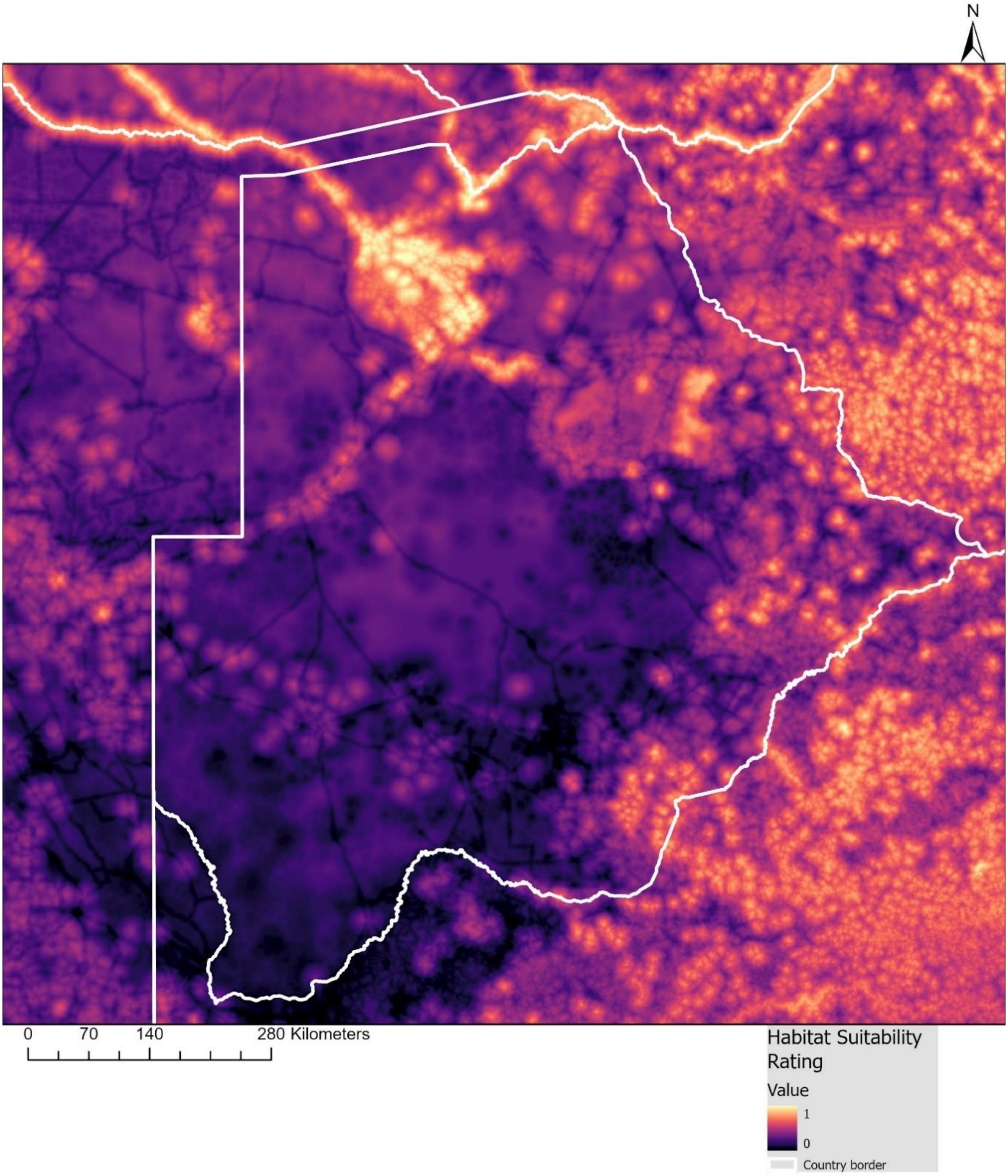

Figure 7: the model showing habitat suitability for elephants across their distribution in Botswana. Values in yellow (i.e., closer to the value of 1) are higher quality habitat, while values in purple (closer to the value of 0) are lower quality habitat.

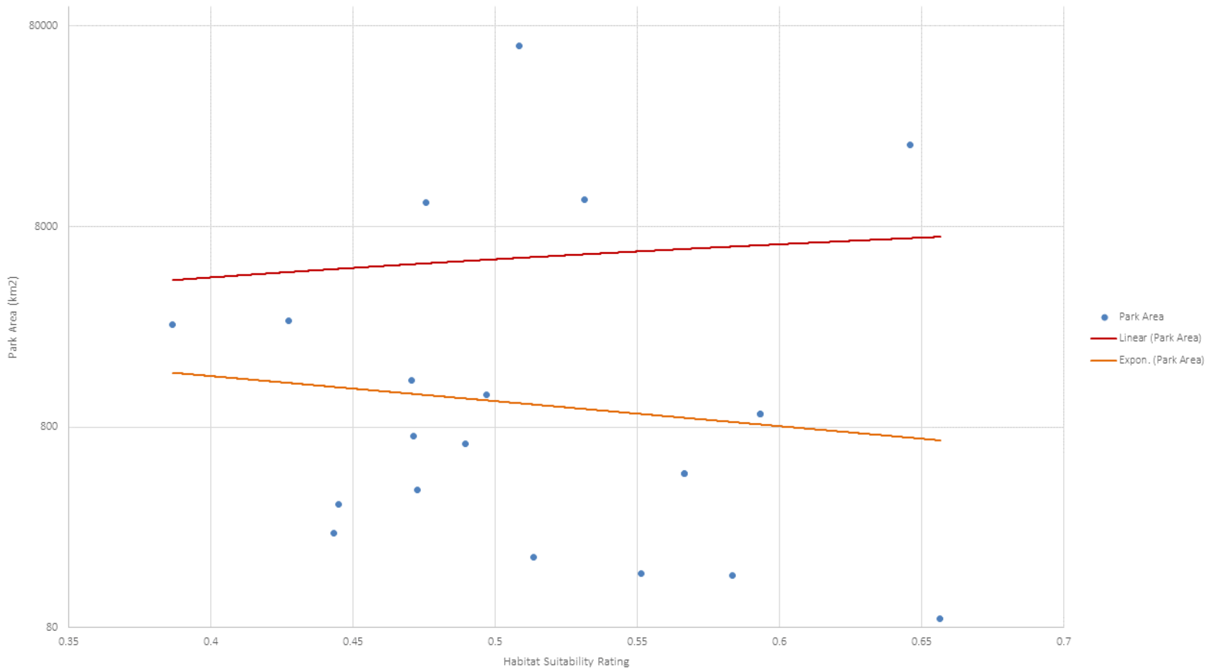

Figure 8: The linear and exponential relationships between the area of a protected area in Botswana and the habitat suitability rating of those areas. The linear trend indicates that larger protected areas in Botswana have better habitat suitability, while the exponential trend and exponential trend indicates that smaller protected areas have higher habitat suitability for elephants.

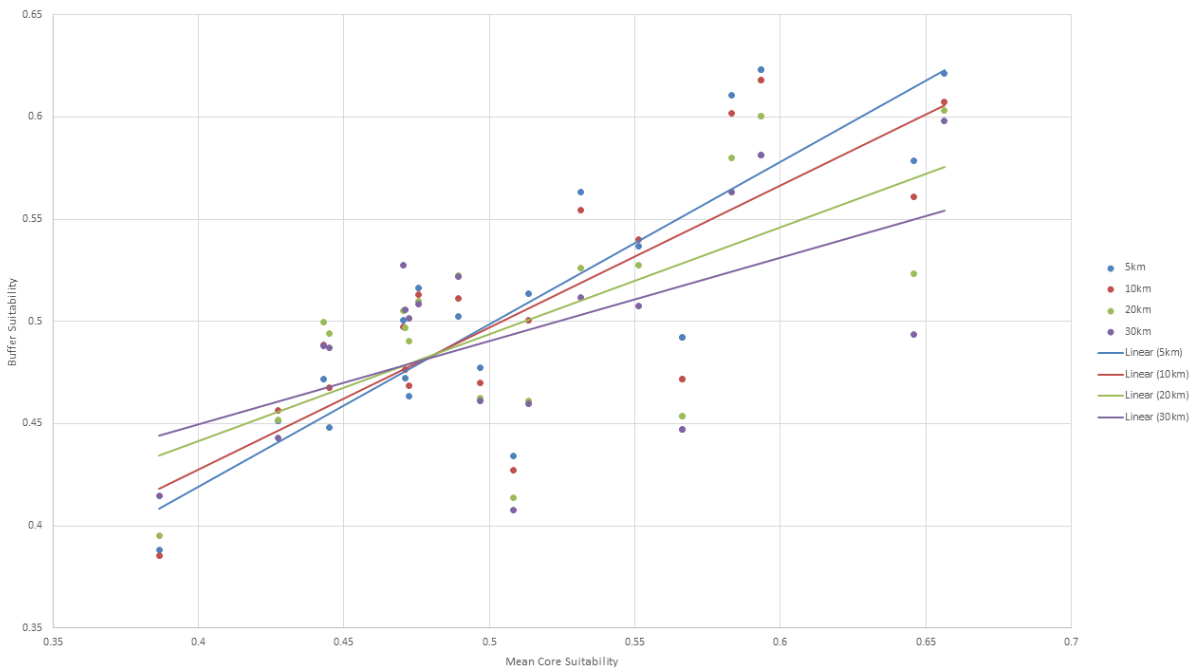

Figure 9: The linear relationships between the habitat suitability within 5, 10, 20 and 30 km buffer zones around protected areas in Botswana and the habitat suitability rating of the core protected areas. The linear trends indicate that on average across Botswana, habitat quality within the immediate buffer zones (5 and 10 km) around protected areas is suitable and reasonable quality habitat for elephants.

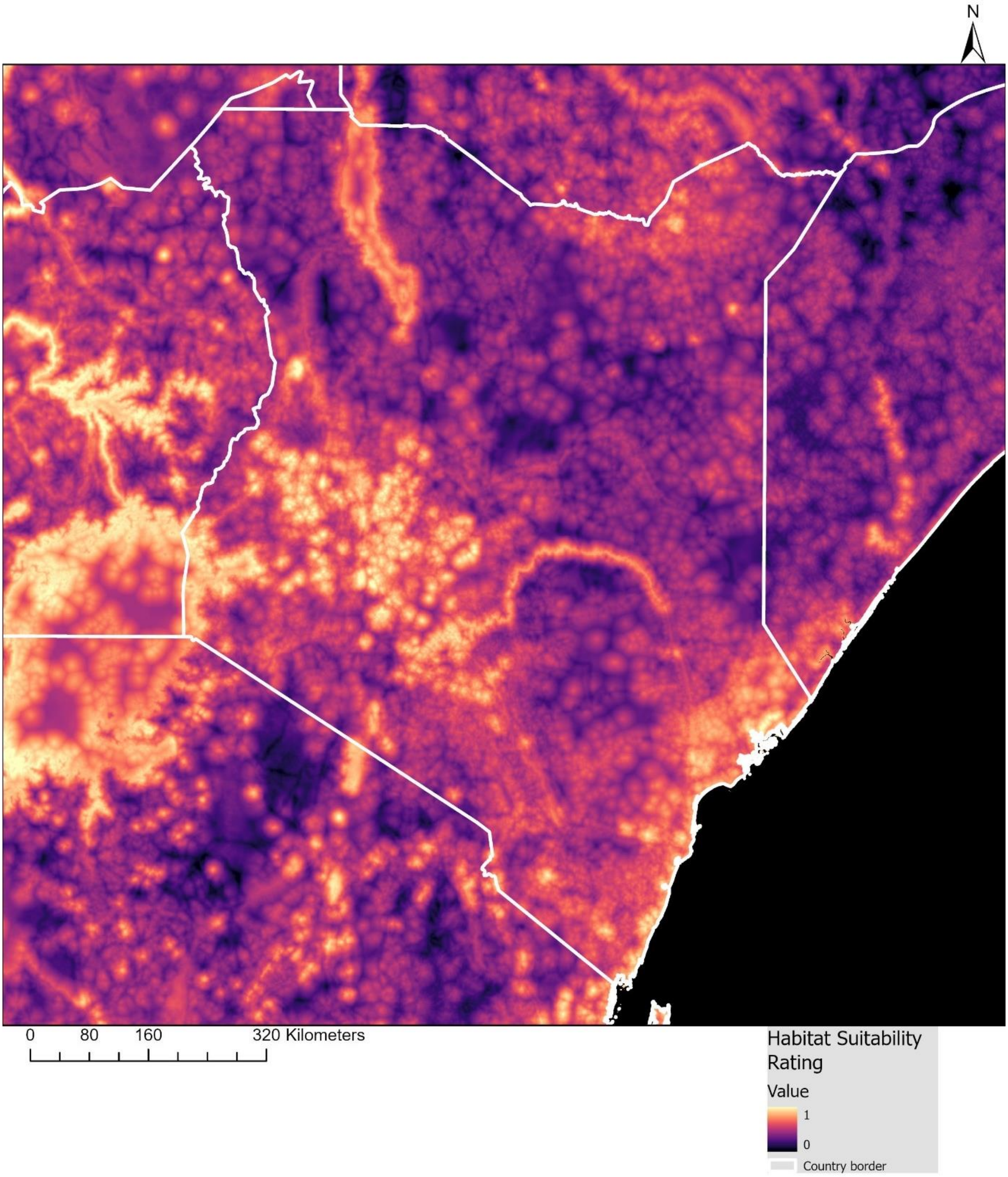

Figure 10: the model showing habitat suitability for elephants across their distribution in Kenya. Values in yellow (i.e., closer to the value of 1) are higher quality habitat, while values in purple (closer to the value of 0) are lower quality habitat.

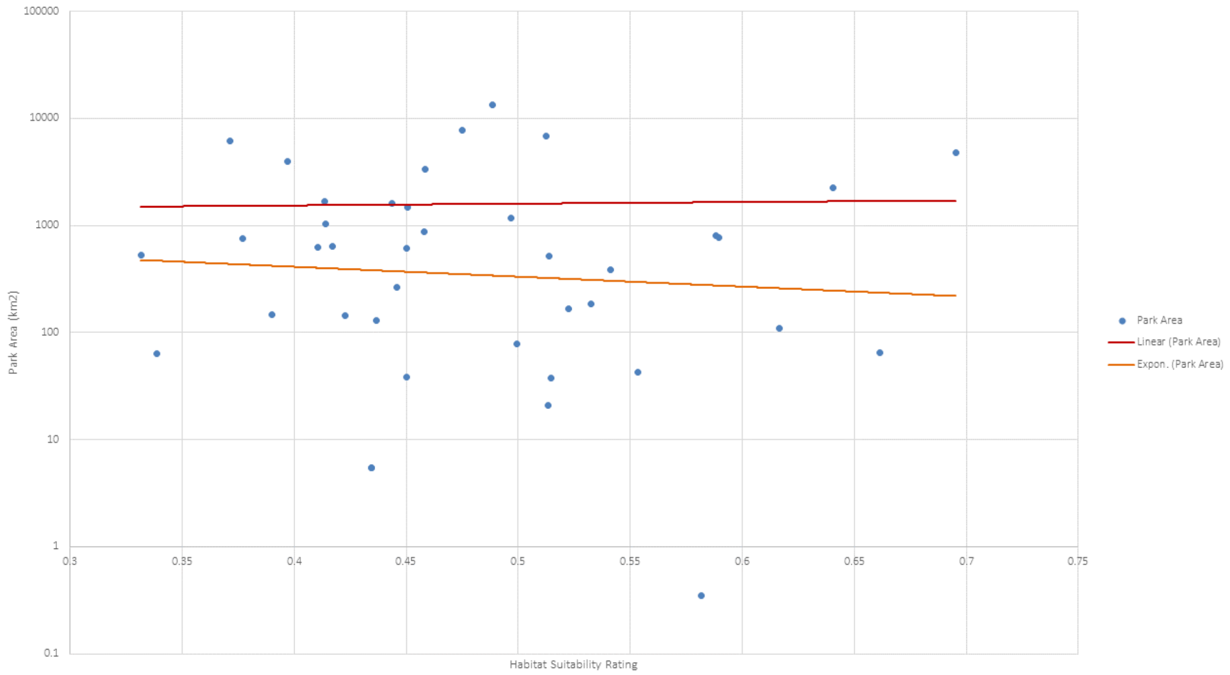

Figure 11: The linear and exponential relationships between the area of a protected area in Kenya and the habitat suitability rating of those areas. The linear trend indicates protected areas across Kenya, regardless of size, have similar habitat suitability while the exponential trend and exponential trend indicates that smaller protected areas have higher habitat suitability for elephants.

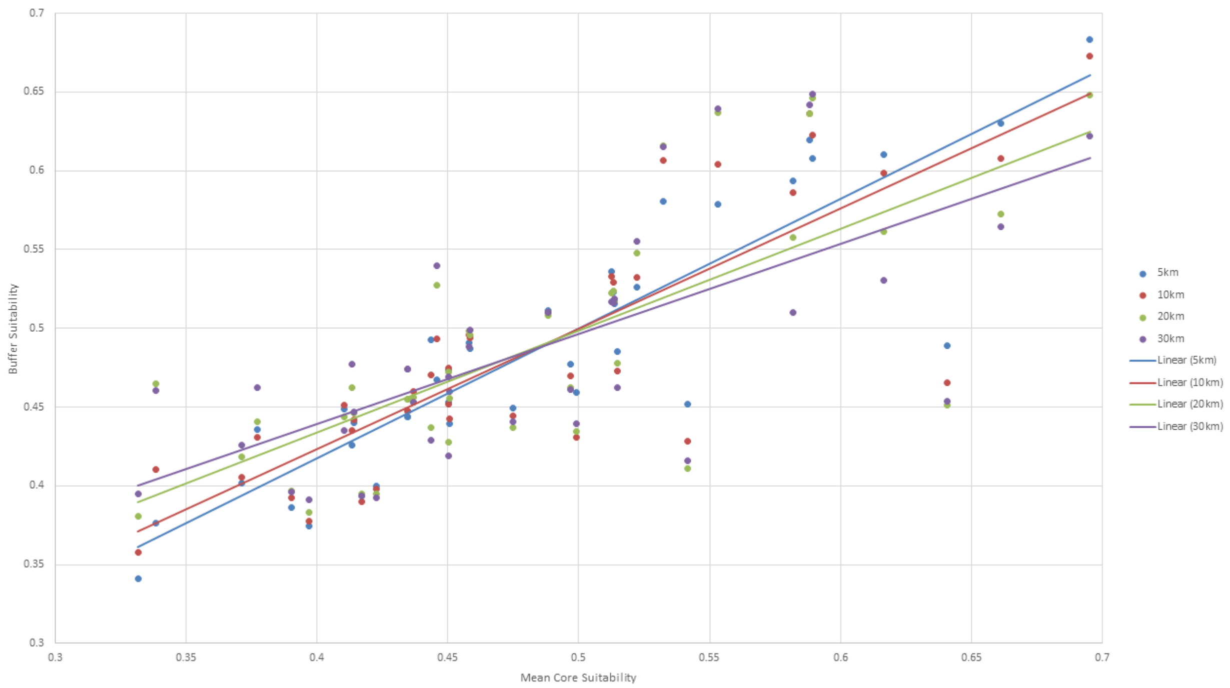

Figure 12: The linear relationships between the habitat suitability within 5, 10, 20 and 30 km buffer zones around protected areas in Kenya and the habitat suitability rating of the core protected areas.

The linear trends indicate that on average across Kenya, habitat quality within the immediate buffer zones (5 and 10 km) around protected areas is suitable and reasonable quality habitat for elephants.

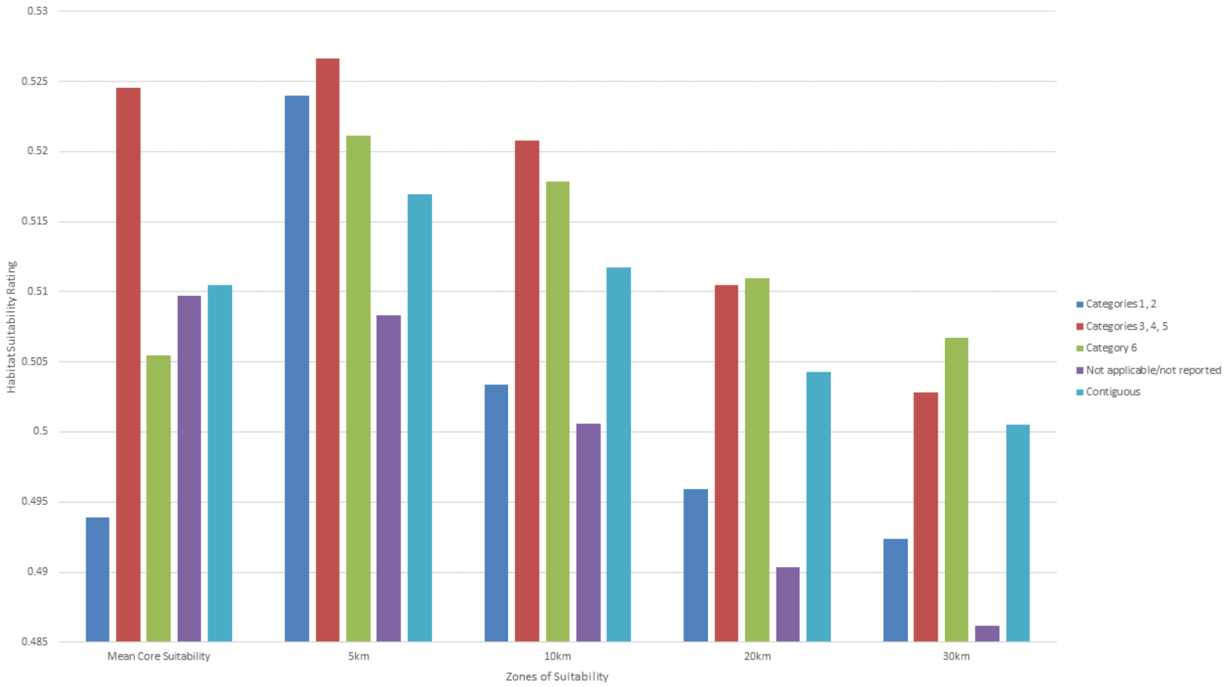

Figure 13: The average habitat suitability across different categories of IUCN protected areas both in the core areas and the 5, 10, 20 and 30 km buffer zones around the core areas. The results indicate that categories 3, 4, 5 and 6 consistently have the highest habitat suitability in core areas and buffer zones. IUCN categories 1 and 2 parks have low habitat suitability within the core areas, with the highest being in the 5 km buffer zone surrounding core areas but overall have low relative habitat suitability. Not applicable or not reported areas consistently have low habitat suitability while contiguous protected areas consistently have mid-high habitat suitability. The definition of each IUCN protected area can be found in Table 2.

4.5 Discussion

My study is novel in providing a comprehensive and standardised habitat suitability model for elephants that is not specific to a region, condition or population. There have been two other continent-wide suitability focussed models for elephants [28,55] but neither use satellite data and rely on statistical modelling and elephant distribution which I believe my model complements by providing an element of *in situ* habitat type. One relies heavily on species distribution models (SDMs)[28] which work well but statistically treat the population as static which it is not, and do not account as well for variability in climate. The second study does not use vegetation or habitat data, but climate and distribution data[55]. Other studies have used case studies from multiple sites across Africa and tied them together which is useful discourse for methods to be used in modelling habitat suitability[30]. The model I provide complements existing regional models by using a simpler method which is continent-wide and provides insights for areas where the establishment of transfrontier areas and wildlife corridors between the smaller areas may be feasible. Some studies also focus on just one region[31,33], which is useful for that area but not necessarily translatable to different parts of the continent. Focussing on one site also discounts connectivity and contiguity between protected areas which is present across many countries. Further, my model does account for roads but does not discriminate between park boundaries and countries as elephants do not necessarily adhere to anthropogenic boundaries. I also found that many studies did not cover the number of variables that I have, with some using just NDVI[33,56], land-cover change[29,57,58] or only one element of human presence like roads which offers low definition between the categories. I believe the scale, flexibility and inclusion of comprehensive variables makes this model unique and complementary to the previous studies in this area and provides an interactive point to build off for elephant managers and researchers while also reaching my aims in the creation of the model.

The results largely matched my hypotheses for this study by showing that firstly, larger protected areas would have lower habitat suitability than expected. Secondly, I also predicted that smaller parks would have higher habitat suitability than larger protected areas which the results provide evidence for. Lastly, I predicted that there would be high or higher habitat suitability in the buffer zones around core protected areas which the analysis indicates is true. While I largely met the predictions made, there was an unexpected result. While I predicted that smaller parks and reserves and the buffer zones around protected areas, with less tourism and human interference, were more likely to have higher overall habitat suitability for elephants, I did not expect the overall low habitat quality of IUCN categories 1 and 2 protected areas which may be linked to their overall larger size, i.e. IUCN categories 1 and 2 PAs tend to be larger than other categories to maintain the habitat matrix for protected species, and the model indicates that larger areas have lower suitability.

I identify two key concerns arising from these results. Firstly, I show that IUCN categories 1 and 2 parks have low habitat quality while categories 3, 4 and 5 have higher habitat suitability (Figure 13). This is concerning given the investment in the maintenance of higher category parks and the resources funnelled[59,60] into them when smaller parks, many of which are private or community-run, lack the same financial and governmental support[59].

Secondly, I identified that there is higher habitat suitability in the 5- to 10 km buffer zones surrounding core protected areas (Figure 6). Due to the nature and history of protected areas, these zones are where many local communities were displaced and relocated to, to set the protected area aside for conservation[15,19]. As habitat suitability in core protected areas is lower, and likely to continue to diminish under climate change conditions[28,61], the chance that elephants leave them to seek better habitat is increasing. Moving outside protected areas would bring them more into human-dominated landscapes and increase the chance of human-elephant conflict in these spaces. In landscapes already being affected by dwindling resources as a result of climate change, especially drought, the competition for resources and space may escalate and cause more conflict between humans and elephants.

Elephants are a highly mobile species in increasing need of water and forage[11,18,62,63]. Considering that habitat fragmentation is one of the primary reasons for elephant population decline[25], finding ways to reconnect habitat will be a critical step forward in managing elephants and their landscapes. The overall mid-range habitat suitability for contiguous protected areas (Figure 13) re-enforces the importance of habitat connectivity, which have been improved through the establishment of transfrontier areas and wildlife corridors[27,64,65]. This model provides the baseline for identifying suitable areas for the introduction of TFAs and wildlife corridors.

This model contributes significantly to the understanding of habitat suitability for elephants on a continental level. The model provides a high resolution and interactive map with flexibility to change the inputs and weightings of those inputs for users, which can be altered to be used for other species and spatial planning. It also provides a novel dataset grounded in satellite data that is standardised across the African continent and interrogates areas of current elephant distribution while providing insight on how and where this may change in the future. This is a significant model and product for ecological researchers, managers and policy makers looking to spatially plan or assess habitat quality for elephants, especially under a scenario of landscape level resource depletion and change as a result of climate change.

I recognise that the model has limitations. Firstly, it does not compare habitat use with habitat availability and while it does not impact the conclusions made, will be in important next step for translating the model to in situ reality. An element that I did not consider in the first instance is the difference between how *Loxodonta africana* and *Loxodonta cyclotis* use their habitats, which there is evidence showing is different[30]. While both species are highly water-dependent, they interact with humans and their environment differently, so this model is better applied to only *L. africana*. While the model covers the distribution of both species, I recommend those working on the *L. cyclotis* species use the Digital Earth Africa platform to refine the model inputs to be more reflective of *in situ* circumstances. Treating the two species as separate research entities is common practice and particularly the inputs for this model cater specifically to the nuance in habitat and behaviour of the savannah elephant. While the species' share some similarities, such as their dependence on surface water, their populations behave differently and use their habitat in distinct ways from each other. Some variables are not included, such as elevation, fences and topography, which may impact habitat suitability. I believe these issues are accounted for in the assumption that proximity to humans would include fencing and proximity to bare/sparse ground cover would account for higher altitudes and more mountainous regions, though elephants do live in high elevation regions such as around Mount Kilimanjaro[20]. I also recognise that evenly distributing the weight of the sub-models is not necessarily applicable to the diverse and robust landscapes across the continent, which the model assumes are similar. However, I also designed this model as a starting point and not a final product with the hopes to generate discussion and provide a baseline for researchers to work from. As such, there are many avenues for future research drawing from this model. Two issues of particular importance are understanding how the model can be altered and used for spatial planning in combination with urban data and city/town/village planning and how it may be used to predict areas of highest risk of increasing of human-elephant conflict due to resource depletion. Importantly, I encourage researchers to use the model to guide their future studies in terms of where funding and research support is most needed.

4.5.1 Recommendations

The key recommendations I make are as follows. I encourage researchers, governments and managers to consider where they invest time and resources in elephant research as it should not necessarily be in large, high-profile protected areas with higher IUCN categorisation. The model presented here provides evidence that smaller protected areas, and in those categories IUCN levels 3-6, may have higher habitat suitability than the counterparts. It has already been shown that there are geographical biases in research occurring in more high-profile protected areas with a need to diversify where and how research is conducted to ensure effective and meaningful elephant research[24]. This model complements and amplifies those results.

Secondly, and most importantly, the evidence shows that the buffer zones around protected areas are largely equal, if not greater, in habitat quality than the core protected areas themselves which suggests an increased risk of human-elephant conflict in many regions. Many protected areas in Africa were established under the 'Yellowstone Model', where land is set aside for 'conservation' and all human inhabitants must be removed in the process[15]. In places like Kenya, this led to the forced displacement and consequent resettlement of communities who once resided in protected areas in the periphery around them[15]. These periphery areas are the buffer zones with high habitat suitability for elephants. Further, for communities that were displaced or originally settled further away from protected areas, elephants still have suitable habitat 20-30 km around protected areas and are a highly mobile species so the chances of increased human-elephant conflict remain a concern. Given it is the communities who will see changes in their interactions with elephants, it is communities who should be leading the management and policy in this area[66–68]. The buffer zones around PAs generally have lower human population density and as such, offer good opportunities for community-led conservation initiatives and the establishment of wildlife corridors without further displacing people. Recognising the crucial role that those working in protected areas hold, while also incorporating the voice and autonomy of communities is a collaborative, ethical and sustainable pathway to manage elephants moving further to seek better habitat. Further, community-based natural resource management projects have shown decreased levels of poaching, decreased human-wildlife conflict and increased quality of life for local people[69–72]. I encourage researchers, managers and policy makers to consider the knowledge and voice of local communities in using this model to manage elephants in the future.

4.6 Conclusion

Elephants are a high conservation priority in Africa and the ongoing threats of habitat fragmentation and climate change continue to put pressure on the remaining population. Elephants are a highly mobile and water-dependent species and it is important to understand the resources they have available to them across their distribution and what their options are as those resources change and deplete. My model provides baseline information which indicates that there is room to interrogate the role and quality of IUCN protected areas in elephant habitat, as well as illustrating the value of smaller, low-profile protected areas in the same space. By addressing these issues in conducting further research and altering the model to fit more specific regions on a need's basis, managing elephants and their response to a changing climate is likely to improve.

4.7 Acknowledgements

I would like to thank Matthew Gale for the support and expertise in helping develop the methods and run the Python analysis for this chapter. I would also like to thank Michael Wellington, Lisa Rebello and Fang Yuan from Geoscience Australia for the collaboration to publish the model as an interactive dataset.

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Chapter 5:

Shifting habitat preferences of African elephants (*Loxodonta africana)* in response to climate extremes.

5.1 Abstract

The role of climate change in the decline of African savannah elephant (*Loxodonta africana)* populations is not well understood. With high susceptibility to drought conditions, elephants rely heavily on their surrounding landscape to thermoregulate but the resources they need are declining. To understand how elephants are responding to landscape level resource depletion, it is necessary to know how they use their landscape under key climate variables linked to drought. I used GPS collar data from eight elephants across Botswana, Namibia, Angola and Zimbabwe to see which habitats they used under extremes of three key climate variables: temperature, precipitation and humidity. I found that during periods of high temperatures, high humidity and low precipitation, elephants spent more time in open and closed forests. During these periods, elephants also spent more time in lower quality habitat which is associated with more human-dominated landscape types. Our results show there is a significant difference between how elephants use their habitats under different climatic extremes and that precipitation has the most influence over habitat use. With drought conditions predicted to worsen, it is critical to address the likelihood that elephants will spend more time in forests, causing greater impact in those habitats and in human spaces with the risk that human-elephant conflict will increase. I suggest the most effective way to deal with higher future human-elephant conflict is to increase collaboration with, and empower, local communities to manage their local elephant populations. I encourage similar studies using GPS-collared elephants across eastern and southern Africa.

5.2 Introduction

African savannah elephants (*Loxodonta africana)* play a critical role ecologically, economically and culturally across their distribution in Africa. Due to a combination of European colonisation, ivory trading, habitat fragmentation and human-elephant conflict, the elephant meta-population has dropped from approximately 26 million to 415,000 in 200 years[1]. To protect the remaining meta-population, managers and conservation scientists need to understand the current and impending risks to their survival. The risks from poaching and habitat fragmentation[1] are well documented but the current and future impacts of climate change remain poorly understood.

Large areas of elephant habitat have been, and are experiencing drought conditions that are becoming longer and more severe[2–4]. While elephants are adapted to short periods of heat and aridity, they are biophysically susceptible to heat stress and overheating[5,6]. Prolonged periods of high ambient temperatures, as with all mammals, can cause disease, deformity and death[7,8]. This is amplified in elephants who have limited heat transfer mechanisms. For example, elephants cannot perspire and this limits their ability to dissipate heat[9–11]. With a low surface area to volume ratio due to their mass, elephants are exceptionally dependent on external water sources, both to ingest and to engage trans-evaporative cooling in place of perspiring [6,9,11,12].

While elephants have a range of thermoregulatory behaviours, many are reliant on the surrounding landscape such as access to surface water, seeking shaded areas and alternating foraging habits[6,9,13]. These adaptive mechanisms to living in a warm, dry environment have been mostly sustainable, though historically, drought related mortality has regulated elephant population size. [14]. However, as the population has declined significantly and drought conditions become longer and more severe, elephants may not be adapted to survive without access to permanent water bodies and increased mobility across landscapes[15]. Of particular concern is the increased occurrence of elephants supplementing their diet in drought-stricken landscapes by raiding agricultural crops which are high in nutrients and water content[16–18] with escalating occurrences of conflict with humans[19–22] which would compound crop raiding events that are already occurring for other reasons not related to climate.

With drought-stricken, depleted landscapes pushing elephants further to find more water and to better forage[6, 13,14], it is critical to understand which habitats they prefer and how these preferences are likely to respond with continuing climate change. This will help to inform managers in areas with the most targeted habitats and predict how elephant habitat use may change over time. This study aimed to a) document the preferred habitats/vegetation types of elephants and whether these vary in response to climate extremes and b) determine whether elephant populations living in different ecosystems show similar responses to extreme climate. I used GPS data over multiple years for eight elephants in two broad localities spanning four countries to test three hypotheses: a) whether they favoured cooler habitats like heavily canopied forests during high temperatures b) spent more time around lower quality habitat in local human communities for their water and high nutrient/water content crops, and c) whether different individuals had nuanced responses.

5.3 Methods

5.3.1 Study sites

GPS collar data were collected from eight elephants across study sites in Namibia, Angola, Botswana and Zimbabwe. Figure 1 shows the location of these sites and Table 1 indicates which elephants were present at the sites during the study times. These sites were prioritised as they have exhibited ongoing drought conditions, particularly over the study period, and represent high density populations of elephants.

The northern region, largely comprising Bwabwata and Luenge-Luiana National Park in Namibia and Angola, primarily comprise Kalahari woodland, Caprivi mopane woodlands, riverine woodlands, shrub savannah biome, Caprivi floodplains and parts of the Okavango Valley. The area has a tropical climate with an average temperature of ~26^{0}C and ~535mL of precipitation annually.

The eastern region, where South Matabeleland intersects the Shashe River in Zimbabwe and Botswana, consists primarily of riverine forest, sandstone outcrops and mopane woodland. The area is also tropical with an average temperature of ~21.67^{0}C and ~588.5mL of precipitation annually.

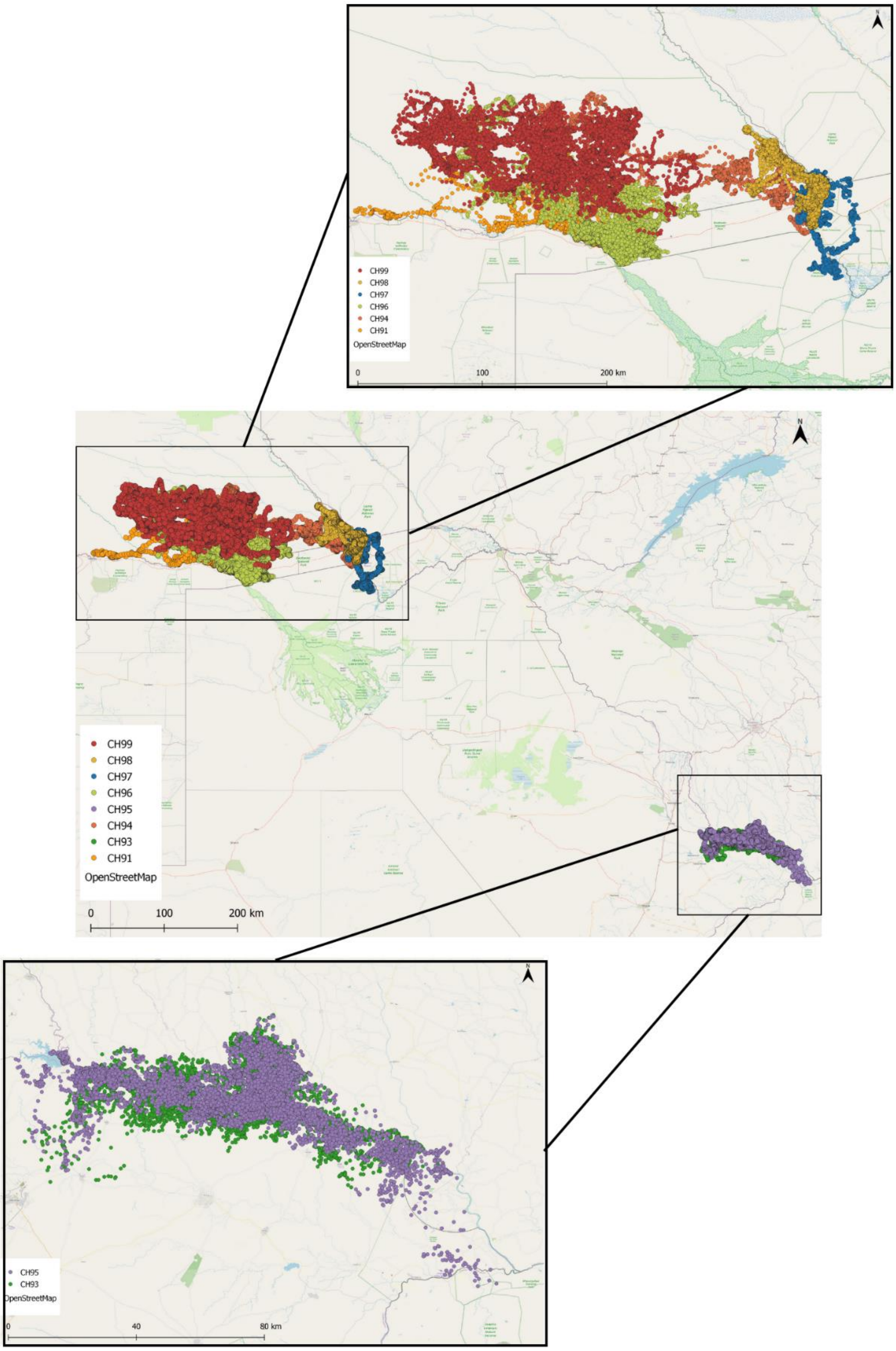


Figure 1: The locations of eight GPS collared elephants, with panned insets on the two primary regions, used in this study. Created using QGIS.

5.3.2 Data collection

5.3.2.1 GPS Collar Data

Data from Inmarsat satellite GPS collars (IM-SAT tags manufactured by Africa Wildlife Tracking) fitted to eight elephants were collected by the staff of Elephants Without Borders, a non-government organisation focussed on the research and conservation of African elephants across the Kavango-Zambezi Transfrontier Area, largely using satellite collars and aerial surveys. See Table 1 for the details of each elephant, including collaring period and data intervals. I aimed to use a variety of locations, ecosystems and time scales to find if there were patterns in occupation time. Data were used from different periods between the years 2015 to 2018 during a period of uncharacteristically moderate to severe drought conditions in these regions[23,24].

Table 1: the details of tracking data for eight elephants used for this study.

Sex	*ID*	*Data start*	*Data end*	*Data intervals*	*Location*	*Country*
Male	CH91	04/11/2015	16/11/2017	4 hours	Luengue-Luiana and Bwabwata National Parks	Angola and Namibia
Male	CH93	19/02/2015	29/01/2018	4 hours	South Matebeland	Zimbabwe and Botswana
Male	CH94	03/11/2015	31/10/2016	4 hours	Leungue-Luiana National Park and Zambezi Region	Angola and Namibia
Male	CH95	19/02/2015	31/07/2018	4 hours	South Matebeland	Zimbabwe and Botswana
Female	CH96	16/05/2015	04/11/2015	4 hours then hourly	Luengue-Luiana and Bwabwata National Parks	Angola and Namibia
Male	CH97	05/11/2015	11/05/2016	4 hours	Kwando Concession, Luengue-Luiana and Bwabwata National Parks	Angola, Namibia and Botswana

Female	CH98	05/11/2015	13/10/2016	4 hours	Luengue-Luiana and Bwabwata National Parks	Angola and Namibia
Female	CH99	03/11/2015	31/07/2018	4 hours	Luengue-Luiana National Park	Angola

5.3.2.2 Vegetation data

I used remotely sourced satellite data from the European Space Agency's Copernicus Global Land Service to classify and locate vegetation types. This freely available dataset provides the most accurate available satellite vegetation data for Africa[25] and includes records covering the key years of this study. The accuracy and details of this data can be found in Chapter 4 of this thesis under section 4.3.3. The data has resolution at 100m providing high level and consistent coverage of multiple habitats and locations.

5.3.2.3 Weather data

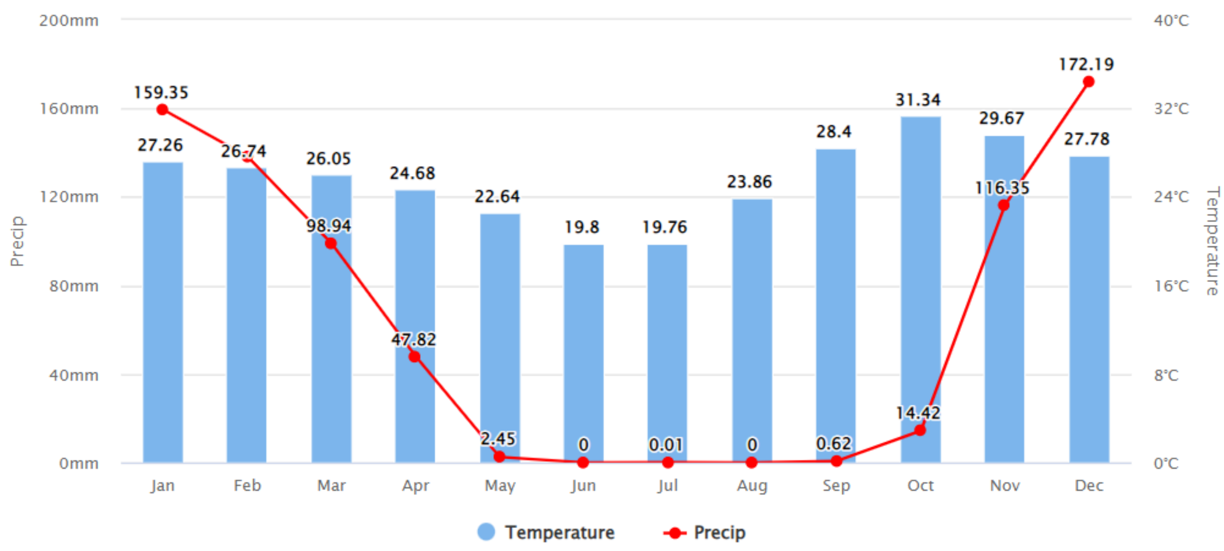
Data for ambient air temperature, humidity and precipitation were drawn from Weather and Climate - The Global Historical Weather and Climate Database. Data were used from the following locations: Luiana, Maramani, Bagani, Cunga, Mbizo and Kongola. The data show a period from 2015-2018 where drought periods waxed and waned and were not necessarily constant so there are examples within the data of non-drought periods. But we were interested in knowing what happened during drought, elephant movement and behaviour is well recorded outside of drought periods

5.3.2.4 Climate change in the Kavango-Zambezi and Tuli-Karoo Regions

Much of southern and eastern Africa has been experiencing varying lengths and levels of drought since the Millennium drought starting in the year 2000. For many of these regions, the droughts have become uncharacteristically longer and more severe with some countries, such as Zimbabwe, experiencing drought for over 20 years[23]. The two regions where this study takes place, the Kavango-Zambezi Transfrontier Conservation Area and the Tuli-Karoo region have both experienced various levels of drought in the last 20 years with records showing that drought conditions (uncharacteristically and ongoing high ambient air temperatures and low precipitation) peaked in 2014 – 2019[26–29]. This aligns with the broader observations of how global climate change has altered water and rain patterns across Africa and global warming has led to increasing ambient air temperatures[30,31]. I used the period of 2015-2018 as a snapshot of high intensity drought that can be attributed to the ongoing effects of climate change. Figure 2 shows the average temperature increase and precipitation decreases over the key regions. Figures 3a and 3b show the annual average air temperature and precipitation for the regions in this study, Kavango East and South Matabeleland to contextualise the upper and lower limits of the variables used.

Figure 2: The average temperatures and precipitation over 120 years across the regions of the case studies. Source: Climate Change Knowledge Portal.

a)



b)

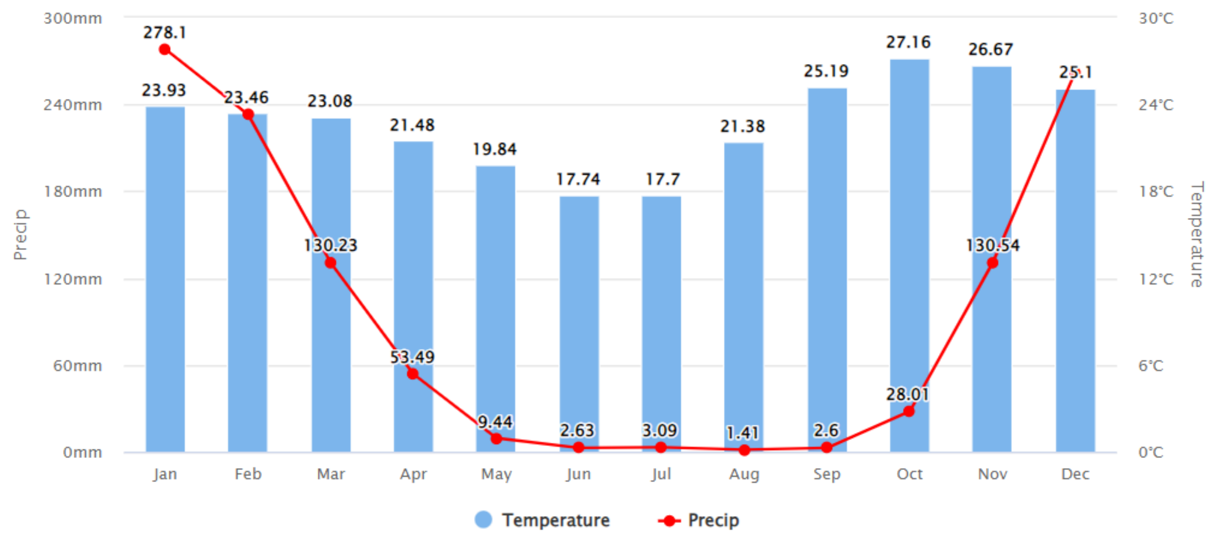


Figure 3 shows the average temperature and precipitation for a) Kavango East and b) South Matabeleland. Source: The Global Historical Weather and Climate Database.

5.3.2.5 Habitat Suitability

In brief, an index model of habitat suitability was created sourcing data from Copernicus Global Land Satellite Data, UN Population Density and FAO roads. The data were processed using fuzzy logic and combined using weighted linear combination with even distributions of habitat type, cropland, roads and human population density across the African continent. The final product is an interactive

Habitat Suitability Model that can be refined into a raster for elephants as done for this chapter which is available through Digital Earth Africa. The model was created using Python, QGIS and ArcGIS Pro. See chapter 3 for details.

5.3.3 Data Analysis

For each individual elephant the temperature, humidity and precipitation for the period of the collaring were downloaded. For each variable, the periods of highest and lowest were recorded. Using traditional seasons was not accurate as they do not account for annual climatic fluctuations and this study aimed to focus on the variables that are changing the most under climate change. Weather variables that were consistently high or low (Table 2) for more than one day were recorded. I used these limitations as I was aiming to look at the scale of variables that have been and are most likely to continue to become more prevalent in the current climate change induced drought scenario, i.e. higher ambient temperatures, lower precipitation and high humidity[32–35]. I consider higher humidity percentages as conditions of biophysical duress for elephants, despite the implication of present precipitation, because when precipitation is present during periods of high temperatures, elephants will still be under duress from heat stress due humidity which amplifies elephants' inability to sweat. The opposing variables (low temperatures, low humidity and high precipitation) were tested as a control to indicate whether a relationship is present. The definition of the variables can be found in Table 2.

Table 2: Definitions of high and low values of weather variables.

Variable	*High*	*Low*
Temperature	>30^{0}C	<20^{0}C
Precipitation	>5mm/day	0mm/day
Humidity	>70%	<30%

The individual elephants' GPS locations during the periods of high and low variables were plotted over the rasters containing the CGLS 100 data and the habitat suitability model using ArcGIS Pro and QGIS 3.24.3. I then extracted point to raster value for both rasters and all variables before exporting as a table to Microsoft Excel. Habitat types that were not used by elephants were not included in the analysis. This provided the number of points that each individual was present in each habitat type and habitat suitability which was then calculated as a percentage to provide occupation time in each habitat type/suitability under each climate variable.

Homogeneity tests were performed over all data combined and for individual elephants to test for differences between elephant occupation times in varying habitats and habitat of varying quality during the periods when climatic variables were most extreme. The data were pooled and contingency stables were appropriate.

5.4 Results

I tracked the occupation time of eight elephants for periods ranging from 6 – 41 months over a three-year period of moderate to severe drought in Botswana, Zimbabwe, Angola and Namibia in nine different habitat types and six different levels of habitat quality. I calculated their occupation time in the habitat categories during periods when climatic variables were most extreme, focussing on the key components of drought conditions: temperature, humidity and precipitation.

When testing the different vegetation types that were favoured under extremes of the different climate variables, I found that elephants spent more time in open forests during periods of higher temperatures (Figure 4a). During periods of lower precipitation, elephants spent more time in shrubs, cropland and herbaceous wetland (Figures 6b). During periods of higher humidity percentage, elephants spent more time in open forest (Figure 5a).

The converse results show that during periods of lower temperatures, elephants spent more time in shrubs and herbaceous wetland (Figure 4b). During periods of high precipitation, elephants spent more time in shrubs, urban development, crops and herbaceous wetland (Figure 6a). Lastly, during periods of lower humidity percentage, elephants spent more time in shrubs and herbaceous wetland (Figure 5b).

When testing the different habitat qualities used under the different climate variables, I found that in high temperatures, humidity and precipitation, elephants spent more time in lower quality habitat (<5/10) (Figures 3a, 5a and 6a). As outlined in Chapter 3, lower quality habitat is associated with human dominated landscapes and high-quality habitat is associated with higher presence of water, forests and herbaceous vegetation which provide more shelter, forage and resources to elephants. During periods of low temperatures, humidity and precipitation, elephants spent more time in higher quality habitat (>5/10) (Figures 4b, 5b and 6b).

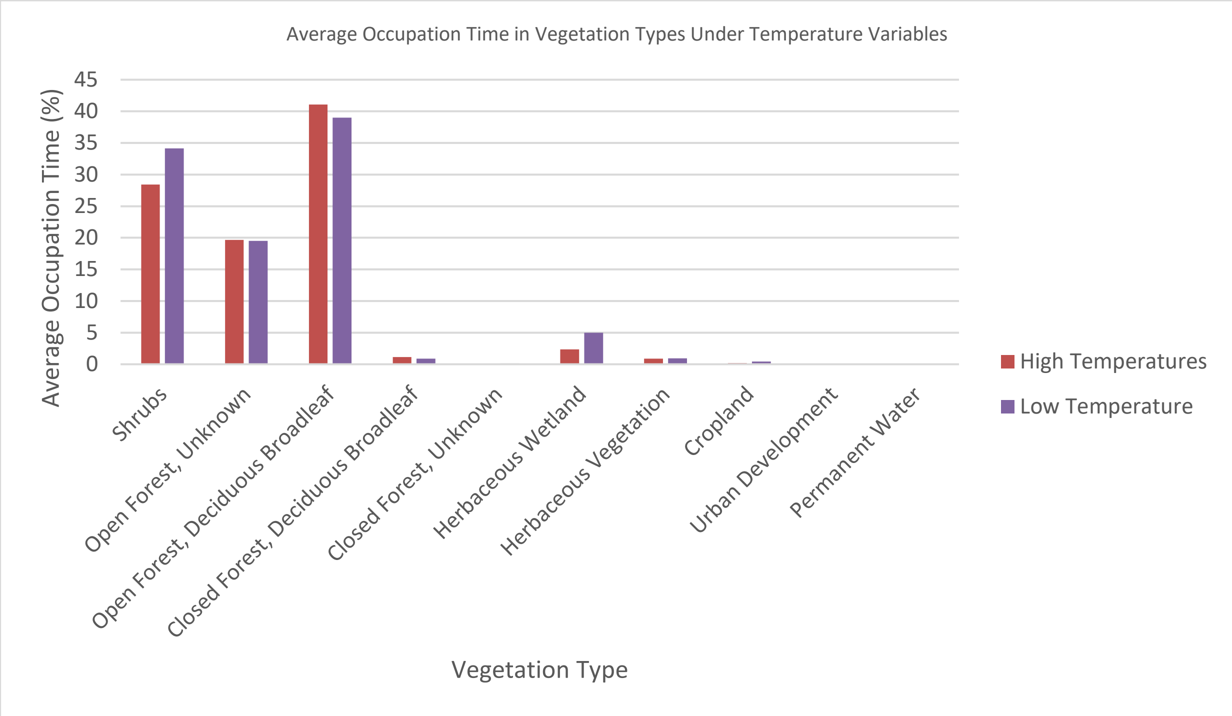
I recognise that the variation and nuance between each elephant's response is reduced by stating only the averages over all observed elephants, especially as the habitat available to each will differ subtly. As such, I used three individuals as examples with the remaining results for individual elephants available in the Appendix. Figures 7a, 7c and 7e show that CH93 spent more time in unknown open forest, shrubs and cropland during periods of high temperatures and humidity and low precipitation. Figures 7b, 7d and 7f show that CH93 spent more time in mid-range (5-6/10) habitat during these conditions. Figures 7a, 7c and 7e show that CH93 spent more time in open and closed deciduous broad-leaf forest during periods of low temperatures and humidity and high precipitation. Figures 7b, 7d and 7f show that CH93 spent more time in low quality habitat (2-4/10) during these conditions.

Figures 6a, 6c and 6e show that CH98 spent more time in unknown open forest, shrubs and closed deciduous broad-leaf forest during periods of high temperatures and humidity and low precipitation. Figures 6b, 6d and 6f show that CH98 spent more time in low to mid-range (3-7/10) habitat during these conditions. Figures 8a, 8c and 8e show that CH98 spent more time in shrubs, herbaceous vegetation and herbaceous wetlands during periods of low temperatures and humidity and high precipitation. Figures 8b, 8d and 8f show that CH98 spent more time in mid to high-quality habitat (5-7/10) during these conditions.

Figures 9a, 9c and 9e show that CH96 spent more time in shrubs and unknown open forest during periods of high temperatures and humidity and low precipitation. Figures 9b, 9d and 9f show that CH96 spent more time in low range (3-4/10) habitat during these conditions. Figures 9a, 9c and 9e show that CH96 spent more time in deciduous open broad-leaf forest during periods of low temperatures and humidity and high precipitation. Figures 9b, 9d and 9f show that CH96 spent more time in mid to high-quality habitat (4-7/10) during these conditions.

5.4.1 Overall averages of occupation time in different habitats in response to climate extremes

a)



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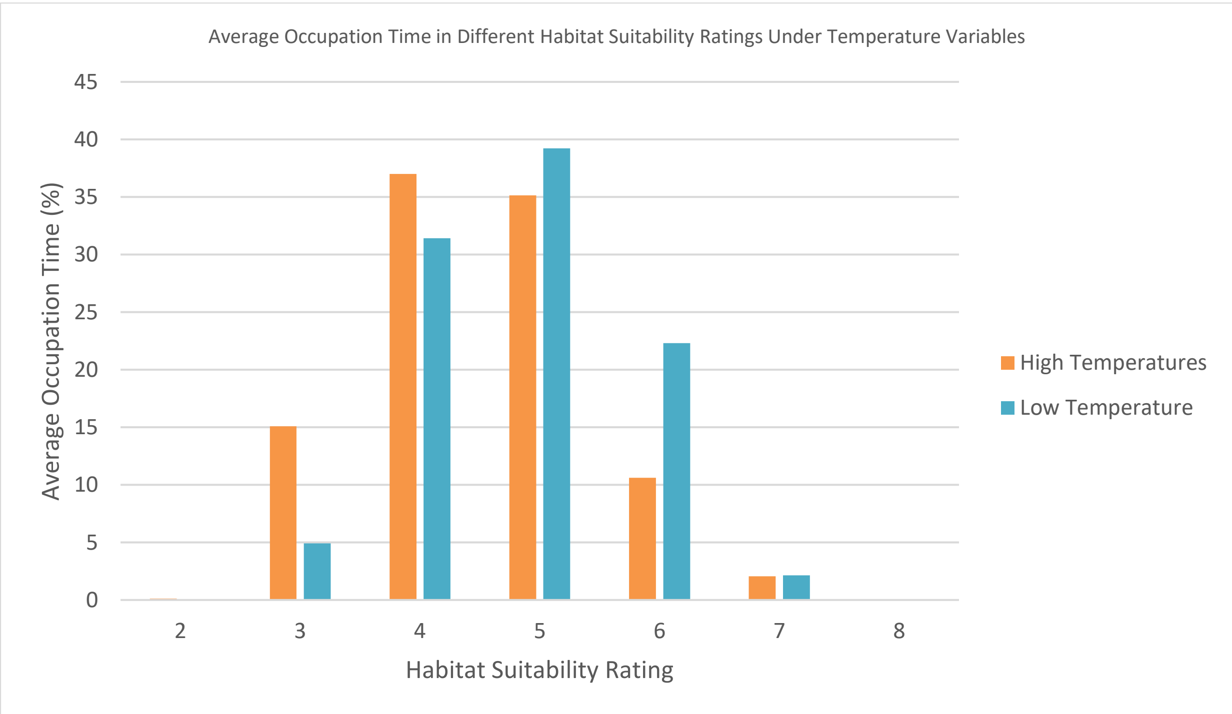
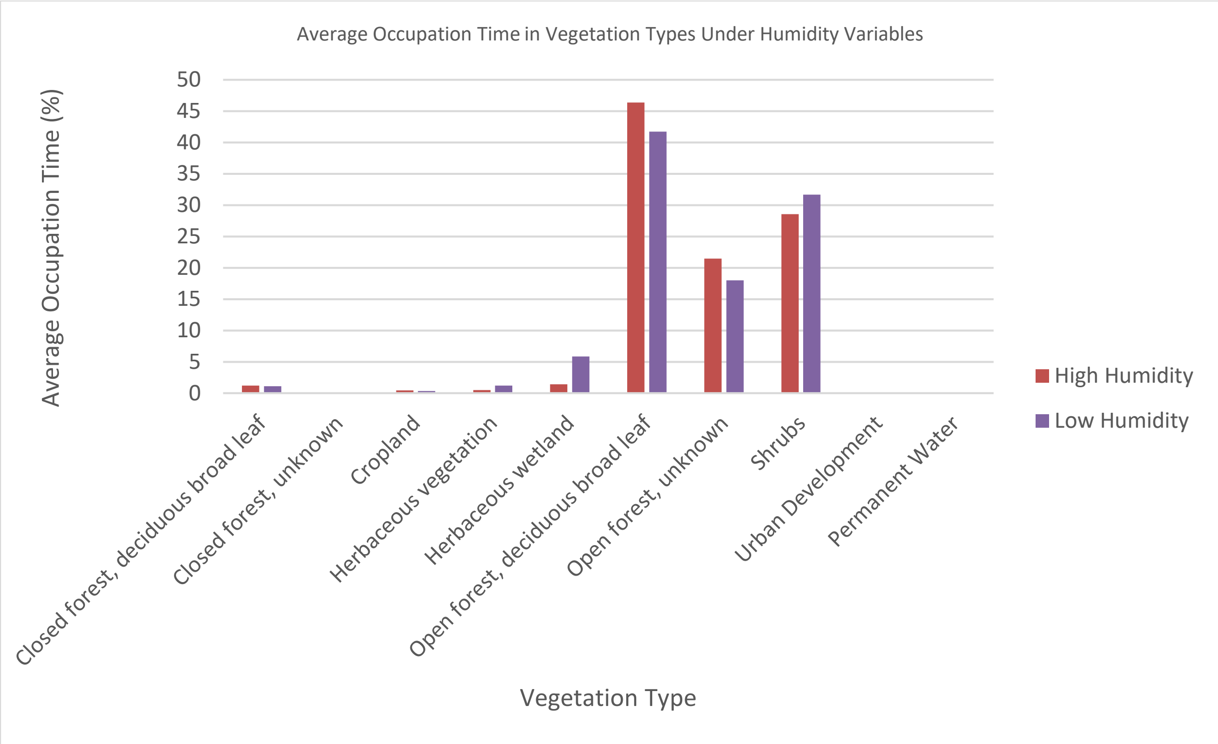


Figure 4: The occupation time in (a) different habitats and (b) different categories of habitat quality during high (>30^{0}C) and low (<20^{0}C) temperatures.

There was no significant difference in elephant use of habitats in high and low temperatures when all data across individuals were pooled (x^2 = 1.508, d.f. = 9, p = 0.997, Figure 4a). Similarly, there was no significant difference in the quality of habitat used in high and low temperatures (x^2 = 10.086, d.f. = 6, p = 0.1211, Figure 4b).

a)



b)

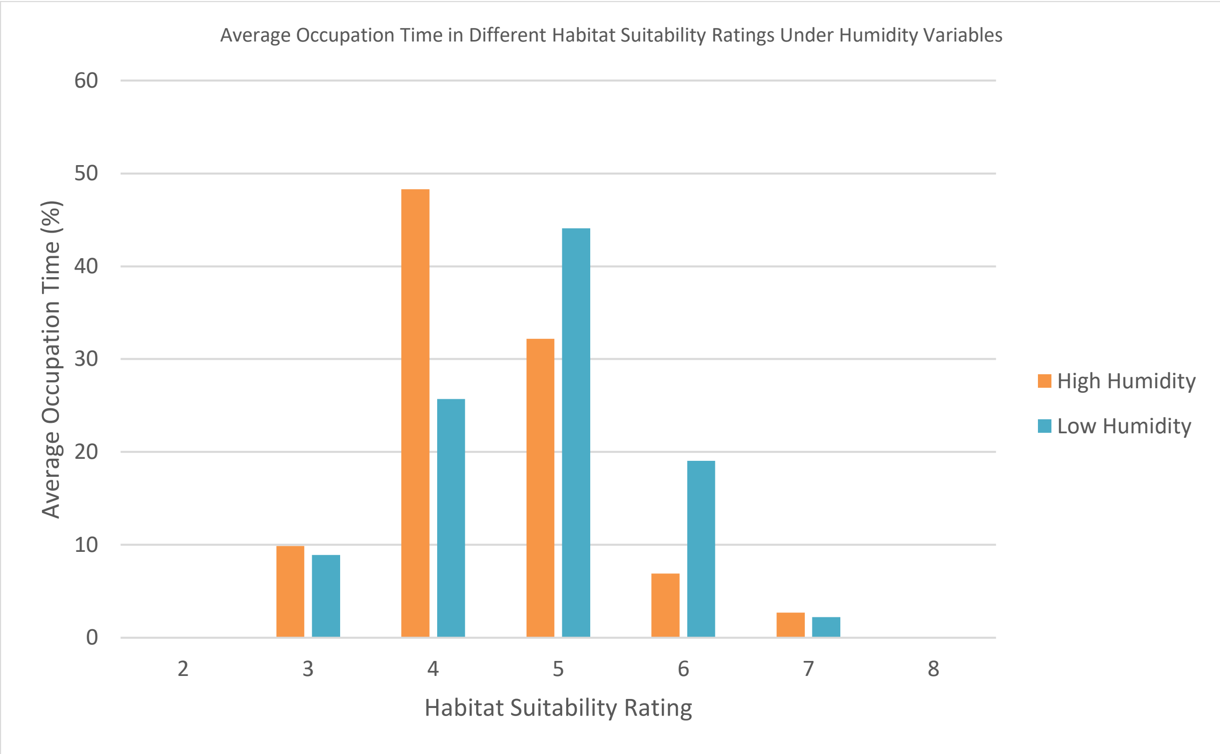
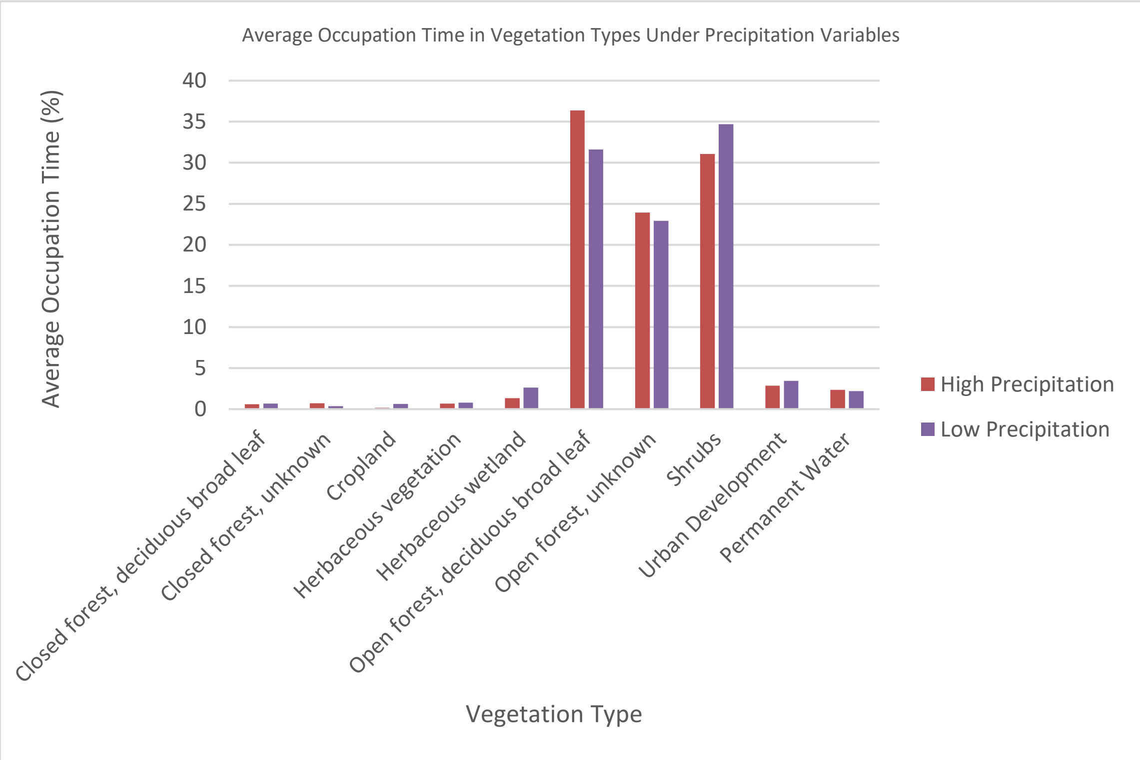


Figure 5: The occupation time in (a) different habitats and (b) different categories of habitat quality during high (>70%) and low (<30%) humidity levels.

There was a significant difference in elephant use of habitats in high and low humidity conditions when all data across individuals were pooled (x^2 = 28.588, d.f. = 9, p = 0.0008, Figure 5a). Differences included lower use of herbaceous wetland but higher use of open forests in high humidity. Similarly, there was a significant difference in the quality of habitat used in high and low humidity levels (x^2 = 14.548, d.f. = 6, p = 0.0231, Figure 5b). Differences included a general increase in use of lower quality habitat in high humidity.

a)



b)

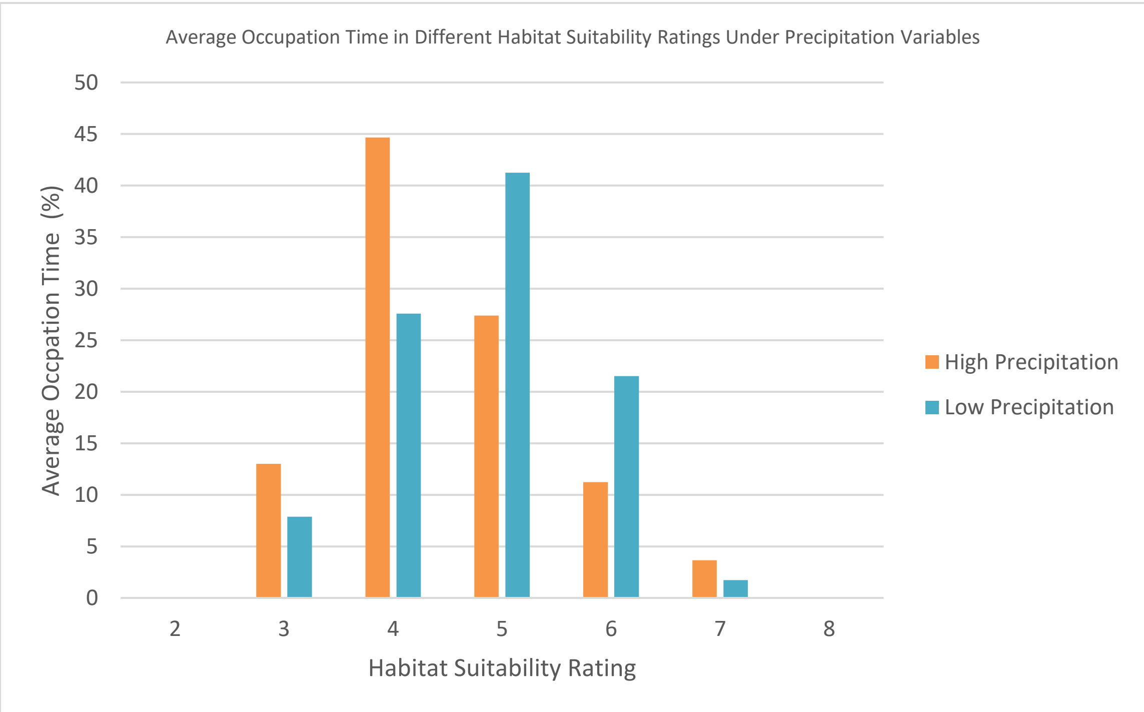


Figure 6: The occupation time in (a) different habitats and (b) different categories of habitat quality during high (>5mm) and low (0mm) precipitation levels.

There was a significant difference in elephant use of habitats in high and low precipitation conditions when all data across individuals was pooled (x^2 = 581.429, d.f. = 9, p = <0.0001, Figure 6a).

Differences included lower use of shrubs and herbaceous wetland and higher use of open forests during periods of high precipitation. There was a near significant difference in the quality of habitat used in high and low precipitation levels (x^2 = 12.036, d.f. = 6, p = 0.0621, Figure 6b) where differences included general increase in use of lower quality habitat in high precipitation.

5.4.2 Individual averages of occupation time in different habitats in response to climate extremes

Elephants CH91, CH93, CH94, CH95, CH96, CH97 and CH98 all showed significant differences in habitat use under the three different climate extremes (p=<0.0001). Elephant CH99 showed significant differences between habitat use under humidity and precipitation scenarios (p=<0.0001) but not between temperature extremes (p=0.255). The Chi-square value, degrees of freedom and significance values for all individuals can be found in A1/Table 3 of the Appendix.

The figures below are examples from three elephant individuals.

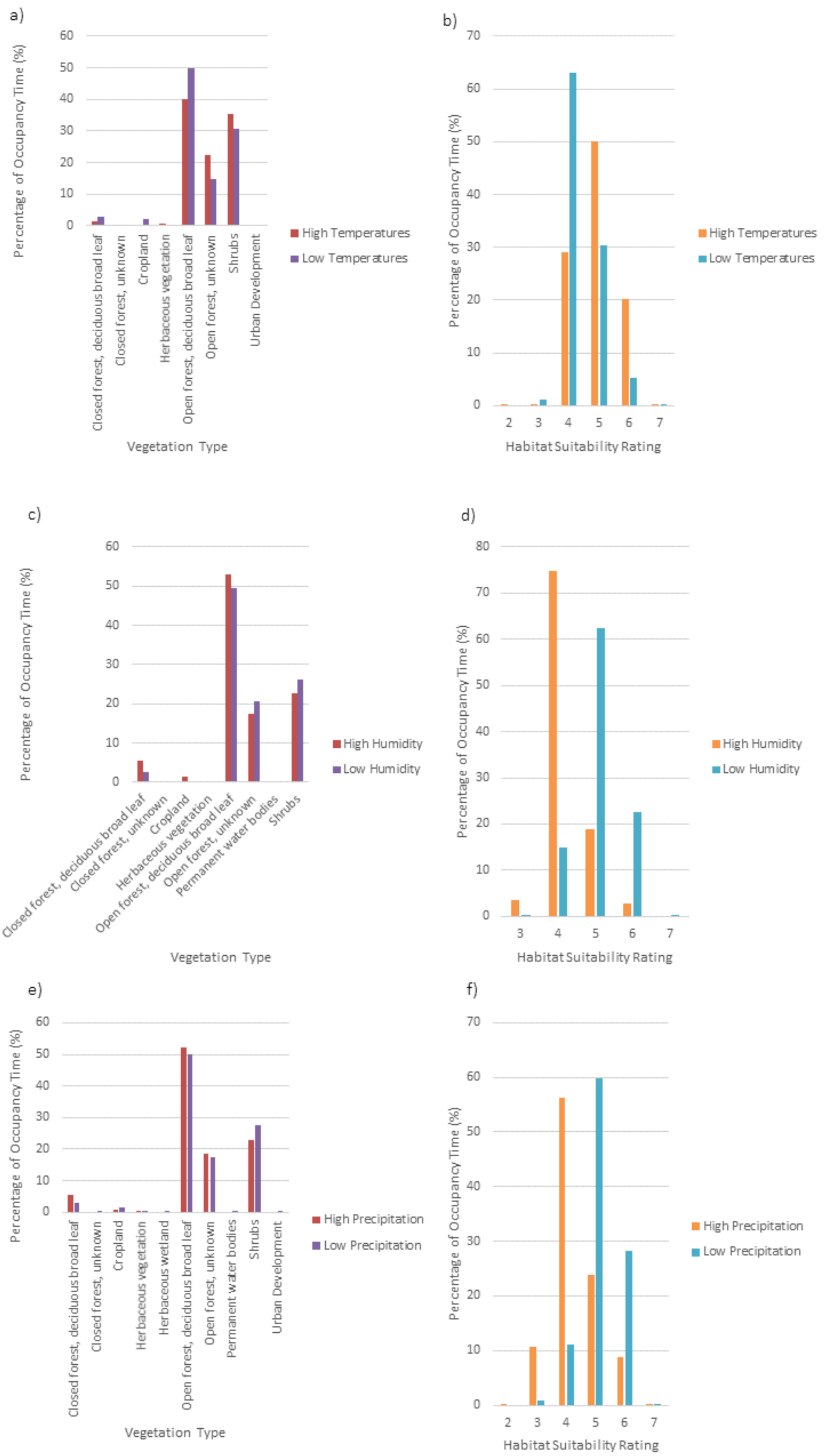


Figure 7: The occupation time of elephant CH93 (from the eastern site) in different habitats and different categories of habitat quality during (a) high (b) low temperatures, (c) high humidity, (d) low humidity, and (e) high precipitation, (f) low precipitation levels.

There was a significant difference in CH93's use of habitat types in high and low temperature levels (x^2 = 157.964, d.f. = 7, p = 0.0008), high and low humidity levels (x^2 = 92.227, d.f. = 7, p = <0.0001) and high and low precipitation (x^2 = 28.482, d.f. = 9, p = <0.0001). Differences included lower use of shrubs in high humidity and low precipitation and higher use of shrubs and unknown open forest in high temperatures.

There was a significant difference in CH93's use of habitat quality in high and low temperature levels (x^2 = 779.058, d.f. = 4, p = <0.0001) where higher quality habitat was used in high temperatures, high and low humidity levels (x^2 = 2309.854, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 2686.711, d.f. = 5, p = <0.0001) where lower quality habitat was used more during periods of high humidity and low precipitation.

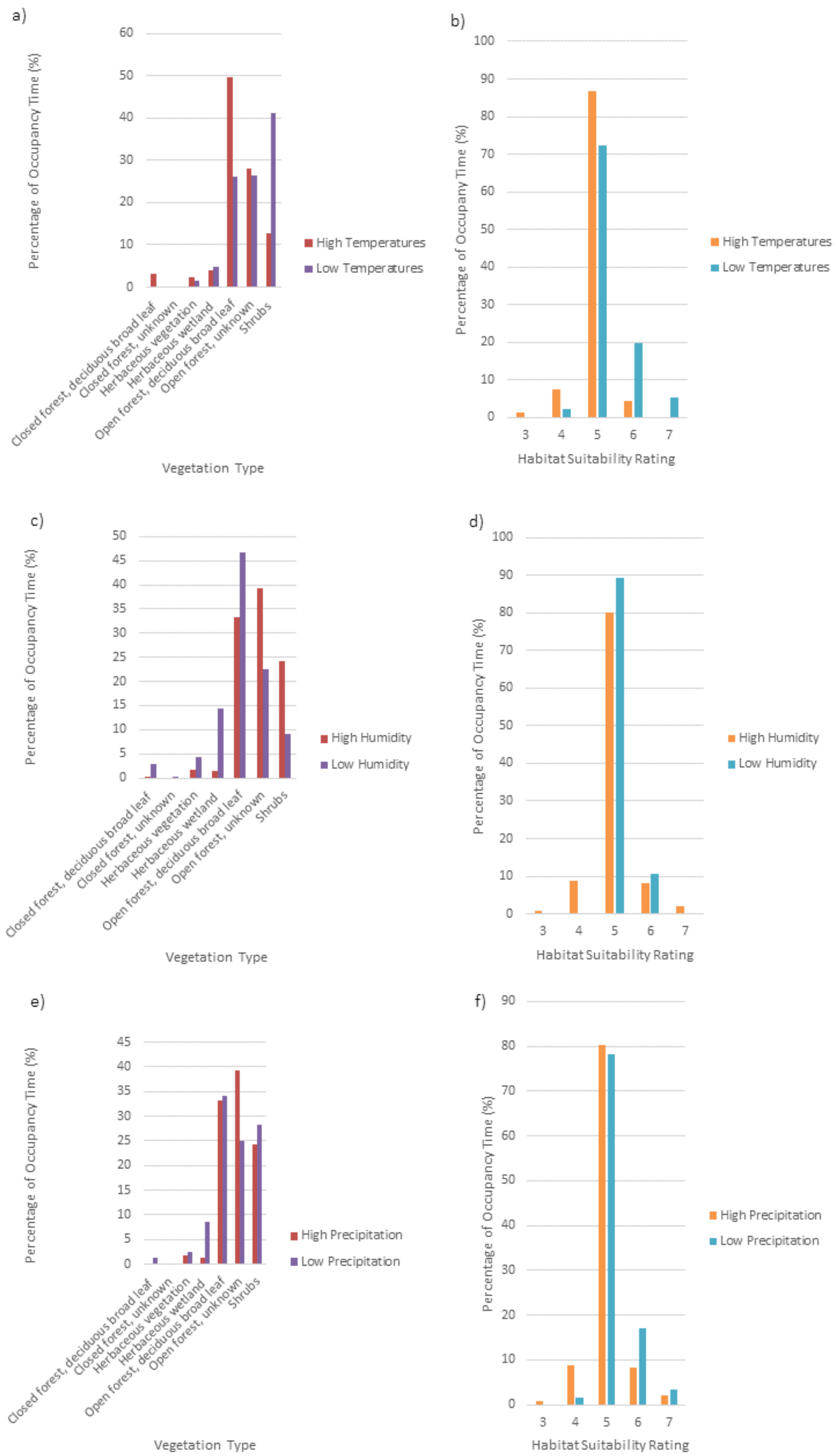

a)
Percentage of Occupancy Time (%)
60
50
40
30
20
10
0
Closed forest, deciduous broad leaf
Closed forest, unknown
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Temperatures
Low Temperatures
b)
Percentage of Occupany Time (%)
100
90
80
70
60
50
40
30
20
10
0
3
4
5
6
7
Habitat Suitability Rating
High Temperatures
Low Temperatures
c)
Percentage of Occupancy Time (%)
50
45
40
35
30
25
20
15
10
5
0
Closed forest, deciduous broad leaf
Closed forest, unknown
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Humidity
Low Humidity
d)
Percentage of Occupancy Time (%)
100
90
80
70
60
50
40
30
20
10
0
3
4
5
6
7
Habitat Suitability Rating
High Humidity
Low Humidity
e)
Percentage of Occupancy Time (%)
45
40
35
30
25
20
15
10
5
0
Closed forest, deciduous broad leaf
Closed forest, unknown
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Precipitation
Low Precipitation
f)
Percentage of Occupancy Time (%)
90
80
70
60
50
40
30
20
10
0
3
4
5
6
7
Habitat Suitability Rating
High Precipitation
Low Precipitation

Figure 8: The occupation time of elephant CH98 (from the northern site) in different habitats and different categories of habitat quality during (a) high and (b) low temperature, (c) high humidity and (d) low humidity and (e) high and (f) low precipitation levels.

There was a significant difference in CH98's use of habitat types in high and low temperature levels (x^2 = 657.035, d.f. = 6, p = <0.0001), high and low humidity levels (x^2 = 556.565, d.f. = 6, p = <0.0001) and high and low precipitation (x^2 = 243.196, d.f. = 6, p = <0.0001). Differences included more time being spent in open forests during times of high temperatures, high humidity and high precipitation with higher time spent in shrubs and herbaceous wetland during periods of lower precipitation. CH98s use of shrubs differed to CH93 as he spent more time in shrubs during periods of low temperatures, humidity and precipitation.

There was a significant difference in CH98's use of habitat quality in high and low temperature levels (x^2 = 548.259, d.f. = 4, p = <0.0001), high and low humidity levels (x^2 = 214.655, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 288.255, d.f. = 4, p = <0.0001) where lower quality habitat was used more during periods of high humidity and low precipitation as can be seen in the habitat use of CH93.

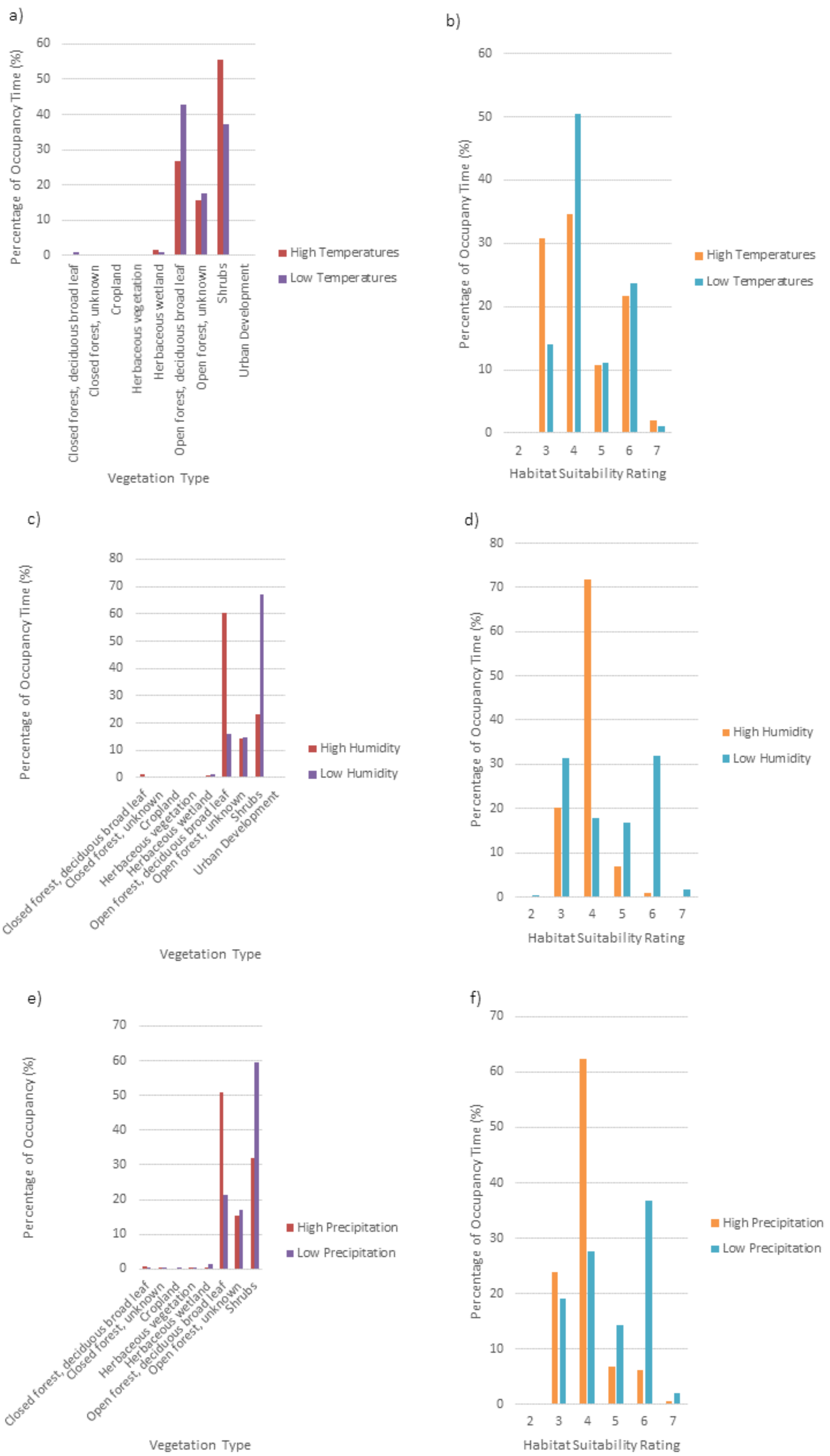

a)
Percentage of Occupancy Time (%)
High Temperatures
Low Temperatures
Closed forest, deciduous broad leaf
Closed forest, unknown
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Urban Development
Vegetation Type
b)
Percentage of Occupancy Time (%)
High Temperatures
Low Temperatures
Habitat Suitability Rating
c)
Percentage of Occupancy Time (%)
High Humidity
Low Humidity
Vegetation Type
d)
Percentage of Occupancy Time (%)
High Humidity
Low Humidity
Habitat Suitability Rating
e)
Percentage of Occupancy (%)
High Precipitation
Low Precipitation
Vegetation Type
f)
Percentage of Occupancy Time (%)
High Precipitation
Low Precipitation
Habitat Suitability Rating

Figure 9: The occupation time of elephant CH96 (from the northern site) in different habitats and different categories of habitat quality during (a) high and (b) low temperature, (c) high humidity and (d) low humidity and (e) high and (f) low precipitation levels.

There was a significant difference in CH96's use of habitat types in high and low temperature levels (x^2 = 693.774, d.f. = 8, p = <0.0001), high and low humidity levels (x^2 = 2285.861, d.f. = 7, p = <0.0001) and high and low precipitation (x^2 = 2336.605, d.f. = 7, p = <0.0001). Differences include higher use of shrubs and open forests with high temperatures and higher use of open forests with higher humidity and precipitation. Lower precipitation showed more use of shrubs.

There was a significant difference in CH96's use of habitat quality in high and low temperature levels (x^2 = 754.704, d.f. = 4, p = <0.0001), high and low humidity levels (x^2 = 3181.136, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 5087.319, d.f. = 5, p = <0.0001) where lower quality habitat was used more during periods of high humidity and low precipitation which is consistent across the three elephant individuals.

5.5 Discussion

This study followed the landscape use of eight elephants across habitats in Zimbabwe, Botswana, Namibia and Angola during periods of moderate to severe drought[2,3]. The three key variables predicted to increase in severity, especially in light of climate change induced drought are higher ambient air temperatures, lower precipitation levels and higher humidity percentages[23,36–38].

From these results, I can infer that elephants do use their habitat differently under different climatic conditions. While I predicted that elephants would spend more time in cooler (i.e., more insulated canopied forests) habitats during high temperatures, for which there is no evidence to date, they did seek open forests more often during times of high temperature and humidity. This suggests that open forest types are being utilised as refuges by elephants during hot conditions. As predicted, while each elephant individual had a nuanced response to the tested climate conditions, there were clear overarching patterns across individuals, herds and ecosystems.

While time spent in crops and urban development was minimal, there was evidence for elephants inhabiting human landscapes during extreme drought conditions. Human variables in the habitat suitability model, e.g., roads, urban development etc, are negatively weighted meaning that human spaces provide low quality habitat. During hot conditions, elephants spent more time in lower quality habitat (Figures 4a, 5a, 7c, 8a, 8c, 9a, 9c) providing further evidence that hot conditions are conducive to increasing occurrences of human-elephant conflict. However, Figures 6b, 7f, 8f and 9f indicate that elephants spend more time in mid-range habitat (5-7/10) during times of low precipitation. Consistently across the average and individual results, the occupation time in different habitats and habitat qualities is distinctly different between the two sub-variables of temperature/humidity and precipitation.

From these results, it can be predicted that the identified patterns in habitat use will both continue and become more pronounced under further extremes of each climate variable. It can be expected that with longer periods of higher ambient air temperature and higher humidity levels[39], elephants will spend more time in open forest types. With increasing periods between precipitation, elephants will spend more time in cropland, herbaceous vegetation and shrubs. Most of these ecosystem types represent natural and expected habitat for elephants, though large scale habitat use changes may cause long-term shifts in habitat structure[40–42]. There are many other factors that may contribute to how elephants utilise these habitats, including habitat use by other mega- and mesoherbivores[43]. The key result from this study is that there are significant differences in how elephants use their landscape under different climate extremes which underpins the concern that climate change will lead to changes in their behaviour. However, it is also concerning that under increasing drought conditions, particularly less precipitation, elephants may spend more time in cropland and within human-dominated landscapes.

Human-elephant conflict is a key issue in landscape management across elephant distribution in Africa. Much of this conflict stems from crop-raiding behaviour in elephants and the risk to both human and elephant lives when elephants enter local communities in search of resources[21,22]. During periods of drought, when the resources they need are already limited or depleted, this relationship becomes more strained as humans and elephants alike need both the water and the crops. Human development in regional Africa is likely to include crops for both food and agriculture which may explain increased occupation time of human dominated spaces during drought conditions. Incidents of crop and village raiding often end in injury or death for either the elephants or the humans[17,44]. As drought increases, so too will human-elephant conflict for resources. This is an economic, cultural and ecological issue that is highly likely to intensify and lead to additional hardships for both elephants and humans.

Many management strategies are in place across Africa to reduce or prevent human-elephant conflict. These include bee-hive fencing, education programs within communities and conservation fencing around protected areas[21,45,46]. While these programs are largely effective, many are short-term and do not account for likely changes in the relationship between elephants and their landscape in response to climate change. Some, such as conservation fencing, relieve the symptoms but not the problem and in turn put more pressure on protected areas and further distance the relationship between humans and elephants[21,47–49].

There is no single solution to this issue but in this thesis I argue for an ethical and philosophical push for a more community centred approach to wildlife management in Africa[50]. Given the relationship between humans and elephants changed during European colonisation from one of flexibility and mobility to one of competition and conflict[51], this is the key relationship in the landscape that needs to be repaired to help humans, elephants and landscape adapt to climate change induced drought.

A community centred approach means the meaningful inclusion and amplification of local voices in elephant management and respectful collaboration with national parks and protected areas to collaboratively tackle the issue. This collaboration and recentering of the management strategies can also be applied to the other patterns present in increased use, probably overuse of forests and foraging sites by elephants[52], in response to drought conditions. Elephants may also encounter issues in using open forests as heat refuges as forest ecosystems become more fragmented[53] and therefore smaller and less accessible. There is an exciting opportunity to combine Western and local knowledge and technologies to approach such landscape level challenges.

The most promising solution, which is anchored in a community-designed approach, is the introduction of wildlife corridors. By connecting key parts of elephant habitat across landscapes, mobility will be increased allowing better access to more forage and water resources[54,55]. This would require community-engagement and autonomy of decisions to be with communities that coexist with elephants but could allow for the establishment of more transfrontier areas which prove beneficial for communities, landscapes and wildlife[26]. For current managers of Protected Areas with elephants, I recommend developing a climate specific plan with local communities to help reduce human-elephant conflict and prioritising the needs of both people and wildlife.

This study has limitations, such as the number of study sites making it difficult to extrapolate this change in habitat use to elephant populations in eastern and western Africa. The study also does not contrast and compare against good or average weather conditions and governmental interactions with landholders in response to those conditions. I acknowledge that I have focussed only on drought but within the confines of a single chapter was unable to explore these options, especially given it was largely testing the remotely sensed data and analysis method, and encourage them to be the next steps in furthering this study. I have also only tested for three variables in isolation and there may be interactions between them. Some other variables may also impact the patterns of habitat use such as wind and dew point temperature. The sample size of individuals is also relatively small but the longevity of data for each elephant is clearly robust enough to cover long periods of drought. Further, while the GPS collar data comes from individuals, it is reasonable to assume that the data drawn from cows reflects the behaviour of a herd and not an individual. The mixed nature of locations and data periods shows patterns across space and time as opposed to within the same confines. Lastly, this study is limited by focussing more on individuals than populations. I was limited in being able to explore this because I did not have information available on herd status, social status or relationships between the elephants. While a comparison between the two 'regions' may have been useful, the data may have been skewed by the uneven distribution of location (i.e. 6 to 2) and individual results were provided to show the nuance between the elephant responses which is lost in population level summaries. However, I recognise that this leaves many opportunities for future directions in this research area.

This method provides a fast and simple way to calculate occupation time in different habitats and habitat quality with largely openly available data. Future research should consider this method for identifying habitat preferences, especially under the lens of climate change and expand our study to more elephant populations and ecosystems across Eastern and Southern Africa. This approach would also benefit from ground-truthing with local communities and elephant managers given appropriate funding and support.

5.6 Conclusion

As climate change continues to have varied impacts across African agricultural, cultural and ecological systems, it is critical to understand and be able to predict the impacts and trickle-down effects. This study has shown that for elephants in Southern Africa, increasing drought conditions are likely to lead to more overlap in space use between elephants and humans and potentially increased instances of human-elephant conflict. With elephants preferencing croplands in low precipitation scenarios, the competition for resources and risk of conflict will increase. Among other issues, such as overuse of sensitive habitats like open forests by elephants, this indicates rising tension in African landscapes because of climate change. I suggest it is critical to invest in community-based projects to manage these tensions and find a collaborative way forward that highlights adaptive management projects like wildlife corridors[53,55].

5.7 Acknowledgements

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Chapter 6:

Conclusions

6.1 Summary

African elephants are a charismatic keystone species with high cultural, ecological and economic value. My research examined how climate change, specifically drought, is a risk to their survival and how their response to changing conditions may impact local communities. Further, I examined the nature of research on elephants and the role of protected areas in elephant conservation, and highlighted current biases and the impact these may have.

This thesis assessed how elephants are susceptible to climate-change induced drought and how their movement and habitat use may change in response to a changing environment. Chapter 2 outlined how elephants are biophysically susceptible to drought from a cellular to a landscape level. Chapter 3 showed that the evidence base available to elephant managers is biased towards small elephant populations that may not be representative of elephants elsewhere and that climate change is not well represented in the literature associated with elephants. Chapter 4 shows that there is high habitat suitability for elephants outside protected areas and that smaller protected areas in IUCN categories 3-6 have the highest habitat suitability. This chapter also has a published output as an interactive habitat suitability dataset available through Geoscience Australia's Digital Earth Africa program. Chapter 5 shows that elephants do use their habitats differently under different climate extremes and use forests and human dominated landscapes more during drought conditions. I have shown that not only are elephants highly susceptible to drought but their behavioural response is likely to lead to increased instances of human-elephant conflict across elephant distribution.

6.2 Significance of research findings

As one of the first full bodies of work dedicated to understanding how climate change impacts elephants, the findings of my thesis have broad implications for elephant conservation and coexistence with local communities in human-dominated landscapes. The results of chapters 2, 3 and 5 can be used as evidence for researchers and managers. They show that climate change is a risk to elephant populations and that research and funding need to be redirected to focus on at-risk populations in under-represented areas. Chapter 4 provides evidence that protected areas are not necessarily the best elephant safe-holds and under a changing climate, human-elephant conflict is likely to increase across Africa.

The results from my combined thesis chapters provide important information, empirical evidence and recommendations that could be used to assist in the design and implementation of policy specific to climate change and community-based natural resource management in elephant conservation. I have also provided a freely available published tool through Digital Earth Africa that allows managers or those interested to create habitat suitability models for elephants (and other species) for areas of interest. The tool is interactive and adjustable which will hopefully assist spatial planning and management of landscapes across Africa as resources change as a result of climate change.

An unexpected direction and result of my thesis, particularly chapter 4, was the interrogation of the establishment, categorisation and maintenance of IUCN protected areas (PAs). Chapter 4 shows that high ranking PAs generally have lower habitat suitability than lower categorised PAs and smaller PAs often have higher habitat suitability. These results provide evidence for the need to reassess and further interrogate the roles of PAs in elephant conservation, especially in the future under a climate change scenario. Given the financial, governmental and spatial investment in PAs, this is a significant implication of my research and a potentially controversial point of discussion.

Critically, this thesis shows the need to further invest research, policy and funding into predicting and mitigating the effects of climate change on elephants across their distribution. It demonstrates that they are already responding to climate change which may lead to further instances of human-elephant conflict in landscapes already strained by resource depletion.

6.3 Limitations

The most significant limitation to this thesis was the lack of fieldwork and on-ground data to assess the analyses. Due to the pandemic and time restrictions on the submission of this thesis, fieldwork was not possible. While excellent data was kindly provided by on-ground collaborators (Elephants Without Borders), this is a project grounded in ecology which can often be refined and ground-truthed with fieldwork. However, given the unexpected pivot to remote sensing technology and necessity for a fully desktop-based PhD, I overcame many barriers to not being able to collect data in-person. By accessing data remotely, there was no need to collect data from communities or organisations and my thesis instead offered these stakeholders a free product to help them analyse a wide range of issues. While this does not account for not meeting people and building meaningful relationships, it was critical to overcoming the barrier of not being able to conduct fieldwork.

I also recognise that I work with the elephant meta-population in most chapters, and only use case studies in Chapter 4, so assumptions are made and applied to the full population which can lead to cases of generalisation. However, very little analysis has been done on the meta-population and my research contributes to finding and analysing landscape scale trends instead of focussing on a few populations (which chapter 2 shows can be problematic). Further, I have only focussed on drought as one of many components of climate change which includes other erratic or worsening weather events like floods and storms. I argue, however, that drought (as characterised by increasing occurrence and intensity of higher ambient temperatures and lower precipitation) is the primary climate risk to elephants as outlined in chapter 1. I believe this is grounds for providing evidence of elephant susceptibility to climate change and encouraging further research in the area to branch out to assess the effect of other climatic changes on elephants.

Lastly, I recognise that this thesis focusses mostly on the African savannah elephant (*Loxodonta africana*) and less so on the forest elephant (*Loxodonta cyclotis*). This is common practice in most African elephant research. The species are genetically and physically different and do not have overlapping ranges. Applying the results of this thesis, particularly on drought and human-elephant conflict, to forest elephants would be inaccurate and does not reflect the nuance of their distinct habitat interactions and behavioural differences. The species' do share some similarities, such as their dependence on water and population decline in response to habitat destruction but this is outweighed by how differently they interact with their environments, local communities and other species. While I recommend researchers also consider how climate change is/will affect forest elephants, there are more significant risks to their livelihood and survival than climate change whereas drought is already proving a stressor on the survival of savannah elephants.

6.4 Management Recommendations - Community-Based Management

For every chapter of this thesis, increasing human-elephant conflict as a result of climate change is a recurring issue and the overarching management recommendation is to invest time, finances and planning into community-based natural resource management (CBNRM). This thesis has shown that climate change is a risk to the viability of elephant populations and will put more strain on the relationship between humans and elephants. Here I conclude the thesis by outlining what CBNRM currently looks like in Africa, and how it may look in the future of elephant conservation.

Colonisation fundamentally changed the relationship between humans and elephants. In countries like Kenya, a formerly flexible and collaborative relationship between humans and elephants was turned into a binary model of human versus elephant[1]. As elephant habitat becomes more fragmented, resources become depleted in response to climate change and as human populations continue to grow, it is evident that a human versus elephant model is unsustainable and detrimental to both parties. As with many colonised continents, the value and success of local peoples' natural resource management is being realised in Africa[2]. The reintroduction of community-based natural resource management (CBNRM) is being heralded as a new ethical phase of conservation and as pressure on elephant populations increases, it is necessary to adapt conservation policy and management in the most effective and ethical way[2].

Colonisation is built into many conservation strategies in Africa. The historical establishment of protected areas in Africa works on the same premise as the establishment of national parks across the world – protecting land from humans by displacing them from it[3]. This is known as the Yellowstone

Model. It perpetuates the colonial notion that people are and should be separate from nature and assumes that humans have a negative impact on the landscape which justifies excluding them from it to protect landscapes[4]. In pre-colonial Africa, while there were areas set aside for agriculture, most landscapes functioned on a more holistic and integrated approach with wildlife and humans and under significantly less strain for resources[1]. For example, the pre-colonial tribes inhabiting the Maasai Mara region were partially nomadic[1]. While this was not implicitly to coexist with wildlife, it did create a flexible relationship between humans and wildlife[1]. As Britain colonised Kenya, the land was claimed as property of the British monarchy along with the wildlife[1]. Colonial administrators would only recognise land claims by agriculturists and pastoral groups and not hunter/gatherers which favoured tribes like the Maasai. This also effectively criminalised hunting[1], the life source of many tribes, and set the precedent for 'illegal poaching' punishable by incarceration or death which is the poaching system we know and admonish today[5]. The establishment of protected areas also set the premise for habitat fragmentation as land was set aside for conservation and cut off from other areas. This process served as a barrier between elephants and resources outside protected areas.

Criminalising hunting not only restricted cultural practices but stopped subsistence hunting and effectively starved hunter/gatherer tribes[1] and made them more susceptible to violence from pastoralist tribes. As with hunting, being in 'protected areas', regardless of their claim to them, became criminalised[1]. The first act of the former military officers in charge of establishing protected areas was to remove all humans from the landscape that they were ordered to 'protect'[1,6]. Since the British monarchy had laid claim to all land and wildlife, wardens were able to 'resettle' people from protected areas[1]. Those who were not complacent were forced onto trucks, had their huts burned down, tracked and arrested or gunned down in the parks[1]. This is how the relationship between humans and nature was fundamentally split into two and weaponised, when the relationship became "us" and "them" where "us" is local communities and "them" is Westerners and the land/wildlife they took with them as they colonised. Elephants often became an enemy as new generations of communities became accustomed to living in a landscape with less wildlife, while elephants would come and interfere with their crops and villages which were no longer adapted to that interaction[7]. This initiated the call to introduce conservation fencing, a process that became militarised[8].

The Yellowstone model focuses strongly on the assumption that protected areas and 'wilderness' are pristine and untouched by humans, which is antithetical to land-use by First Nations communities globally[4,9]. A parallel model to this is fortress conservation. This is the idea that the best option for land and biodiversity is to be protected from human disturbance by setting up a fortress around the area and calling it protected from humans[10]. In Africa, we see this implemented through fencing under the guise of conservation. Figure 1 shows the relationship between the Yellowstone model and fortress conservation. Fortress conservation is more successful in places like Europe where use of nature (i.e., not just recreation of nature) is not a core component of the culture[11]. However, in places like Africa where livelihoods are dependent on the direct use of nature, fortress conservation is instead a key component contributing to neo-colonialism, militarisation of conservation and enforcement of the Yellowstone model[9–11]. Fortress conservation runs on the premise that the only people who are allowed into protected areas (other than those 'protecting it') are tourists[10]. This has led to conservation areas becoming recreation space for wealthier people across Africa often to the exclusion of local people.

Fortress conservation has, critically, introduced militarisation of conservation areas and is described as green militarisation[6,8]. The militarisation draws from key colonial measures: military generals and ex-militia were the first park wardens and key strategists and tasked with the construction of protected areas and brought with them military tactics to be used against local people[8,12,13]. Further, anti-poaching units are predicated on military personnel, equipment and training[8].

Figure 1: the intersection of the two key pillars in establishing protected areas across Africa.

Poaching is also a side-effect of the fortress conservation model as the fences and fortresses can be justified through the notion of keeping poachers out and keeping wildlife safe within them. This has emphasised and prioritised the militarisation of conservation efforts in places like South Africa and has turned conservation into warfare between local people (often conflating subsistence hunting with illegal killing and associating local people with poachers)[5,14]. Today, most anti-poaching units in South Africa are under the leadership and management of ex-military officials[6,8]. Further, many anti-poaching teams consist of local people[6] and other Africans which sanctions violence between local people and the teams. The fractured relationship between local people and nature can become a complex issue of gatekeeping by the "us" in the "us" and "them" divide. It also allows the face of green militarisation to be Africans which, while exploitative, may make it more amenable when Africans are being paid for enforcing and, in theory, agree with the foundations of fortress conservation. There has been a resurgence of fortress conservation in response to the amplified poaching in the last decade[12]. From an ecological perspective, conservation fences further fragment habitat, inhibit natural migration of wildlife seeking resources, create edge effects and can lead to overpopulation of wildlife[15–19]. While they 'protect' local people from wildlife impacts, like crop-raiding, and 'protect' wildlife from poaching, they are a fallible solution that addresses a symptom and not a cause. They are a fortress of colonialism and not of protection as they are designed to appear.

The deconstruction of fortress conservation and the Yellowstone model lies in communities having autonomy over land and allowing movement and fluidity within, which is the broad area of CBNRM. CBNRM is defined by natural resource and landscape management being designed and implemented by First Nations communities[4]. Some of these programs in Africa, like CAMPFIRE (Communal Areas Management Programme for Indigenous Resources), have been running for several decades. While many of these projects make movements towards returning sovereignty and autonomy to local people, others are still under the influence of Western organisations and community engagement is tokenistic and exploitative[10,20]. For many organisations, especially those linked to ecotourism, CBNRM can include employing local people in low-level roles in the protected areas and running community outreach programs to nearby villages[4,20], in theory, to educate them about the protected areas and wildlife within. Neither practice gives back autonomy, profit and power to local communities so while palatable as a CBNRM model to some, they do not meet the basic premises of CBNRM.

CBNRM did not start as a management strategy but as a government experiment. In Zimbabwe in 1975, the government implemented the Parks and Wildlife Act where wildlife became communal property of people instead of state property[21]. Further, the legislation stated that if a private landholder is able to fence the perimeter of their property, then any wildlife that is within or breaches the perimeter belongs to the landowner[21]. In the 1980s, landholders (particularly agriculturalists) could earn more money from the hunting and auctioning of wildlife than through livestock and agriculture[21]. This saw a large-scale shift in land use from agriculture to wildlife conservation[21]. Communities surrounding private land were not receiving any benefit while also losing local stocks of food supply. As a result, local districts of Zimbabwe were given the right to manage and benefit from wildlife that resided in community land[21].

This model held a lot of benefits for the community and for independence from colonial strongholds in the conservation sector. Other countries followed suit, namely Zambia, Malawi and Tanzania[22,23]. Namibia began designing and implementing CBNRM models in 1996 having had 20 years to learn from the history of the movement and has gone on to become one of the leaders in the CBNRM space. After gaining independence from South Africa in 1990, Namibia became the first country in Africa to incorporate environmental protection into its constitution[24]. The government passed a law enabling communities to set up 'conservancies', giving them the right to manage and benefit from their own natural resources[24]. Since then, there has been a 47% increase in wildlife sightings in Namibia (since 2004), 132,000 km2 of land is protected under community-based models and there are 59 community-led conservation areas set up to protect wildlife[24]. The community conservancy program across Namibia is widely regarded as the highest standard of CBNRM on a country-wide basis and is often used as a prime example of cross-governmental and community collaboration in the conservation space.

The primary lesson learnt from the history of CBNRM deployment across Africa, especially as seen in Namibia, is that the only pragmatic and functional solution is if ownership belongs to the community and they receive full benefits from using wildlife on the land, be it through hunting, tourism or trade[2,25]. In other, more heavily colonised places such as South Africa, land use is still more contentious. Where Eurocentrism and anthropocentrism is most prominent, the value of nature is still below that of humans. In the hierarchy of land use, conservation and local community occupation are both residual land uses that conflict with each other[26]. These places, in particular, are the places where genuine CBNRM is needed the most for the survival of both wildlife and people but where there is the most resistance and difficulty in implementation.

Much like humans and landscapes, elephants stand a lot to gain from a return to CBNRM. With long lifespans, the ability to share intergenerational knowledge and high intelligence – there is the possibility that elephants will revert to past behaviours or routes (or an adapted variation thereof) in response to resource decline. For example, elephant matriarchs may lead their herds outside of protected areas in search of resources like water and high-quality forage. The elephants could follow their own routes that pre-date colonisation and human expansion, though many are likely to intersect with roads, urban development or other anthropogenic factors and lead to human-elephant conflict[1]. It is likely that local communities who have historically coexisted with elephants in that region may know or be able to predict these routes before human-elephant conflict arises. There is already evidence that elephants are moving further out of protected areas and into human spaces in search of resources in countries like Zambia where conservation fencing is less common[27].

The evidence of a colonial divide between elephants and humans is prevalent and the relationship between humans and elephants has, in some places, become violent and combative[1]. To understand where this relationship can be made more positive and flexible, it is necessary to understand how CBNRM works well and where there are weaknesses. CBNRM has objective strength in being able to tap into generations of environmental and ecological knowledge built around and for the landscape that elephants inhabit, including the potential for knowing past migration and habitat use[23,24]. There is the perpetual caveat that colonisation destroyed the languages, stories and intergenerational knowledge that may hold this information so, in many places, it may not be available. However, CBNRM also increases quality of life for local people, provides meaningful employment and gives some autonomy back to people of their traditional land[23,28,29]. CBNRM, or a variation thereof, is already being implemented across Africa to varying levels of success such as the CAMPFIRE program in Zimbabwe and the community conservancy model in Namibia[21,24,30–32]. The core component that sets these programs apart is that local communities have full autonomy over wildlife and are allowed to treat wildlife as a financial resource. The idea of trophy hunting is becoming less palatable to some western people, but under community control, can be fully sustainable and profitable and allows communities to better integrate into a post-colonial economy and rebuild the community livelihood on their terms[23,28]. For many communities, cultural and sustenance hunting and the wildlife trade pre-dates colonisation and was a key part of livelihoods and is not a new concept[29]. There are now new applications to account for a new market that involves profiting from Westerners.

CBNRM does not have a singular application or definition across countries, localities and communities. There is location-specific nuance and many CBNRM projects are marred by power and politics, and many remain under state control. For example, in Zimbabwe, despite being one of the first nations to invest in CBNRM in the 1970s, there are problems with how much money goes back to government and rural district councils instead of back to the communities[21]. The issues of power and politics are not just enforced by Westerners but also federal and local governments who act as neo-colonial forces[30]. The reality of human-wildlife conflict in communities is if people cannot benefit from wildlife, they may kill them. Wildlife, especially large species like elephants, inadvertently cause harm to communities through crop-raiding, village raids or volatile interactions so the financial and physical cost of coexisting with them can be much higher than the cultural benefit of a post-colonial relationship[4]. CBNRM needs to be pivoted around incentivising communities to protect wildlife by providing them a direct way to profit from wildlife[2,25]. This means that land use for wildlife must be valuable, more so than agriculture or livestock[2] which circles back to how CBNRM projects were initiated in the first place.

True CBNRM requires investment in community control instead of state control and must become about community instead of power and politics[2]. The reality is that CBNRM may not be palatable to Westerners and can include trophy hunting, wildlife trade and profiting from wildlife[2,25]. This discomfort does not override the rights of Africans to exist in and manage their lands and wildlife, and there is no evidence to show that CBNRM leads to further wildlife population declines or unethical practices. Further, the resurgence of Green Militarisation in response to poaching is politically unstable and in the face of climate change, using wildlife can be favourable given communities have the opportunity to turn wildlife from an enemy into an asset and for wildlife conservation to be a valuable land use[2].

Importantly, dismantling the oppressive and unsustainable practices of fortress conservation and the Yellowstone Model requires philosophical reframing from an “us versus them” mentality regarding communities and Westerners to a collaborative effort working towards the same goal. This concept already exists as the South African concept of Ubuntu. Ubuntu is an African philosophy and value system that is largely regarded as a core cultural value in sub-Saharan Africa and pre-dates colonisation[33]. Ubuntu is pivoted on building and maintaining community and communal relationships rather than focus on respect and autonomy seen in most Western cultures[33]. While nuanced based on the location, the priority of Ubuntu is grounded in justice and mutual care and act towards a communal good[33]. The core concepts for CBNRM exist and are already entrenched in many African cultures, it is a lack of investment and support from governments and Westerners acting as a barrier to implementing Ubuntu in the wildlife conservation space.

To avoid exploitation and misuse of power, investment has to be in grassroots organisations. We need to support and incentivise grassroots organisations that are community initiated, managed and designed. This is the key to handing power back to communities and deplatforming the power and politics at play, especially taking power from the state and reinvesting it in communities.

Three key components need to be returned to communities in full for CBNRM to be implemented sustainably, ethically and meaningfully across Africa: knowledge, rights and benefit. Figure 2 outlines how these concepts relate to each other. Investing time, planning and finances into these components of landscape and wildlife management becoming fully community controlled is a critical step towards repairing the relationship between local communities and elephants, while also ensuring that repair is happening on the terms of local communities.

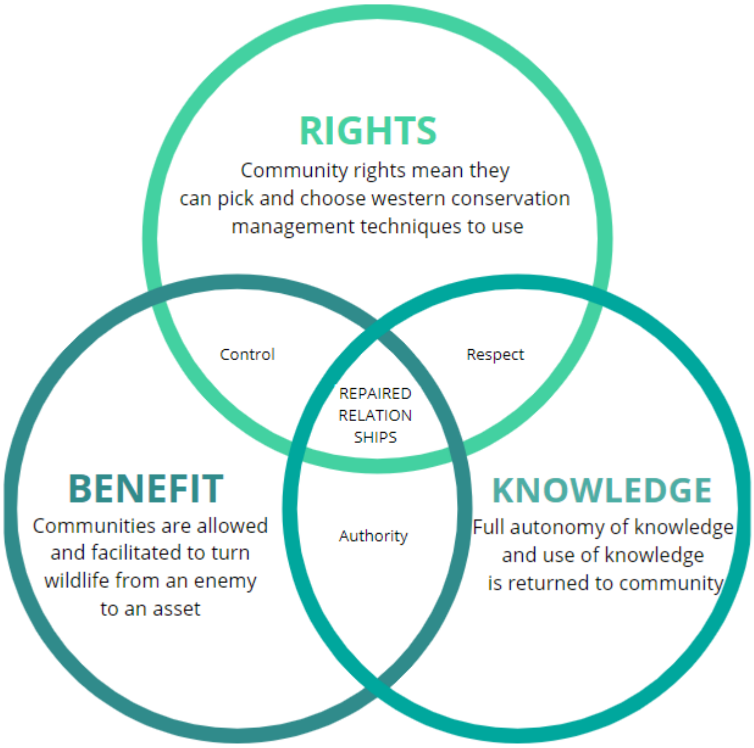

Figure 2: the relationships and intersections between the three main components that need to be returned to communities in order for CBNRM to work sustainability and ethically[34].

While CBNRM is pivoted around endorsing elephant and landscape management by local communities, it is not a clear-cut solution. Firstly, time and resources need to be dedicated to repairing the relationship between humans and elephants without the unsolicited influence of Westerners and federal governments and on the terms of local people[1]. This relationship will be key to the successful and meaningful integration of CBNRM into conservation of elephants in Africa. Secondly, local people must have full autonomy over the definition and implementation of CBNRM which is not necessarily the case for many protected areas claiming to implement CBNRM strategies[2,25]. Thirdly, there is still also an inherit “us” versus “them” mentality built into CBNRM between local people and Western management[4]. While Western management still reflects colonisation and associated historical issues, there are technologies and methods that can be brought into CBNRM that complement local knowledge and practices.

Lastly, it is essential to understand that decolonisation is not a metaphor[35]. As climate continues to shift and change African landscapes and alter the relationship between local communities and elephants, it is critical to manage elephant populations in the most sustainable, effective and ethical way which largely all leads back to the integration and adaptive implementation of CBNRM. However, the theory and philosophy of CBNRM is only meaningful if it ends in the act of giving land back[35]. This must be achieved academically, philosophically, physically and culturally.

6.5 Future Research

Based on the results of my research and the conclusions of my thesis, I recommend three directions for future research in elephant conservation to move forward.

Firstly, further research is required on how climate change can be accounted for and mitigated in a nuanced and effective way in elephant conservation and management. While I have identified and provided evidence for the problem, the implementation of management strategies and climate research specific to the most at-risk elephant populations will be critical in managing elephants under worsening climate scenarios. I recommend that this research draws from information we know about desert adapted elephants, while recognising that the adaption has occurred over several generations[36] and the rate of climate change is faster. However, climate change also intersects with several other primary causes of elephant decline like poaching, habitat fragmentation and human-elephant conflict so it is critical for climate change, or at least drought, to be considered in future elephant research.

Secondly, while this thesis focussed on African savannah elephants (*L. africana*), similar climate-associated issues are likely to be present within the *L. cyclotis* species and other large, charismatic species. This applies particularly to those that share the biophysical inhibition of not being able sweat and being heavily water-dependent, such as Rhinoceros (*Rhinocerotidae*) and Hippopotamus (*Hippopotamus amphibius*). I recommend that researchers working on African species, particularly mega-fauna, consider how drought will affect their species and the implications of this for their survival, their habitat and the species they coexist with. The habitat suitability model created as part of chapter 3 can act as a starting point for this by providing an opportunity to alter the inputs and create habitat suitability models for priority species. As aforementioned, while forest elephants are treated separately from the savannah elephants, they do share the inability to sweat and high dependence on surface water, so while they may not be affected by precipitation in tropical zones, increasing ambient air temperature and temporal changes in their habitat as a result of climate change may also prove a risk to their viability.

Lastly, this thesis points to a recommendation for wildlife conservationists regarding overall research direction. As shown, species like elephants are inherently linked to humans, regardless of their location, interactions or behaviour. Treating elephant, and other wildlife research, as isolated from humans (i.e., keeping ecology and society as separate topics and not considering both in studies) is not representative of the wider reality of that species and does not acknowledge the history of that species within their landscape and how their relationship with the landscape and people has or will change. While some aspects of wildlife biology, like biochemistry and physiology, can be considered separate from human interactions, it is likely that there is information within local communities that can contribute to understanding the factors influenced by humans. For example, stress chemicals in elephant dung fluctuate depending on their proximity to fences and roads[37]. Alongside my call to invest time and money into grassroots community-based management, I urge researchers to consider the role of colonisation in shaping landscapes, wildlife and the relationships and livelihoods of local people and how this affects the positionality of theoretical frameworks. In a time where anthropogenic climate change is one of the primary causes of wildlife decline, there is limited time and minimal margins for error in wildlife conservation and management and treating ecology and society as separate entities is now ineffective, unethical and not reflective of the reality of African landscapes.

I recognise that I fall short in meaningfully contributing to the building and maintenance of relationships with local communities, which was a significant portion of the original plan for this thesis, but those relationships must be created in-person and on the terms of the communities which was restricted by the pandemic restricting fieldwork. I hoped instead to be able to provide them with a freely available product and support from within the academic community to invest in CBNRM. In the future, I aim to build these relationships and provide my skills to these communities to bring more integrity to my work and practice what I preach.

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Appendix 1

A summarised version of my literature review (Chapter 2) was published in *The Conversation* and can be accessed here. Below is a copy of the article.

THE CONVERSATION

Academic rigour, journalistic flair

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Climate change is leaving African elephants desperate for water

Published: January 6, 2023 7.36am AEDT

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African elephant numbers have dropped from about 26 million in the 1800s to 415,000 today. While this is largely due to European colonisation, poaching and habitat loss, these majestic animals now face another grave challenge.

Climate change is causing droughts in much of Africa to become longer and more severe. This damages elephant habitats and denies them the water they need. Due to their unique physiology, African elephants need hundreds of litres of water each day to survive.

The African savanna elephant is listed as endangered. If the situation doesn't change, Africa – indeed, the world – may lose one of its most iconic animal species.

The carcass of an elephant discovered this year. It is suspected to have died due to the ongoing drought in Kenya. DANIEL IRUNGU/EPA

A tragic plight

Elephants are not just important for their ecological, cultural and economic value. They are also a keystone species – that is, they help hold ecosystems together. This means their decline has far-reaching consequences.

Many African ecosystems pivot around the lives of elephants. Elephant feeding habits, such as pushing over trees and peeling off bark, can turn woody vegetation into grasslands. This makes room for smaller species to move in. Their digging for water in dry riverbeds creates water holes other animals can use. And as they migrate, elephants help spread seeds in their dung.

Under climate change, long, intense droughts across southern and eastern Africa are escalating. Some have lasted more than 20 years.

The conditions have left many elephants desperate for water. Research as far back as 2003 shows elephants in Zimbabwe were dying during drought. And in 2016, when a drying El Nino weather pattern hit southern Africa, there were reports of more elephant deaths, prompting a local conservation group to drill bore holes to provide relief.

Drought can also reduce the availability of food, causing elephants to starve. It can also mean young elephants die or don't develop properly, because their parched mothers produce less milk.

Read more: Rumble in the jungle: an ear to the ground can tell us how elephants are faring in the wild

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Drought can mean young elephants don't develop properly. Attila Balazs/EPA

A unique physiology

So, why do elephants struggle in drought and heat?

When elephants experience high internal temperatures, it can disrupt the function of cells, tissues and organs such as the liver and cause them to become sick and die.

Humans and other animals also suffer heat stress. But elephants are particularly vulnerable because they can't sweat it off.

The graphic below shows how heat accumulates and dissipates in elephants.

Heat accumulates through an elephants' natural metabolism and physical activity, as well as being absorbed from the environment.

But it does not always effectively dissipate. Elephants' thick skin slows heat loss – and their lack of sweat glands exacerbates this.

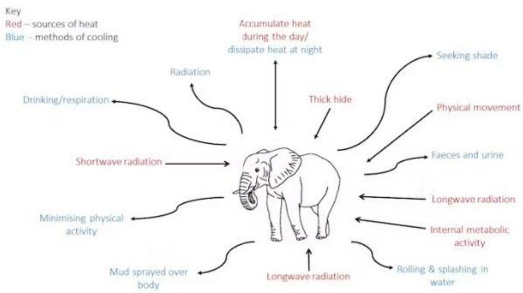

Figure 1: the sources of heat gain in elephants, how heat is retained, and how they dissipate heat.

What's more, elephants are the largest of all land mammals, weighing up to eight tonnes. They also have a large body volume – which generates heat – but a relatively small surface area (their skin) from which to lose this heat.

Water is essential for elephants to cope with heat. They swim and spray their skin with mud and water; the subsequent evaporation mimicks sweating and cools them down.

And elephants cool themselves internally by drinking several hundred litres of water a day.

Let elephants roam free

Creating artificial water sources is a common management intervention when elephants need water. This includes the use of pipes, bores and pumps.

But this measure can be problematic. Sometimes, the water is sourced from supplies needed by local people. And large numbers of elephants congregating around water can permanently damage the local environment and reduce food availability for other animals.

Historically, elephants migrated to water during drought. But the introduction of fenced areas in the landscape has disrupted this movement.

Fences were constructed to mark out colonial land ownership, separate people from large animals and deter poachers.

But as climate change worsens in Africa, elephants and other wildlife must be able to move freely between connected habitats.

Wildlife corridors may provide an answer. These are protected channels of vegetation that enable animals to move between fragmented patches of habitat. Wildlife corridors work well for megafauna in India and the United States and would likely increase mobility for much of Africa's wildlife.

Introducing more wildlife corridors, especially in southern and eastern Africa, would require removing fences. This change would have repercussions.

Nearby communities – which have not coexisted with elephants since colonisation – would have to adjust to the change. The removal of fences may also lead to an increase in poaching. And letting elephants roam the landscape may make them less accessible to tourists, which could reduce tourism revenue.

But communities have coexisted with elephants in the past. And community-based projects have been shown to reduce conflict between humans and wildlife. In some cases, they've also led to lower poaching rates and increased quality of life for communities.

Community management projects, such as in Northern Kgalagadi in Botswana, show how local expertise – drawn from millennia of experience and knowledge – can guide wildlife management. Research has shown successful outcomes – both socially and ecologically – in places where elephants share landscapes with people.

Read more: Africa's great migrations are failing but there is a solution - and you can eat it too

African elephants should be free to roam the landscape. Ben Curtis/AP

Protecting a keystone species

Ensuring African elephants survive drought will increasingly require new conservation strategies, including community-based management. Without this, already dwindling elephant populations will continue to decline.

This would be bad news for the health and stability of natural ecosystems in Africa – and a blow to Africa's people.

Appendix 2

The raw data used to analyse and calculate the results for Chapter 3.

Table S1. Research and populations by country.

Country	Total Population	Percentage of Total Population	Total Research Published	Percentage of Research
Botswana	131626	31.68	49	9.12
Zimbabwe	82630	19.89	52	9.68
Tanzania	50433	12.14	46	8.57
Kenya	22809	5.49	109	20.30
Namibia	22754	5.48	23	4.28
Zambia	21967	5.29	13	2.42
South Africa	18841	4.54	153	28.49
Mozambique	10884	2.62	8	1.49
South Sudan	7103	1.71	1	0.19
Burkina Faso	6850	1.65	7	1.30
Uganda	4923	1.19	5	0.93
Angola	3396	0.82	1	0.19
Benin	2984	0.72	9	1.68
Malawi	1307	0.31	2	0.37
Ethiopia	1017	0.24	8	1.49
Chad	794	0.19	1	0.19
Mali	253	0.06	2	0.37
Rwanda	88	0.02	0	0.00
Swaziland	42	0.01	1	0.19
Senegal	1	0.00	0	0.00
Eritrea	0	0.00	4	0.74

The most research on elephants published in the last 20 years was done in South Africa [28.5%] and Kenya [20.3%] while respectively having 4.5- and 5.5% of the total population. The countries with the highest elephant population are Botswana [31.7%] and Zimbabwe [19.9%] and have published 9.1- and 9.7% of research.

Table S2. Areas with the most research published.

Area	Total population	Percentage of population	Total research published	Percentage of research
Kruger National Park	17086	4.11	64	12.21
Other Private Reserves	2482	0.60	51	9.73
Laipikia-Samburu Ecosystem	6365	1.53	44	8.40
Northern Botswana	129939	31.28	44	8.40
Amboseli Ecosystem	1656	0.40	31	5.92
Hwange National Park	45846	11.04	28	5.34
Addo Elephant Park	595	0.14	21	4.01
Tsavo National Park	9504	2.29	20	3.82
Serengeti Ecosystem	6087	1.47	16	3.05
Etosha National Park	2911	0.70	14	2.67
Rest of Zambezi Valley	8200	1.97	14	2.67
Pilanesburg Provincial Reserve	240	0.06	12	2.29
Tembe Elephant Park	220	0.05	10	1.91

The areas with the most research on elephants being published in the last 20 years are Kruger National Park [12.2%] and Other Private Reserves [9.7%] which are all located around Kruger National Park and both are in South Africa and have 4.5- and 0.6% of the total elephant population.

Table S3. Areas with the highest elephant population.

Area	Total population	Percentage of population	Total research published	Percentage of research
Northern Botswana	129939	31.27834	44	8.396947
Hwange National Park	45846	11.03585	28	5.343511
Kruger National Park	17086	4.112867	64	12.21374
Ruaha - Runga Ecosystem	14284	3.438382	6	1.145038
Selous - Mikumi Ecosystem	14040	3.379647	9	1.717557
Zambezi Region	13116	3.157226	4	0.763359
Gornarezhou National Park	11120	2.676757	6	1.145038
Tsavo National Park	9504	2.287761	20	3.816794
Laipikia-Samburu Ecosystem	6365	1.532155	44	8.396947
Serengeti Ecosystem	6087	1.465236	16	3.053435
Luangwa Game Management Areas	5869	1.41276	1	0.19084
Jonglei National Park	5644	1.358599	0	0

The areas with the highest elephant population are Northern Botswana [31.3%] and Hwange National Park in Zimbabwe [11%] and have produced 8.4- and 5.3% of elephant research in the last 20 years.

Table S4. Fencing status of included areas.

Fencing status	Total population	Percentage of population	Total research published	Percentage of research
Fenced	31096	7.5	132	26.08695652
Partially fenced	268510	64.4	155	30.63241107
Unfenced	117529	28.2	219	43.28063241

The areas with the highest elephant population are partially fenced [64.4%] followed by unfenced [28.2%] and fenced [7.5%] have produced 30.6-, 43.3- and 26% of elephant research in the last 20 years.

Table S5. Management/ownership status of included areas.

Management status	Total population	Percentage of population	Total research published	Percentage of research
Publicly [government/state]	120563	28.9	266	52.56916996
Privately	25226	6	86	16.99604743
Joint	271346	65	154	30.43478261

The areas with the highest elephant population are jointly managed [65%] followed by publicly managed [28.9%] and privately [6%] have produced 30.4-, 52.6- and 16.9% of elephant research in the last 20 years.

Table S6. Management/ownership status of included areas.

Proportion of each country's elephant population that has not been researched in the last 20 years.

The areas with the highest elephant population are jointly managed [65%] followed by publicly managed [28.9%] and privately [6%] have produced 30.4-, 52.6- and 16.9% of elephant research in the last 20 years.

Country	Total number of areas	Total places without research	Percent of places without research
Namibia	6	1	16.66666667
South Africa	24	7	29.16666667
Botswana	3	1	33.33333333
Kenya	24	8	33.33333333
Tanzania	25	12	48
Malawi	8	4	50
Rwanda	2	1	50
Zambia	16	8	50
Benin	5	3	60
Swaziland/Eswatini	3	2	66.66666667
Uganda	12	8	66.66666667
Ethiopia	10	7	70
Zimbabwe	36	26	72.22222222
Angola	4	3	75
Mozambique	16	12	75
South Sudan	5	4	80
Burkina Faso	9	8	88.88888889
Chad	14	13	92.85714286
Eritrea	1	1	100
Senegal	1	1	100

Table S7: Count of the topic of research papers for the countries with the highest elephant populations

Botswana	Behaviour	11
	Climate Interactions	2
	Ecology	25
	HEC	8
	Poaching	1
Kenya	Behaviour	27
	Climate Interactions	5
	Ecology	27
	HEC	32
	Poaching	11
Mozambique	Behaviour	3
	Climate Interactions	0
	Ecology	1
	HEC	2
	Poaching	1
Namibia	Behaviour	12
	Climate Interactions	4
	Ecology	3
	HEC	3
	Poaching	0
South Africa	Behaviour	64
	Climate Interactions	6
	Ecology	66
	HEC	3
	Poaching	1
Tanzania	Behaviour	10
	Climate Interactions	2
	Ecology	15
	HEC	12
	Poaching	4
Zambia	Behaviour	1
	Climate Interactions	2
	Ecology	3
	HEC	4
	Poaching	3
Zimbabwe	Behaviour	7
	Climate Interactions	11
	Ecology	24
	HEC	7
	Poaching	3

Appendix 3

The full results and data informing the analyses in Chapter 5.

Table A1: The results of Chi-square tests run on each individual elephant testing the relationship between occupation time in either end of climate extremes.

Variable:	**Temperature**	**Humidity**	**Precipitation**
CH91			
Vegetation Type			
X2=	202.6644991	248.4287108	38.14629544
DF=	6	6	6
p=	< .00001	<0.0001	<0.0001
Habitat Suitability			
X2=	2622.763844	1230.219447	1295.812461
DF=	5	4	5
p=	<0.0001	<0.0001	<0.0001
CH93			
Vegetation Type			
X2=	157.963699	92.22692849	28.4819271
DF=	7	7	9
p=	<0.0001	<0.0001	0.0008
Habitat Suitability			
X2=	779.0572162	2309.854315	2686.710778
DF=	4	4	5
p=	<0.0001	<0.0001	<0.0001
CH94			
Vegetation Type			
X2=	27.63030527	248.4287108	38.14629544
DF=	6	6	6
p=	0.0001	<0.0001	<0.0001
Habitat Suitability			
X2=	1204.344713	1230.219447	51.9173523
DF=	5	4	5
p=	<0.0001	<0.0001	<0.0001
CH95			
Vegetation Type			
X2=	255.7868807	221.1808214	380.3138145
DF=	8	5	7
p=	<0.0001	<0.0001	<0.0001
Habitat Suitability			

X2=	592.203261	146.0082326	445.0908037
DF=	5	4	5
p=	<0.0001	<0.0001	<0.0001
CH96			
Vegetation Type			
X2=	693.7741547	2285.861111	2336.604857
DF=	8	7	7
p=	<0.0001	<0.0001	<0.0001
Habitat Suitability			
X2=	754.7038564	3181.135575	5087.318647
DF=	4	4	5
p=	<0.0001	<0.0001	<0.0001
CH97			
Vegetation Type			
X2=	99.10154872	208.7432611	230.5353069
DF=	7	7	7
p=	<0.0001	<0.0001	<0.0001
Habitat Suitability			
X2=	96.59430703	1075.493363	227.9864662
DF=	4	5	5
p=	<0.0001	<0.0001	<0.0001
CH98			
Vegetation Type			
X2=	657.0347864	556.5646978	243.1959482
DF=	6	6	6
p=	<0.0001	<0.0001	<0.0001
Habitat Suitability			
X2=	548.2597194	214.6555517	288.2549379
DF=	4	4	4
p=	<0.0001	<0.0001	<0.0001
CH99			
Vegetation Type			
X2=	6.568531534	77.29937441	1783.002242
DF=	5	5	5
p=	0.255	<0.0001	<0.0001
Habitat Suitability			
X2=	69.68130817	1336.772588	267.6082735
DF=	3	4	3
p=	<0.0001	<0.0001	<0.0001

Individual averages of occupation time in different habitats in response to climate extremes

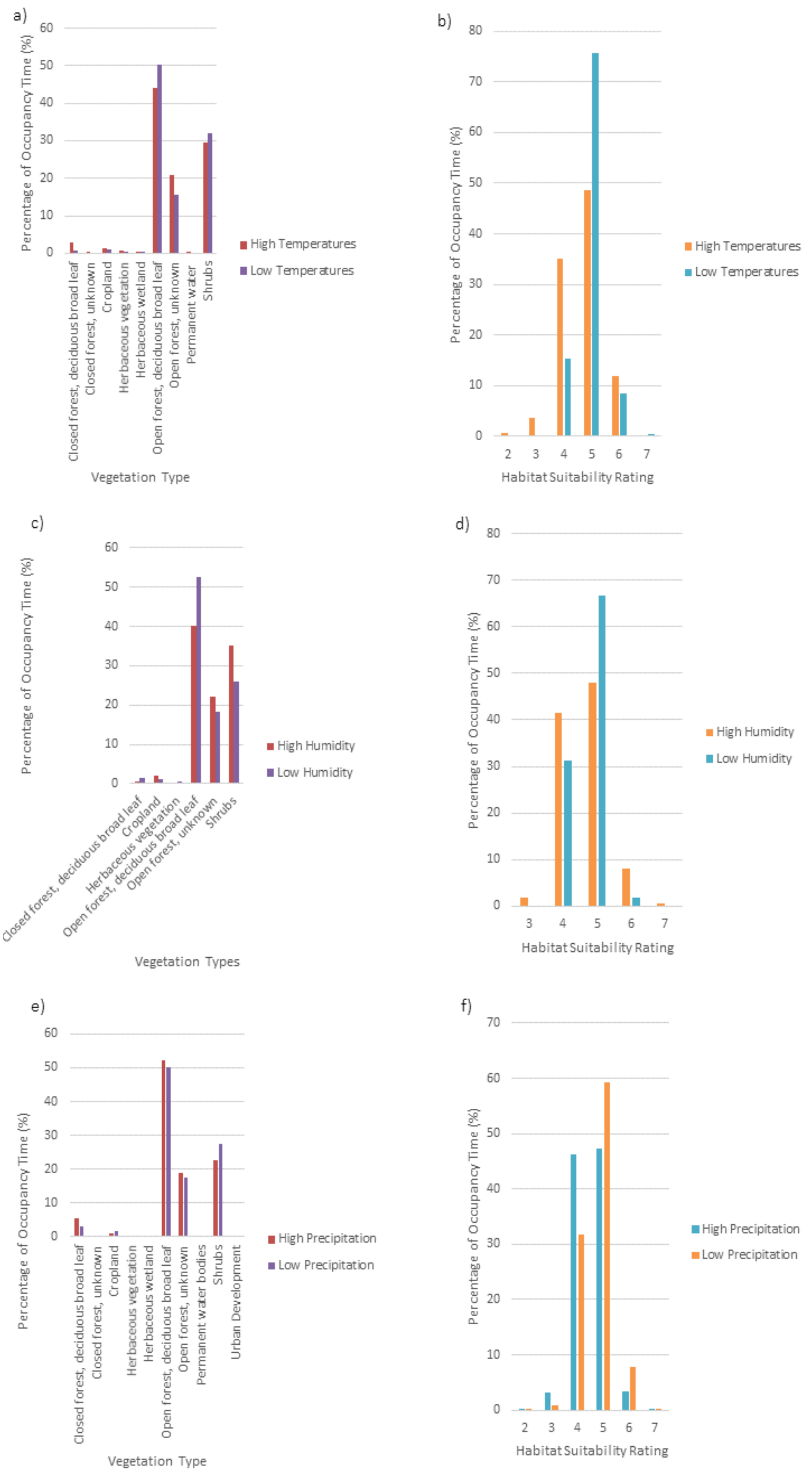

Figure A2a, A2b, A2c, A2d, A2e and A2f: The occupation time of elephant CH95 (from the eastern site) in different habitats and different categories of habitat quality during extreme high and low temperature, humidity and precipitation levels.

There was a significant difference in CH95s use of habitat types in high and low temperature levels (x^2 = 255.787, d.f. = 8, p = <0.0001), high and low humidity levels (x^2 = 221.181, d.f. = 5, p = <0.0001) and high and low precipitation (x^2 = 380.314, d.f. = 7, p = <0.0001).

There was a significant difference in CH95s use of habitat quality in high and low temperature levels (x^2 = 96.594, d.f. = 4, p = <0.0001), high and low humidity levels (x^2 = 1075.493, d.f. = 5, p = <0.0001) and high and low precipitation (x^2 = 227.986, d.f. = 5, p = <0.0001).

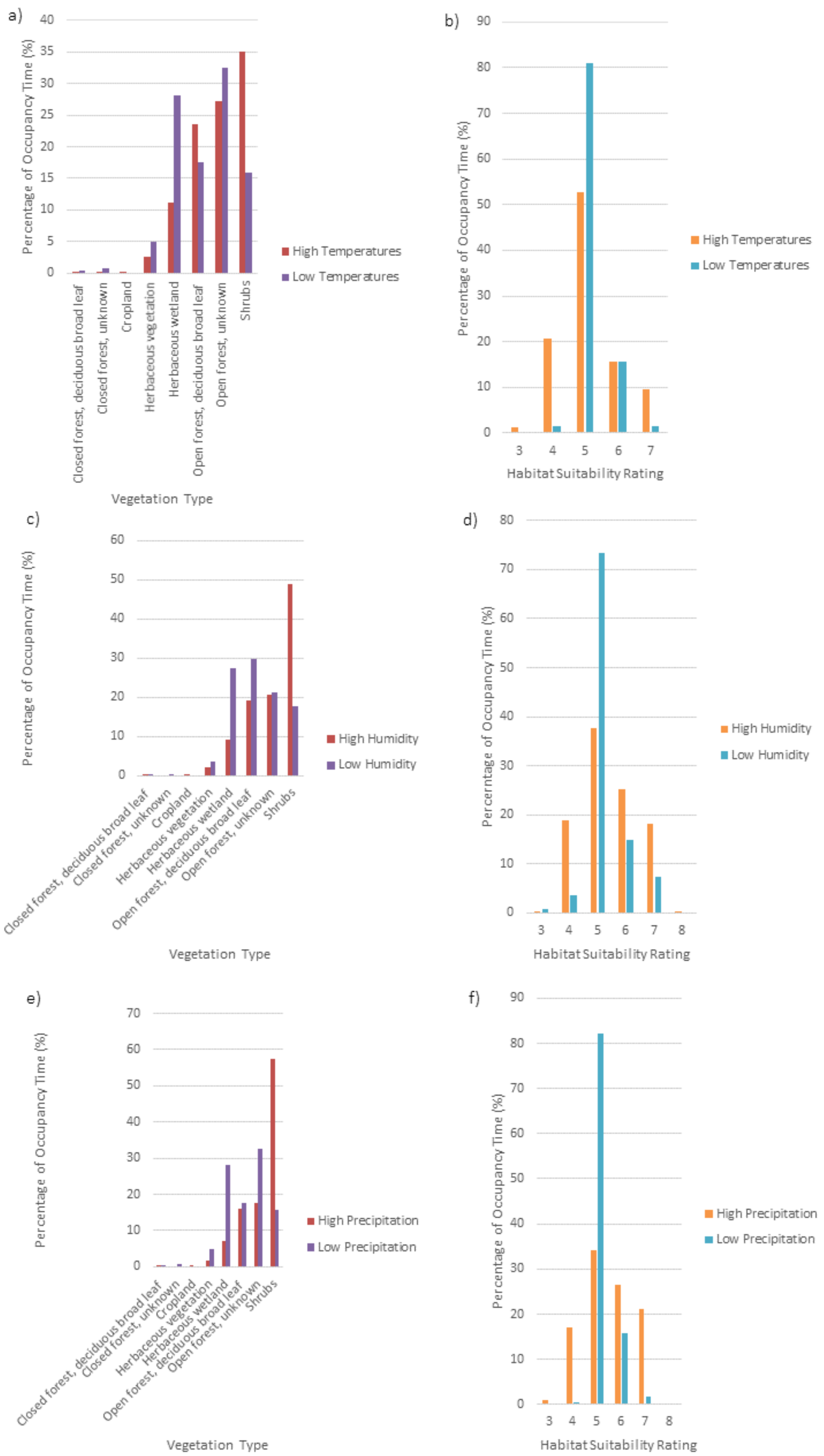
a)
Percentage of Occupancy Time (%)
40
35
30
25
20
15
10
5
0
Closed forest, deciduous broad leaf
Closed forest, unknown
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Temperatures
Low Temperatures
b)
Percentage of Occupancy Time (%)
90
80
70
60
50
40
30
20
10
0
3
4
5
6
7
Habitat Suitability Rating
High Temperatures
Low Temperatures
c)
Percentage of Occupancy Time (%)
60
50
40
30
20
10
0
Closed forest, deciduous broad leaf
Closed forest, unknown
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Humidity
Low Humidity
d)
Percerntage of Occupancy Time (%)
80
70
60
50
40
30
20
10
0
3
4
5
6
7
8
Habitat Suitability Rating
High Humidity
Low Humidity
e)
Percentage of Occupancy Time (%)
70
60
50
40
30
20
10
0
Closed forest, deciduous broad leaf
Closed forest, unknown
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Precipitation
Low Precipitation
f)
Percentage of Occupancy Time (%)
90
80
70
60
50
40
30
20
10
0
3
4
5
6
7
8
Habitat Suitability Rating
High Precipitation
Low Precipitation

Figure A3a, A3b, A3c, A3d, A3e and A3f: The occupation time of elephant CH97 (from the northern site) in different habitats and different categories of habitat quality during extreme high and low temperature, humidity and precipitation levels.

There was a significant difference in CH97s use of habitat types in high and low temperature levels (x^2 = 255.787, d.f. = 8, p = <0.0001), high and low humidity levels (x^2 = 221.181, d.f. = 5, p = <0.0001) and high and low precipitation (x^2 = 380.314, d.f. = 7, p = <0.0001).

There was a significant difference in CH97s use of habitat quality in high and low temperature levels (x^2 = 592.203, d.f. = 5, p = <0.0001), high and low humidity levels (x^2 = 146.008, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 445.091, d.f. = 5, p = <0.0001).

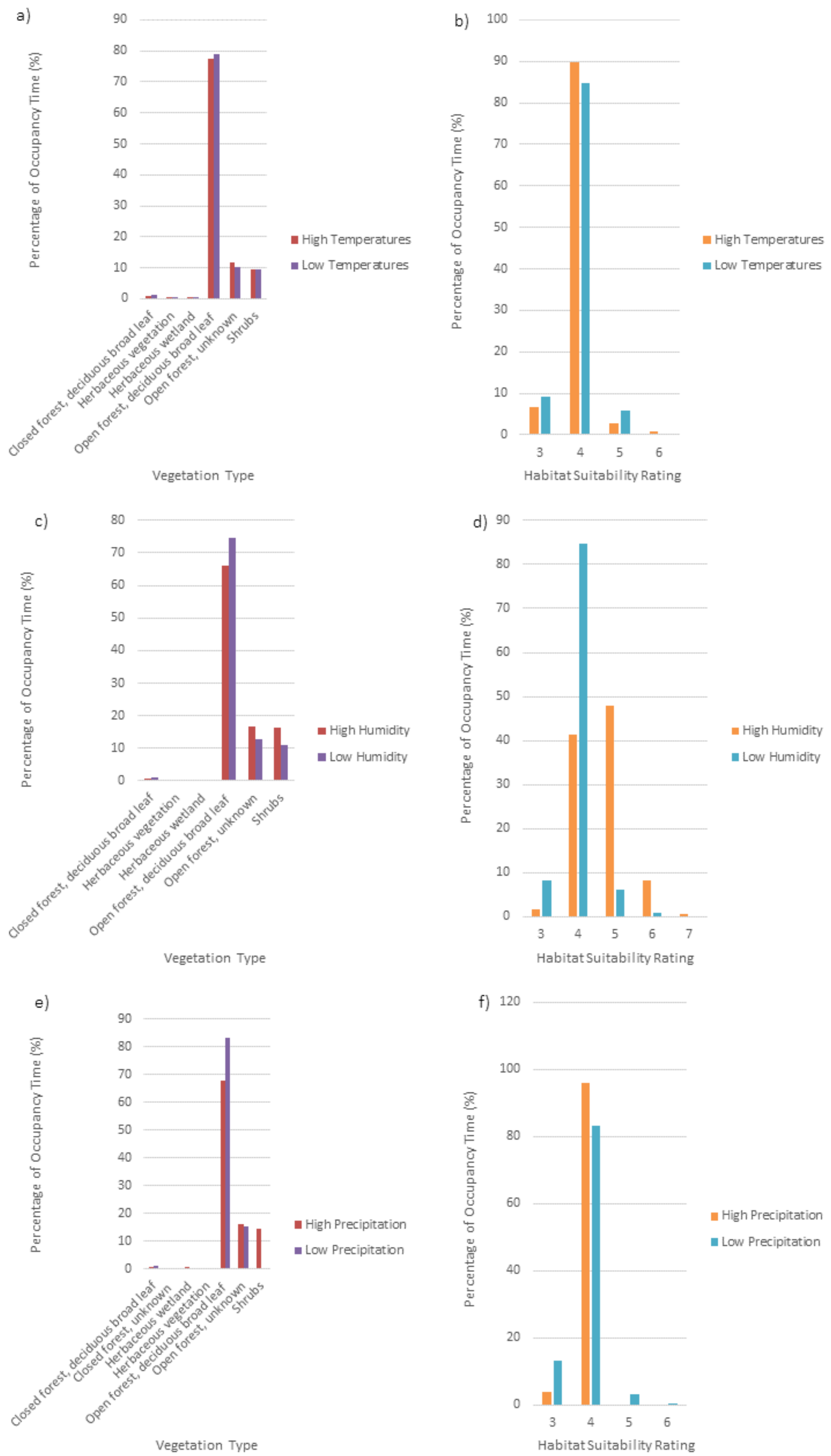
a)
Percentage of Occupancy Time (%)
Closed forest, deciduous broad leaf
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Temperatures
Low Temperatures
b)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Temperatures
Low Temperatures
c)
Percentage of Occupancy Time (%)
Closed forest, deciduous broad leaf
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Humidity
Low Humidity
d)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Humidity
Low Humidity
e)
Percentage of Occupancy Time (%)
Closed forest, deciduous broad leaf
Closed forest, unknown
Herbaceous wetland
Herbaceous vegetation
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Precipitation
Low Precipitation
f)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Precipitation
Low Precipitation

Figure A4a, A4b, A4c, A4d, A4e and A4f: The occupation time of elephant CH99 (from the northern site) in different habitats and different categories of habitat quality during extreme high and low temperature, humidity and precipitation levels.

There was not a significant difference in CH99s use of habitat types in high and low temperature levels (x^2 = 6.569, d.f. = 5, p = 0.255), high and low humidity levels (x^2 = 77.299, d.f. = 5, p = <0.0001) and high and low precipitation (x^2 = 1738.002, d.f. = 7, p = <0.0001).

There was a significant difference in CH99s use of habitat quality in high and low temperature levels (x^2 = 69.681, d.f. = 3, p = <0.0001), high and low humidity levels (x^2 = 1336.772, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 267.608, d.f. = 3, p = <0.0001).

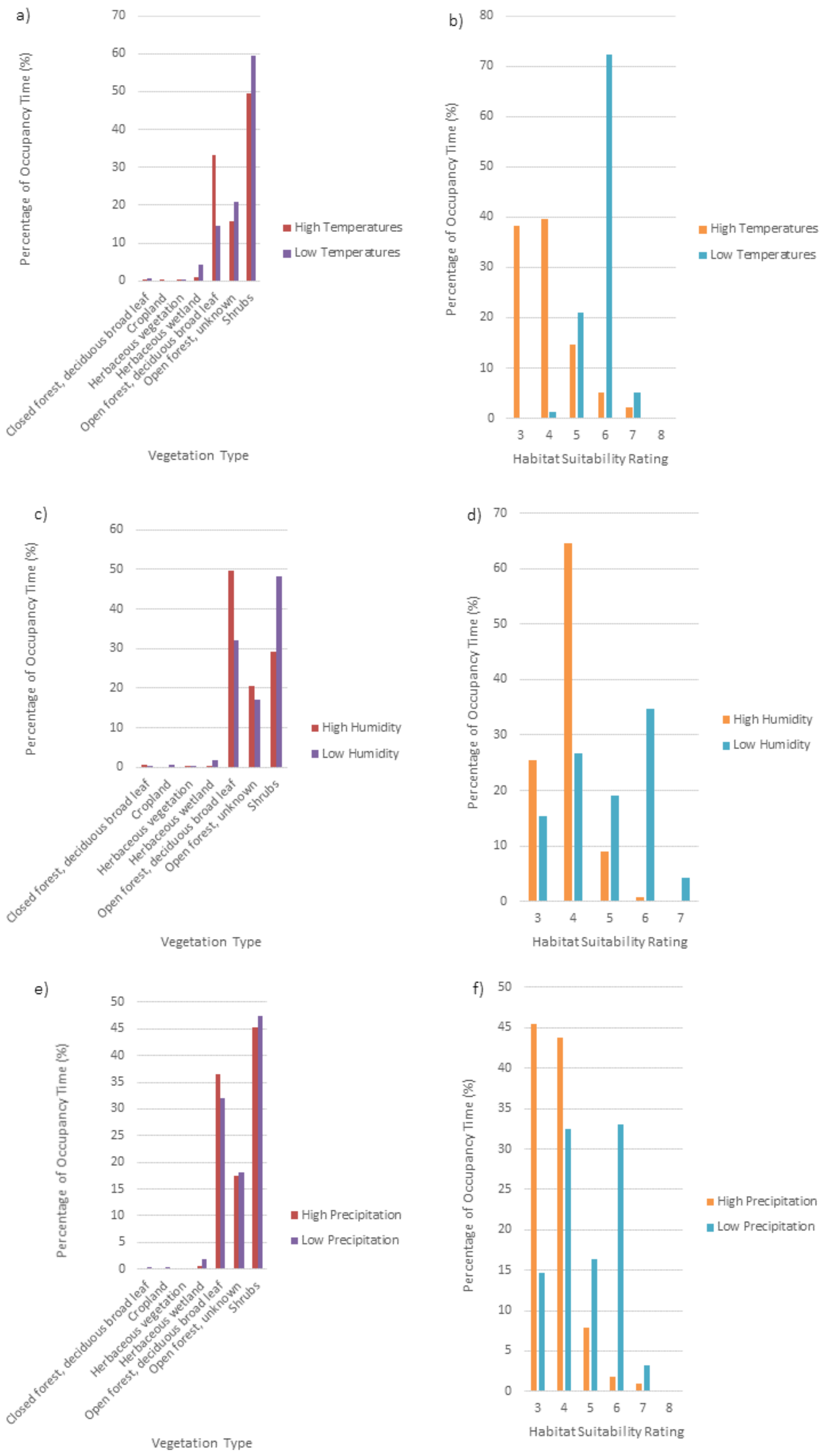
a)
Percentage of Occupancy Time (%)
Vegetation Type
Closed forest, deciduous broad leaf
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
High Temperatures
Low Temperatures
b)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Temperatures
Low Temperatures
c)
Percentage of Occupancy Time (%)
Vegetation Type
Closed forest, deciduous broad leaf
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
High Humidity
Low Humidity
d)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Humidity
Low Humidity
e)
Percentage of Occupancy Time (%)
Vegetation Type
Closed forest, deciduous broad leaf
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
High Precipitation
Low Precipitation
f)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Precipitation
Low Precipitation

Figure A5a, A5b, A5c, A5d, A5e and A5f: The occupation time of elephant CH91 (from the northern site) in different habitats and different categories of habitat quality during extreme high and low temperature, humidity and precipitation levels.

There was a significant difference in CH91s use of habitat types in high and low temperature levels (x^2 = 202.664, d.f. = 6, p = <0.0001), high and low humidity levels (x^2 = 248.429, d.f. = 6, p = <0.0001) and high and low precipitation (x^2 = 38.146, d.f. = 7, p = <0.0001).

There was a significant difference in CH91s use of habitat quality in high and low temperature levels (x^2 = 2622.763, d.f. = 5, p = <0.0001), high and low humidity levels (x^2 = 1230.219, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 1295.812, d.f. = 3, p = <0.0001).

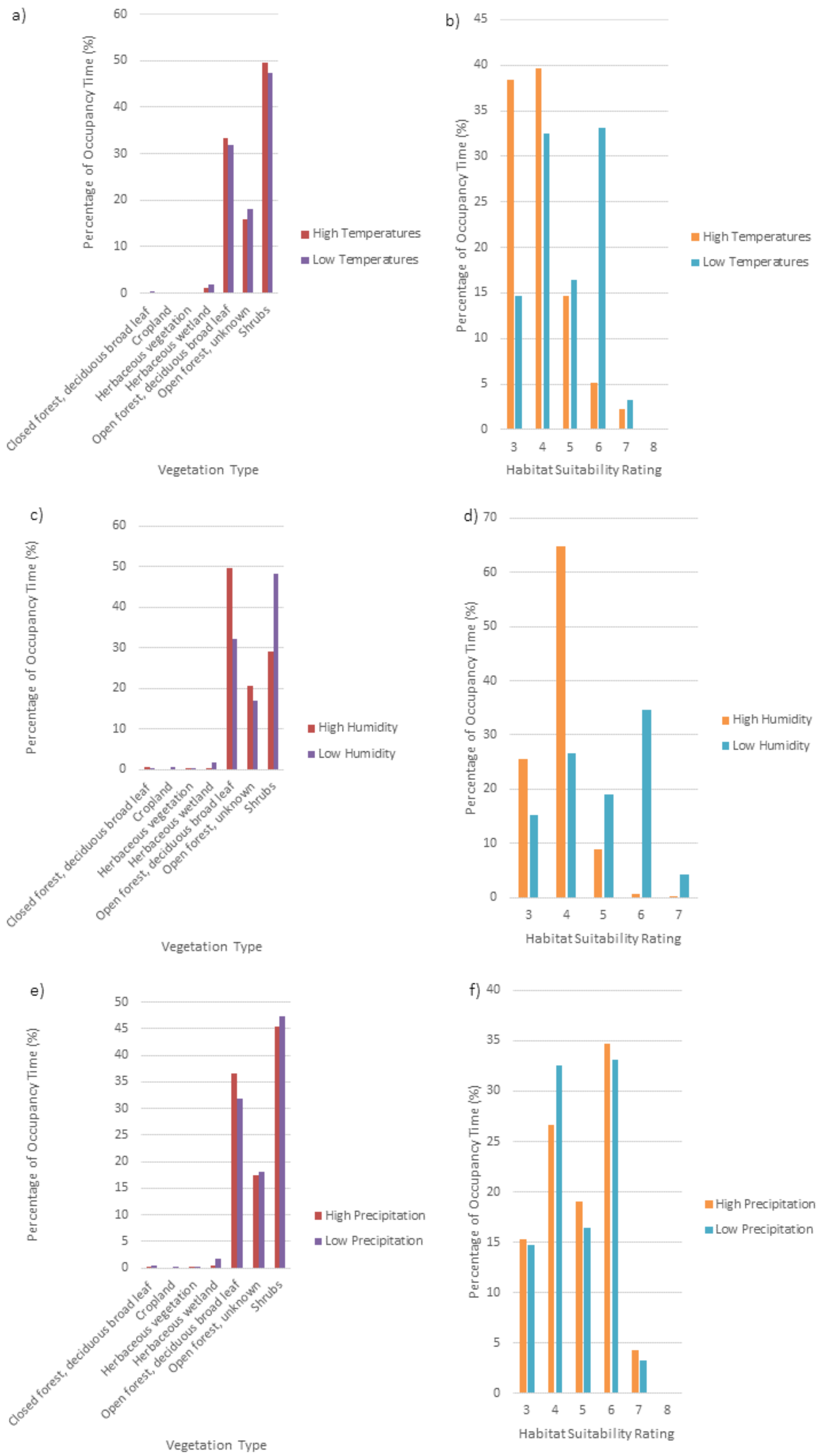
a)
Percentage of Occupancy Time (%)
Closed forest, deciduous broad leaf
Cropland
Herbaceous vegetation
Herbaceous wetland
Open forest, deciduous broad leaf
Open forest, unknown
Shrubs
Vegetation Type
High Temperatures
Low Temperatures
b)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Temperatures
Low Temperatures
c)
Percentage of Occupancy Time (%)
Vegetation Type
High Humidity
Low Humidity
d)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Humidity
Low Humidity
e)
Percentage of Occupancy Time (%)
Vegetation Type
High Precipitation
Low Precipitation
f)
Percentage of Occupancy Time (%)
Habitat Suitability Rating
High Precipitation
Low Precipitation

Figure A6a, A6b, A6c, A6d, A6e and A6f: The occupation time of elephant CH94 (from the northern site) in different habitats and different categories of habitat quality during extreme high and low temperature, humidity and precipitation levels.

There was a significant difference in CH94s use of habitat types in high and low temperature levels (x^2 = 27.630, d.f. = 6, p = <0.0001), high and low humidity levels (x^2 = 248.428, d.f. = 6, p = <0.0001) and high and low precipitation (x^2 = 38.146, d.f. = 7, p = <0.0001).

There was a significant difference in CH94s use of habitat quality in high and low temperature levels (x^2 = 1204.344, d.f. = 5, p = <0.0001), high and low humidity levels (x^2 = 1230.219, d.f. = 4, p = <0.0001) and high and low precipitation (x^2 = 51.917, d.f. = 3, p = <0.0001).

Appendix 4: Out of Africa

Below is my contribution to a book I am co-editing, called '*yindyamarra*: pursuing decoloniality in academia one School at a time.' The footnotes are comments by one of my reviewers, Adégbóyèga Adéníran, a colleague and Yòrùbá man.

Out of Africa by Rachael Bina Gross

Positionality: My identity and position in relation to decoloniality is something that has changed and strengthened as a result of my contribution to this publication, and my position as an editor for the collection. I am white, from a low socio-economic, single disabled parent family in rural NSW on Gundangara Country and have now lived on Ngunawal/Ngunnawal Country for many years. I am a conservationist, ecologist and science communicator and a settler. Bar one course during my undergraduate degree, I have no formal training in Indigenous cultural and natural resource management. My background is predominantly in Western biological and environmental sciences. Yet as my PhD goes on, it has changed to reflect the reality of working with nature – the only ethical and effective way forward is decolonial. While not the first in my family to go to university, I am the first in the last two generations to go on to do a PhD. And while I am well educated, through the sheer perseverance and sacrifice of my mother, my rural background has not been conducive to understanding or learning about anything to do with the Country I am or have been on. Coming from a public education system, I recognise I allowed and encouraged me to be ignorant, indoctrinated by colonial systems and actively contribute to the oppression of Indigenous peoples in both 'Australia' and Africa. Though I recognise that this shortfall, to put it lightly, also plagues the private education system. Above all, I now understand that I have responsibilities as a second-generation Shoah (Holocaust) survivor and am (now) proud of my Ashkenazi Jewish ethnicity. Both my grandparents, and the small remnants of their family, were refugees of the Shoah. My people were lucky to be taken in and defended by many Aboriginal communities. I acknowledge that I am white passing, fully abled, heterosexual and cisgender woman and have benefitted entirely from the privileges that provides. I say white passing because of how Jews' identity has been politicised and stripped of self-determination which is a uniquely not unique position to be in. I acknowledge that I can also take off my Magen David and be non-denominational passing as well. Taking off this symbol of Judaism is something that I did for many years. That is until I was quite far through this process for the book...and now I don't take it off.

I acknowledge that I live, research, teach, walk and survive on stolen land. Country stolen through the same *tree* of perpetrators who continue to instigate the ethnic cleansing and genocide of Jews. Comparing the Shoah to colonisation is harmful, reductive and detracts from the weight and impact of both events but is a testament to the reach and presence of the oppressive system we are in. Having been victim of antisemitism and hate crimes within my university, and the progressive city where I live, I recognise how insidious racism in academia can be. But I am very much shielded by my privilege. I recognise that most Indigenous academics are not. The dog whistles, harmful stereotypes and conspiracy theories are as present for minorities in academia as they are outside of it. And I can't begin to comprehend the extent of it behind closed doors for Indigenous and non-white scholars. This privilege as a white scholar in a colonial system has even allowed me to be an editor of this book, meaning I have the power to wield it as a weapon in a space that I don't need to fight very hard to be in, like my workplace in academia. I hope this piece shows just part of my journey in how the Fenner Circle changed my emotional and academic trajectory for me and strengthened my own identity and shaped my perspective of how our Ashkenazi obligation of *"never again"* goes far beyond my own people. I have chosen to footnote some of the comments from one of my reviewers, Adégbóyèga Adéníran, because I think they show that i) I still have a long way to go and ii) they add more information for the reader that is not my place to share. These comments are footnoted, and I have not made the changes suggested so as to keep their context.

Do better: During research for my Honours project in 2017, I was sent to KwaZulu Natal in South Africa to collect data on African elephants. I was not invited onto these lands or waterways by the Tembe and Thonga peoples who are the traditional custodians, yet I flew in and flew out with only one goal: to best understand how elephants are vulnerable and responding to climate change. I left with armfuls of data that I collected from "Tembe Elephant Park" and continued without question. I didn't even know the Zulu word for elephant, Indlovu. Before I arrived, I was warned about the racial divide of South Africa and how Apartheid was still fresh in the minds of the country. My supervisor was a "white South African" and spent months preparing me for the culture shock but did not forewarn me of the harm and perpetuation of neo-colonial[1] practices that parachute/colonial science, that I was practising, causes. While I sought out the opinions and knowledge of local people, namely the safari guides working for the in-situ "ecotourism" company, I neither paid them for their time and knowledge nor

[1] I would stick with colonial here because what is *perpetuated* is colonialism/coloniality. Neo, post, and other prefixes assume some kind of changes to the fundamental nature and order of things. Maybe for theoretical purpose (and we know how inadequate some theoretical concepts can be), but changes to strategies and techniques of domination, do not mean a change to the principle of domination itself. But feel free to choose the language you deem fit. I only refrain from those prefixes when describing historical forms of injustice and domination. I also believe it is one way that colonialism and academe make us believe that an era has ended e.g., post-modernism, post - colonial. Etc. It is untrue in the real world that colonialism or modernism has changed or ended, but it is real to the/some academics that they have ended.

engaged with them in a meaningful and respectful way. On reflection, the evidence of me not being meaningful or respectful or even engaging is abundantly clear. All I knew was that Tembe was the name of the local tribe (self-described as a tribe to me by Sakile, one of the local guides), and I knew the stakes they had in the park but nothing further than that despite being on their land for three months. It is worth saying that this is the information given to me by Tembe people working within the reserve, however there is little institutionally/academically verifiable information beyond this. However, much of South Africa was originally occupied by the San/Saan People, the original tribes, cultures and languages of southern Africa. The land was colonised by Europeans and subject to lateral violence and invasion by other southern African tribes.

In 2019, following a year to reflect on the damage caused by my previous research approach, I decided to continue with the topic in a PhD project with a new supervisor. From the previous supervisor, I had learnt a sense of entitlement to land and knowledge in South Africa, despite being a white "Australian". I did not question that I was turning up out of nowhere, having spoken to no locals to ask permission or to work with them and extracting data from a sacred place and a sacred species. This is a pitfall of academia, not just my supervisor. We have no one enforcing rules and guidelines about working on stolen land, in Australia or overseas. In fact, there are not even rules or guidelines to be enforced or breeched which is even more unsettling. While I questioned her perspective on the violent history and value of traditional knowledge, I did not hold myself accountable to the point of unlearning settler-coloniser behaviour or making reparations. We, as students, can sometimes assume our supervisors are morally aligned with us and are there to teach us to be the best version of ourselves. This is not necessarily the case and, certainly in my experience, we often do not have the tools or confidence to challenge our supervisors early on. Personally, I was so excited to be involved in the project that I was borderline blindly absorbing everything my supervisor did and said. I was wrong. It was wrong to not stop and question her authority, knowledge and positionality, and to assume only she knew best about how to navigate conservation issues involving colonial violence as a white person. By assuming that, we are susceptible to inheriting their mistakes and they become our own. It is our responsibility to break the supervisory chains and make reparations for them. Still, when I started my PhD I was on the same path as my Honours program in terms of not considering or meaningfully incorporating the Indigenous peoples.

My research in 2017 actively contributed to the oppressive academic tourism and systems of parachute and colonial science and as a result, the integrity and ethics of my research was compromised[2]. I was and had done wrong to the detriment of the Tembe and Thonga peoples. My experience of Honours feels bittersweet. I regret my approach, I regret my ignorance and I regret my choice in supervisor and weakness in not challenging her perspective. I did, however, find my niche and passion as a scientist - elephants.

During my PhD induction, we took part in a yarn with the Fenner Circle about their work in decolonising the academic process[3]. It was then that I first heard a meaningful Acknowledgement of Country. It was also the first time I had heard of a positionality statement. While I knew of the violent, colonial history of "Australia" and had participated in Invasion Day protests and other similar activities, I realised my allyship was surface level and performative at best. I didn't know that allyship fit into the decolonial space or was a philosophy inherent to my beliefs. It hadn't occurred to me that the decolonial philosophies I believed in could be applied to a space like my PhD. Or even that decolonisation was a word and philosophy. Meeting the members of the Circle and seeing how their research was pivoted around the disruption of colonial norms shifted how I perceived my own work and the system I work in. Importantly, seeing members apply what they were unlearning and relearning outside of "Australia" was a wake-up call. I ineffectively sat with the white guilt of benefiting from systems that actively oppress Indigenous peoples for a long time. I began to see how insidious and silent the system is and how I had contributed to it to the detriment of the Tembe and Thonga peoples, and to the peoples whose Country I lived and worked on. Even in a short time, the Circle had given me pause for thought. White guilt is not useful unless it is actioned on, and I think many people use it as a way to make colonisation about themselves. I wanted to put mine into useful and meaningful action. I wanted to use my white guilt as a driver for personal change and incorporate it into my relational accountability, not continue to sit in it and wallow in self-pity. I wanted to engage my white guilt as a construct of challenging myself and the system I am in.

After the yarn, I joined the Circle but mostly in the periphery. I had trepidation about joining the yarns as a novice and was apprehensive about making more mistakes or offending members of the wider community. The space of recognising, accepting and reframing white guilt into action and reparation is uncomfortable and at times, exhausting to see how much work is to be done. Initially this discomfort

[2] Comments like this requires some context of your knowledge space which I think is okay to acknowledge. Personal transformations require that we identify and name the different stages along a timeline of our growth or regression. You have described some of the existing conditions that precede this encounter with new, uncomfortable truths. Since this is about
personal journey and transformation, it would be good to see a little more of your state of knowledge. Other people should not assume who or what you were and how good or how bad things were. This I think is part of reflexive work.

[3] Here I see the value of spaces to encountering new truths and information. While this may be accidental in some ways, do you think it is something to encourage other to seek those kinds of spaces? The value of certain spaces and structures in shaping our understanding of injustices.

and inexhaustible task of decolonising felt like an insurmountable barrier to actively engaging in the Circle[4]. In modern "allyship" the guiding principles are to be quiet and listen, and don't take up space that an oppressed person could be filling and to not expect the oppressed to teach you about their oppression. The contradictions of wanting to help, make reparations and contribute but feeling like I was taking up space I shouldn't was the main barrier, alongside feeling inexperienced, to me engaging. Luckily, I have since been taught that in order to be a good accomplice, you need to be prepared to effectively and confidently stand up for oppressed people when they cannot be or are not there. That means being taught, making mistakes, listening and practicing in a safe place with volunteer knowledge sharers, which is what the Circle allows/encourages.

While processing a major shift in mindset and philosophy, I did start reading every shared paper, listening to every podcast and watching every interview shared by the Fenner Circle and seeking out more information from Indigenous academics and activists from around the world. Simultaneously, I began reflecting on my past research and saw where I had gone wrong and the neo-colonial behaviours I had perpetuated. This was the spark for me to shift the focus of my research. I realised that climate change affects people more than elephants, and that the people who had coexisted with a population of elephants 98% bigger than the current population would know exactly how to manage them. Realising the narrative spun by white colonial settlers in Africa, perpetuated worldwide by white media like the BBC, that Africans are inexperienced, not knowledgeable and uncivilised when it comes to their own wildlife is now the battle that I choose to fight every day, both on social media and in my research[5]. Across Africa, the concept of wildlife conservation is weaponised and has been used to displace local people from their land. At the crux of this colonisation in the conservation space is the ongoing narrative of Black men poaching elephants without holding the Western syndicates accountable for their role. Most importantly, traditional, cultural and subsistence hunting is conflated with poaching, reducing the nuance of how we, outside of National Parks, perceive and discuss "poaching". In particularly stressed countries like Zimbabwe where "poaching" has the highest rates, the role of colonisation is subtle but dangerous. Most countries in Africa have their local population as the majority, which is counterintuitive to the general definition of colonisation. But the effect of European colonial settlement is entrenched in political systems, gender inequities and economic outcomes. In a place where a mismatched economy and political hierarchy, resulting from European

[4] A dint of despair is a human expectation especially when confronting such an ontologically uncomfortable situation.
[5] This is certainly a fight to take on but surely trying to understand how much this historical power relationships have shaped the "*being*" of these Africans in accepting as *commonsense* many of the false orthodoxies you are rallying against. If you haven't already read it, I'll suggest a reading of Maldonado-Torres (2013) on the coloniality of Being and the impact on contemporary colonised populations. These conversations have been ongoing for over a century especially in the intellectual African and African – American/Caribbean circles (e.g., WEB DuBois, Frantz Fanon, Walter Rodney, Cheikh Anta Diop etc). Unfortunately, they are all men too.

colonial practices, has led to widespread famine, poverty and inequality with many locals having no choice but to meet the highly paid demand of poached wildlife to survive. That demand comes, now, primarily from wealthy and protected constituents. There is a disconnect between the people who can pay the poaching fines and remain anonymous while driving poverty-stricken locals into poaching and are often murdered or face jail time. There are exceptions to this rule, but the fact is that poaching likely wouldn't occur without the presence of European colonisation.

This punishment of colonially impoverished people for surviving is a very active and insidious notion leveraging off Western media protects National Parks and their white constituents, allowing for the continued oppression of the locals as they become labelled as violent savages killing wildlife for money. Working in elephant conservation, especially from a community perspective, is very much influenced by Western media. Respected white conservationists are put on a pedestal in stark contrast to Black African men who are put on the global stage to be lynched for being colonised. Being a conservationist whose main philosophy is, loudly, "not anti-poacher, but anti-poaching" has, unsurprisingly, created controversy. I've chosen to use this knowledge and my platform to try and educate people about this on my social media channels in the hopes of shifting the angry energy from Black men to rich Westerners who create and fund the poaching industry. In turn, I have received death threats, been accused of hating elephants and, strangely, been called a racist. This is shouldering just a sliver of the burden that comes with having to teach colonisers to stop colonising. It is not reparations for my past actions, but it is a first step.

My research originally pivoted around two main themes: elephant conservation and climate change. This has now been expanded to include two more pillars: shifting policy and management, and decolonisation. This is supported by delving into the colonial history of national parks and protected areas and the people who had set up elephant research centres. It should not have surprised me how white and colonised this space is, but it did surprise me. I spent most of my life aiming to be involved in the conservation industry, I had it on a pedestal and the discovery of the injustice and lack of ethics was a shock. I also started to look into research on parachute and colonial science and realised how prevalent it is, especially across Africa. Many fellow conservationists had made and were continuing to make the same white saviour mistakes that I had, especially those from the UK[6]. The concept of white saviourism is nuanced and fluid in how it is problematic. In this case, my thinking that I could help "save the elephants" was misguided white saviourism. As I struggled to find Black African researchers and

[6] The UK (and the anglosphere) is the source and custodian of colonial domination, at least in the English – speaking worlds. This recalcitrance is explained by their history and this behavior permeates all academic domains.

academics, and ingesting the material shared by the Circle, I realised (and was taught) that academia and Western science is a system intentionally built for and by white men. I have felt the weight of extra hoops to jump through as a woman but failed to fully consider the circus of extra hoops that non-white people had to jump through after me to be in a system designed to oppress them and their knowledge. It made sense that I couldn't find many published African academics. The people with the longest history and most knowledge could not contribute because they were purposefully excluded from the accepted (read: colonial) scientific process. Nor should Indigenous knowledges be forced into a colonial framework to be considered "science". Engaging with the content from the Fenner Circle made me realise that firstly, colonisation is very much alive and well and is a pillar of academia, and secondly, that I had perpetuated it and it was my responsibility to move forward in a way that places/directs me and my work towards dismantling the colonial systems and practice in academia and conservation. Further, realising that the major global conservation industries are active colonisers, especially in the poaching and illegal wildlife trade markets, was a turning point for how I perceived the entire conservation industry. I questioned my once firm and directed future and role in it in the future.

I now work on a (bare minimum) basis that if my work cannot benefit local Africans, then I will not go through with it. It's begun with an in-prep paper on the biases that colonisation has caused in elephant research and this being a primary cause of their steep population decline. This paper has not been well received. I spent days searching for appropriate African academics and editors to request as peer-reviewers. This request was ignored. I would understand if the request was disregarded so as to minimise the minority tax on Indigenous scholars, but I believe it was simply a case of those scholars not being considered experts and so were not contacted. It was assumed that US academics would be better to review the work; an assumption with which I disagreed. COVID has also been very bittersweet as I cannot go back to South Africa, or venture into Botswana and Zambia onto the lands of the Tembe/Thonga, Batswana and Bemba peoples, to see the elephants or meet the communities that I work with. But it does mean that I am redistributing my funds to pay locals to collect the data, so the money is being spent in a better place and I am bypassing the trap of parachute science. I have drawn up agreements with the locals that I'm working with in Mozambique, Zambia and Botswana so that all my research will be given back to them in full to use at their discretion. I will not undertake any research on land or waterways without the full permission and inclusion of locals, or if I am not able to pay them with for their time and knowledge. I now avoid working with "National Parks" and "protected areas" as much as possible, unless there is an opportunity to discuss reallocation of management to local people.

The scary part? This is the absolute bare minimum but I am under no requirement from the university to do so. The only help I've had to reach and breach the bare minimum threshold of decolonising my research came from the Fenner Circle and support from my immediate supervisors. Regardless, my PhD has been redesigned to pivot around local communities, elephants and climate change instead of colonisers, elephants and climate change and this in no small part is due to the philosophy and support of the Circle. I was working primarily with GPS data from elephant collars. I have since begun working in participatory mapping, a new but highly inclusive and empowering process in Africa that may hold the key to prioritising the power and necessity for Indigenous sovereignty. I understand that this is far from enough, but the Fenner Circle has challenged me to keep improving and learning from mistakes made in the past[7].

Outside of research and focussing on the stolen land on which I live, work and study, being challenged to write meaningful and unique Acknowledgements of Country and positionality statements has been pivotal to how I teach in the university space, especially in seeing how little traditional management and knowledge is incorporated into the curriculum. Very little has changed in academia since I finished my undergraduate degree in 2016. Going beyond the standard set by the University can be difficult and often not received well. It is critical to show the work has been done to understand the history of the land and waterways you're on, the reparations to be made and rent to be paid. I hope to have these critical discussions and pass on the torch to my students. Engaging with the Fenner Circle has made me highly critical of the academic content I consume and the Western system of science that does not acknowledge the oldest scientists in the world. While my supervisors are very supportive, they are not knowledgeable or able to guide so the Circle is a critical safe place for me to learn and discuss major changes.

Having been rightfully challenged by one of my reviewers I understand that without nuance, this piece can seem as though I am taking lessons learnt in an Indigenous Australian context and sticking them on to Africa. If anything, that idea of Indigenous cultures being monolithic very much furthers the problems I discuss. I recognise I may have glossed over the work I have done in the African decolonial context. Honestly, it is because I am still working through the process of unlearning and finding the middle point of social and physical sciences. I am not yet at a level where I feel confident in being able to accurately and critically portray the state of decolonisation in Africa, particularly the countries where I do research

[7] The work of *penance and restitution* being pursued here is commendable. However, as a personal logic, I am also interested in perspectives that seek to pursue and find the ***dangerous balance*** between existing problems in their diversity and the future that our resistance and actions imagines.

– South Africa, Botswana and Zambia. I do not think that at this point, I can do justice to the struggles and perseverance of decolonisation in these regions so it is best for me to keep being challenged, learning and trying to integrate it into my work based on the resources I can access. My methods are still morphing to suit my refreshed philosophies, and I find it difficult to gain from academic journals what is much better said in person with people directly involved. Ultimately, I don't have the answer – I don't know how I will "close the gap" in elephant conservation and management or if it is even possible and what role I could play to help. I am still working out the nuance and intricacy of taking the broad philosophies I learn in the Fenner Circle and seeing how they fit into the wider world of conservation. What I can say though is that the Fenner Circle, a powerhouse run by Indigenous Australians, has taught me the skills I need to start and struggle through this journey. I understand that the philosophies, pedagogy and reality of decolonisation is different in every country, state and tribe.

Engaging with the Circle is truly a critical part of research and academia at the ANU, and I truly believe all academics would benefit greatly from participation and pushing through the challenging discomfort of decolonisation to collectively work towards a white-decentred future for the academy. We, as white people, need to learn that we have and will make mistakes in this space and it is our responsibility to learn from them and move towards reparations, both inside and outside the academy. Importantly, we need to learn to work to fix others mistakes too and question and disrupt the authority of those 'teaching' us, like our supervisors, so that their mistakes are not repeated. We have a fundamental responsibility to dismantle and destroy systems of oppression that we have built and that we have perpetuated. That starts with questioning the narratives we have been sold and challenge and disrupt the colonial practices they perpetuate and wield the powerful weapon in the privilege we hold. The narrative of Africa is wrong. Africa is not a wild, unruly place sold to us in the "classics" like Out of Africa, it is a thriving, diverse, sovereign and robust continent and group of Peoples, despite many European efforts to destroy that.

While we cannot expect Indigenous peoples to teach us, we can embrace and be grateful for the knowledge and education some are willing to impart, which is a huge part of what the Circle is. In Judaism, one of our driving mitzvahs ('commandments') is Tikun olum, best translated as "repair the world" and we use it as a social policy to safeguard those who are disadvantaged. It has wide applications, and interpretations, but it overrules almost all other mitzvahs; it is always the priority. For Ashkenazi Jews, those targeted by the Shoah, it means we must protect and fight alongside and for those who face the same enemies and oppressors which encapsulates all other minorities. At every High Holiday, every Shabbat and every discussion of our history, it all comes back to one thing קיינמאל

מער (keynmal mer - never again). For both Tikkun olum and keynmal mer, your identity as a religious, ethnic or ethnoreligious Jew is irrelevant. They are obligations for all of us, and to help everyone. I have an unquestionable obligation to work towards reparations, giving land back and providing support wherever support is needed. Just like my people received from Aboriginal communities when it was needed. My privilege has brought me to the place I currently am, as a conservationist and a researcher. This piece and this process for me has been as much about finally reckoning with my own identity and realising the obligations I have, to use my privilege to enact change and progress through my life and work, a gift given through the sacrifice of my ancestors to me. These philosophies I grew up with are, for me, clearly reflected in the core of the Fenner Circle as it is an open and safe space for all. It is safe for those learning to help, those who need help and those who are in the difficult limbo space in between. The value of that cannot be described in numbers or words, it is immeasurable...and it is decolonial.